AMERICAN ELECTRICIANS'
HANDBOOK

BOOKS BY

TERRELL CROFT

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AMERICAN ELECTRICIANS' HANDBOOK

A REFERENCE BOOK FOR PRACTICAL ELECTRICAL WORKERS

BY

TERRELL CROFT

Consulting Electrical Engineer

FIRST EDITION
EIGHTH IMPRESSION

TOTAL ISSUE, 38,000

McGRAW-HILL BOOK COMPANY, INC.
239 WEST 39TH STREET. NEW YORK

LONDON: HILL PUBLISHING CO., LTD.
6 & 8 BOUVERIE ST., E. C.
1913

First Edition

First Impression, December, 1913
Second Impression, April, 1914
Third Impression, October, 1915
Fourth Impression, October, 1917
Fifth Impression, August, 1918
Sixth Impression, March, 1919
Seventh Impression, October, 1919
Eighth Impression, January, 1920

THE MAPLE PRESS YORK PA

PREFACE

This is a practical man's handbook.

In compiling it, the aim has been to collect such information as will enable practical electrical men—wiremen, contractors, linemen, small plant superintendents, operators and construction engineers—to select and install commercial electrical apparatus and materials intelligently for the performance of given services, and to qualify them for operating the equipment after it has been installed.

For a dozen years the compiler has maintained a personal file of loose-leaf notes on practical electrical subjects. This material constituted the nucleus around which The American Electricians' Handbook has been assembled. Additional matter has been collected from many sources. Extracts from standard books and from technical magazines have been utilized freely. Much of the text is from articles prepared by the compiler and printed in trade papers. The endeavor has been to give proper credit for all material that has appeared previously.

While this is not a so-called "theoretical" book it is theoretical to the extent that the information that it gives is based on sound physical laws, as all good engineering practice must be. However, the truths arising from the laws have been given rather than the deduction of the laws themselves. Theoretical discussion has been included only where it may be of assistance in enabling the reader to understand why he should do certain things in certain ways.

Some relatively simple subjects have been treated at considerable length, and others of a more complicated nature may, perhaps, appear to have been slighted. There are two reasons for this: *first*, space limitation considerations and *second*, the desire to cover thoroughly those things which the practical man encounters most frequently.

Illustrations and diagrams, every one of which has been especially prepared for this book, have been used very freely, because one illustration will frequently explain more than several pages of text. Many special problems are solved to indicate the proper application of the rules which are given. No attempt has been made to treat apparatus or materials involving voltages exceeding 2400.

Although this handbook has been prepared primarily for men of little schooling, it is designed to give practical information on materials, and suggestions for the selection, installation and operation of equipment, that will be of service to the technically trained engineer.

In books of this character some typographical errors are inevitable. The compiler and publishers will be glad to have notice of any that are discovered, and to have suggestions for the future enlargement and improvement of the book.

TERRELL CROFT.

UNIVERSITY CITY,
ST. LOUIS, MO.
November, 1913

THE AMERICAN ELECTRICIANS' HANDBOOK

CONVERSION TABLES AND USEFUL FACTORS

CONVERSION FACTORS (*Standard Handbook*)

These factors were calculated with a double length slide-rule and checked with those given by Carl Hering in his "Conversion Tables."

1. Length

1 mil = 0.0254 mm. = 0.001 in.
1 mm. = 39.37 mils = 0.03937 in.
1 cm. = 0.3937 in. = 0.0328 ft.
1 in. = 25.4 mm. = 0.083 ft. = 0.0278 yd. = 2.54 cm.
1 ft. = 304.8 mm. = 12 in. = 0.333 yd. = 0.305 m.
1 yd. = 91.44 cm. = 36 in. = 3 ft. = 0.914 m.
1 m. = 39.37 in. = 3.28 ft. = 1.094 yd.
1 km. = 3,281 ft. = 1,094 yd. = 0.6213 miles.
1 mile = 5,280 ft. = 1,760 yd. = 1,609 m. = 1.609 km.

2. Surface

1 cir. mil = 0.7854 sq. mil = 0.0005067 sq. mm. = 0.0000007854 sq. in.
1 sq. mil = 1.273 cir. mil = 0.000645 sq. mm. = 0.000001 sq. in.
1 sq. mm. = 1,973 cir. mil = 1,550 sq. mil = 0.00155 sq. in.
1 sq. cm. = 197,300 cir. mil = 0.155 sq. in. = 0.00108 sq. ft.
1 sq. in. = 1,273,240 cir. mil = 6.451 sq. cm. = 0.0069 sq. ft.
1 sq. ft. = 929.03 sq. cm. = 144 sq. in. = 0.1111 sq. yd. = 0.0929 sq. m.
1 sq. yd. = 1,296 sq. in. = 9 sq. ft. = 0.00836 are = 0.000207 acre.
1 sq. m. = 1,550 sq. in. = 10.7 sq. ft. = 1.195 sq. yd. = 0.000247 acre.
1 acre = 43,560 sq. ft. = 4,840 sq. yd. = 4,047 sq. m. = 0.4047 hectare = 0.004047 sq. km. = 0.001562 sq. mile.
1 sq. mile = 27,880,000 sq. ft. = 3,098,000 sq. yd. = 2,590,000 sq. m. = 640 acres = 2.59 sq. km.

3. Volume

1 cir. mil-ft. = 0.0000094248 cu. in.
1 cu. cm. = .061 cu. in. = 0.0021 pt. (liq.) = 0.0018 pt. (dry).
1 cu. in. = 16.39 cu. cm. = 0.0346 pt. (liq.) = 0.0298 pt. (dry). = 0.0173 qt. (liq.) = 0.0148 qt. (dry) = 0.0164 l. or cu. dm. = 0.0036 gal. = 0.0005787 cu. ft.
1 pt. (liq.) = 473.18 cu. cm. = 28.87 cu. in.
1 pt. (dry) = *550.6 cu. cm.* = 33.60 cu. in.

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through a pipe depends, to a large extent on the hydraulic pressure in the pipe. (Water pressure is measured in pounds per square inch.) Similarly, electric pressure or e.m.f., measured in volts causes electricity to flow. A volt means somewhat the same thing in speaking of a flow of electricity as a pound pressure does in speaking of a flow of water. A higher hydraulic pressure is required to force a given amount of water through a small pipe than through a large one. Similarly a higher voltage is required to force a given

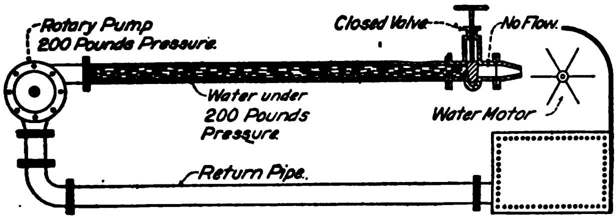


FIG. 7.—Water flow blocked by a closed valve.

amount of electricity through a small wire than through a large one. If the voltage impressed on a circuit is increased the current will be correspondingly increased. See Fig. 6.

16. **The distinction between amperes and volts** should (Timbie) be clearly understood. The amperes represent the rate of electricity flow (see Par. 12) through a circuit while the volts represent the pressure causing the flow. In the case of both electricity and water there may be great pressure and yet no current. If the path of the water is blocked by a closed valve (Fig. 7) there

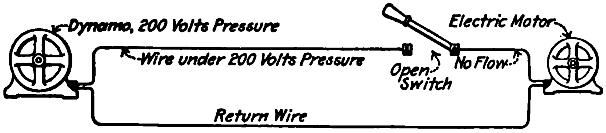


FIG. 8.—Electricity flow blocked by an open switch.

will be no current (flow of water)yet there may be high pressure. If the path of electricity is blocked by an open switch, Fig. 8, there will be no current of electricity, though the pressure (voltage) might be high. Furthermore, it is evident that, with a given hydraulic pressure, more water will flow through a large pipe than through a small one. Similarly with a given voltage, more electricity will flow through a large wire than through a small one.

17. **Resistance** is the physical property of a material by virtue of which it opposes *the flow of* an electric current. **The ohm** is the *practical unit of resistance.* If a pressure of 1 volt is impressed on a *circuit and 1 ampere flows, that* circuit has a resistance of 1 ohm. A *column of mercury 106.3* cm. long, having a cross-sectional area of 1 *square millimeter will have* a resistance of 1 ohm. A piece of *copper wire 1000 ft. long* has a resistance of almost exactly 1

18. A resistor is an object having resistance; specifically, resistor is a conductor inserted in a circuit to introduce resistanc **A rheostat** is a resistor so arranged that its effective resistance ca be varied.

19. What Determines Resistance.—The amount of resistan offered to the flow of water through a pipe or to the flow of electricit through a conductor is determined by somewhat analogous pro erties of the pipe and of the conductor respectively, as follows:

20. Properties Determining Flow

Of water through a pipe	Of electricity through a wire
1. Diameter of pipe. 2. Length of pipe. 3. Material of pipe and its internal smoothness.	1. Diameter of wire. 2. Length of wire. 3. Material of wire and its ter perature.

With both electricity and water flow (assuming a constar pressure) the longer the wire or pipe the less the flow; the smalle the diameter of wire or pipe, the less the flow and vice versa.

21. The resistances of different materials vary greatly. Som such as the metals, conduct electricity very readily, hence are calle conductors. Others such as wood or slate are, at least whe moist, partial conductors. Still others, such as glass, porcelain an paraffin, are called insulators because they are practically non conducting. No material is a perfect conductor and no materia is a perfect insulator.

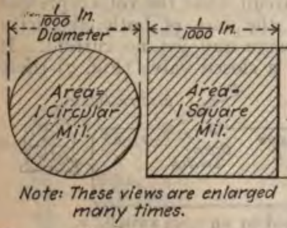


FIG. 9.—Circular mil and square mil.

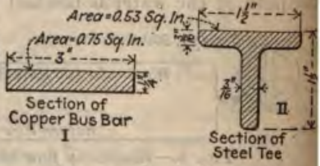


FIG. 10.—Conductor sections.

22. A circular mil is the area of a circle $\frac{1}{1000}$ in. in diamete A mil is $\frac{1}{1000}$ of an inch. See Fig. 9. The areas of electric con ductors are usually measured in cir. mils. Since the area of an figure varies as the square of its similar dimensions, the area c any circle can be expressed in cir. mils by squaring its diamete expressed in thousandths. Thus, since $\frac{3}{8}=\frac{375}{1000}=0.375$, the are of a circle $\frac{3}{8}$ in. in diameter would be $375\times375=140{,}625$ cir. mil The area of a circle 0.005 in. diameter would be $5\times5=25$ cir. mil

23. A square mil is the area of a square having sides $\frac{1}{1000}$ i long. See Fig. 9. Areas of rectangular conductors are sometim measured in square mils. Areas in sq. mils are obtained by mult *plying together the length and breadth of the rectangle* expresse *in thousandths of an inch.* Thus, the area of a rectangle ½ wide and 2 in. long would be $500\times2000=1{,}000{,}000$ sq. mils.

24. To reduce square mils or square inches to circular mils or the reverse use the following formulas:

$$\text{Sq. mils} = \text{cir. mils} \times 0.7854$$

$$\text{Cir. mils} = \frac{\text{sq. mils}}{0.7854}$$

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854}$$

$$\text{Sq. in.} = \text{cir. mils} \times 0.0000007854$$

Example.—The sectional area of the bus bar, in Fig. 10, I, is in cir. mils:

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} = \frac{3 \times \frac{1}{4}}{0.0000007854} = \frac{0.75}{0.0000007854} = 955{,}000 \text{ cir. mils.}$$

Example.—The sectional area of the steel tee, shown in Fig. 10, II, in cir. mils is:

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} = \frac{0.53}{0.0000007854} = 674{,}800 \text{ cir. mils.}$$

25. The circular mil-foot (cir. mil-ft.) is the unit conductor. A wire having a sectional area of one circular mil and a length of one foot is a cir. mil-ft. of conductor. The resistance of a cir. mil-ft. of a metal is sometimes called its **specific resistance** or its **resistivity**. The resistance of a cir. mil-ft. of copper under different conditions is given in Fig. 11. Resistances for other metals and alloys are given in Table 28.

26. To obtain the resistance of a conductor of any common metal or alloy use the value given for the resistance of a cir. mil-ft. of the material in Table 28 in the following formula:

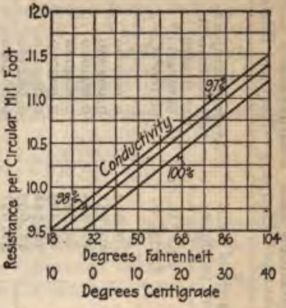


FIG. 11.—Curves showing resistance per circular mil-foot of pure copper at various temperatures and conductivities.

$$R = \frac{p \times l}{\text{cir. mils}} \quad \text{or} \quad \frac{p \times l}{d^2}$$

Wherein R = resistance of the conductor in ohms, p = resistance of a cir. mil-ft. of the material composing the conductor, from Table 28, l = length of conductor in feet, d = diameter in mils and d^2 = diameter in mils squared or, what is the same thing, the area of the conductor in circular mils. The other forms of the formula are:

$$p = \frac{d^2 \times R}{l} \qquad l = \frac{d^2 \times R}{p} \qquad d = \sqrt{\frac{p \times l}{R}}$$

Example.—Taking from the Table 29 the resistance of a cir. mil-ft. of copper at 23° C. (75° F.) as 10.5 ohms, what is the resistance of 500 ft. of copper wire, 0.021 in. diameter?

Solution.—Substituting in the formula:

$$R = \frac{pl}{d^2} = \frac{10.5 \times 500}{21 \times 21} = \frac{5250}{441} = 11.9 \text{ ohms.}$$

27. *The resistances of conductors that are not circular in section can be computed* *by first getting their areas in sq. in. and then reducing this sq. in. value to cir. mils as indicated above. Then proceed with the formula in the preceding paragraph.*

28. Approximate Specific Resistances and Temperature Coefficients of Metals and Alloys

(International Textbook Company—Electrical Engineer's Handbook)

Metal	*p* Resistance of 1 cir. mil-foot in ohms		*a* Average temperature coefficient per degree C. between 0° and 100° C.	*a* Average temperature coefficient per degree F. between 32° and 212° F.	Percentage conductivity	Relative resistance
	0° C. or 32° F.	23.8° C. or 75° F.				
Silver, pure annealed	8.831	9.674	0.004000	0.002220	108.60	0.925
Copper, pure annealed	9.390	10.351	0.004280	0.002380	102.10	0.980
Copper, annealed	9.590	10.505	0.004020	0.002230	100.00	1.000
Copper, hard-drawn	9.810	10.745	0.004020	0.002230	97.80	1.022
Gold (99.9% pure)	13.216	14.404	0.003770	0.002090	72.55	1.378
Aluminum (99.5% pure)	15.219	16.758	0.004230	0.002350	63.00	1.587
(Commercial—97.5% pure)	16.031	17.699	0.004350	0.002420	59.80	1.672
Zinc (very pure)	34.595	37.957	0.004060	0.002260	27.72	3.608
Iron, (approx. pure)	54.529	62.643	0.006250	0.003470	17.50	5.714
Iron "E. B. B." iron wire	58.702	65.190	0.004630	0.002570	16.20	6.173
Platinum (pure)	65.670	71.418	0.003669	0.002038	14.60	6.845
Iron, "B. B." iron wire	68.680	76.270	0.004630	0.002570	13.50	7.407
Nickel	74.128	85.138	0.006220	0.003460	12.94	7.726
Tin (pure)	78.489	86.748	0.004400	0.002450	12.22	8.184
Steel (wire)	81.179	90.150	0.004630	0.002570	11.60	8.621
Substance						
Brass	43.310	....	....	....	22.15	4.515
Phosphor-bronze	51.005	....	0.000640	0.000356	18.80	5.319
Aluminum bronze	73.989	....	0.001000	0.000556	12.96	7.714
German silver *Cu* 50, *Zn* 35, *Ni* 15	127.800	....	0.000400	0.000220	7.50	17.300
Platinoid, *Cu* 59, *Zn* 25.5, *Ni* 14, *W* (tungsten) 55	251.030	....	0.000310	0.000172	3.82	26.180
Manganin *Cu* 84, *Ni* 4, *Mn* 12	280.790	....	0.000000	....	3.41	29.330
Constantan, *Cu* 58, *Ni* 41, *Mn* 1	{300.77 312.80}	....	±0.000010	0.000005	{3.19 3.07}	{31.35 32.57}
Gray cast iron	684.000	....	....	....	....	....

29. Change of Resistance with Change of Temperature.—' resistance of all pure metals increases as they become hot. ' resistance of certain alloys is not affected by the temperature. wiring for light and power, changes in resistance due to change temperature are so slight that they may be wholly disregard Sometimes, with electrical machinery, changes in resistance du changes in temperature may be of importance, in that speeds, tages or currents may be appreciably affected thereby. The p portion that resistance increases per degree rise in temperatur called the **temperature coefficient of resistance.** See Table for values. For all pure metals, the coefficient is practically same and is 0.004 for temperatures in degrees Centigrade and 0.0 for temperatures in degrees Fahrenheit.

30. To find the resistance of a conductor at any ordinary tempe ture, use this formula:

$$R_h = R_c + a \times R_c\ (T_h - T_c) \text{ or } T_h - T_c = \frac{R_h - R_c}{a \times R_c}$$

Wherein R_h = resistance in ohms hot, R_c = resistance in ohms c T_h = temperature of conductor hot, in degrees, T_c = temperatur conductor cold in degrees and a = the temperature coefficient of material of the conductor from Table 28. (This is an approxin method, but it is sufficiently accurate for all ordinary work.)

Example.—The resistance of a cir. mil-ft. of annealed copper is 9.59 o at 32° F. What will its resistance be at 75° F.?

Solution.—From Table 28 the coefficient is 0.00223. Substitute in formula:

$$\begin{aligned} R_h = R_c + a \times R_c(T_h - T_c) &= 9.59 + 0.00223 \times 9.59(75 - 32) \\ &= 9.59 + 0.00223 \times 9.59 \times 43 \\ &= 9.59 + 0.92 \\ &= 10.51 \text{ ohms, at } 75° \text{ F.} \end{aligned}$$

31. The Temperature Rise in a Conductor can be Determi with the above Formula by Measuring Hot and Cold Resistanc The expression "$T_h - T_c$" is the difference between the hot cold temperature and is therefore the temperature rise or fall.

Example.—The resistance of a set of copper coils measured 20 ohm a room temperature of 20° C. After carrying current for some time resistance measured 20.78 ohms. What was the temperature rise in coil?

Solution.—The temp. coef. of copper per degree C. is, from Table 0.004. Substitute in the formula:

$$T_h - T_c = \frac{R_h - R_c}{aR_c} = \frac{20.78 - 20.0}{0.004 \times 20} = \frac{0.78}{0.08} = 9.75° \text{ C.}$$

Therefore the average temperature rise in the coil was $9\frac{3}{4}$° C.

32. Contact resistance is the resistance at the point of con of two conductors. Heat is always developed at such a p when current flows. The greater the clamping pressure betw the conductors in contact and the greater the area of contact, less the contact resistance will be. The nature of the surf in contact must also be considered. Smooth surfaces have contact resistance than do rough surfaces. Contacts should alw be so designed *that, for a given current, the area of contact be large enough that the contact resistance will not be so gr to cause excessive heating.* Table 33 indicates safe values

33. Safe Current Densities for Electrical Contacts and fo Cross Sections

Kind of contact	Material	Current density: Amperes per square inch	Current density: Square mils per ampere
Sliding contact (brushes)	Copper brush	150 to 175	5700 to 670
	Brass gauze brush	100 to 125	8000 to 1000
	Carbon brush	30 to 40	25000 to 3330
Spring contact (switch blades)	Copper on copper	60 to 80	12500 to 1670
	Composition on copper	50 to 60	16700 to 2000
	Brass on brass	40 to 50	20000 to 2500
Screwed contact	Copper to copper	150 to 200	5000 to 670
	Composition to copper	125 to 150	6700 to 800
	Composition to composition	100 to 125	8000 to 1000
Clamped contact	Copper to copper	100 to 125	8000 to 1000
	Composition to copper	75 to 100	10000 to 1300
	Composition to composition	70 to 90	11000 to 1400
Fitted contact (taper plugs)	Copper to copper	125 to 175	5700 to 800
	Composition to copper	100 to 125	8000 to 1000
	Composition to composition	75 to 100	10000 to 130c
Fitted and screwed contact	Copper to copper	200 to 250	4000 to 50c
	Composition to copper	175 to 200	5000 to 57c
	Composition to composition	150 to 175	5700 to 67c
Cross section	Copper wire	1200 to 2000	500 to 8c
	Copper wire cable	1000 to 1600	600 to 10c
	Copper rod	800 to 1200	800 to 12c
	Composition casting	500 to 700	1400 to 20c
	Brass casting	300 to 400	2500 to 33c
	Brass rod	575 to 750	1300 to 17c

34. Ohm's Law.—There is a simple relation between the ele tromotive force (volts), the current (amperes) and the resistanc (ohms) in an electric circuit. This relation is expressed by Ohm law, viz: *The electric current in a conductor equals the electromoti force divided by the resistance.* Expressing this law in symbols:

$$I=\frac{E}{R} \quad \text{or} \quad R=\frac{E}{I} \quad \text{or} \quad E=I\times R$$

Wherein, I = the current in amperes, E = the electromotive forc in volts and R = the resistance in ohms.

In the above form, Ohm's law applies only to direct-currer circuits or non-inductive alternating-current circuits. Whe inductive alternating-current circuits are involved it must b modified before application. See index.

35. In applying Ohm's law many errors are made. It can b applied to an entire circuit or to only a portion of a circuit. Whe applied to an entire circuit (Timbie): *The current (amperes) i the entire circuit equals the voltage across the entire circuit divided b the resistance (ohms) of the entire circuit.* Note that the word *enti* pplies to current, voltage and resistance alike. When appli but part of a circuit (Timbie): *The current in a certain part o* *circuit equals the voltage across that same part divided by the resistance of that part.*

36. Examples of the Application of Ohm's law.

Example.—What will be the current in the circuit of Fig. 12?

Solution.—An entire circuit is shown. It is composed of a dynamo, line wires and a resistance coil. The e.m.f. developed by the dynamo (do not confuse this with the e.m.f. impressed by the dynamo on the line), is 120 volts. The resistance of the entire circuit is the sum of the resistances of dynamo, line wires and resistance coil. Substituting in the formula:

$$I = \frac{E}{R} = \frac{120}{1+1+9+1} = \frac{120}{12} = 10 \text{ amp.}$$

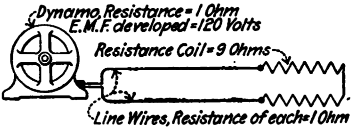


FIG. 12.—An entire dynamo circuit.

Example.—What current will flow in the circuit of Fig. 13?

Solution.—This again is an entire circuit. Substituting in the formula:

$$I = \frac{E}{R} = \frac{1}{0.5+0.5+2+0.5} = \frac{1}{3.5} = 0.28 \text{ amp.}$$

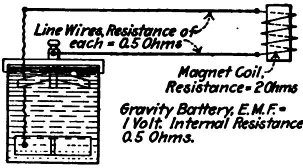


FIG. 13.—An entire battery circuit.

Note that the internal resistance of the battery must be considered.

Example.—With 10 amp. flowing, what will be the voltage or drop across each of the line wires in Fig. 14?

Solution.—Each has a resistance of 0.1 ohm, hence

$$E = I \times R = 10 \times 0.1 = 1 \text{ volt.}$$

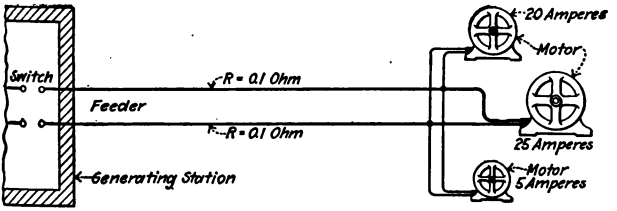


FIG. 14.—Feeder to motors.

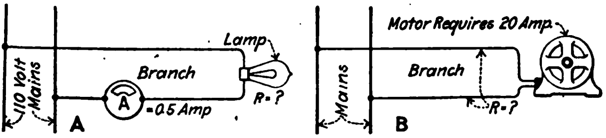


FIG. 15.—Portions of circuits.

Example.—What is the resistance of the incandescent lamp of Fig. 15? It is tapped to a 110-volt circuit and the ammeter reads 0.5 amperes. The branch wires are so short that their resistance can be neglected.

Solution.—*Substitute in the formula:*

$$R = \frac{E}{I} = \frac{110}{0.5} = 220 \text{ ohms.}$$

Example.—The motor of Fig. 15*B* takes 20 amperes and the drop in voltage in the branch wires should not exceed 5 volts. What is the greatest resistance that can be permitted in the branch conductors?

Solution.—Substitute in the formula:

$$R = \frac{E}{I} = \frac{5}{20} = 0.25 \text{ ohms.}$$

This (0.25 ohm) is the resistance of both wires. Each would have a resistance of 0.125 ohm.

Example.—The arc lamp Fig. 16 takes 5 amperes. The resistance of each branch wire is 0.1 ohm. What will be the drop in volts in each branch wire?

Solution.—Substitute in the formula:

$$E = R \times I = 0.1 \times 5 = 0.5 \text{ volts.}$$

In both branch wires or in the branch circuit the volts lost would be $2 \times 0.5 = 1$ volt.

Example.—Three motors (Fig. 14) taking respectively 20 amperes, 25 amperes and 5 amperes (these values were stamped on the name plates of the motors) are located at the end of a feeder having a resistance of 0.1 ohm on each side. What will be the volts drop in the feeder?

Solution.—Substitute in the formula:

$$E = R \times I = (0.1 + 0.1) \times (20 + 25 + 5) = 0.2 \times 50 = 10 \text{ volts.}$$

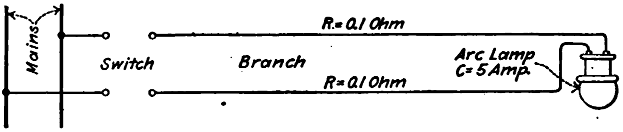


FIG. 16.—Portion of a circuit.

37. Power in direct-current circuits is equal to the product of volts and amperes. (For "power in other alternating-current circuits" see index.) Expressing this as a formula:

$$P = I \times E \qquad P = \frac{E^2}{R} \qquad P = I^2 \times R$$

and also

$$I = \frac{P}{E} \qquad I = \sqrt{\frac{P}{R}} \qquad E = \frac{P}{I} \qquad E = \sqrt{R \times P}$$

$$R = \frac{E^2}{P} \qquad R = \frac{P}{I^2}$$

Wherein, I = current in amperes, E = voltage or electromotive force in volts, R = resistance in ohms and P = the power in watts.

38. In applying the above equations be careful that the values of current, voltage, and resistance used in any one problem all apply to the same circuit or to the same portion of a circuit.

Example.—How many watts are consumed by the incandescent lamp in Fig. 17?

Solution.—Substitute in the formula:

$$P = I \times E = \tfrac{1}{2} \times 110 = 55 \text{ watts.}$$

Example.—How many watts are taken by the motor of Fig. 18? How many kw.? How many h.p.?

Solution.—Substitute in the formula:

$$P = I \times E = 70 \times 220 = 15{,}400 \text{ watts.}$$

$$\text{kw.} = \frac{\text{watts}}{1000} = \frac{15400}{1000} = 15.4 \text{ kw.}$$

$$h.p. = \frac{\text{watts}}{746} = \frac{15400}{746} = 20.6 \text{ h.p.}$$

Example.—In the transmission line of Fig. 19, what amount of power will be lost in the line wires to the motor?
Solution.—Substitute in the formula:

$$P = I^2 \times R = (40 \times 40) \times (0.3 + 0.3) = 1600 \times 0.6 = 960 \text{ watts.}$$

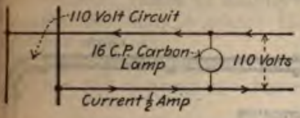


FIG. 17.—Incandescent lamp branch circuit.

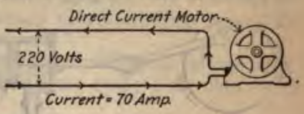


FIG. 18.—Electric motor.

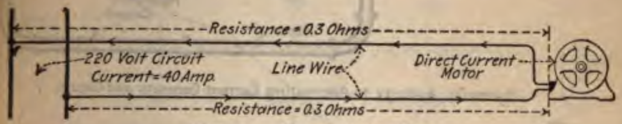


FIG. 19.—Transmission line.

39. **Watts, Kilowatts and Horse-power.**—One horse-power equals 746 watts, therefore:

$$\text{h.p.} = \frac{\text{watts}}{746} = \text{watts} \times 0.0013 \qquad \text{watts} = \text{h.p.} \times 746$$

$$\text{h.p.} = \frac{\text{kw.}}{0.746} = \text{kw.} \times 1.34 \qquad \text{kw.} = \text{h.p.} \times 0.746.$$

Example.—Watts = 2460, h.p. = ?.
Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{\text{watts}}{746} = \frac{2460}{746} = 3.3 \text{ h.p.}$$

Example.—A motor takes 30 kw. How many horse-power is it taking?
Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{\text{kw.}}{0.746} = \frac{30}{0.746} = 40.2 \text{ h.p.}$$

or

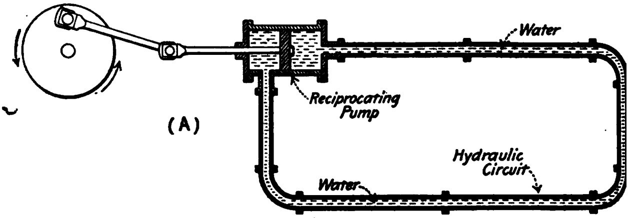
$$\text{h.p.} = \text{kw.} \times 1.34 = 30 \times 1.34 = 40.2 \text{ h.p.}$$

40. **An alternating current** is one that reverses in direction at regular intervals. In Fig. 20*A* as the hydraulic pump operates, the current of water will flow back and forth through the pipe. This action is analogous to that of an alternating current of electricity. With the arrangement of Fig. 20*B*, corresponding to a direct-current circuit, the current of water will always be in the same direction. For a true analogy the pump of Fig. 20*B* should be of the centrifugal type because with that type the hydraulic pressure is constant. With the reciprocating pump of Fig. 20*B* the water pressure (corresponding to the voltage of an electric circuit) would vary, although it would always be in the same direction. In the ordinary direct-current circuit the pressure is constant.

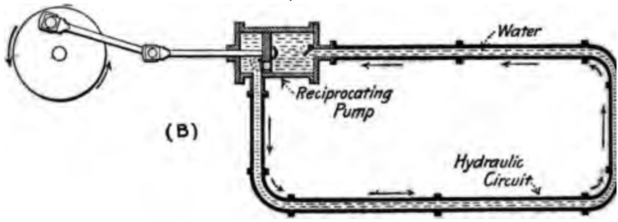
41. **A cycle** is a complete set of values through which an alternating current repeatedly passes. See Fig. 21. The expression "60 cycles per second means that the current referred to makes 60 complete cycles in a second. It therefore requires $\frac{1}{60}$ second to complete 1 cycle. See Fig. 21. With a 25-cycle current, $\frac{1}{25}$ second is required to complete 1 cycle. See Fig. 22.

2

42. The frequency of an alternating current is the number (cycles completed in a second. A frequency of 60 cycles (Fig. 21 is common for lighting and power installations while (Fig. 2: 25 cycles is used for power transmission. When used for lightin



Hydraulic Analogy to Alternating Current Generator and Circuit.



Hydraulic Analogy to Direct Current Generator and Circuit.

FIG. 20.—Hydraulic analogies.

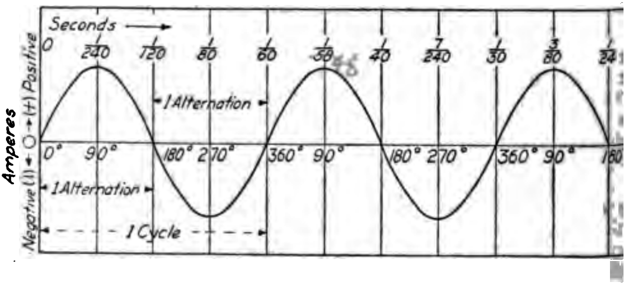


FIG. 21.—Curve of a 60-cycle alternating current.

there is sometimes a flickering of incandescent lamps on 25 cycle *Some* arc lamps do not operate well on 25 cycles. Frequenci *much lower than 25* cycles cannot be used for incandescent lightin *Some of the older stations* generate at 125 or 133 cycles and 15 cycl *has been used for railway* work.

43. The word "phase," when properly used in alternating-current terminology, refers to time. When two alternating currents are in phase they reach their corresponding zero, maximum and intermediate values at exactly the same instants. If currents or voltages are not in phase they reach corresponding values at different instants.

A three-phase current consists of three different alternating currents out of phase 120 degrees (which are really time degrees—

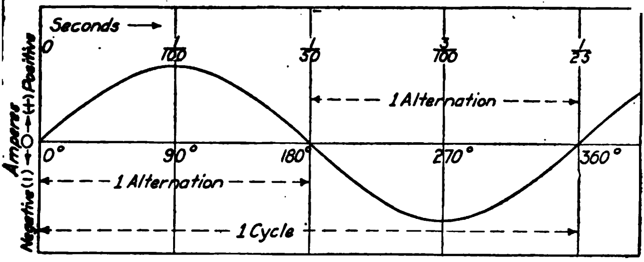


Fig. 22.—Curve of a 25-cycle alternating current.

each degree representing a certain definite amount of time) with each other. A two-phase current consists of two different alternating currents out of phase 90 degrees (which represents a certain definite amount of time) with each other.

Sometimes each of the three wires of a three-phase circuit is called a "phase wire" or for short a "phase." Also, any pair of wires of a polyphase circuit across which the normal voltage of the circuit should exist is sometimes referred to as a "phase" of the circuit.

44. The effective value of an alternating current is that value which will produce the same heating effect as will the same intensity of direct current. Measuring instruments indicate effective values. An effective alternating current of 10 amp. will produce the same heating effect as 10 amp., direct current. A similar statement is true for any other values of alternating and direct currents. Alternating e.m.fs. and currents are constantly changing in value, within a certain range, from instant to instant even if the load is constant. It is not practicable to deal with or indicate with instruments these constantly changing values. Effective values are ordinarily referred to when speaking of alternating currents. The practical man deals almost exclusively with effective values. See Fig. 23. Effective values are sometimes called virtual values.

45. The maximum value of an alternating current or voltage is the greatest value that it attains. This is an instantaneous value. See Fig. 23.

$$\textit{Effective value} = 0.707 \times \text{maximum value}$$

$$\textit{Maximum value} = \frac{\text{effective value}}{0.707}$$

Example.—What is the effective voltage of a circuit that has a maximu voltage of 156?
Solution.—Substitute in the formula:
Effective value = 0.707 × maximum value = 0.707 × 156 = 110 volts.
Example.—If a voltmeter on an alternating-current circuit reads 220 what is the maximum instantaneous voltage?
Solution.—Substitute in the formula:

$$\text{Maximum value} = \frac{\text{Effective value}}{0.707} = \frac{2200}{0.707} = 3110 \text{ volts.}$$

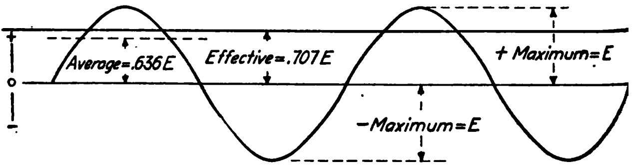


FIG. 23.—Alternating electromotive-force values.

46. The instantaneous value of an alternating current o voltage is its value at some designated instant or, in other word at some designated point in its cycle.

47. The effect of resistance in alternating-current circuits i the same as in direct-current circuits and Ohm's law is used i calculating its effect. This is true only when there is no inductanc or permittance (capacity) in the circuit.

48. The power loss in any conductor traversed by an alte nating current or a direct current is

$$P = I^2 \times R \text{ or } I = \sqrt{\frac{P}{R}} \text{ or } R = \frac{P}{I^2}$$

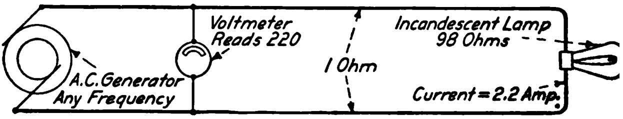


FIG. 24.—Resistance in an alternating-current circuit.

Wherein P = the power lost in the conductor in watts, I = curre in amperes in the conductor and R = resistance of conductor i ohms. This rule is perfectly general and applies to all dire current circuits and all alternating-current circuits of ordinar voltages and frequencies. The watts power loss, P, reappea as heat power and heats the conductors. See 304 and 305 fo another way of stating this law.

Example.—What is the power loss in the incandescent lamp in Fig. 24
Solution.—Substitute in the formula:
$P = I^2 \times R = (2.2 \times 2.2)98 = 4.84 \times 98 = 474$ watts.
Example.—What is the power loss in the inductive winding of Fig. 2 with an alternating current of 3 amp.?
Solution.—Substitute in the formula:
$R = I^2 \times R = (3 \times 3)7 = 9 \times 7 = 63$ watts.

49. **Inductance in alternating-current circuits** has very]
nounced effects. When an alternating current flows through
inductance a counter e.m.f. is generated. This counter e.:
opposes the e.m.f. developed by the generator, with the re
that the active e.m.f., that which actually forces current thro
the circuit, is less than the impressed e.m.f. The amount tha
is less depends on the amount of inductance. The subject is too complicated for a full discussion here. The practical man can calculate his circuits with the formulas found in this book without a thorough understanding of the matter.

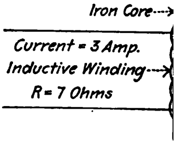


FIG. 25.—Inductiv sistance in an alternat current circuit.

50. **Impedance** is the name given to that quantity which represents the combined resisting effect of actual (ohmic) resistance and of the inductive resistance (reactance). If impedance in ohms is multiplied by current in amperes the resulting value will be the impressed e.m.f.

51. **Power in Alternating-current Circuits.—Power factor** is
ratio of true watts to apparent watts in an alternating-curr
circuit. It is the number by which the apparent power must
multiplied to obtain the real power. Power factor is usu
expressed in a per cent. and cannot be greater than 100 per cen

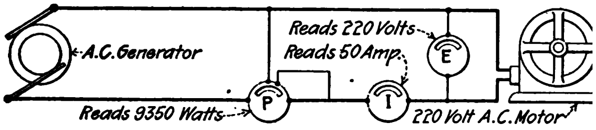


FIG. 26.—Example of power factor.

For Example.—In Fig. 26, which shows a single-phase circuit, the amme
I, reads 50 amp. and the voltmeter, E, 220 volts. The apparent powe
the product of volts and amperes or $IE = 50 \times 220 = 11000$ watts. But
wattmeter, P, reads 9350 watts. A wattmeter always indicates real
true power. Therefore the power factor (for a single-phase circuit

$$\text{power factor} = \frac{\text{true watts}}{\text{apparent watts}} = \frac{9350}{11000} = 0.85 \text{ or } 85 \text{ per cent.}$$

52. **The power factor in a non-inductive circuit,** one contain
resistance only, is always 1, or 100 per cent., that is, the product
volts and amperes in such a circuit gives true power.

53. **The power factor in a circuit containing inductance**
capacity may be anything between 0 and 1 (0 and 100 per cen
depending on the amount of inductance or capacity in the circ

54. **Effects of Low Power Factor** (*General Electric Co. publi
tion*).—It is usually considered that the wattless component o
current at low *power factor* is circulated without an increas
mechanical input over that necessary for actual power requirem
This is inaccurate because internal work or losses due to this
current are produced and must be supplied by the prime
Since these extra losses manifest themselves in heat, the c
of the machine is reduced. Also wattless components of

heat the line conductors, just as do energy components, and cause losses in them. The loss in any conductor is always (see **48**)

$$P = I^2R$$

where P = the loss in watts, I = the current in amperes in the conductor and R = the resistance in ohms. However, the increase in losses in the generating equipment and line due to low power factor are usually relatively small and it can be said that very little more coal is burned to supply energy at low power factor than at high power factor. This statement is made with the assumption that the efficiency of the prime mover at different loads is constant.

55. Correction of Low Power Factor.—In industrial plants, excessively low power factor is usually due to underloaded induction motors because the power factor of motors is much less at partial loads than at full-load. Where motors are underloaded new motors of smaller capacity should be substituted. (See Induction Motors, Index.) Power factor can be corrected by installing synchronous motors (see Index) which, when overexcited, have the property of neutralizing the wattless or induction components of currents inherent to low power factor.

56. The Cosine of the Angle of Lag is Equal to the Power Factor.—Cosines for different angles can be found in trigonometric tables in handbooks. (See **10.**) The symbol ϕ, a Greek letter, pronounced phi, is often used to designate the angle of lag, hence power factor is sometimes referred to as "Cos ϕ" (Cosine phi). This means the cosine of the angle ϕ.

57. Typical power factors of various kinds of central-station loads as given by F. D. Newbury before the 1911 convention of the N.E.L.A. are given below.

INCANDESCENT LIGHTING WITH SMALL LOWERING TRANSFORMERS.—Power factor, 0.90 to 0.95.

ALTERNATING-CURRENT INCLOSED-ARC LAMPS WITH CONSTANT-CURRENT TRANSFORMERS.—Power factor, from 0.60 to 0.75, depending upon whether the transformers are carrying their rated number of lamps. Average 0.70.

DIRECT-CURRENT METALLIC-ARC LAMPS WITH RECTIFIERS.—Power factor, from 0.55 to 0.70, depending upon whether or not the rectifiers are carrying their rated number of lamps. Average 0.65.

SINGLE-PHASE INDUCTION MOTORS, SQUIRREL-CAGE ROTOR.—$\frac{1}{20}$ h.p. to 1 h.p., power factor, 0.55 to 0.75, average 0.68 at rated load; 1 h.p. to 10 h.p., power factor, 0.75 to 0.86, average 0.82, at rated load.

POLYPHASE INDUCTION MOTORS, SQUIRREL-CAGE ROTOR.—1 h.p. to 10 h.p., power factor, 0.75 to 0.91, average 0.85 at rated load; 10 h.p. to 50 h.p., power factor, 0.85 to 0.92, average 0.89, at rated load.

POLYPHASE INDUCTION MOTORS, PHASE-WOUND ROTORS.—5 h.p. to 20 h.p., power factor, 0.80 to 0.89, average 0.86 at rated load; 0 h.p. to 100 h.p., power factor, 0.82 to 0.90, average 0.87 at ted load.

NDUCTION MOTOR LOADS IN GENERAL.—Power factor, fro to 0.85, depending on whether motors are carrying th loads.

ROTARY CONVERTERS, COMPOUND WOUND.—Power factor a full-load can be adjusted to practically 100 per cent. At ligh loads it will be lagging, and at overloads slightly leading.

ROTARY CONVERTERS, SHUNT WOUND.—The power factor can b adjusted to any desired value, and will be fairly constant at al loads with the same field rheostat adjustment. Rotary converters however, should not be operated below 0.95 power factor leadin or lagging at full-load or overload.

SMALL HEATING APPARATUS.—This load has the same character istics as an incandescent-lighting load. The power factor of th load unit is practically unity, but the distributing transformers wil lower it to some extent.

ARC FURNACES.—Power factor, 0.80 to 0.90.

INDUCTION FURNACES.—Power factor, 0.60 to 0.70.

ELECTRIC-WELDING TRANSFORMERS.—Power factor, 0.50 to 0.70

SYNCHRONOUS MOTORS.—Adjustment between practically zer power factor leading to zero power factor lagging.

The author made the following general statements regardin probable power factors: (1) Operating power factors above 0.9 will be obtained only when practically all of the load is synchronou motors or converters which may be operated at practically unit power factor. Even with this character of load the generator should be capable of operating satisfactorily at 0.93 power facto to provide for unforeseen contingencies. (2) Power factors of 0.9 to 0.95 can be safely predicted only when the load is entirely incan descent lighting or heating, or if a large non-inductive load, such a synchronous motors or converters, is used with a smaller proportio of inductive motor load. (3) For the average central-station load consisting of lighting and motor service, a power factor of 0.8 should be assumed. (4) A power factor of 0.70 should be assume for a plant having a large proportion of induction motors, ar lighting, electric furnaces or electric welding load.

58. Kilowatts and Kilovolt-amperes (*General Electric Com pany*).—The term kilowatt (kw.) indicates the measure of powe which is all available for work. Kilovolt-amperes (kva.) indicat the measure of apparent electrical power made up of two compo nents, an energy component and a wattless or induction component Kw. indicates real power and kva. apparent power. They ar identical only when current and voltage are in phase, that is, whe the power factor is 1. Ammeters and voltmeters indicate tota effective current and voltage regardless of the power factor, whil a wattmeter indicates the effective product of the instantaneou values of electromotive force and current. A wattmeter, then indicates real power.

Standard guarantees on alternating-current generators are mad on the basis of loads at 100 per cent. power factor, because thi has seemed to be the best method, but it must not be inferred that *given generator will deliver* its rated power output at all pov *factors. The generator rating* in kw. will be reduced in propor *to the power factor* and probably in a greater ratio if the p *actor is very low. In* general, a generator will carry a kva *the extent of its normal* kw. rating if the power factor of th is not below 80 per cent. The actual power output, however, must be reduced in proportion to the power factor. The method of rating alternating-current generators by kva. instead of by kw. is now in general use.

In discussing an alternating-current load, it is well to state it in terms of kw., power factor and kva. thus: 200 kw., 80 per cent. power factor (250 kva.). This shows that the current in the circuit corresponds to 250 kva. and heats the generator and conductors to that extent, but that only 200 kw. is available for doing work.

59. For a single-phase circuit the relations between kilowatts and kilovolt-amperes are:

$$\text{kilovolt-amperes} = \frac{\text{volts} \times \text{amperes}}{1000} \qquad \text{or kva.} = \frac{E \times I}{1000}$$

$$\text{kw.} = \text{kva.} \times \text{power factor} \qquad \text{kva.} = \frac{\text{kw.}}{\text{power factor}}$$

$$\text{power factor} = \frac{\text{kw.}}{\text{kva.}}$$

For an example see Fig. 27.

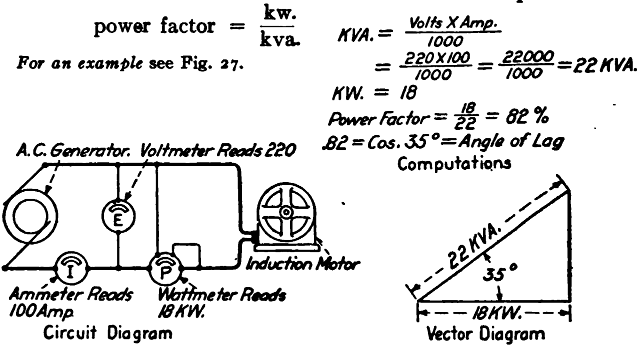


FIG. 27.—Illustrating the distinction between kw. and kva.

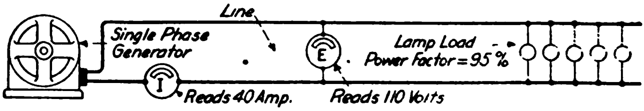


FIG. 28.—A power factor problem.

59A. For a single-phase circuit the following equations show the relations between power, current, voltage and power factor.

$$I = \frac{P}{E \times p.f.} \qquad E = \frac{P}{I \times p.f.} \qquad P = E \times I \times p.f. \qquad p.f. = \frac{P}{E \times I}$$

Wherein, I = current in amperes, P = power in watts, E = pressure in volts between lines and $p.f.$ = power factor.

Examples.—Figs. 27 and 28 show examples of the application of the above tions. *The product of* volts and amperes (*EI*) is called volt-amperes; *bove paragraph.*

Example.—In the circuit of Fig. 28, what is the actual load in watts? In kilowatts? Current = 40 amp., voltage at load = 110, power factor of load = 95 per cent.
Solution.—Substitute in the formula

$$P = E \times I \times p.f. = 110 \times 40 \times 0.95 = 4,180 \text{ watts}$$

$$\text{kw.} = \frac{\text{watts}}{1000} = \frac{4180}{1000} = 4.18 \text{ kw.}$$

60. To find amperes in the line in single-phase circuits (*Westinghouse Diary*) multiply the power in kilowatts by the value, for the proper voltage and power factor, shown in table 61.

61. Amperes per Phase per Kilowatt, Single-phase Circuits

Volts	Power factor			
	100 per cent.	90 per cent.	80 per cent.	70 per cent.
110	9.09	10.01	11.36	12.98
220	4.54	5.05	5.68	6.49
440	2.27	2.52	2.84	3.24
1,100	0.909	1.01	1.136	1.298
2,200	0.454	0.505	0.568	0.649

62. A two-phase current consists of two currents that differ in phase by 90°. See curves of Fig. 29. If two sets of coils are arranged on an armature (Fig. 29) so that the e.m.f. in one set will

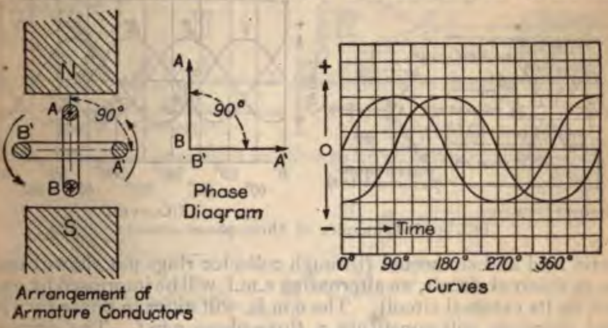


FIG. 29.—Diagrams for two-phase currents.

attain its maximum value 90° later than that in the other, the e.m.fs. will force two-phase currents through an external circuit. Instead of being on the same armature each of the sets of coils might be on different armatures which are so mechanically connected together as to preserve the 90° phase relation. (See section on "Motors and Generators" for information on practical machines.)

63. Application of the Two-phase System.—Several years ago certain engineers advocated two-phase generators and distributing systems *in preference to three-phase*, as it was believed that *unbalanced load on the phases* would have less adverse effect on *the performance of the two-phase equipment.* Recent experienc seems to indicate that the three-phase system is preferable to the two-phase for both transmission and distribution. It is seldom that two-phase equipment is now purchased except for additions to existing two-phase installations. See Par. 243 for relative weights of copper for different systems.

64. To find amperes per phase in two-phase circuits (*Westinghouse Diary*) multiply the load in kw. by the value in the following table corresponding to the proper power factor and voltage.

65. Amperes per Phase per Kilowatt, Two-phase Circuits

Volts	Power factor			
	100 per cent.	90 per cent.	80 per cent.	70 per cent.
110	4.54	5.04	5.67	6.48
220	2.27	2.52	2.83	3.24
440	1.13	1.26	1.41	1.62
1,100	0.454	0.504	0.567	0.648
2,200	0.227	0.252	0.283	0.324

66. A three-phase current consists of three alternating currents that differ in phase by 120°, as indicated in Fig. 30. If three coils be arranged 120° apart on an armature (Fig. 30) rotated in a mag-

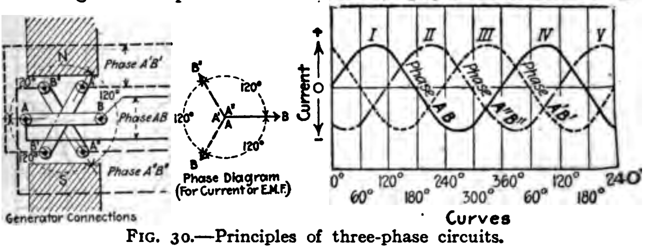


FIG. 30.—Principles of three-phase circuits.

netic field and connected (through collector rings not shown) each to an external circuit, an alternating e.m.f. will be impressed by each coil on its external circuit. The e.m.fs. will differ in phase by 120 and therefore will constitute a three-phase e.m.f. The current in the circuits will constitute a three-phase current. Three single phase generators, if mechanically coupled together so as to maintain a 120° phase relation, would produce a three-phase e.m.f. Practical three-phase generators usually have more than two poles and consequently have more coils than indicated in Fig. 30. Modern alternating-current generators have revolving fields and stationary armatures.

66A. Coil Connections.—Fig. 31 shows four methods of connecting three-phase generator (or other apparatus) coils and the external circuits for each. *Method I*, although it would work, is seldom if ever used for economic reasons hereinafter given. It shows the *elementary three-phase* circuit and illustrates the principle. Each of *the three-phases* would carry a current differing in phase by 1 from the currents in the other two. One common return, as shown at *II* can be substituted for the three return wires of *I*. Now with a balanced load, *i.e.*, one loading each of the phases equally, this return wire would carry no current, hence it is usually omitted (**star** or **Y-connection** of *III*). In *IV* is shown the delta connection.

67. The voltage and current relations in a star or Y-connected three-phase circuit are indicated in Fig. 32. Although the armature coils of the generator are said to be 120° apart, when they are Y-connected as shown in *I*, the e.m.fs. in any two are 60° apart and

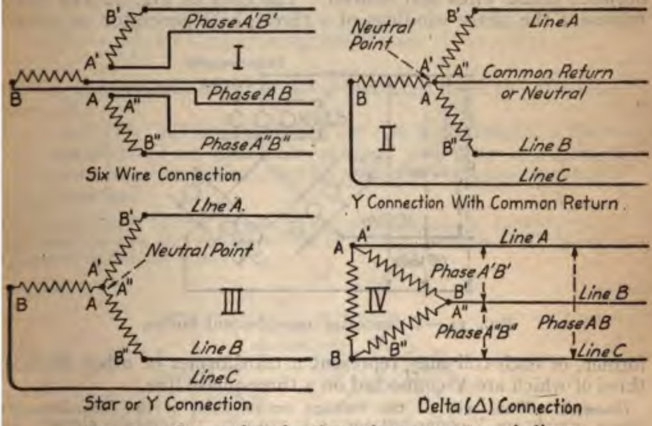


FIG. 31.—Connections for three-phase generator windings.

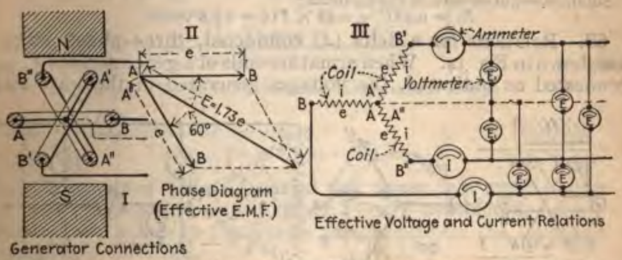


FIG. 32.—Properties of a star, or Y-connected three-phase circuit.

these e.m.fs. are added as shown in the *phase diagram II*. The sum of the voltages of any two coils is then equal to $\sqrt{3}$ or 1.73 times the voltage developed in 1 coil. The following formulas show *the relation of* voltage and current in the circuit. (*All are effective values* and balance is assumed.) See Fig. 32.

$$I = i$$
$$E = E_1 \times \sqrt{3} = E_1 \times 1.73$$
$$E_1 = \frac{E}{\sqrt{3}} = \frac{E}{1.73} = E \times 0.577 \text{ or approximately } E_1 = 0.58E$$
$$E_1 = e$$

Wherein I = amp. per phase in the line, i = amp. per phase in each coil, E = volts between phase wires on the line, e = volts across each group of armature coils connected across each phase, E_1 = volts between phase wires and neutral. The coils in Fig. 32 *III* may represent the phase windings of a three-phase generator or trans-

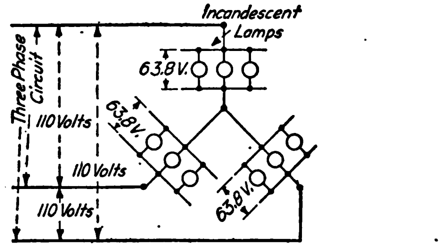


FIG. 33.—Y-connected incandescent lamps.

former, or each coil may represent a transformer or other device three of which are Y-connected on a three-phase line.

Example.—What will be the voltage across each of the incandescen lamps, which are Y-connected across a 110-volt, three-phase circuit, i Fig. 33?
Solution.—Substitute in the formula:

$$E_1 = 0.58E = 0.58 \times 110 = 63.8 \text{ volts.}$$

68. Relations for a delta (Δ) connected, three-phase circui are shown in Fig. 34. When armature coils of a generator, see *I*, ar connected as indicated, the voltages generated in them are 120'

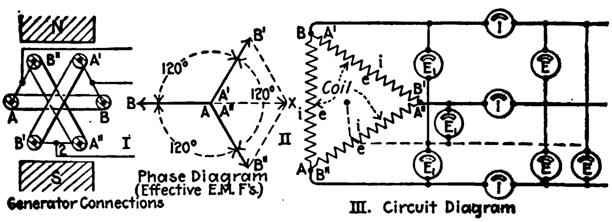


FIG. 34.—Properties of a Δ (delta)-connected, three-phase circuit.

part. It would appear that the current might flow around throu e coils and not into the external circuit, but it is evident from se diagram, *II*, that the sum of the effective voltages gener wo of the coils is equal and opposite to that of the third. H stead of tending to force current around internally, the voltages nd to force current out into the line. The following formulas dicate the relations of the voltages and currents. (All are ective values and the circuit is assumed to be balanced.) See g. 34.

$$I = i \times \sqrt{3} = i \times 1.73$$

$$i = \frac{I}{\sqrt{3}} = I \times 0.577 \text{ or approximately } i = I \times 0.58$$

$$E = e$$

$$E_1 = \frac{e}{\sqrt{3}} = e \times 0.577 \text{ or approximately } E_1 = e \times 0.58$$

ierein the symbols have the same meanings as in the preceding ragraph.

Each coil (Fig. 34) may represent the phase windings of a three-ase transformer or generator or each coil may represent a nsformer or other device three of which are Δ-connected on a ee-phase line.

xample.—Each of the groups of incandescent lamps, delta-connected oss the 110-volt, three-phase circuit of Fig. 35, takes 10 amp. What is current in the line wires?

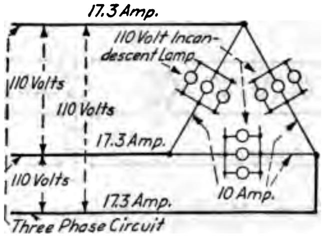


FIG. 35.—Delta (Δ)-connected incandescent lamps.

olution.—Substitute in the formula:

$$I = i \times 1.73 = 10 \times 1.73 = 17.3 \text{ amp.}$$

19. Relations of voltage, current and power that apply to any ee-wire three-phase circuit either Δ- or Y-connected.—Refer Fig. 36 for a key to the letters that appear in the following mulas.

For a non-inductive load:

$$I = \frac{P}{E \times \sqrt{3}} = \frac{0.577 \times P}{E} \text{ or approximately } = \frac{0.58 \times P}{E}$$

$$E = \frac{P}{I \times \sqrt{3}} = \frac{0.577 \times P}{I} \text{ or approximately } = \frac{0.58 \times P}{I}$$

$$P = E \times I \times \sqrt{3} = 1.73 \times E \times I$$

For an inductive load:

$$p.f. = \frac{P}{1.73 \times I \times E} = \frac{0.577 \times P}{I \times E} \text{ or approximately } = 0.$$

$$E = \frac{P}{p.f \times 1.73 \times I} = \frac{0.577 \times P}{p.f. \times I} \text{ or approximately } =$$

$$I = \frac{P}{p.f. \times 1.73 \times E} = \frac{0.577 \times P}{p.f. \times E} \text{ or approximately } =$$

$$P = 1.73 \times E \times I \times p.f.$$

Wherein I = line current in amperes, P = the power trans in watts, E = voltage across lines and $p.f.$ is the power factoı circuit.

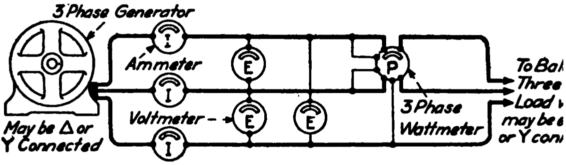


FIG. 36.—Relations for any (Δ- or Y-connected), three-phase cir

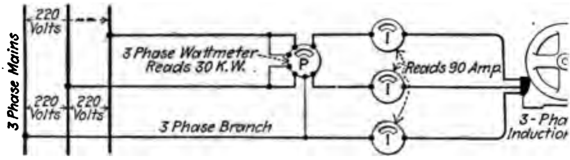


FIG. 37.—Motor on a three-phase circuit.

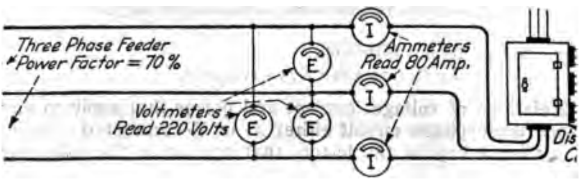


FIG. 38.—Load on a three-phase circuit.

Example.—What is the power factor in the 220-volt circuit to th in Fig. 37? The three ammeters each indicate 90 amp. and the thre wattmeter indicates 30 kw. (30,000 watts).

Solution.—Substitute in the formula:

$$p.f. = \frac{0.577 \times P}{I \times E} = \frac{0.577 \times 30{,}000}{90 \times 220} = \frac{17{,}310}{19{,}800} = 0.88 = 88 \text{ per cent}$$

factor.

Example.—The power factor on the feeder of Fig. 38 is known to be 70 per cent. The current in each line is 80 amp. and the voltage across each phase is 220. What actual power is being delivered to the panel box?

Solution.—Substitute in the formula:

$$P = 1.73 \times E \times I \times p.f. = 1.73 \times 220 \times 80 \times 0.70 = 21313.6 \text{ watts}$$

$$kw. = \frac{\text{watts}}{1,000} = \frac{21313.6}{1,000} = 21.3 \text{ kw.}$$

Examples.—Fig. 39 shows some numerical examples of voltage and current relations in a three-phase circuit. For convenience the voltage on the main is taken as 100. For any other voltage the values given in the illustration would vary proportionally. For 200 volts they would be twice as great as

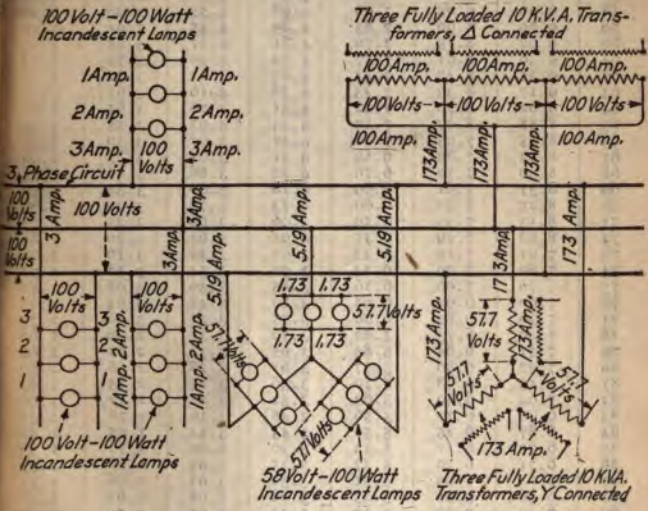


FIG. 39.—Examples of current and voltage relations with three-phase circuits.

shown, for 220 volts they would be 2.2 times as great, etc. Note that when a group of three devices is connected in Δ, each device has line voltage impressed on it and must be designed for that voltage; the current in the line will be 1.73 times the current through the device. When Y-connected, each of the three devices must be designed for $\frac{1}{1.73}$ or 0.577 times the line-voltage and the line current will be the same as the current through it.

70. To find amperes per phase in three-phase circuits multiply the load in kw. by the value in table 71 corresponding to the proper power factor and voltage.

71. Amperes per Kilowatt in Each Leg of a Bal

Power factor	Volts be					
	100	110	125	200	220	250
50	11.55	10.50	9.24	5.77	5.25	4.62
51	11.32	10.29	9.06	5.66	5.15	4.53
52	11.10	10.09	8.88	5.55	5.05	4.44
53	10.89	9.90	8.72	5.44	4.95	4.36
54	10.69	9.72	8.55	5.34	4.86	4.28
55	10.50	9.54	8.40	5.25	4.77	4.20
56	10.31	9.37	8.25	5.15	4.69	4.12
57	10.13	9.21	8.10	5.06	4.60	4.05
58	9.96	9.05	7.96	4.98	4.53	3.98
59	9.79	8.90	7.83	4.89	4.45	3.92
60	9.62	8.75	7.70	4.81	4.37	3.85
61	9.46	8.61	7.57	4.73	4.30	3.79
62	9.31	8.47	7.45	4.65	4.23	3.72
63	9.17	8.33	7.33	4.58	4.16	3.67
64	9.02	8.20	7.22	4.51	4.10	3.61
65	8.88	8.07	7.10	4.44	4.03	3.55
66	8.75	7.95	7.00	4.37	3.97	3.50
67	8.62	7.83	6.89	4.31	3.91	3.45
68	8.49	7.72	6.79	4.24	3.86	3.40
69	8.37	7.61	6.69	4.18	3.80	3.34
70	8.25	7.50	6.60	4.13	3.75	3.30
71	8.13	7.39	6.50	4.06	3.69	3.25
72	8.02	7.29	6.41	4.01	3.64	3.20
73	7.91	7.19	6.33	3.95	3.59	3.16
74	7.80	7.09	6.24	3.90	3.54	3.12
75	7.70	7.00	6.16	3.85	3.50	3.08
76	7.60	6.91	6.08	3.80	3.45	3.04
77	7.50	6.82	6.00	3.75	3.41	3.00
78	7.40	6.73	5.92	3.70	3.36	2.96
79	7.31	6.64	5.85	3.65	3.32	2.92
80	7.22	6.56	5.77	3.61	3.28	2.88
81	7.13	6.48	5.70	3.56	3.24	2.85
82	7.04	6.40	5.63	3.52	3.20	2.82
83	6.96	6.32	5.56	3.48	3.16	2.78
84	6.87	6.25	5.50	3.43	3.12	2.75
85	6.79	6.17	5.43	3.39	3.09	2.72
86	6.71	6.10	5.37	3.35	3.05	2.68
87	6.64	6.03	5.31	3.32	3.01	2.66
88	6.56	5.96	5.25	3.28	2.98	2.62
89	6.49	5.90	5.19	3.24	2.95	2.59
90	6.41	5.83	5.13	3.20	2.91	2.56
91	6.34	5.77	5.08	3.17	2.88	2.54
92	6.28	5.70	5.02	3.14	2.85	2.51
93	6.21	5.64	4.97	3.10	2.82	2.48
94	6.14	5.58	4.91	3.07	2.79	2.46
95	6.08	5.52	4.86	3.04	2.76	2.43
96	6.01	5.47	4.81	3.00	2.73	2.40
97	5.95	5.41	4.76	2.97	2.70	2.38
98	5.89	5.36	4.71	2.94	2.68	2.35
99	5.83	5.30	4.66	2.91	2.65	2.33
100	5.75	5.25	4.62	2.88	2.63	2.31

72. Methods of determining the power factor of circui described in the division of this section subjected "Measurer Testing and Instruments."

73. Skin Effect.—When an alternating current flows t a conductor there is an inductive action whereby the cu the conductor is forced toward its surface. The current d greater at the surface than at the center and under certa

-phase Line (*Power*, Nov. 21, 1911)

wo wires						
550	1,100	1,150	2,200	2,300	6,600	Power factor
2.10	1.050	1.004	0.525	0.502	0.175	50
2.06	1.029	0.985	0.515	0.492	0.172	51
2.02	1.009	0.966	0.505	0.483	0.168	52
1.98	0.990	0.947	0.495	0.474	0.165	53
1.94	0.972	0.930	0.486	0.465	0.162	54
1.91	0.954	0.913	0.477	0.456	0.159	55
1.87	0.937	0.897	0.469	0.448	0.156	56
1.84	0.921	0.881	0.460	0.440	0.153	57
1.81	0.905	0.866	0.453	0.433	0.151	58
1.78	0.890	0.851	0.445	0.425	0.148	59
1.75	0.875	0.837	0.437	0.418	0.146	60
1.72	0.861	0.823	0.430	0.411	0.143	61
1.69	0.847	0.810	0.423	0.405	0.141	62
1.67	0.833	0.797	0.416	0.398	0.139	63
1.64	0.820	0.784	0.410	0.392	0.137	64
1.61	0.807	0.772	0.403	0.386	0.134	65
1.59	0.795	0.761	0.397	0.380	0.132	66
1.57	0.783	0.749	0.391	0.374	0.130	67
1.54	0.772	0.738	0.386	0.369	0.129	68
1.52	0.761	0.728	0.380	0.364	0.127	69
1.50	0.750	0.717	0.375	0.359	0.125	70
1.48	0.739	0.707	0.369	0.354	0.123	71
1.46	0.729	0.697	0.364	0.349	0.121	72
1.44	0.719	0.688	0.359	0.344	0.120	73
1.42	0.709	0.678	0.354	0.339	0.118	74
1.40	0.700	0.669	0.350	0.334	0.117	75
1.38	0.691	0.661	0.345	0.330	0.115	76
1.36	0.682	0.652	0.341	0.326	0.114	77
1.35	0.673	0.644	0.336	0.322	0.112	78
1.33	0.664	0.636	0.332	0.318	0.111	79
1.31	0.656	0.628	0.328	0.314	0.109	80
1.30	0.648	0.620	0.324	0.310	0.108	81
1.28	0.640	0.612	0.320	0.306	0.107	82
1.26	0.632	0.605	0.316	0.302	0.105	83
1.25	0.625	0.598	0.312	0.299	0.104	84
1.23	0.617	0.591	0.309	0.295	0.103	85
1.22	0.610	0.584	0.305	0.292	0.102	86
1.21	0.603	0.577	0.301	0.288	0.100	87
1.19	0.596	0.570	0.298	0.285	0.099	88
1.18	0.590	0.564	0.295	0.282	0.098	89
1.17	0.583	0.558	0.291	0.279	0.097	90
1.15	0.577	0.552	0.288	0.276	0.096	91
1.14	0.570	0.546	0.285	0.273	0.095	92
1.13	0.564	0.540	0.282	0.270	0.094	93
1.12	0.558	0.534	0.279	0.267	0.093	94
1.10	0.552	0.528	0.276	0.264	0.092	95
1.09	0.547	0.523	0.273	0.261	0.091	96
1.08	0.541	0.518	0.270	0.259	0.090	97
1.07	0.536	0.512	0.268	0.256	0.089	98
1.06	0.530	0.507	0.265	0.254	0.088	99
1.05	0.525	0.502	0.263	0.252	0.087	100

there may be practically no current flowing along the axis e conductor. Although skin effect and self induction both nate *from the same magnetic field they are not otherwis d. Since it increases* voltage drop and energy loss, sk *amounts to an increase* in resistance and is so consider *llowing table gives* values by which actual resistance *ors must be multiplied* to obtain their virtual resist to alternating currents. Non-conducting cores are sometim placed in the centers of large cables for alternating currents so th all of the metal will be worked at the best possible efficiency. S Table 182 for such conductors.

74. Skin effect in conductors of magnetic materials is mu greater than in those of non-magnetic materials due to the strong magnetic field that a given current will set up in a magnetic met See the tables in the *Standard Handbook.*

75. Skin effect in stranded conductors is, for all practical pu poses, equal to that in solid conductors of equal diameters. Tab 76 gives values for solid conductors.

76. Skin Effect Factors For Copper Wire.—Values by whi the real (ohmic) resistance of solid, round, copper conducto must be multiplied to obtain their virtual resistance to alternati currents of commercial frequencies.

Frequency	Factors for different copper wire sizes (B. & S. Gage) and diameters							
	4	3	2	1	0	00	000	000
25 cycles..	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.0
60 cycles..	1.000	1.000	1.000	1.000	1.001	1.002	1.005	1.0
130 cycles..	1.000	1.001	1.002	1.005	1.008	1.010	1.017	1.0

Frequency	Factors for different copper wire sizes (B. & S. Gage) and diameters.—*Continued*							
	1/2"	3/4"	1"	1 1/8"	1 1/4"	1 1/2"	1 3/4"	2"
25 cycles..	1.002	1.007	1.020	1.035	1.053	1.098	1.170	1.2
60 cycles..	1.008	1.040	1.111	1.168	1.239	1.420	1.622	1.8
130 cycles..	1.039	1.156	1.397	1.545	1.694	1.983	2.272	2.5

Example.—A No. 000 wire 1,000 ft. long has an actual resistance 0.0489 ohms. Its resistance to a 130-cycle alternating current would $0.0489 \times 1.017 = 0.0497$ ohms.

77. Self induction is the phenomena whereby an e.m.f. induced in a conductor by a change of current in the conduct itself. Such an e.m.f. always produces currents and magne fields in such a direction that they tend to oppose the induci currents and fields.

78. Work is the overcoming of mechanical resistance throu a certain distance. Work is measured by the product of t mechanical resistance times the space through which it is overcom Work is measured by the product of the moving force times t distance through which the force acts in overc[illegible] the resistan Work is, therefore, measured in foot-pounds[illegible] lb. is [illegible]

Example.—What work is done if a weight of 6 [illegible]d through a d tance of 8 ft.?

Solution.—Work = ft. × lb. = 8 × 6 = 48 ft-lb.

Example.—If 20 gal. of water are pumped [illegible] vertical height of 32 *what work has been done?*

Solution.—A gallon of water weighs 8 lb[illegible]fore Work = ft. × lb. = 32 × (20[illegible],120 ft-lb.

le.—If the piston in a steam engine travels, during a certain 1½ ft. and the total pressure on the piston is 40,000 lb., what work uring the interval?
n.—Work = ft. × lb. = 1.5 × 40,000 = 60,000 ft-lb.

Energy is capacity for doing work. Any body or medium s of itself capable of doing work is said to possess energy. l clock spring possesses energy because, in unwinding, it can k. A moving projectile possesses energy because it can ne the resistance offered by the air, by armor plate, etc., is do work. A charged storage battery possesses energy it can furnish electricity to operate a motor. Energy can essed in foot-pounds.

Energy of one sort may be transformed into energy of another Ieat energy in coal may be transformed (with a certain th a boiler, a steam engine and a generator, into electrical The energy possessed by a stream of falling water may be med, with a waterwheel and generator, into electrical There is a definite numerical relation between different energy. Thus 1 B.T.U., the unit of heat energy = 778 ft-lb. rical units, energy is expressed in watt-hours or kilowatt-

A kilowatt-hour represents the energy expended if work is r one hour at the rate of 1 kw.

A horse-power-hour represents the energy expended if done for one hour at the rate of 1 h.p.

Power is rate of doing work. The vork is done the greater the power l be required to do it. For example, i.p. motor can raise a loaded elevator in distance in 2 minutes a 20-h.p. vill (approximately) be required to the same distance in 1 minute.

The horse-power is the unit of power bout equal to the power of a strong o do work for a short interval. cally a horse-power is 33,000 ft-lb. ute, = 550 ft-lb. per second, = 1,980,-). per hour. Expressed as a formula:

$$\frac{L \times W}{33{,}000 \times t} = \frac{\text{foot-pounds per minute}}{33{,}000}$$

i, h.p. = horse-power, L = distance, in ough which W is raised or overcome; ght, in pounds, of the thing lifted or a or pull in pounds of the force over- nd t is the time in minutes required e or overcome the weight W through ance L.

FIG. 40.—Bucket in shaft.

le.—What horse-power is required in raising the load and bucket, 200 lb., shown in Fig. 40, from the bottom to the top of the shaft, e of 100 ft., in 2 minutes?
n.—*Substitute in the formula:*

$$h.p. = \frac{L \times W}{33{,}000 \times t} = \frac{100 \times 200}{33{,}000 \times 2} = 0.3 \text{ h.p.}$$

Example.—What average horse-power is required while moving the box loaded with stone, in Fig. 41, from A to B, 650 ft., in 3 minutes? It takes a horizontal pull of 150 lb. to move the box.

Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{650 \times 150}{33{,}000 \times 3} = 0.98 \text{ h.p.}$$

85. Electric power is expressed numerically in watts or in kilowatts. A kilowatt is 1,000 watts. The watt represents the amount of power in a circuit when the current in that circuit is 1 amp. and the electromotive force is 1 volt.

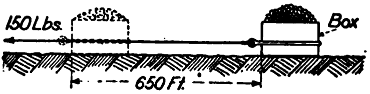


FIG. 41.—Moving loaded box.

86. Efficiency is the name given to the *ratio of output to input.* No machine gives out as much energy or power as is put into it. There are some losses in even the most perfectly constructed machines. Efficiency is usually expressed as a percentage, thus, "the efficiency of a certain motor is 80 per cent." This means that only 80 per cent. of the energy or power received by the motor as electricity is delivered by the motor at the pulley. Another way of stating the definition is:

$$\text{efficiency} = \frac{\text{output}}{\text{input}}$$

It follows that

$$\text{input} = \frac{\text{output}}{\text{efficiency}}$$

and, $\text{output} = \text{input} \times \text{efficiency}.$

When using the formulas, output and input must be expressed in the same units.

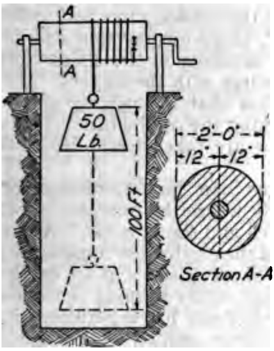
87. Output is the useful energy delivered by a machine and **input** is the energy supplied to a machine.

Example.—If 45 kw. is supplied to a motor and its output is found to be 54.2 h.p., what is its efficiency?

Solution.—Since 1 h.p. = 0.746 kw., 54.2 h.p. = 54.2 × 0.75 = 40.6 kw. Then substituting in the formula

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{40.6}{45} = 0.90 = 90 \text{ per cent. efficiency.}$$

88. Torque is the measure of the tendency of a body to rotate. It is the measure of a turning or twisting effort and it is usually expressed in pounds-foot or in pounds force at a given radius. Torque may exist even if there be no motion. Thus, in Fig. 42, the torque at the circumference of the drum is 50 lb. so long as the weight is supported, whether the drum be moving or standing still. It is assumed that the hoisting rope has no weight. Torque is sometimes expressed as the product of the force introducing the tendency to rotate times the distance from the center of rotation to the point of application of the force. For instance, in Fig. 43 the torque tending to turn the cylinder in the brick wall would be 100 × 12 = 1,200 lb-ft. (In some books this would, inaccurately, be expressed as 1,200 ft-lb.) cylinder cannot turn and no work could be done, yet there torque. Probably the most preferable way of expressing the torq is in terms of pressure (or force) and radius. Thus: "100 lb. foi at 12 ft. radius." Ordinarily the expression is given for unit or 1- radius. Then, for the case of Fig. 43, the torque would be 1,2 lb. at 1 ft. radius. Because of the fact that many writers a **engineers erroneously express units of both work and torque** foot-pounds, a confusion sometimes exists regarding the distincti between the two. Work (see 7 is properly expressed in fo pounds (ft-lb.), while torq should be expressed in pounds-fe (lb-ft.), or preferably in poun at a given radius.



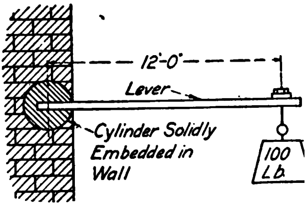


FIG. 42.—Example of work and of torque. FIG. 43.—An example of torq

89. Centigrade and Fahrenheit Thermometer Scales

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	De F.
0	32.	21	69.8	41	105.8	61	141.8	81	177
1	33.8	22	71.6	42	107.6	62	143.6	82	179
2	35.6	23	73.4	43	109.4	63	145.4	83	181
3	37.4	24	75.2	44	111.2	64	147.2	84	183
4	39.2	25	77.	45	113.	65	149.	85	185
5	41.	26	78.8	46	114.8	66	150.8	86	186
6	42.8	27	80.6	47	116.6	67	152.6	87	188
7	44.6	28	82.4	48	118.4	68	154.4	88	190
8	46.4	29	84.2	49	120.2	69	156.2	89	192
9	48.2	30	86.	50	122.	70	158.	90	194
10	50.	31	87.8	51	123.8	71	159.8	91	195
11	51.8	32	89.6	52	125.6	72	161.6	92	197
12	53.6	33	91.4	53	127.4	73	163.4	93	199
13	55.4	34	93.2	54	129.2	74	165.2	94	201
14	57.2	35	95.	55	131.	75	167.	95	203
15	59.	36	96.8	56	132.8	76	168.8	96	204
16	60.8	37	98.6	57	134.6	77	170.6	97	206
17	62.6	38	100.4	58	136.4	78	172.4	98	208
18	64.4	39	102.2	59	138.2	79	174.2	99	210
19	66.2	40	104.	60	140.	80	176.	100	212
20	68.	......	......	......	......	......	......	......	....

For values *not appearing* in the table use the following formu

$$\textit{Temp. C.} = \tfrac{5}{9} \times (\text{Temp. F.} - 32.)$$

$$\textit{Temp. F.} = (\tfrac{9}{5} \times \text{Temp. C.}) + 32.$$

MEASURING, TESTING AND INSTRUMENTS

90. **Electricians often test circuits for the presence of voltage by touching the conductors with the fingers.** This method is safe where the voltage does not exceed 250 and is often very convenient for locating a blown-out fuse or for ascertaining whether or not a circuit is alive. Some men can endure the electric shock that results without discomfort whereas others cannot. Therefore, the method is not feasible in some cases. Which are the outside wires and which is the neutral wire of a 110–220 volt, three-wire system can be determined in this way by noting the intensity of the shock that results by touching different pairs of wires with the fingers. Use the method with caution and be certain that the voltage of the circuit does not exceed 250 before touching the conductors. (This and the several paragraphs that follow are taken from *Electrical Engineering*.)

91. **The presence of low voltages can be determined by "tasting."** The method is feasible only where the pressure is but a few volts and hence is used only in bell and signal work. Where the voltage is very low, the bared ends of the conductors constituting the two sides of the circuit are held a short distance apart on the tongue. If voltage is present a peculiar mildly burning sensation results which will never be forgotten after one has experienced it. The "taste" is due to the electrolytic decomposition of the liquids on the tongue which produces a salt having a taste. With relatively high voltages, possibly 4 or 5 volts, due to as many cells of battery,

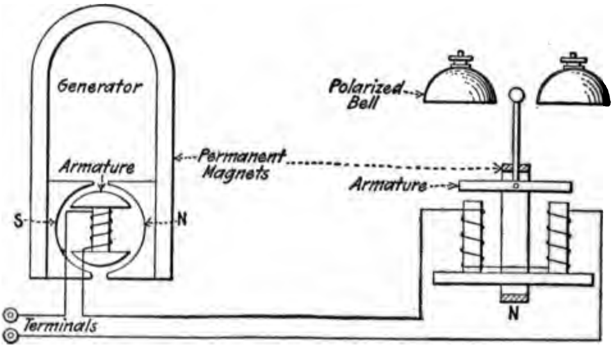


FIG. 44.—Circuits of testing magneto.

it is best to first test for the presence of voltage by holding one of the bared conductors in the hand and touching the other to the tongue. Where a terminal of the battery is grounded, often a taste can be detected by standing on moist ground and touching a conductor from the other battery terminal to the tongue. Care should be exercised to prevent the two conductor ends from touching each other at the tongue, for if they do a spark can result that may burn.

The magneto test set is one of the most valuable testing ments to the practical man because of its simplicity and the iat it is always ready for service. Fig. 44 shows the circuit ig. 45 a perspective view of a testing magneto. The appara-nsists of a small hand-operated alternating-current generator es with a polarized electric bell. Alternating current will ells of this type. If the external circuit connected to the ials of the magneto is closed ie crank of the generator is l, current will flow and the ill ring.

resistance through which tos will ring is determined eir design. An ordinary to will ring through possi-,000 to 40,000 ohms. Elec-ic capacity effects must be ered when testing with a to. When testing long cir-such as telephone lines or s that are carried in cable considerable distance, the the magneto may ring, due acity, apparently indicating -circuit, whereas the circuit e perfectly clear or open.

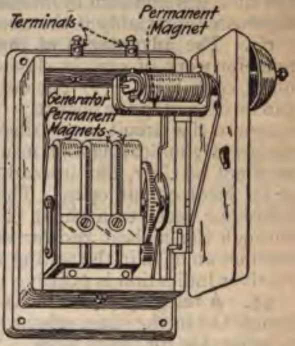
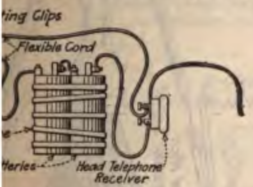


FIG. 45.—Assembly of testing magneto.

ts associated with iron, such as field coils of generators, may considerable inductance. With highly inductive circuits test, the magneto may "ring open"; that is, the bell may ig at all, even though the inductive circuit connected to it be ly closed. In ordinary wiring work the effects of capacity ductance are usually negligible and the true condition of the will be indicated by the performance of the magneto bell.



6.—Head-telephone and dry-battery testing set.

93. A telephone receiver in combination with one or two dry cells constitutes an excellent equipment for certain tests. A "head" telephone receiver (Fig. 46) is usually preferable to those of the watch-case types, because it is held on the head by the metal strap, allowing the unrestricted use of both hands. Metal testing clips—suspender will do—are soldered to the flexible testing cords. The tele-receiver is extremely sensitive and will give a weak "click" when the current to it passes through an exceedingly high nce. In using, one clip is gripped on one conductor of the *to be tested* and the other clip is tapped against the other *tor. Prolonged connection should be avoided because it will* *wn" the battery.* A vigorous click of the receiver indicate a closed circuit, while a weak click or none at all, indicates an open circuit. After practice it is possible to determine approximately the resistance of the circuit under test by the intensity of the receiver click. When the battery and receiver test set are connected to a circuit having some electrostatic capacity, the receiver will give a vigorous click when the clips are first touched to the circuit terminals, even though the circuit be open. With successive touchings the click will diminish in intensity if the circuit is open, but will not diminish appreciably if the circuit is closed.

94. **The advantages of the telephone receiver over the magneto** for work of certain classes are: (1) The receiver and battery outfit costs little. (2) The outfit can be made so compact that it can be carried in the pocket. (3) In making insulation tests with a magneto the circuit may "ring clear"; that is, the bell will not ring, apparently indicating high insulation resistance, whereas the circuit may not be clear, but instead the magneto may be out of order or its local circuit open. The indication is negative. With the telephone receiver a slight click is produced even when testing through the highest resistances. The absence of a click usually signifies an open in the testing apparatus itself. Thus the telephone receiver indication is positive.

95. **A telegraph sounder is sometimes used for testing.** It is connected in the same way as the telephone receiver of Fig. 47, and is adaptable for rough work. When the circuit under test is closed and the flexible cord clips are touched to the circuit conductors, the sounder clicks. Where the circuit is open there is no click. One feature of the sounder method is that the click is audible at a considerable distance from the instrument.

96. **An electric bell outfit for testing** is shown in Fig. 47. When the free ends for testing are touched to a closed circuit of not too high resistance the bell rings. Where the circuit is open the bell will not ring. Flexible cord can be used for the testing conductors of the outfit and testing clips can be provided as in Fig. 47.

FIG. 47.—Electric bell testing outfit.

FIG. 48.—A practical test-lamp outfit.

97. **A test lamp** (Fig. 48), consisting merely of a weatherproof socket of moulded mica, into which is screwed an 8 or 16 c-p. carbon lamp of the voltage of the circuits involved, is very conve-

:nt for rough tests on interior-lighting and motor-wiring systems. rcelain sockets are undesirable because they are so readily broken. ass sockets should not be used because they may fall across nductors and thereby cause short-circuits. Testing clips may be dered to the ends of the leads which are moulded in the socket. me uses of the testing lamp are given in a following paragraph, d it is very convenient for testing for defective fuses.

98. **Rules for Use of Ammeter and Voltmeter** (*Timbie's ements of Electricity*).—Place ammeter in series, always using a ort-circuiting switch, where possible, as shown in Fig. 49, to pre-

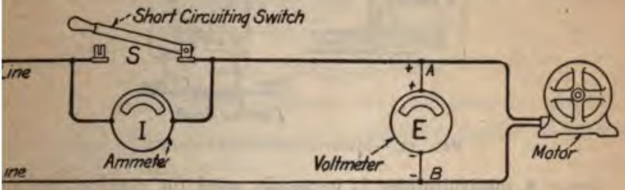


FIG. 49.—Ammeter and voltmeter connections.

nt injury to the instrument. Place voltmeter in shunt (Fig. 49). t the + side of the instrument on the + side of the line. Fig. 49 ows the correct use of an ammeter and a voltmeter to measure current and the voltage supplied to the motor. The short-cuiting switch *S* must be opened before the ammeter is read. All current that enters the motor must then flow through the am-ter and be indicated. The ammeter is of very low resistance bout 0.001 or 0.002 ohm) and does not appreciably cut down the w of current. The voltmeter is of very high resistance (about ,000 ohms) and does not allow any appreciable current to flow

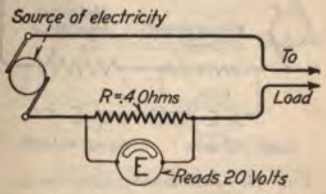


FIG. 50.—Current measurement with voltmeter.

rough itself. Yet enough goes through the voltmeter to cause to indicate the voltage across the terminal *AB* of the motor. ppose the voltage across the motor to be 110, what would happen an ammeter of 0.002 ohm resistance were by mistake placed ross *AB*? (Remember Ohm's law is always in operation.)

99. ***Ohm's law is often* applied in making determinations** of *stance, voltage, current* and power. In 35 and 36 examples are n *that indicate* the application of Ohm's law to measurements

100. A method of measuring current with a voltmeter is shown in Fig. 50. If a resistor of known resistance be connected in series in a circuit and the voltage across the coil measured with a voltmeter the current can be determined by Ohm's law thus:

Example.—(Fig. 50.) If the drop around 0.4 ohm resistance in series in a circuit is 20 volts, what is the current in the circuit?
Solution.—Substitute in the Ohm's law formula:

$$I = \frac{E}{R} = \frac{20}{0.4} = 50.\text{ amp.}$$

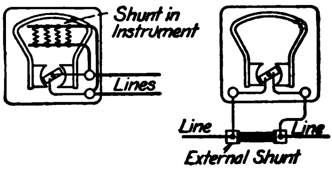


FIG. 51.—Millivoltmeters and shunts.

101. A millivoltmeter is generally used for making measurements like that of 99. A millivoltmeter reads in thousandths of volts so that a resistor of small resistance can be used. Ammeters, particularly those for large currents, are often millivoltmeters calibrated in amperes which are connected around a resistor, in series with the circuit (Fig. 51). The resistor is sometimes in the instrument case and is sometimes inserted in the bus-bars of a switchboard. See Fig. 51. Such resistors are called **shunts** and when furnished by instrument makers are carefully calibrated.

102. Resistance can be measured with a voltmeter as indicated in Fig. 52. A resistor of known resistance, a source of electricity

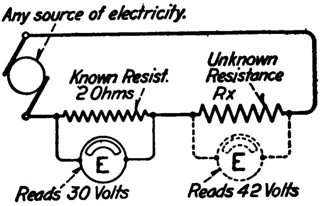


FIG. 52.—Resistance measurement.

and one voltmeter is required. The same constant current flows through both the known and the unknown resistance. The voltmeter reading E is taken and then the reading Ex. The voltage drops will be proportional to the resistances or:

$$\frac{R}{E} = \frac{R_x}{E_x} \text{ or } R_x = \frac{E_x \times R}{E}$$

Example.—Substituting the values from Fig. 52 in the formula:

$$R_x = \frac{E_x \times R}{E} = \frac{42 \times 2}{30} = \frac{84}{30} = 2.8 \text{ ohms.}$$

103. **Very small resistances can be measured,** as indicated in Fig. 53, with an ammeter and a millivoltmeter. This method is convenient for measuring the resistance of bus-bars, joints between conductors, switch contacts, brush-contact resistance and other low resistances. As large a current as is feasible should be used. This is another application of Ohm's law.

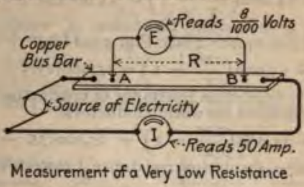


FIG. 53.—Measurement of very low resistance.

Example.—What is the resistance of the portion of the bus-bar between *A* and *B*, Fig. 53?
Solution.—Substitute in Ohm's law formula:

$$R = \frac{E}{I} = \frac{0.008}{50} = 0.00016 \text{ ohms.}$$

104. **Insulation resistance is usually measured** as suggested in Fig. 54. A voltmeter of known resistance, preferably of high resistance, and a source of e.m.f. (batteries or a generator), are required. First the voltage of the e.m.f. source is taken as shown

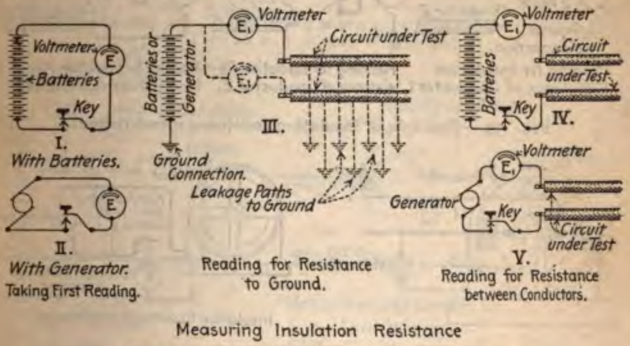


FIG. 54.—Measuring insulation resistance.

at *I* or *II*. The apparatus is then arranged as shown at *III* to measure the resistance from each side of the circuit to ground. At *IV* or *V* are shown the connections for measuring the resistance between conductors. If E = voltage of e.m.f. source, E_1 = reading of voltmeter when connected in series with insulation resistance to be measured, R_v = resistance, in ohms, of voltmeter and R_x insulation resistance sought, the following formula is used:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) \quad \text{(See Fig. 54.)}$$

Example.—In a certain (Fig. 55) test where a 110-volt generator was used as a source of e.m.f. and a voltmeter having a resistance of 15,000 ohms was used to read voltages. the readings indicated in Fig. 55 were obtained. What was the insulation resistance to ground of each side of the circuit and what was the insulation resistance between circuits?

Solution.—For the resistance of *conductor* 1 (see Fig. 55) substitute in the formula:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{5} - 1\right) = 15{,}000(22 - 1) = 15{,}000 \times 21$$

$= 315{,}000$ ohms = insulation resistance of conductor 1 to ground.

For the resistance of conductor 2 (see Fig. 55, *III*):

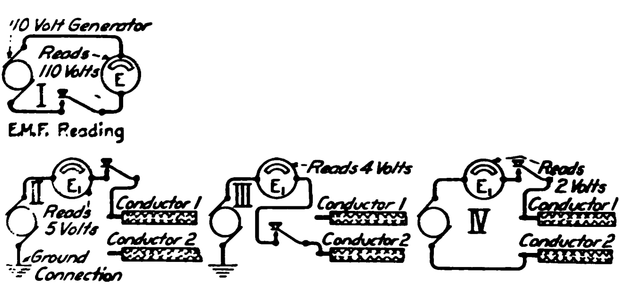
$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{4} - 1\right) = 15{,}000(27.5 - 1) = 15{,}000 \times 26.5$$

$= 397{,}500$ ohms = insulation resistance of conductor 2 to ground.

For the insulation resistance between conductors:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{2} - 1\right) = 15{,}000(55 - 1) = 15{,}000 \times 54$$

$= 810{,}000$ ohms = insulation resistance between conductors 1 and 2.



Reading for Insulation Resistance of Conductor 1. Reading for Insulation Resistance of Conductor 2. Reading for Insulation Resistance Between Conductors.

FIG. 55.—Example of insulation resistance measurement.

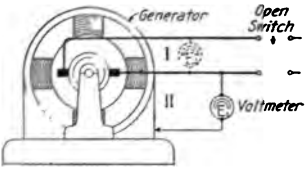
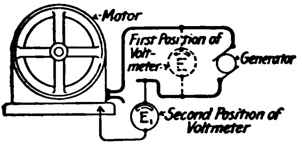


FIG. 56.—Measuring insulation resistance of a generator.



Insulation Resistance of a Motor.

FIG. 57.—Measuring insulation resistance of a motor.

105. The insulation resistance of a generator can be determined with a voltmeter of known resistance which is successively connected and read in positions *I* and *II*, Fig. 56. The formula of 104 is used. *The external circuit* connected to the generator should be cut off *while the measurements* are being taken so that its insulation resistance will not affect the readings.

106. *The insulation resistance of a motor* can be measured with a voltmeter as suggested in Fig. 57. The formula of 104 used. Unless the external circuit has high insulation resistance its resistance will affect the result.

107. Power, in direct-current or non-inductive alternating-current electric circuits, **can be measured** with a voltmeter and an ammeter. For two-wire circuits the power in watts, in accordance with Ohm's law, equals the product of volts times amperes, thus:

$$P = I \times E$$

Wherein P is the power in watts, I is the current in amperes and E is the e.m.f. in volts.

Example.—See 38 for examples of power problems. Although no instruments are shown in these, the principles are the same as if instruments were used.

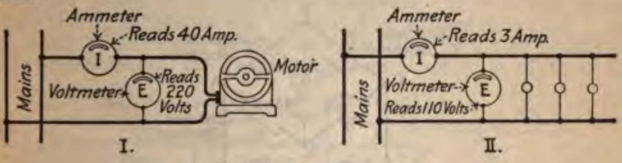


FIG. 58.—Power measurements.

Example.—In Fig. 58, *I*, the power taken by the motor is, substituting in the formula:

$$P = I \times E = 40 \times 220 = 8{,}800 \text{ watts}$$

or in kilowatts $= \dfrac{8800}{1000} = 8.8$ kw.

Example.—In Fig. 58, *II*, the power taken by the lamps is:

$$P = I \times E = 3 \times 110 = 330 \text{ watts}$$

or in kilowatts $\dfrac{330}{1000} = 0.33$ kw.

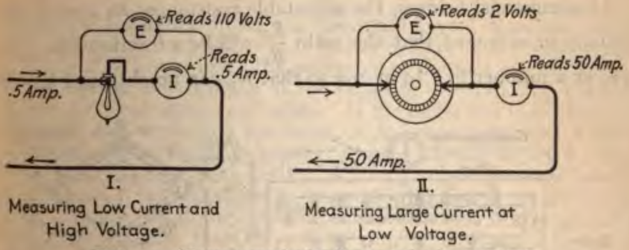


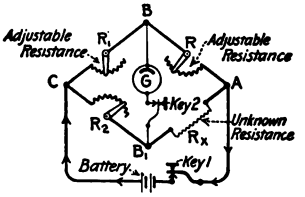
FIG. 59.—Correct methods of connecting instruments.

108. Methods of measuring power in alternating-current circuits are given in Pars. 59, 59A, and 148A to 151.

109. All ammeters and voltmeters (except electrostatic) **consume power when in use and introduce some error** (Timbie's *Elements of Electricity*). For minimum error (see Fig. 59, I) *when measuring a low current and high voltage, the voltmeter should be placed around both the ammeter and the apparatus under test. When measuring the power consumed by a piece of apparat[us] through which a large current at low voltage is flowing,* the voltm[eter] *should be placed immediately across the piece of apparatus under test and not across the ammeter.* (Fig. 59II.)

110. The Wheatstone bridge is an instrument for measuring medium and high resistances. It is not suitable for measuring resistances of less than 1 ohm. An elementary diagram is shown in Fig. 60. R_1, R_2 and R are adjustable resistances, R_x is the unknown resistance and G is a delicate galvanometer. A battery supplies electricity. It can be shown that if, when both keys are pressed, the galvanometer shows no deflection:

$$\frac{R_1}{R} = \frac{R_2}{R_x} \quad \text{or} \quad R_x = \left(\frac{R_2}{R_1}\right) R.$$



Wheatstone Bridge Diagram.

FIG. 60.—Elementary diagram of the Wheatstone bridge.

Example.—If $R_2 = 100$ ohms, $R_1 = 10$ ohms and $R = 672$ ohms what is the value of the unknown resistance?

Solution.—Substitute in the formula:

$$R_x = \left(\frac{R_2}{R_1}\right) R = \left(\frac{100}{10}\right) 672 = 10 \times 672 = 6{,}720 \text{ ohms.}$$

The unknown resistance is 6,720 ohms.

In commercial bridges, the adjustable resistances R_2 and R_1 are usually so arranged that the ratio $\frac{R_2}{R_1}$ will be a fraction like $\frac{1}{10}$ or $\frac{1}{100}$ or a number like 10 or 100 so that R_x can be obtained readily

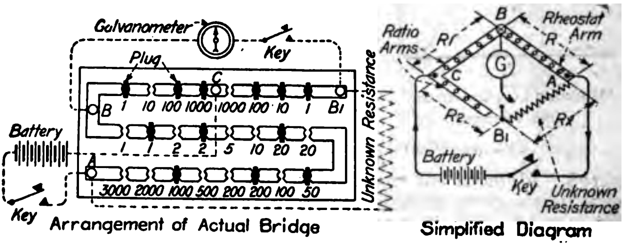


FIG. 61.—Post-office pattern of Wheatstone bridge.

by dividing or multiplying R by an easily handled number. R_1 and R_2 are sometimes called the ratio arms and R is called the rheostat arm. For most accurate results the resistances R, R_1, ar should be as nearly as possible equal to R_x.

111. A diagram of a commercial bridge of the post-office pattern is shown in Fig. 61. Its principle is similar to that of Fig. 60. Brass plugs are used to vary the resistance in arms R, R_1 and R_2. When a plug is inserted in the opening between two resistance coils it shunts out the coil. In using this bridge the ratio $\frac{R_2}{R_1}$ is arranged by the operator to correspond to R_x. Then R is adjusted until a balance is obtained. When R_x is greater than R the ratio must be 10, 100 or 1,000, and when R_x is smaller than R the ratio must be 0.1 or 0.01 or 0.001. If $R_1 = R_2$ the value of R_x equals R.

112. Directions for using a Wheatstone Bridge.—(1) Insert the unknown resistance. (2) Make a mental estimation of the probable value of the unknown resistance. If it is not greater than the total resistance in the arm R or smaller than that of any one coil in R, R_1 and R_2 may be made equal by taking plugs from the proper holes. (3) Take a plug from a coil, in R, of about the

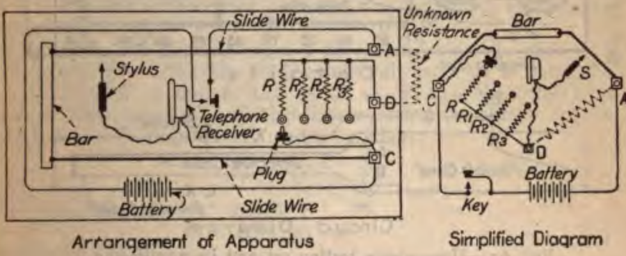


FIG. 62.—The ohmmeter.

estimated resistance of R_x and press the keys. Note the deflection of the needle, whether it is to the right or left. Now unplug a coil in R of about twice the resistance of the first one unplugged. If the needle now deflects in the opposite direction the value of R_x lies between these two values. If the deflection is in the same direction the unplugged resistance in R is too great and a value of about one-half that originally selected should be tried. Systematically narrow down the limits until the best possible balance is obtained. (4) Usually it is impossible to secure an exact balance. When this is the case proceed as indicated in the following example: Assume that the coil of smallest resistance in the R arm is of 0.1 ohm. With this added the galvanometer deflects two divisions to the right. The deflection without is three divisions to the left. Therefore a difference of 0.1 ohm makes a difference of five scale divisions. The resistance that would give no deflection is $\frac{3}{5} \times 0.1 = 0.06$ ohm. (5) Be careful not to allow the *metal parts of the bridge plugs to become wet or greasy from the hands.* (6) *Use a twisting motion when inserting the plugs. Put them in firmly* but do not use enough force to twist off the *insulating handles.* (7) When closing the keys, close the battery *first and in opening* the keys open the galvanometer key fir

113. How to Make a Slide-wire Bridge (*J. W. Himmelsbach, Power*, June 4, 1912).—The very satisfactory apparatus described in Fig. 63 can be easily and cheaply made. The only expensive part is a direct-reading, differential millivoltmeter having the zero in the middle of the scale, which reads 75 millivolts on either side of the zero point. Mount on a piece of well-seasoned 5×18×1-in. oak four binding-posts, *A*, *B*, *C*, *D*, and two lamp sockets, *L*, *L*, as shown; *M* and *N* are two small wire brads driven in the board, leaving only 1/8 in. projecting.

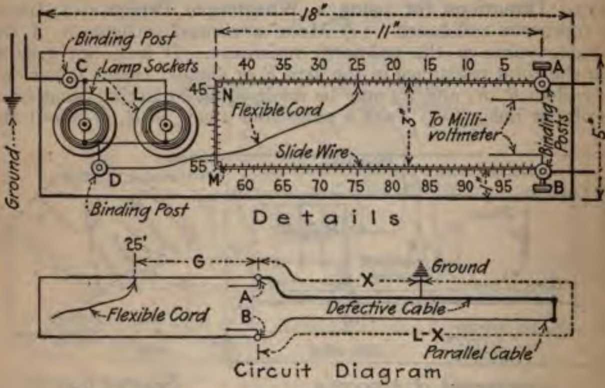


FIG. 63.—Home-made testing set and its application.

From *A* to *N*, *N* to *M*, and *M* to *B*, paste strips of paper 1 in. wide upon which a scale has been drawn, with divisions every 1/8 in., which will give 200 divisions. Mark every second division from 0 to 100, starting at *A*. Then stretch a piece of No. 26 or 28 B & S. gage, german-silver wire from *A* around *N* and *M* to *B*. This wire must be stretched tightly so that reading the scale will give correct proportional lengths of wire.

The lamp sockets are to be wired in parallel. Connect permanently to *D* a piece of flexible wire (lamp cord will do) to the end of which is soldered a knife-edge contact. This wire must reach from post *D* to post *A*. Binding posts *A* and *B* must have two connectors, as two sets of leads are fastened to them; this completes the testing set.

114. To Prepare for Testing for a Cable-ground with the Home-made Slide-wire Bridge.—Connect to the binding posts *A* and *B* respectively (Fig. 63), one lead to the available end of the grounded conductor and one lead to a conductor parallel to the grounded conductor and having the same destination. The ends of these two conductors, away from the testing set, must be joined together. Connect the millivoltmeter to the posts *A* and *B*.

If a 125-volt, direct-current circuit is available, connect one side post *C* and ground the other, and place two 16 c-p. lamps in the ckets. If no direct-current circuit is available, five or six battery ells connected in series can be used. Connect one terminal to ' and ground the other; short-circuit the lamp sockets with a lug fuse.

115. To locate the grounded point in a cable with the home-ade slide-wire bridge, run the knife-edge contact connected D (Fig. 63) along the graduated wire until the millivoltmeter ads zero. Suppose the reading on the wire is 25 divisions from . Referring to the lower diagram, if the total length of the ble loop is L, and the distance from the station to the ground is , then the following proportion holds good:

$$25 : X = 75 : L - X$$

lving for X,

$$75X = 25L - 25X$$
$$100X = 25L$$
$$X = 0.25L$$

d if the length of the cable is known, the distance X can readily determined.

Designating the distance from A to the point on the slide wire hich gives zero deflection on the millivoltmeter as G, and the istance from B around to this point as H, also the total loop ngth of the conductor, and the distance from the station to the round, L and X, respectively, as before, then:

$$G : X = H : L - X$$
$$GL - GX = HX \quad (1)$$

ut G plus H equals 100; therefore,

$$H = 100 - G \quad (2)$$

bstituting (2) in (1),

$$GL - GX = 100X - GX$$
$$100X = GL$$
$$X = \frac{G \times L}{100}$$

hich is the formula to be used when locating grounds with this pparatus.

If the ground is due to water—which will mean that it is not onfined to one point—this method is not very satisfactory. If wo or three conductors in the faulty cable are grounded, thus aking it impossible to get a cable clear from ground for a return, will, in all probability, be unnecessary to make the location st as a double ground is equivalent to a short-circuit, and short-ircuits are usually very apparent.

116. The ohmmeter is a special form of slide-wire Wheat-tone bridge. There are several types. One is shown in Fig. 62. he slide wire connected through a bar of practically zero sistance forms two arms of the bridge. A known resistance , R_1, R_2, or R_3, forms the third arm and the unknown resistance rms the fourth arm. Instead of a galvanometer a telephone ceiver is used. It is connected to a metal-pointed stylus which an be *touched at any point* along the slide wire. The batter y *is on the telephone receiver.* At the point where tapping t

4

slide wire with the stylus produces no sound in the receiver the unknown resistance is indicated directly in ohms on a scale under the slide wire.

Several scales indicating ohms can be provided under the slide wire and each scale may be printed in a different color. The holes of R, R_1, R_2, and R_3 are marked each with the color corresponding to the scale that is to be used when the plug is in the corresponding hole. A battery is used in some ohmmeters and an induction coil or a magneto in others.

117. To use the ohmmeter of Fig. 62, connect the unknown resistance as shown. Close the key. Pass the stylus along the wire gently tapping it and hold the telephone receiver to the ear. The unknown resistance will be indicated on the scale at the point where tapping produces no sound in the receiver. The plug P must be in some one of the resistance holes while the test is being made. Read from the scale of the color corresponding to the color at the hole in which P is inserted.

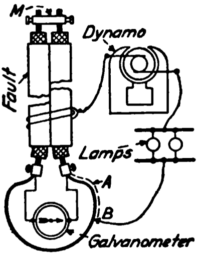


FIG. 64.—Locating a fault in a cable.

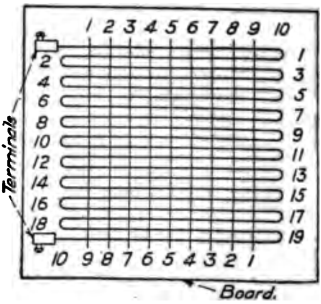


FIG. 65.—Home-made wire bridge.

118. Locating Faults in a Cable (*Standard Underground Cable Co.*).—Fig. 64 shows a simple method, using a dynamo, a galvanometer, and 10 or 15 ft. of bare wire. This method is only applicable when both conductors of the cable are of the same size. After making the connections shown it is only necessary to move the stylus b along the bare wire until the galvanometer is not deflected in either direction.

Let A = the length of the wire between the balance point B and the faulty conductor, C = the total length of the wire, and L = the total length of the cable circuit, = twice the length of the cable. Then distance to the fault $= \frac{A \times L}{C}$.

Fig. 65 shows a simple form of wire bridge which can be used for tests of this kind. The length A can be read directly and the value of C is 200. If a galvanometer is not available a telephone receiver can be used in its place. While the use of alternating currents may introduce errors due to self induction and capacit such errors will not generally be sufficiently great to interfere wi practical results.

119. Testing Cables For Insulation with a Telephone Receiv and Battery (*Standard Underground Cable Co.*).—An extreme simple way to determine whether or not the insulation resistan of any particular wire is high or not, is as follows: A telephone receiver and battery are connected as shown in Fig. 66. One side of the battery is attached to the lead sheath of the cable or to ground, and the other side to a telephone receiver. A rubber insulated wire is attached to the other side of the telephone. To test, press the telephone receiver to the ear, and touch the wire *L* to the conductor *E*; a click will always be heard the first time. After keeping both wires in conta for several seconds, break and make the connection once more; no sound is heard at the instant of reconnection the wire is n faulty. With intervals of time between break and make of o second with a battery of 1 volt it can be assumed that no click ind cates at least a resistance of 50 megohms. When more battery used this number is increased about in proportion to the numb of cells. Care must be taken that sounds in the telephone due induction are not misconstrued for those produced by leaks.

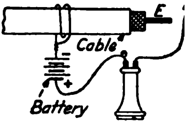


Fig. 66.—Test for ins lation resistance.

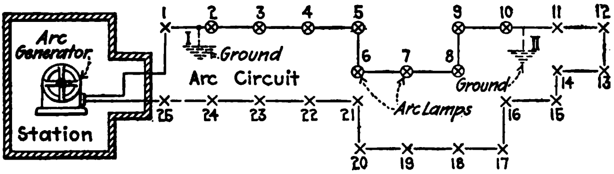


Fig. 67.—Effect of two grounds on an arc circuit.

120. Grounds on series arc or incandescent lighting circui frequently reveal their locations automatically. If there are tw good grounds on the circuit the lamps connected in the line betwee the grounds will not burn because the grounds will shunt the out. For example, in Fig. 67 with a good ground at *I* and *II*, th lamps Nos. 2 to 10 would be shunted out. Sometimes there ma be two grounds on a circuit, but they may not be "good" enoug to shunt out the lamps. (This paragraph and those that follo on testing arc circuits are from *Electrical World*.)

The presence of but one ground on a circuit, irrespective of ho "good" it is, will not reveal itself automatically and the prop operation of the circuit will not be affected by one ground. How ever, *where there is one ground*, it constitutes a serious men *to the lives of the station* operators and trouble-men. Furt more, *another ground* may occur at any time that may caus shunting out of lamps or possibly a fire or destruction of equipment. Hence, it is very desirable to maintain the circuits entirely clear of grounds. It is the practice in all well-maintained stations to test each series circuit for grounds, some time during every afternoon, and if a ground is discovered a trouble-man is sent out to locate and clear it before the circuit is thrown into service for the night.

121. **The usual method of testing dead series circuits for grounds** is to disconnect the circuit from all station apparatus and then to connect one terminal of a magneto test set to the circuit and the other to ground. If the bell rings vigorously when the crank is turned, the circuit is grounded. If it does not, the circuit is clear. If the circuit is very long or in cable for a considerable portion of its length, the bell may ring some even if the circuit be clear of grounds.

122. **The method of locating a ground on a dead arc circuit** is illustrated in Fig. 68. Disconnect all station apparatus and temporarily ground one side of the circuit as at *B* (Fig. 68). Proceed out along the line and connect some testing instrument (a

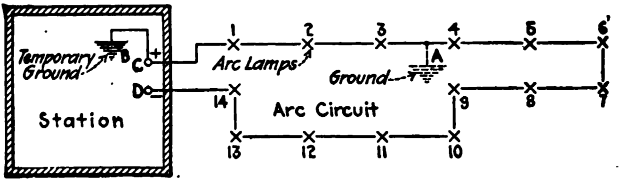


Fig. 68.—Locating a ground on a dead arc circuit.

magneto test set is most frequently used) in series with the circuit at some point. If when the crank is turned the magneto bell rings, indicating a closed circuit, the tester is between the station ground and the ground on the circuit. If the magneto "rings open," the tester is between the circuit ground and the ungrounded station end of the circuit. If in Fig. 68 the test is inserted at lamps 1, 2 or 3, the magneto should ring "closed," while if inserted at any of the other lamps it should ring "open."

123. **In locating either a ground or an open on a series circuit,** unless the tester has an idea as to the location of the trouble, he should proceed first to the middle point of the circuit and there make his first test. This first test will indicate on which side of the middle point the trouble is. He should then proceed to the middle point of the half of the circuit that shows trouble and there make another test. This will localize the trouble to one quarter of the circuit. This "halving" of the sections of the circuit should be continued until the trouble is finally found.

If there is more than one ground on a series circuit the trouble is tedious to locate. If the tests made at different points on the *circuit are confusing,* indicating the existence of several grounds *the best procedure* is to open the circuit into several distinct sectio[ns] *and then test each* one as a unit, following the methods describ[ed in] *preceding paragraphs.*

124. A ground on a series circuit can sometimes be located with the current from the arc generator or rectifier by placing a temporary ground on the circuit at the station. For example, if in Fig. 68 a temporary ground is connected to terminal *B* and the device that supplies the operating current to the circuit is connected to terminals *C* and *D* and normal operating current thrown out on the circuit, the lamps 1, 2, and 3 will not burn, indicating that the ground is between lamps 3 and 4. The use of this method is attended by some fire risk; hence, the method should be used with caution.

125. A method of locating a ground on a series circuit with a lamp bank is suggested in Fig. 69. A bank of 110-volt incandescent lamps, each of the same candle-power, is connected in series as

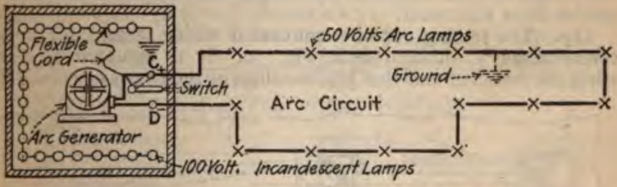


FIG. 69.—Locating a ground on a "live" arc circuit with an incandescent lamp bank.

indicated and one end of the bank is permanently grounded. There should be a sufficient number of lamps in the bank so that the sum of the voltages of all of the lamps is at least equal to the voltage impressed on the series circuit by the arc generator or the regulator. For instance, if the voltage impressed on the series circuit is 6,600, there should be at least sixty 110-volt incandescent lamps in the bank ($6{,}600 \div 110 = 60$).

In locating a ground, the flexible cord which is connected to the center point of the double-throw switch is successively placed on different points on the conductor that connects the incandescent lamps in series, the switch being thrown to one or the other of the circuit terminals, *C* or *D*. Move the flexible cord along until the incandescent lamps in the bank, between the point of connection of the cord and the permanent ground, burn at about full brilliancy. When this condition obtains, the voltage impressed across the lamps that are burning fully brilliant is approximately equal to the voltage impressed on the portion of the arc circuit (to which the switch connects) between the station and the ground. The voltage required across each lamp of the outside circuit being known, the number of lamps between the station and the ground can be readily computed, and thereby the ground is located.

Great care must be exercised in using this method. Practically *all series lighting circuits* operate at very high voltage. Hence *when the flexible cord is* being moved along the conductor, the arc *generator or regulator* should be entirely disconnected. If it *not some one may be killed.*

Example.—Consider Fig. 69. There is a ground on the circuit. It is found that two of the incandescent lamps of the bank burn at full brilliancy between the fixed-point connection and the lamp-bank ground. Since 110-volt lamps are used in the bank the voltage across these two is 220. This means that the voltage on the arc circuit between points *C* and *G* is about 220. Since the arc lamps each require about 50 volts there must be 220 ÷ 50 = 4.4 or in round numbers 4 arc lamps between *C* and the ground *G*. After making a test with the switch point at *C*, it should be thrown over to *D* and a check test made from the other end of the circuit. The method of figuring is the same in each case.

126. **To locate an "open" on a series circuit** ground one end of the circuit at the station as in Fig. 68. Then make tests at different points out on the circuit with the magneto connected in between line and ground. So long as the magneto bell indicates a closed circuit, the open is on the line side of the tester. When the magneto indicates an open circuit the open is toward the station from the tester.

127. **The testing out of a concealed wiring system for proper connections** is illustrated in Fig. 70. It is assumed that the wires are installed and that the locations of their runs are concealed

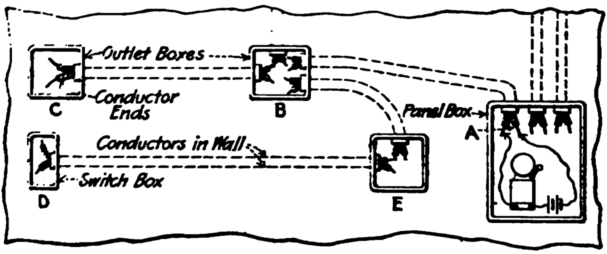


FIG. 70.—Testing out wiring for proper connections.

by the plastering. Only the ends of the conductors are visible at the outlets. It is necessary to identify the conductor ends at each outlet. These tests are usually made with an electric-bell outfit (Fig. 47) because the sound of the bell will indicate a closed circuit to the wireman in a distant room. Hence, a single man can test out such a system. In testing out, first skin the ends of all of the conductors and see that none is in contact with any other or with the outlet box. Next, select a pair of conductors (Fig. 70*A*), preferably the pair that serves the group, and connect the bell outfit to the ends of the pair as shown. Then proceed to the outlet (Fig. 70*B*) at which the pair of conductors should terminate and successively touch together the ends of all the wires that terminate in that box until a pair is discovered that, touching together the ends of which, rings the bell. This identifies one pair. Tag this pair so that it can be readily found again and repeat the process on some other pair. Continue thus until all of the conductors are identified. (This paragraph and those that follow on practical electrical tests from Electrical Engineering

128. **The method of testing out the connections for three-**

switches is shown in Fig. 71. When finally connected the circuits should be as shown at *I*. It is assumed that the conductors are in place and concealed within walls or ceilings and that only the ends are visible at the outlets, as at Fig. 71, *II*. First, identify the feed conductors and bend back their ends at the outlet box as at A_3. Next, twist together, temporarily, the bared ends of any two of the conductors at each of the switch outlets as at A_3 and C_3. The conductors having their ends thus twisted together will be the switch conductors. Now, at the lamp outlet, or outlets, identify the short-circuited switch conductors as directed in a

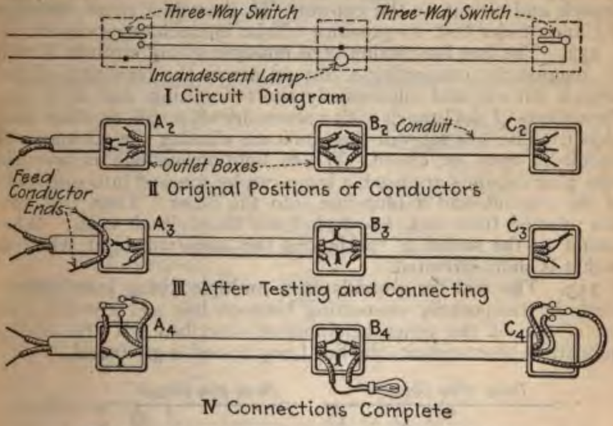


FIG. 71.—Testing out three-way switch connections.

preceding paragraph and connect and solder these switch conductors together as at B_3. Connect the remaining conductor ends at the lamp outlets to the lamps, B_4, connect one of the feed conductors to the center point of the three-way switch (A_4), and connect the other feed conductor to the lamp wire. The switch conductors are connected to the two points of the switch. At C_4 the same procedure is followed.

129. In testing out a new wiring installation for faults each branch circuit, main and feeder should be treated individually. It is usually impracticable to test an installation as a unit, as open switches and loose connections in cut-outs may render such a test worthless. If a test is made from the cut-out, on the two conductors of each individual circuit, the above-mentioned possible elements of uncertainty are eliminated. Test each side of each circuit separately unless the lamps are in position.

130. Open circuits in multiple* wiring installations are usually *readily located. *If* the lamps are in position and lighting voltage *vailable, it can be impressed* on the circuit. The lamps on the *enerator side of the "open"* will then burn while those on the fa*le will not, which localize* the "open." Where lighting voltage not available, all of the lamps can be taken out of the sockets and each of the sides of the circuit can be grounded at the cut-out. Then a telephone-and-battery, a bell-and-battery, or a magneto test set can be connected temporarily and successively between one line and ground and between the other line and ground at each outlet on the branch. When the test set indicates an open circuit, the "open" is between the tester and the ground made at the cut-out.

131. **The test for short-circuits on a multiple system** is made by temporarily connecting a test set across the terminals of each branch and circuit at the cut-out. If there is a short-circuit on the lines under test, its presence will be immediately evident.

132. **The test for continuity of multiple wiring circuits** is made by temporarily connecting a test set across the terminals of each branch cut-out and successively short-circuiting, one at a time, the sockets of the branch with a screw-driver, a nail, or other metal object. The test set will then indicate whether the wiring of the circuit is open or closed. Where lighting voltage is available and plug cut-outs are used, a lamp can be screwed into one socket of the cut-out and a plug-fuse into the other. Then the tester can proceed from socket to socket and short-circuit each. Where circuit to the socket is continuous the lamp will light when the socket is short-circuited.

133. **The test for grounds on a multiple wiring installation** is made by temporarily connecting between line and ground a test set of one of the types hereinbefore described. If the test set indicates a short-circuit, the line being tested is grounded.

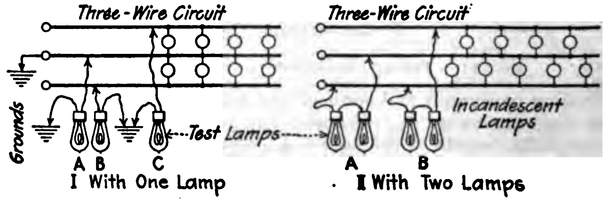


FIG. 72.—Locating neutral wire with test lamp.

134. **The testing of three-wire circuits to identify the neutral,** is effected as suggested in Fig. 72. Where the neutral is grounded, a test lamp can be successively connected between each of the three conductors and ground (Fig. 72, *I*). When the ungrounded side of the lamp is touched to the neutral wire it will not burn, but when touched to either of the outside wires it will burn. A method that can be used with either a grounded or an ungrounded neutral is illustrated in Fig. 72, *II*. Connect the two test lamps in series *successively between* one of the line wires and the other two. When *connected across the* two outer wires both lamps will burn at fu *voltage, but when* connected between one of the outer wires a *eutral they* will burn at only half voltage. The "touchin *t described* in a previous paragraph (90) can also be applie

135. Polarity of direct-current circuits can be determined holding the two conductors in a glass vessel of water as indica in Fig. 73. It may be necessary to pour a little common salt

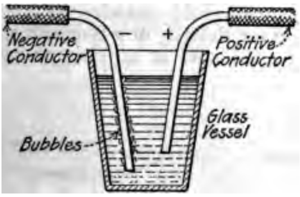


Fig. 73.—Determination of polarity with conductor ends in water.

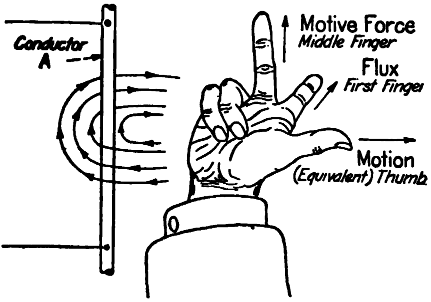


Fig. 74.—Application of right-hand rule.

acid into the water to render it conducting. Pure water is a po conductor. Bubbles will form only on the negative conductor, i dicating the presence of current and the polarity of the circuit. Be careful not to touch the conductor ends together which will cause a short-circuit.

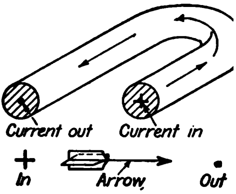


Fig. 75.—Symbols indicatir direction of current flow.

136. A Hand Rule to Determine the Direction of an Induced e.m.f.—(See Fig. 74.) Use the *right hand.* Extend the thumb in the direction of the motion, or of the equivalent motion, of the conductor and the forefinger in the direction of the magnetic flux. Then the middle finger will point in the direction of the induced e.m.f. (Magnetic flux flows from the north (*N*) to the south (*S*) pole of magnet.) This rule can be remembered by associating the soun of the following word groups: "thumb—motion," "forefinger force" and "middle finger—motive force."

***137. Symbols for indicating* the direction of an e.m.f. or cur into or out of the end of a conductor** are shown in Fig. 75.

138. Hand Rule for Direction of Magnetic Field about a Straight Wire.—(See Fig. 76.) If a wire, through which electricity is flowing, is so grasped with the *right hand* that the thumb points in the direction of electricity flow, the fingers will point in the direction of the magnetic field and vice versa.

139. Hand Rule for Polarity of a Solenoid or Electromagnet.—(See Fig. 77.) If a solenoid or an electromagnet be so grasped

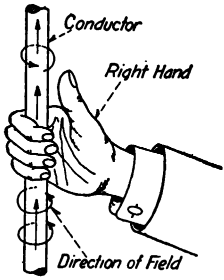


FIG. 76.—Hand rule for direction of field.

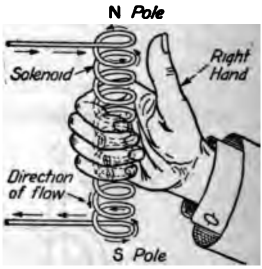


FIG. 77.—Hand rule for determining polarity of a solenoid.

with the *right hand* that the fingers point in the direction of electricity flow, the thumb will point toward the north (—) pole.

140. Rule for Determining Direction of Current Flow with Compass.—(See Fig. 78.) If a compass is placed under a conductor, in which electricity is flowing from south to north, the north end of the needle will be deflected to the west. If the compass is placed over the conductor, the north end of the conductor will be deflected to the east. If the direction of current flow in the conductor is reversed the direction of deflection of the needle will be reversed correspondingly.

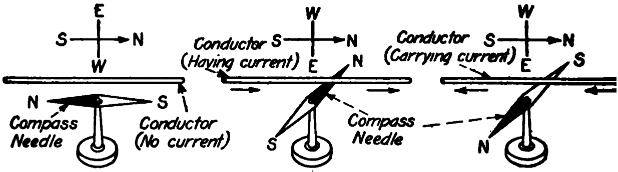


FIG. 78.—Performance of a compass needle near a conductor.

141. Ground Detectors.—(*Factory Mutual Insurance Co's Book of Rules.*) The purpose of the ground detector is to give warning when the first break in insulation occurs, thereby giving time to repair it before the second one, with its possible accompanying fire, can follow. The instant a detector shows a ground steps should be taken to find and remedy it. By throwing off one circuit after another, the one on which the ground exists will so be found, as when it is cut off the detector lamps will again burn with equal brilliancy. Inspection along this circuit will then generally soon disclose the trouble. Where the circuits are not well sub-divided by switches, fuses may be removed to accomplish the same result.

142. Ground Detectors for Two-wire Direct-current Circuits.—Fig. 79 shows a very good and simple detector for any two-wire low-voltage system. The lamps for the detector should each be of the same candle-power and voltage—the voltage being about the same as that of the regular lamps in the plant—and two lamps should be selected which, when connected in series, burn with equal brilliancy. Although somewhat greater sensitiveness can be obtained with low candle-power lamps, such as 8 c-p., for example, it is believed in general to be preferable to use lamps of same candle-power as those throughout the plant, as then a burned-out or broken detector lamp can be immediately replaced by a good lamp from the regular stock, thus avoiding the necessity of keeping on hand a few spare special lamps.

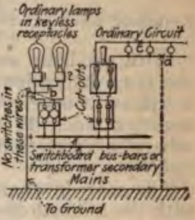


FIG. 79.—Two-lamp ground detector.

The detector lamps, being two in series across the proper voltage for one lamp, burn only dimly. If, however, a ground occurs on any circuit, as at *a*, the current from the positive bus-bar through lamp No. 1 divides on reaching *b*, instead of all going through lamp No. 2, as it did when there was no ground. Part now goes down the ground wire and through the ground to *a*, as indicated by the broken line, and thence through the wires to the negative bus-bar. This reduces the resistance from *b* to the negative bus-bar, and therefore more current flows through lamp No. 1 than before, while less current flows through lamp No. 2. Lamp No. 1 consequently brightens and lamp No. 2 dims. If the ground had occurred at *c* instead of *a*, lamp No. 2 would have brightened and lamp No. 1 dimmed.

Attention is called to the following points, which are frequently neglected in this form of detector:

1. The lamp receptacles should be keyless and there should be no switches of any kind in any of the connecting wires, so that the detector will always be in operation. In order to be of the greatest value, the indications must be given instantly when a ground occurs. The observer should not have to wait until the engineer or electrician remembers to close a switch.

2. The wires should be protected by small fuses where they connect to the bus-bars. If these fuses are omitted, a short-circuit across these wires would either burn up the wires or blow the main generator fuses.

3. The lamps should be placed very close together, within 1 or 2 in. of each other if possible. The farther apart they are, the harder it is to detect any slight difference in brilliancy between them.

4. The ground wire should be carefully soldered to a pipe which is thoroughly connected to the ground, or some other equally good ground connection should be provided.

143. **A lamp ground detector for a three-wire Edison system** is shown in Fig. 80. In principle it is exactly the same as the two-lamp detector of Fig. 79. Its indications are as follows:

Switch on point No. 1	Ground at *a*—A bright, B and C dim. Ground at *b*—B and C bright, A dim. Ground at *c*—A bright, B and C dim.
Switch on point No. 2	Ground at *a*—A and B bright, C dim. Ground at *b*—C bright, A and B dim. Ground at *c*—C bright, A and B dim.

With the lamp switch at point No. 1, grounds at *a* and *c* give the same indication, but by throwing the switch to point No. 2, it will be at once evident whether the ground is on the positive or negative side. It is to remove the uncertainty which would otherwise exist that this switch is needed. It should have no "off" position.

The man in charge of a plant can readily familiarize himself with the indications of the detector by purposely putting a ground on the different wires and noting the indications.

If the neutral is permanently grounded, a ground detector is, of course, of no use.

144. **The same degree of sensitiveness on both sides can be obtained** by means of the lamp switch in Fig. 80, but for grounds on the neutral, there is never more than half the full voltage available to operate the lamps, so that the indications are necessarily less sensitive.

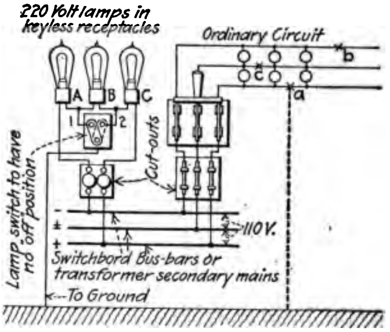
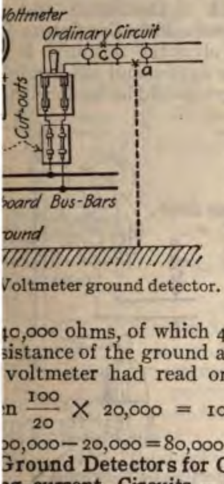


FIG. 80.—Lamp ground detector for three-wire system.

145. **An ordinary voltmeter can be used as an intermittent ground detector** on direct-current circuits of any voltage, as shown in Fig. 81. The voltmeter ordinarily used to indicate the pressure on the system can, of course, be used for this purpose, *the voltmeter switch* shown in the cut being arranged to give *the different desired* connections.

example, the system shown in Fig. 81 were of about 100 e voltmeter would register 100 when the levers of the ere on the inside contact points as shown. If, now, -hand lever were moved to the outside contact point dotted, and there were a ground on the system, as at *a*, vould pass from the positive bus-bar through the circuit nce through the ground to the ground wire, and through neter to the negative bus-bar, causing the voltmeter omething below 100, unless the ground at *a* were practically a perfect connection, in which case the voltmeter reading would be 100. If the positive side of the system were entirely free from grounds, the voltmeter reading would be 0.



Voltmeter ground detector.

Assume that under these conditions the voltmeter reads 50, and that the resistance of the voltmeter itself was 20,000 ohms, it will be evident that if, with no external resistances, as when connected directly to the bus-bars, the voltmeter reads 100, while now it reads 50, the total resistance under the new conditions 40,000 ohms, of which 40,000 − 20,000 = 20,000 ohms must sistance of the ground at *a*.

voltmeter had read only 20 the total resistance would n $\frac{100}{20} \times 20{,}000 = 100{,}000$, and the resistance of the 00,000 − 20,000 = 80,000 ohms.

Ground Detectors for Ordinary Low-voltage Three-phase ng-current Circuits.—A lamp detector connected as in nay be used. The indi- the same as that with p detectors described Thus, when a ground one wire, the lamp at- that wire dims and the brighten.

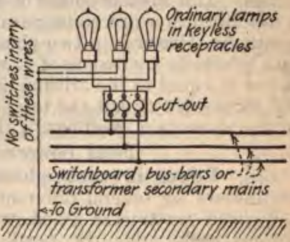


FIG. 82.—Three-phase lamp detector.

rdinary two-phase (or hase) systems, where s are entirely insulated h other, the two-lamp can be used, one detec- ach phase. There are, in this class of wiring omplicated systems, to ch the lamp detector principle is applicable, although nethod of connections differs in each case, so that no can be given.

testing of **lighting fixtures prior to installation** i best accomplished with a voltmeter, Fig. 83. The test for short-circuit and continuity is illustrated at *I*. If the voltmeter does not give a reading with the lamps out of the sockets, the fixture wiring is clear of short-circuits. After the test for short-circuits has been made each socket is short-circuited with a metal object—a screw-driver is frequently used—and if the voltmeter indicates the full voltage of the circuit each time a socket is short-circuited, it signifies that the circuit to that socket is continuous.

The fixture can be tested for grounds as at Fig. 83, *II*. If there is no deflection of the voltmeter with one lead from the voltmeter touching the metal work of the fixture and the other successively each of the fixture conductors, the fixture is clear of grounds. Be certain that one voltmeter terminal is in actual contact with the metal work of the fixture and not insulated therefrom by the lacquer finish. This test should be made with the lamps out of the socket.

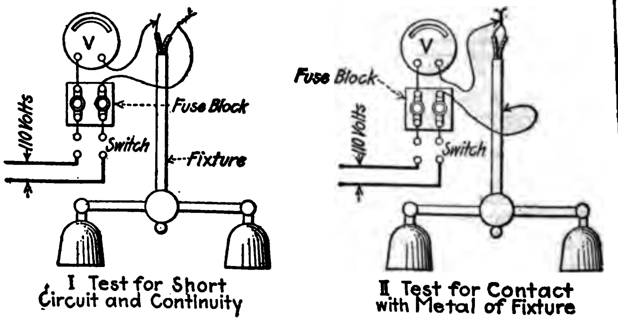


FIG. 83.—Methods of "testing out" fixtures.

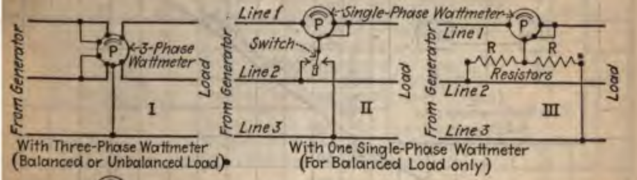
148. The measurement of the power in a single-phase circuit is described in a preceding paragraph.

148 A. Power in a two-phase system. In the four-wire circuit each phase is treated as if it were a separate circuit and the total power is equal to the arithmetic sum of readings, P_1 and P_2. In the three-wire circuit the total power is equal to the algebraic sum of the wattmeter readings. That is:

$$\text{Total power} = P_1 + P_2 \text{ in watts.}$$

149. Power in three-phase circuits can be measured with wattmeters by several different methods. See Fig. 84. At *I* a polyphase wattmeter is shown. An instrument of this type automatically adds the portions of power consumed in each phase and indicates their sum. Instruments made by different manufacturers are arranged differently and must be connected accordingly. Directions accompany each instrument. Diagrams *II* and *III* show how the power can be measured, in a balanced circuit, with one wattmeter. One pressure lead is connected to the line in which the wattmeter is inserted and the other pressure ıd is connected successively to the other two lines. *The total ·wer in I is equal to the sum or difference of the two readings.* If sistors are used as indicated in *III*, the power can be ascertained ithout any shifting of leads. The wattmeter reading of *III* ultiplied by 3 will be the true power in a balanced circuit. The sistance of each of the resistors *R* and *R* must be equal to the sistance of the potential or voltage coil of the wattmeter.

With two wattmeters (as in Fig. 84, *IV*) the total power is qual to the (sum or difference) of the two wattmeter readings. If ıe power factor is greater than 0.50 the total power is their arithıetical sum of the readings. If it is lower than 0.50 one of the eadings is negative and the power is their arithmetical difference.



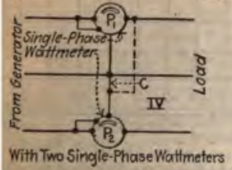


FIG. 84.—Three-phase power measurements with wattmeters.

To ascertain whether one of the wattmeters is reading negative, temporarily transfer the connection of one of the potential wires (for example *c* in *IV*, as shown by the dotted line) from the midlle wire to the outside wire. If its wattmeter reverses, one of the nstruments, that of the lesser indication, is reading negatively. The nature of the load usually enables one to judge roughly what he power factor is. With incandescent lamps and fully loaded notors the power factor will be high, but with under and lightly oaded motors it is likely to be low. See 151 for method of deternining the **power factor** of three-phase circuits **with wattmeters.**

150. **The methods of measuring the power factors of cir**cuits are described in other paragraphs.

151. **The method of determining three-phase power factor** *v***ith wattmeters** was well described by C. E. Howell in *Electrical World*. It is necessary to know the power factor in order to conect watt-hour meters correctly where the wiring is concealed. An abstract follows:

Fig. 85 shows the power-factor curve for two single-phase ıeters on a polyphase circuit. It also gives a diagram of connecions and instructions as to how to use the curve. The figure hould be self-explanatory. Fig. 86 gives, first, a method of hecking results obtained by employing the curve given in Fig. 85 nd a diagram of the connections for obtaining data for the check. he second part of Fig. 86 gives a method of determining the rect connections for two single-phase meters, or one polyphase meter, on a three-phase circuit. If this part of Fig. 86 is emplo errors in meter connections on three-phase circuits due to power factor being near 50 per cent. should be a minimum.

To illustrate the use of the above instructions: A 100- three-phase, 440-volt induction motor was operating on 30 per full-load or 40 h.p. (29.8 kw.) at 60 per cent. power factor (a ward determined) when an order "came through" to place a p phase watt-hour meter on the installation. Immediately the meter had been connected the following question was as

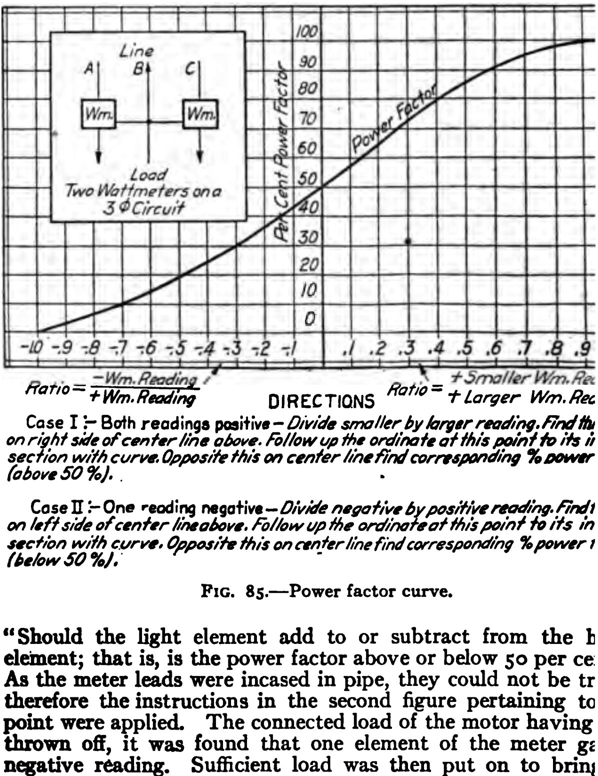
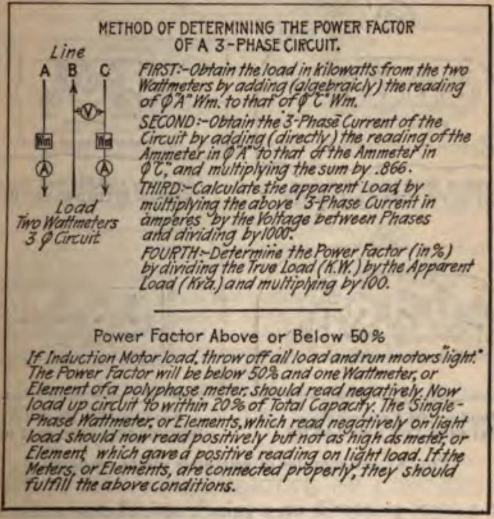


FIG. 85.—Power factor curve.

"Should the light element add to or subtract from the h element; that is, is the power factor above or below 50 per ce As the meter leads were incased in pipe, they could not be tr therefore the instructions in the second figure pertaining to point were applied. The connected load of the motor having thrown off, it was found that one element of the meter ga negative reading. Sufficient load was then put on to bring motor to about 80 per cent. of its full-load rating. Each ele of the meter (taken separately) now read positively, but th ment which on no-load gave a negative reading on 80 per load read lower than the heavy element. The meter had *correctly connected* when installed. Later both methods *above to determine* the power factor of a three-phase circuit lied and both gave approximately 60 per cent. power factor 30 per cent. load).

52. **To correctly read the consumption indicated on the s of a recording watt-hour meter** (sometimes, but erroneously, ed a recording wattmeter) these directions should be followed: *les and Regulations of the Commonwealth Edison Co., Chicago.)* Fig. 87 for examples.



te.—This is based on the fact that on "no-load" the Power Factor of an ction Motor is below 50%.

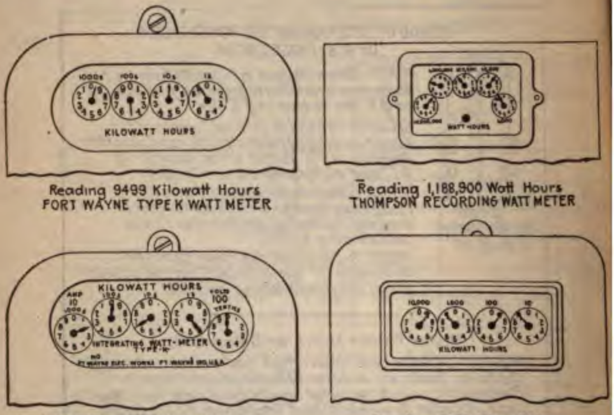
FIG. 86.—Chart of instructions for power factor test.

ne pointer on the right-hand dial of a five-dial meter registers one-tenth) of a kilowatt-hour or 100 watt-hours for each divi- of the dial. A complete revolution of the hand of this dial will e the hand of the second dial one division and register 1 (one) r. or 1,000 watt-hr. A complete revolution of the hand of econd dial will move the third hand 1 (one) division and register w-hr. or 10,000 watt-hr. and so on.

cordingly, read the hands from left to right and add 2 (two) ers to the reading of the lowest dial to obtain the reading of meter in watt-hours. Where there are 4 dials on the meter, pointer on the right-hand dial registers 1 kw-hr. or 1,000 watt- or each division of the dial, and it is necessary to add 3 (three) ers to the reading of the lowest dial to obtain the reading in -hours, or the meter reads directly in kilowatt-hours.

nds *should always be read* as indicating the figure which *have last passed,* and not the one to which they are nearest.

Thus, if a hand is very close to a figure, whether it has passed the figure or not must be determined from the next lower dial. If the hand of the lower dial has just completed a revolution, the hand of the higher dial has passed the figure, but if the hand of the lower dial has not completed a revolution, the hand of the higher dial has not yet reached the figure, even though it may appear to have done so.



Reading 9499 Kilowatt Hours FORT WAYNE TYPE K WATT METER

Reading 1,188,900 Watt Hours THOMPSON RECORDING WATT METER

Reading 1965.9 Kilowatt Hour FORT WAYNE TYPE K WATT METER

Reading 8889 Kilowatt Hours THOMPSON RECORDING WATT METER

FIG. 87.—Examples of watthour meter readings.

When 1 (one) pointer is on 9 (nine), special care must be take that the pointer on the next higher dial is not read too high, as will appear to have reached the next number, but will not hav done so until the hand at 9 (nine) has come to zero.

The hands on adjacent dials revolve in opposite direction Therefore a reading should always be checked after being writte down, as it is easy to mistake the direction of the rotation.

To determine the consumption for a given time, subtract th reading at the beginning of the period from the reading at the en Always observe if a constant is marked at the bottom of the di plate. If so, the difference of the readings must be multiplied b this constant to obtain the consumption.

153. Test to Determine the Horse-power of an Electric Moto —Applying the principles, outlined elsewhere in this section, to motor under test for output, the power delivered being measur with a prony brake, Fig. 88, may be taken as an example.

Example.—The torque is 10 lb. at 3 ft. radius, or 30 lb-ft., or 30 lb. at 1 radius. Since the motor pulley is turning at the rate of 1000 r.p.m. a poi on its circumference travels $2\pi R = 2 \times 3.14 \times 1 \times 1000 = 6{,}280$ ft. per minut At its circumference the pulley is overcoming a resistance of 30 lb. Ther fore it is doing work at the rate of $30 \times 6{,}280 = 188{,}490$ ft-lb. per minut Since, when work is done at the rate of 33,000 ft-lb. per minute, a hor is developed, the motor is delivering 188,490 ÷ 33,000 = 5.7 h.p. It l be noted that, though the torque at the circumference of the motor was considered in the example, it is not necessary to take the torque .t point. The torque may be taken at any point if the radius to that

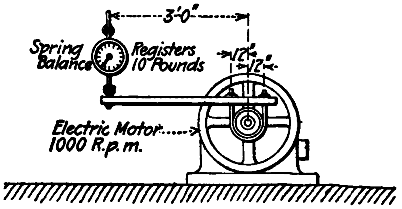


FIG. 88.—Horse-power determination with a prony brake.

is used instead of the radius of the pulley. The formula for determinie horse-power output of a motor under test with a prony brake is

$$\text{h.p.} = 2 \times \pi TS \div 33{,}000,$$

: $\pi = 3.1416$, T = torque in pounds-feet and S is the speed of the motor volutions per minute. Substituting the values from the above example s formula:

$$\text{h.p.} = 2 \times 3.14 \times 30 \times 1{,}000 \div 33{,}000 = 5.7 \text{ h.p.}$$

is is the same result secured by the former and longer method. In ic units, work is expressed in kilogram-meters, so, conversely, torque d be expressed in meter-kilograms or in kilograms at a given radius in rs.

;4. **The testing of motors and generators for faults** is treated ie section on motors and generators which occupies an indelent portion of this book.

PROPERTIES AND SPLICING OF CONDUCTORS

;5. **Electric Wire and Cable Terminology.**—(*U. S. Bureau of dards Publication No.* 37.)

'ire.—A slender rod or filament of drawn metal. (The defini- restricts the term to what would ordinarily be understood by term "solid wire." In the definition, the word "slender" is l in the sense that the length is great in comparison with the aeter. If a wire is covered with insulation, it is properly called nsulated wire; while primarily the term "wire" refers to the al, nevertheless when the context shows that the wire is insu- d the term "wire" will be understood to include the insulation.)

onductor.—A wire or combination of wires not insulated from another, suitable for carrying a single electric current. (The 1 "conductor" is not to include a combination of conductors lated from one another, which would be suitable for carrying ral different electric currents. Rolled conductors, such as bars, are, of course, conductors, but are not considered under terminology here given.)

'randed Conductor.—A conductor composed of a group of wires ny combination of groups of wires. (The wires in a stranded *luctor are usually twisted* or braided together.)

Cable.—(1) A stranded conductor (single-conductor cable); (2) a combination of conductors insulated from one another (mul ple-conductor cable).

The component conductors of the second kind of cable may either solid or stranded, and this kind of cable may or may not ha a common insulating covering. The first kind of cable is a sing conductor, while the second kind is a group of several *conducto* The term "cable" is applied by some manufacturers to a sol wire heavily insulated and lead covered; this usage arises from t manner of the insulation, but such a conductor is not included und this definition of "cable." The term "cable" is a general one a in practice it is usually applied only to the larger sizes. A sm cable is called a "stranded wire" or a "cord," both of which a defined below. Cables may be bare or insulated, and the latt may be armored with lead or with steel wires or bands.

Strand.—One of the wires or groups of wires of any strand conductor.

Stranded Wire.—A group of small wires, used as a single wi (A wire has been defined as a slender rod or filament of dra metal. If such a filament is subdivided into several smaller fil ments or strands, and is used as a single wire, it is called "strand wire." There is no sharp dividing line of size between a "strand wire" and a "cable." If used as a wire, for example in windi inductance coils or magnets, it is called a stranded wire and not cable. If it is substantially insulated, it is called a "cord," defin below.)

Cord. A small cable, very flexible and substantially insulat to withstand wear. (There is no sharp dividing line in respe to size between a "cord" and a "cable," and likewise no sha dividing line in respect to the character of insulation between "cord" and a "stranded wire." Usually the insulation of a co contains rubber.)

Concentric Strand.—A strand composed of a central core su rounded by one or more layers of helically laid wires or groups wires.

Concentric Lay Cable.—A single-conductor cable composed of central core surrounded by one or more layers of helically la wires.

Rope Lay Cable.—A single-conductor cable composed of a cent core surrounded by one or more layers of helically laid groups wires. (This kind of cable differs from the preceding in that t main strands are themselves stranded.)

N-Conductor Cable.—A combination of N conductors insulat from one another. (It is not intended that the name as here giv be actually used. One would instead speak of a "3-conduct cable," a "12-conductor cable," etc. In referring to the gene case, one may speak of a "multiple-conductor cable," as in defi tion for "*Cable*" above).

N-Conductor Concentric Cable.—A cable composed of an insulat *central* conducting core with tubular stranded conductors laid ov *it concentrically* and separated by layers of insulation. (Usual *only 2-conductor* or 3-conductor. Such conductors are used carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.)

Duplex Cable.—Two insulated single-conductor cables twisted together. (They may or may not have a common insulating covering.)

Twin Cable.—Two insulated single-conductor cables laid parallel, having a common covering.

Triplex Cable.—Three insulated single-conductor cables twisted together. (They may or may not have a common insulating covering.)

Twisted Pair.—Two small insulated conductors twisted together, without a common covering. (The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord.")

Twin Wire.—Two small insulated conductors laid parallel, having a common covering.

155A. The weights of wires, of the metals that are ordinarily used, can be computed for wires of any diameter and any length with the following formula, by using values from Table **156.**

$$W = k \times D^2 \times l \text{ or } D = \sqrt{\frac{W}{k \times l}}$$

or

$$W = k \times \text{cir. mil} \times l$$

Wherein W = weight in pounds, k = constant from **156,** differing in value for each metal and equal to the weight of a cir. mil-ft. of the metal, D = the diameter of the wire in mils or thousandths of an inch and l is the length of the wire in feet.

Example.—What is the weight of a bare 500,000 cir.-mil copper cable 2,000 ft. long?

Solution.—Substitute in the formula:

$$W = k \times \text{cir. mil} \times l = 0.00000303 \times 500{,}000 \times 2{,}000 = 3{,}030 \text{ lb.}$$

The wire will weigh 3,030 lb.

156. Weights of 1 Cir. Mil-ft. of Metals

Metal	k Weight in pounds of 1 cir. mil-ft.
Copper	0.00000303
Aluminum	0.000000916
Galvanized iron	0.00000264
Galvanized crucible steel	0.00000264

157. Wire Gages.—Diameters of wires are usually expressed according to some wire gage. Unfortunately there are many gages originated by different manufacturers for their products. Wire sizes are referred to by gage numbers and, usually, the smaller the number the bigger the wire. The ordinary uses of the different gages are indicated in **162.** The only legal gage in this country is the U. S. standard for plate. Wire-measuring gages (Figs. 89 and 90) are made of steel plate. With the kind shown in Fig. 89 the wire being measured is inserted in the slots in the periphery until a slot is found in which the wire just fits. Its gage number is indicated opposite the slot. A measuring gage like that of Fig. 89 indicates the numbers of one gage or syster only. A gage like that of Fig. 90 indicates the numbers of fou gages but has the disadvantage that, to use it, the end of th wire must be available to push through the slot. The wire i pushed as far toward the small end of the slot as it will go an its gage number will be indicated opposite the point where th wire stops. The gage of Fig. 90 is arranged to indicate gag

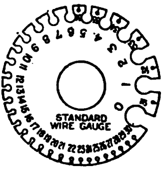


FIG. 89.—Standard wire gage (greatly reduced).

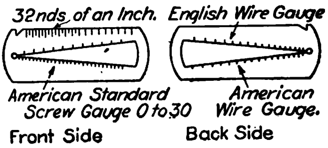


FIG. 90.—Angular wire gage (greatly reduced).

numbers for the American Screw Gage, English Wire Gage, Ame ican Wire Gage and one scale is divided into 32nds of an inch.

158. Wire gage systems and wire-measuring gages are incoı venient and confusing and the practice of **measuring wires an plates with a micrometer** (Fig. 91) is becoming prevalent. Son concerns now make a practice of specifying the diameters of a wires in thousandths of an inch and, doubtless, the practic will ultimately become universal. The micrometer measur

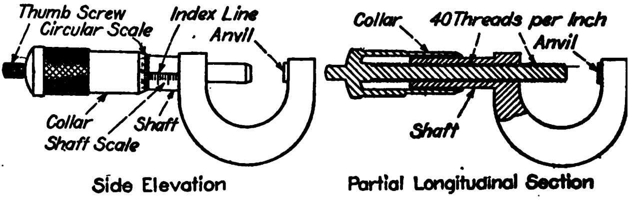


FIG. 91.—A micrometer caliper.

very accurately to thousandths of an inch and ten thousandth can be estimated. The wire to be measured is placed betwee the *thumb screw* and the *anvil* (Fig. 91) and the screw turne until the wire is lightly held between the screw and the anvi The screw has 40 threads to the inch so that one complete tur of the screw in a left-handed direction will open the micromet $\frac{1}{40}$ of an inch. On the edge of the *collar* is a *circular scale* divide into 25 divisions, hence, when the screw is turned through one o these divisions, the micrometer will open $\frac{1}{25}$ in. $\times \frac{1}{40}$ in. $= \frac{1}{1000}$ in *The shaft on which the collar* turns is marked into tenths of a *inch and each* $\frac{1}{10}$ *is* subdivided into four parts. Each of thes *parts must be* equal to $\frac{1}{10}$ in. by $\frac{1}{4}$ in. $= \frac{1}{40}$ in. $=$ 0.025 *herefore a* complete rotation of the collar or 25 of its divisi *ll equal one* division of the shaft or 0.025 in.

159. To read a micrometer (see Fig. 92 and the paragra above) note the number on the *circular scale* nearest the *in line*. This indicates the number of thousandths. Note the nu ber of small divisions uncovered on the *shaft scale*. Each one these small divisions indicates 0.025 in. ($\frac{25}{1000}$). Add together number of thousandths indicated on the *circular* scale and 0.025 the number of small divisions wholly uncovered on the shaft sc: The sum will be the distance that the jaws are apart.

Examples are shown in Fig. 92.

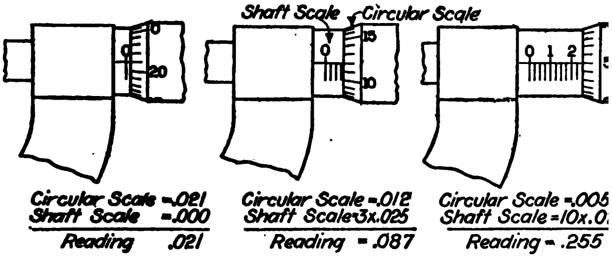


FIG. 92.—A micrometer caliper.

160. The most important of the different gages that are use in this country are indicated by numerical comparison Table 164. Some of these gages are known by several nan The **different names for each gage** system, their abbreviati and the **materials ordinarily measured by each** are indicated table 162.

161. Tensile Strength of Pure Copper Wire in Pounds

Size, B. & S.	Hard drawn		Annealed		Size, B. & S.	Hard drawn		Anneale	
	Actual	Average per square inch	Actual	Average per square inch		Actual	Average per square inch	Actual	Average
0000	8,260	49,700	5,320	32,000	7	1050.0	64,200	556.0	34,[illegible]
000	6,550	49,700	4,220	32,000	8	843.0	65,000	441.0	34,[illegible]
00	5,440	52,000	3,340	32,000	9	678.0	66,000	350.0	34,[illegible]
0	4,530	54,600	2,650	32,000	10	546.0	67,000	277.0	34,[illegible]
1	3,680	56,000	2,100	32,000	12	343.0	67,000	174.0	34,[illegible]
2	2,970	57,000	1,670	32,000	14	219.0	68,000	110.0	34[illegible]
3	2,380	57,600	1,323	32,000	16	138.0	68,000	68.9	3[illegible]
4	1,900	58,000	1,050	32,000	18	86.7	68,000	43.4	
5	1,580	60,800	884	34,000	19	68.8	68,000	34.4	
6	1,300	63,000	700	34,000	20	54.7	68,000	27.3	

Different Names, Abbreviations and Uses of the Principal Wire and Sheet Metal Gages

n No. le 164	Common name and abbreviation	Other names and abbreviations	Ordinarily used for measuring
1	Brown & Sharpe (B. & S.).	American Wire Gage (A.W. G.). United States Standard. American Standard Wire Gage.	Almost universally used in America in lighting and power practice for measuring bare and insulated copper wire under ½ in. in diameter. All electrical wires and rod except those of iron and steel. All metal plates except those of copper, iron, steel and zinc. Thickness of wall of brazed brass, zinc and copper tubing.
2	Birmingham (B. W. G.).	Stubs Iron Wire Gage (Not Stubs Steel Wire Gage). Old English Standard (Not English Standard). Iron Wire Gage.	Galvanized iron and steel wire. Norway iron wire. Iron rivets, copper rivets. Thickness of wall of all seamless tubing except iron and steel. Sometimes used by A. T. & T. Co. for bare copper telephone line wire. Sheet copper.
3	Trenton.........	....	Trenton Iron Works iron wire. Quite similar to Washburn and Mohn Gage. Seldom used.
4	American Screw.	....	Numbered sizes of wood and machine screws, particularly those smaller than 0.2421 in. (No. 14).
5	New British Standard (N. B. S.).	Standard Wire Gage (S. W. G.). British Imperial (I. W. G.). English Legal Standard (S. W. G.). British Standard.	Seldom used in America in lighting and power practice. Used by some American telephone and telegraph companies for bare copper line wire.
6	Washburn & Mohn (W. & M.).	Roebling. American Steel and Wire Co's. Iron Wire Gage (A. S. W.). G. W. Prentiss Gage, Holyoke, Mass.	Iron and steel wire. Sometimes used for galvanized iron telephone and telegraph wire. Wire nails. Brass and iron escutcheon pins.

ɛ. Different Names, Abbreviations and Uses of the Principal Wire and Sheet Metal Gages (*Continued*)

·lumn No. Table 164	Common name and abbreviation	Other names and abbreviations	Ordinarily used for measuring
7	London Gage....	Old English (Not Old English Standard), from Brass Manufacturers list.	For brass wire, but seldom used.
8	Stubs Steel Wire Gage.	(Not Stubs Iron Wire Gage).	Drill rod.
9	Steel Music Wire Gage (M. W. G.).	Hammacher & Schlemmer (H. & S.). Felten & Guilleanme (F. & G.).	Steel music wire.
10	United States Standard (U. S. S.).	....	Iron and steel plate. This is the legal standard in America for these materials.

163. Equivalent Cross-sections of Wires

Brown & Sharpe Gage

ɩuivalent section	Number of wires of various sizes						
	2	4	8	16	32	64	128
0000	0	3	6	9	12	15	18
000	1	4	7	10	13	16	One each
00	2	5	8	11	14	17	1 and 3
0	3	6	9	12	15	18	2 " 4
1	4	7	10	13	16	..	3 " 5
2	5	8	11	14	17	..	4 " 6
3	6	9	12	15	18	..	5 " 7
4	7	10	13	16	..	..	6 " 8
5	8	11	14	17	..	..	7 " 9
6	9	12	15	18	..	..	8 " 10
7	10	13	16	..	..	..	9 " 11
8	11	14	17	..	..	..	10 " 12
9	12	15	18	..	..	..	11 " 13
10	13	16	..	..	..	..	12 " 14
11	14	17	..	..	..	..	13 " 15
12	15	18	..	..	..	..	14 " 16
13	16	..	..	..	..	..	15 " 17
14	17	..	..	..	..	..	16 " 18
15	18	..	..	..	..	..	..

:xample.—Two No. 4, eight No. 10 and 32 No. 16 are all equivalent to a s-section of one No. 1.

Iore current can be carried, with the same temperature rise, using divided circuits. The greater the number of divided uits, for the same equivalent cross-section, the greater the *ount of current that* the combination can carry. Consult *le 170 for safe carrying* capacities of individual conductors.

164. Comparison of Wire

Dimensions in mils or

Gage No.	1 American. B. & S.	2 Birmingham Stubs.	3 Trenton	4 American Screw	5 British Imperial.
7–0	....	....	....	....	500.0
6–0	....	....	....	....	464.0
5–0	....	....	450.0	....	432.0
4–0	460.0	454.0	400.0	....	400.0
3–0	409.6	425.0	360.0	31.5	372.0
2–0	364.8	380.0	330.0	44.7	348.0
0	324.9	340.0	305.0	57.8	324.0
1	289.3	300.0	285.0	71.0	300.0
2	257.6	284.0	265.0	84.2	276.0
3	229.4	259.0	245.0	97.3	252.0
4	204.3	238.0	225.0	110.5	232.0
5	181.9	220.0	205.0	123.6	212.0
6	162.0	203.0	190.0	136.8	192.0
7	144.3	180.0	175.0	150.0	176.0
8	128.5	165.0	160.0	163.1	160.0
9	114.4	148.0	145.0	171.3	144.0
10	101.9	134.0	130.0	189.4	128.0
11	90.7	120.0	117.5	202.6	116.0
12	80.8	109.0	105.0	215.8	104.0
13	72.0	95.0	92.5	228.9	92.0
14	64.1	83.0	80.6	242.1	80.0
15	57.1	72.0	70.0	255.2	72.0
16	50.8	65.0	61.0	268.4	64.0
17	45.3	58.0	52.5	281.6	56.0
18	40.3	49.0	45.0	294.7	48.0
19	35.9	42.0	40.0	307.9	40.0
20	32.0	35.0	35.0	321.0	36.0
21	28.5	32.0	31.0	334.2	32.0
22	25.3	28.0	28.0	347.4	28.0
23	22.6	25.0	25.0	360.5	24.0
24	20.1	22.0	22.5	373.7	22.0
25	17.9	20.0	20.0	386.8	20.0
26	15.9	18.0	18.0	400.0	18.0
27	14.2	16.0	17.0	413.2	16.4
28	12.6	14.0	16.0	426.3	14.8
29	11.3	13.0	15.0	439.5	13.6
30	10.0	12.0	14.0	452.6	12.4
31	8.9	10.0	13.0	465.8	11.6
32	7.9	9.0	12.0	479.0	10.8
33	7.1	8.0	11.0	492.1	11.0
34	6.3	7.0	10.0	505.3	9.2
35	5.6	5.0	9.5	518.4	8.4
36	5.0	4.0	9.0	531.6	7.6
37	....	....	8.5	544.8	6.8
38	4.0	....	8.0	557.9	6.0
39	3.5	....	7.5	571.1	5.2
40	3.1	....	7.0	584.2	4.8

165. How to Remember the Brown & Sharpe Wire-gage Table (*Westinghouse Diary*).—A wire that is three sizes larger than another wire has half the resistance, twice the weight and twice the area. A wire that is ten sizes larger than another wire has one-tenth the resistance, ten times the weight and ten times the area. No. 10 wire is 0.10 in. in diameter (more precisely 0.102); it has an area of 10,000 cir. mils (more precisely 10,380); it has a resistance of 1 *ohm per thousand feet* at 20 deg. cent. (68 deg. fahr.), and weighs 32 *lb. (more precisely 31.4* lb.) per thousand feet.

eet Metal Gages

ıths of an inch

7 Old English London Gage	8 S.W.G.	9 H., S.&Co. "F.&G." Steel Music Wire Gage	10 U. S. Stand.	Gage No.
....	......	....	500.0	7–0
....	......	....	468.7	6–0
....	......	....	437.5	5–0
454.0	......	....	406.2	4–0
425.0	......	....	375.0	3–0
380.0	......	8.7	343.7	2–0
340.0	......	9.3	312.5	0
300.0	227.0	9.8	281.2	1
284.0	219.0	10.6	265.6	2
259.0	212.0	11.4	250.0	3
238.0	207.0	12.2	234.4	4
220.0	204.0	13.8	218.7	5
203.0	201.0	15.7	203.5	6
180.0	199.0	17.7	187.5	7
165.0	197.0	19.7	171.9	8
148.0	194.0	21.6	156.2	9
134.0	191.0	23.6	140.6	10
120.0	188.0	26.0	125.0	11
109.0	185.0	28.3	109.4	12
95.0	182.0	30.3	93.7	13
83.0	180.0	32.3	78.1	14
72.0	178.0	34.2	70.3	15
65.0	175.0	36.2	62.5	16
58.0	172.0	38.2	56.2	17
49.0	168.0	40.0	50.0	18
40.0	164.0	42.0	43.7	19
35.0	161.0	44.0	37.5	20
31.5	157.0	46.0	34.4	21
29.5	155.0	48.0	31.2	22
27.0	153.0	51.0	28.1	23
25.0	151.0	55.0	25.0	24
23.0	148.0	59.0	21.9	25
20.5	146.0	63.0	18.7	26
18.75	143.0	67.0	17.2	27
16.5	139.0	71.0	15.6	28
15.5	134.0	74.0	14.1	29
13.75	127.0	78.0	12.5	30
12.25	120.0	82.0	10.9	31
11.25	115.0	86.0	10.1	32
10.25	112.0	....	9.4	33
9.5	110.0	....	8.6	34
9.0	108.0	....	7.8	35
7.5	106.0	....	7.0	36
6.5	103.0	....	6.6	37
5.75	101.0	....	6.2	38
5.0	99.0	....	......	39
4.5	97.0	....	......	40

reight of 1,000 ft. of No. 5 wire is 100 lb. The relative f resistance (for decreasing sizes) and of weight and area reasing sizes) for *consecutive* sizes are: 0.50, 0.63, 0.80, 25, 1.60, 2.00. The relative values of the diameters of sizes of wire are: 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. resistance, drop one cipher from the number of circular e result is the number of feet per ohm. To find weight, *ır ciphers from the* number of circular mils and multiply *eight of No. 10 wire.*

166. Table of Wire Cables.

Number of wires used in cable		1	3	7	12	19	27
Inches per twist			2½	3	4½	5	6½
Sizes of wire in cable			Circular mils				
B. & S. Ga. No.	Diam. mils	Circular mils					
30	0.0100	101	303	707	1212	1919	2727
29	0.0112	127	381	889	1524	2413	3429
28	0.0126	160	480	1120	1920	3040	4320
27	0.0142	202	606	1414	2424	3838	5454
26	**0.0159**	**254**	**762**	**1778**	**3048**	**4826**	**6858**
25	0.0179	321	963	2247	3852	6099	8667
24	0.0201	404	1212	2828	4848	7676	10908
23	0.0226	510	1530	3570	6120	9690	13770
22	0.0253	643	1929	4494	7716	12217	17361
21	**0.0285**	**810**	**2430**	**5670**	**9720**	**15390**	**21870**
20	0.0320	1022	3066	7154	12264	19418	27594
19	0.0359	1287	3861	9009	15444	24453	34749
18	0.0403	1624	4872	11368	19488	30856	43848
17	0.0452	2048	6144	14336	24576	38912	55295
16	**0.0508**	**2583**	**7749**	**18081**	**30996**	**49077**	**69741**
15	0.0571	3257	9771	22799	39084	61883	87939
061	0.0610	3733	11199	26131	44796	70927	100821
14	0.0641	4107	12321	28749	49284	78033	110889
065	0.0650	4225	12675	29575	50700	82725	114075
13	**0.0720**	**5179**	**15537**	**36253**	**62148**	**98401**	**139833**
075	0.0750	5632	16896	39424	67584	107008	152064
12	0.0808	6530	19590	45710	78360	124070	176310
083	0.0830	6905	20715	48335	82860	131195	186435
11	0.0907	8234	24702	57638	98808	156446	222318
095	**0.0950**	**9052**	**27156**	**63364**	**108624**	**171988**	**244404**
10	0.1019	10381	31143	72667	124572	197239	280287
9	0.1144	13094	39282	91658	157128	248746	353538
8	0.1285	16509	49527	105563	198108	313671	446743
7	0.1443	20816	62448	145712	....	....	....
6	0.1620	26251	78753	183757	....	....	....

167. Allowable Current-carrying Capacity of Copper Wires.—If there is too much current in a given conductor it will become so hot that it will be unsafe or may, if insulated, damage its insulation. Certain safe current values have been determined for different size conductors and some are listed in Table 170. Less current is permissible in rubber insulated wires than in wires insulated with other materials because relatively small temperature rises may injure rubber insulation. For interior wiring, the National Electrical Code values should be used, unless local municipal rules similar to the Chicago Rules are mandatory. A 50 deg. fahr. rise in temperature is permissible in bare line-wires suspended in air. The General Electric Co. values indicate what that concern recommends as safe practice, with an initial temperature of 20 deg. cent.

168. Slow-burning **weather-proof conductors** (Fig. 95) are *sometimes used for interior* exposed wiring in damp dark places, *where there are corrosive* vapors where the voltage does not exceed 50. *They are cheaper* than rubber-insulated conductors. Th

ircular Mils in Strands. *The Benedict & Burnham Co.*

37	48	61	75	91	108	127	147	169
7	8½	9	10½	11	12½	13		
cables								
3737	4848	6161	7575	9191	10908	12827	14700	16900
4699	6096	7747	9525	11557	13716	16129	18522	21294
5920	7680	9760	11200	14560	17280	20320	23373	26871
7474	9696	12322	15150	18382	21816	25654	29547	33969
9398	**12192**	**15494**	**19050**	**23114**	**27432**	**32258**	**37338**	**42926**
11877	15408	19581	24075	29211	34668	40767	47040	54080
14948	19392	24644	30300	36764	43632	51308	59388	68276
18870	24480	31110	38250	46410	55080	64770	74823	86021
23791	30864	39223	48225	58513	69444	81661	94374	108498
29970	**38880**	**49410**	**60750**	**73710**	**87480**	**102870**	**119070**	**136890**
37814	49056	62342	76650	93002	110376	129794	150087	172549
47619	61766	78507	96525	117117	138996	163449	189189	217503
60088	77952	99064	121800	147784	175392	206248	238728	274456
75775	98304	124928	153600	186368	221184	260096	301056	346112
95571	**123984**	**157563**	**193725**	**235053**	**278964**	**328041**	**379554**	**436358**
120509	156336	198677	244375	296387	351756	413639	478632	550264
138131	179184	227713	279975	339703	403164	474091	546987	628849
151959	197136	250527	308025	373737	443656	521589	603582	693914
156325	202800	257725	316875	384475	556300	536575	621075	714025
191623	**248592**	**315919**	**388425**	**471289**	**559332**	**651733**	**761166**	**875082**
208384	270336	343552	422390	512512	608256	715264	826875	950625
241610	313440	398330	489750	594230	705240	829310	959763	1103401
255485	331440	421205	517875	628355	745740	876935	1012683	1164241
304658	395232	502274	617550	749294	889272	1045718	1210398	1391546
334924	**434496**	**552172**	**678900**	**822822**	**977616**	**1149604**	**1326675**	**1525225**
384097	498288	633241	778575	944671	1121148	1318387	1526007	1754389
484478	628512	798934	982050	1191554	1414152	1662938	1924818	2212886
10833	792432	1007049	1238175	1502319	1782972	2096643	2426823	2790021
......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......

sulation consists of an inner weather-proof coating and an outer re-resisting coating. The code requires that the fire-resisting oating be $\frac{6}{10}$ the thickness of the entire coating. To meet this ndition the manufacturers use one weather-proof braid and two re-resisting braids. The fire-resisting compound consists of a ixture containing white lead, oxide of zinc, chalk, or some milar substance. The outer braid is rubbed smooth on the itside. The manufacture of slow-burning weather-proof con-ictors has been discontinued by some manufactures and they are ow seldom used.

Wires with a fire-resisting outer coating have the advantage iat dust and lint do not readily adhere to their outer surfaces, as often the case with weather-proofed braids. If dust does collect, *can be easily swept off. Slow-burning* weather-proof wire is *eaper than slow-burning* wire. It is not suitable for out-of-door *rice. See Table 177* for properties.

169. Dimensions, Weights and Resistances of

American or Brown & Sharpe's

B. & S. or American Wire Gage No.	Diam., inches	Area		Carrying capacities		Weight. Sp. gr. 8.9	
		Circular mils. (d^2) 1 m. = 0.001 in.	Sq. mils. ($d^2 \times 0.7854$)	Rubber ins., amps.	Other ins., amps.	Lbs. per 1,000 ft.	Pounds per mile
0000	0.460000	211600.00	166190.0	225	325	639.33	3375.7
000	0.409640	167805.00	131790.0	175	275	507.01	2677.0
00	0.364800	133079.40	104520.0	150	225	402.09	2123.0
0	0.324860	105538.00	82887.0	125	200	318.86	1683.6
1	0.289300	83694.20	65733.0	100	150	252.88	1335.2
2	0.257630	66373.00	52130.0	90	125	200.54	1058.8
3	0.229420	52634.00	41339.0	80	100	159.03	839.68
4	0.204310	41742.00	32784.0	70	90	126.12	665.91
5	0.181940	33102.00	25998.0	55	80	100.01	528.05
6	0.162020	26250.50	20617.0	50	70	79.32	418.81

No. 6 and larger conductors, where they are to be used in interior work or outside pole-line construction, solid wires up to and including No. 00 can the greater ease of handling stranded conductors. See Table 175 for proper-

7	0.144280	20816.00	16349.0	38	54	62.90	332.11
8	0.128490	16509.00	12966.0	35	50	49.88	263.37
9	0.114430	13094.00	10284.0	28	38	39.56	208.88
10	0.101890	10381.00	8153.2	25	30	31.37	165.63
11	0.090742	8234.00	6467.0	20	27	24.88	137.37
12	0.080808	6529.90	5128.6	20	25	19.73	104.18
13	0.071961	5178.40	4067.1	14	.....	15.65	82.632
14	0.064048	4106.70	3225.4	15	20	12.44	65.674
15	0.057068	3256.70	2557.8	.....	.....	9.84	51.956
16	0.050820	2582.90	2028.6	6	10	7.81	41.237
17	0.045257	2048.20	1608.6	.....	.....	6.19	32.683
18	0.040303	1624.30	1275.7	3	5	4.91	25.925
19	0.035876	1287.10	1011.69	.....	.....	3.88	20.507
20	0.031961	1021.50	802.28	The above		3.09	16.315
21	0.028462	810.10	636.25	values are		2.45	12.936
22	0.025347	642.70	504.78	those speci-		1.94	10.243
23	0.022571	509.45	400.12	fied in the		1.54	8.1312
24	0.020100	404.01	317.31	1915		1.22	6.4416
25	0.017900	320.40	251.64	National		0.97	5.1216
26	0.015940	254.01	199.50	Electrical		0.77	4.0656
27	0.014195	201.50	158.26	Code.		0.61	3.2208
28	0.012641	159.79	125.50	In lighting		0.48	2.5344
29	0.011257	126.72	99.526	work, no		0.38	2.0064
30	0.010025	100.50	78.933	wire smaller		0.30	1.5840
31	0.008928	79.71	62.604	than No.		0.24	1.2672
32	0.007950	63.20	49.637	14 is used,		0.19	1.0032
33	0.007080	50.13	39.372	except in		0.15	0.7920
34	0.006304	39.74	31.212	fixtures		0.12	0.6336
35	0.005614	31.52	24.756	....		0.10	0.5280
36	0.005000	25.00	19.635	....		0.08	0.4224
37	0.004453	19.83	15.567	....		0.06	0.3168
38	0.003965	15.72	12.347	....		0.05	0.2640
39	0.003531	12.47	9.7939	....		0.04	0.2112
40	0.003144	9.89	7.7676	....		0.03	0.1581

[1] Calculated on the basis of Dr. Matthiesen's standard, namely, 1 mil. of 59-9 deg. Fahr.

Solid, Bare Copper Wire.[1] (Approximate)

enedict & Burnham Co.).

Length		Resistance at 75 deg. Fahr.			B. & S. or American Wire Gage No.
	Feet per ohm, 75 deg. F.	R. ohms per 1,000 ft.	Ohms per mile	Ohms per lb.	
56	20383.0	0.04906	0.25903	0.000076736	0000
97	16165.0	0.06186	0.32664	0.00012039	000
49	12820.0	0.07801	0.41187	0.00019423	00
14	10166.0	0.09838	0.51937	0.00038500	0
95	8062.3	0.12404	0.65490	0.00048994	1
99	6393.7	0.15640	0.82582	0.00078045	2
29	5070.2	0.19723	1.0414	0.0012406	3
93	4021.0	0.24869	1.3131	0.0019721	4
00	3188.7	0.31361	1.6558	0.0031361	5
61	2528.7	0.39546	2.0881	0.0049868	6

drawn into conduits, should be cables so they will be flexible. For but for larger conductors cables should be employed because of are cables.

90	2005.2	0.49871	2.6331	0.0079294	7
05	1590.3	0.62881	3.3201	0.012608	8
28	1261.3	0.79281	4.1860	0.020042	9
38	1000.0	1.0000	5.2800	0.031380	10
20	793.18	1.2607	6.6568	0.050682	11
69	629.02	1.5898	8.3940	0.080585	12
91	498.83	2.0047	10.585	0.12841	13
38	395.60	2.5278	13.347	0.20322	14
63	321.02	3.1150	16.477	0.31658	15
14	248.81	4.0191	21.221	0.51501	16
59	197.30	5.0683	26.761	0.81900	17
76	156.47	6.3911	33.745	1.3023	18
47	123.99	8.0654	42.585	2.0759	19
00	98.401	10.163	53.658	3.2926	20
56	78.067	12.815	67.660	5.2355	21
15	61.911	16.152	85.283	8.3208	22
56	49.087	20.377	107.59	13.238	23
21	38.918	25.695	135.67	21.050	24
96	30.864	32.400	171.07	33.466	25
51	24.469	40.868	215.79	35.235	26
55	19.410	51.519	272.02	84.644	27
22	15.393	64.966	343.02	134.56	28
32	12.207	81.921	432.54	213.96	29
97	9.6812	103.30	545.39	340.25	30
22	7.8573	127.27	671.99	528.45	31
56	6.0880	164.26	867.27	860.33	32
71	4.8290	207.08	1093.4	1367.3	33
10	3.8281	261.23	1379.3	2175.5	34
35	3.0363	329.35	1738.9	3458.5	35
63	2.4082	415.24	2192.5	5497.4	36
06	1.9093	523.76	2765.5	8742.1	37
5	1.5143	660.37	3486.7	13772.0	38
3	1.2012	832.48	4395.5	21896.0	39
4	0.9527	1049.7	5542.1	34823.0	40

per wire of $\frac{1}{16}$ in. diameter equals 13.59 ohms at 15.5 deg. cent. or

170. Allowable or Safe Carrying

(Voltage drop is not taken into account in this

American or Brown and Sharpe gage number	Diam. of solid wire in mils	Area in circular mils	II National Electrical Code (inside wiring) 1915 Rules					
			Table A. Rubber insulation, amps.	Table B. Other insulations, amps.	C Drop in volts per 1,000 ft. of wires (500 ft. 2-wire circuit) with allowable currents		D Length in feet of 2-wire circuit (single distance) over which N.E.C. safe currents can be transmitted with 1-volt drop, assuming 11 ohms the resistance of a cir. mil foot of commercial copper wire	
					Table A. Rubber insulation, volts	Table B. Other insulations, volts	Table A	Table B
[1]18	40.3	1,624	3	5	......	......	....	....
[1]16	50.8	2,583	6	10	......	......	....	....
14	64.1	4,107	15	20	40.2	53.5	12.4	9.4
12	80.8	6,530	20	25	33.8	42.2	14.8	11.9
10	101.9	10,380	25	30	26.6	31.8	18.9	15.8
8	128.5	16,510	35	50	23.3	33.3	21.4	15.0
6	162.0	26,250	50	70	20.9	29.4	23.9	17.0
5	181.9	33,100	55	80	18.3	26.6	27.4	18.8
4	204.3	41,740	70	90	18.5	23.7	27.1	21.1
3	229.4	52,630	80	100	16.7	21.0	29.9	23.9
2	257.6	66,370	90	125	14.9	20.8	33.5	24.1
1	289.3	83,690	100	150	13.1	19.7	38.1	25.4
0	325.0	105,500	125	200	13.0	20.8	38.4	24.0
00	364.8	133,100	150	225	12.4	18.6	40.4	26.9
000	409.6	167,800	175	275	11.5	18.0	43.7	27.8
...	......	200,000	200	300	11.0	16.5	45.5	30.3
0000	460.0	211,600	225	325	11.7	16.9	42.7	29.6
		250,000	240	350	10.5	15.4	47.5	32.5
		300,000	275	400	10.0	14.7	49.5	34.0
		350,000	300	450	9.4	14.2	53.0	35.4
		400,000	325	500	8.9	13.8	56.0	36.4
		500,000	400	600	8.8	13.2	56.8	37.9
		600,000	450	680	8.2	12.5	60.6	40.2
		700,000	500	760	7.8	11.9	63.6	41.9
		800,000	550	840	7.5	11.5	66.5	43.3
		900,000	600	920	7.3	11.2	68.2	44.5
		1,000,000	650	1,000	7.1	11.0	70.0	45.5
		1,100,000	690	1,080	6.9	10.8	72.5	46.3
		1,200,000	730	1,150	6.7	10.5	74.8	47.5
		1,300,000	770	1,220	6.5	10.3	76.8	48.5
		1,400,000	810	1,290	6.4	10.1	78.6	49.5
		1,500,000	850	1,360	6.2	9.9	80.5	50.2
		1,600,000	890	1,430	6.1	9.8	81.8	50.8
		1,700,000	930	1,490	6.0	9.6	83.0	52.0
		1,800,000	970	1,550	5.9	9.5	84.5	52.8
		1,900,000	1,010	1,610	5.8	9.3	85.5	53.7
		2,000,000	1,050	1,670	5.7	9.2	86.5	55.5

[1] Wires smaller than No. 14 American Wire Gage shall not be used except

170A. The allowable or safe current-carrying capacity of aluminum wire is, where the wire is insulated, specified in the *Nat. Elec. Code* as 84 per cent. of the values for copper wire (with the same insulation) which are given in *Columns A* and *B* in 170.

171. Slow-burning **conductors** (Fig. 95) are insulated with *three braids impregnated* with a fire-resisting compound, the same *that is used on slow-burning* weather-proof conductors. The *are approved (N.E.C.)* for interior exposed wiring, in dry plac

Capacity of Copper Wires, Amperes

table and should be considered separately)

E Bare wires in still air; temp. rise 50 deg. fahr. Std. U. G. Cable Co., amps.	General Electric Co., low tension cable — Single conductor: F Rubber insulation, 30 deg. cent. rise, amps.	General Electric Co., low tension cable — Single conductor: G Varnished cambric ins. or paper, 60 deg. cent. rise, amps.	General Electric Co., low tension cable — Triple conductor: H 30 deg. cent. rise, amps.	Circular mils	I National Electrical Code (inside wiring) 1911 Rules Now Obsolete — Table A. Rubber insulation, amps.	I National Electrical Code (inside wiring) 1911 Rules Now Obsolete — Table B. Other insulations, amps.
6.0	....	....	....	[1]1,624	3	5
8.5	....	....	....	[1]2,583	6	8
12.1	22	....	18	4,107	12	16
17.1	28	....	24	6,530	17	23
24.3	37	24	31	10,380	24	32
41.5	47	36	40	16,510	33	46
58.8	57	60	56	26,250	46	65
69.7	74	72	63	33,100	54	77
83.3	89	81	74	41,740	65	92
98.8	105	96	87	52,630	76	110
117.6	119	120	99	66,370	90	131
140.0	145	143	120	83,690	107	156
169.8	168	178	140	105,500	127	185
201.5	196	220	162	133,100	150	220
240.2	227	272	188	167,800	177	262
274.5	263	310	215	200,000	200	300
286.0	270	331	221	211,600	210	312
324.6	306	390	252	250,000	235	350
373.0	343	450	285	300,000	270	400
419.0	381	510	315	350,000	300	450
463.0	416	560	347	400,000	330	500
549.0	487	660	403	500,000	390	590
631.0	557	770	455	600,000	450	680
708.0	621	870	515	700,000	500	760
781.0	677	970	....	800,000	550	840
852.0	735	1,060	....	900,000	600	920
922.0	792	1,150	....	1,000,000	650	1,000
991.0	854	1,230	....	1,100,000	690	1,080
1,058.0	908	1,300	....	1,200,000	730	1,150
1,123.0	960	1,370	....	1,300,000	770	1,220
1,187.0	1,010	1,440	....	1,400,000	810	1,290
1,250.0	1,060	1,500	....	1,500,000	850	1,360
1,312.0	1,110	1,560	....	1,600,000	890	1,430
1,373.0	1,158	1,605	....	1,700,000	930	1,490
1,433.0	1,200	1,650	....	1,800,000	970	1,550
1,492.0	1,248	1,700	....	1,900,000	1,010	1,610
1,550.0	1,290	1,750	....	2,000,000	1,050	1,670

for fixture and signal wiring and pendant cords.

where the voltage does not exceed 550. They are particularly applicable for hot, dry places wherein ordinary insulations would soon perish. The outer braid is finished like that for slow-burning weather-proof conductors and has the same properties. See *177*.

172. **Weather-proof slow-burning conductors** have a fire-r
ting coating next to the conductor and a weather-proof coati
the outside. They are approved by the N.E.C.

173. **Properties of Rubber-insulated Wire and Cable.**

(Standard Underground Cable Co. Se

Size B. & S.	Area cir. mils	*A* Dia. bare mils	*B* Insulation 64th in.	Solid wire				Stranded or cable	
				Single braid		Double braid		Single braid	
				C Dia. mils	Lb. per 1,000 ft.	*D* Dia. mils	Lb. per 1,000 ft.	Dia. mils	Lb. per 1,000 ft.
.....	....	....	....	....	......	.....	......	.....	......
18	1,624	40	2	143	14.5	185	19.1	.....	......
16	2,582	51	2	155	18.9	197	23.9	.....	......
14	4,106	64	3	208	33.0	258	40.0	216	34.3
12	6,530	81	3	225	43.1	275	51.5	235	44.9
10	10,381	102	3	246	58.1	296	67.2	260	60.6
9	13,094	114	3	258	68.4	308	78.2	274	70.0
8	16,509	128	3	273	82.1	322	92.2	290	85.5
6	26,251	162	4	337	130.0	387	142.0	360	136.0
5	33,102	182	4	357	154.0	407	167.0	396	166.0
4	41,742	204	4	393	190.0	457	208.0	422	198.0
3	52,634	229	4	418	228.0	482	247.0	451	238.0
2	66,373	258	4	447	276.0	511	297.0	504	293.0
1	83,694	289	5	530	363.0	614	395.0	571	377.0
0	105,593	325	5	565	439.0	649	474.0	613	457.0
00	133,100	365	5	605	528.0	689	564.0	659	556.0
000	167,805	410	5	650	646.0	734	685.0	709	675.0
0000	211,600	460	5	700	793.0	784	835.0	767	833.0

174. **Rubber-covered or rubber-insulated wires and cable** (see Fig. 93), when protected with one braid over the insulation are known as single-braid, and when two braids are used, to insur against injury by abrasion, they are known as double-braid rubber covered wire or cable. Rubber-covered conductors are used fo inside wiring where concealed or in damp places and throughou where the voltage exceeds 550. Conductors insulated with les expensive materials (see following paragraphs) can be used out-of doors, on pole lines and inside in dry places where the wires ar exposed. The use of single-braid rubber-covered wires is permissi ble for exposed interior wiring in damp places and in wooden and metal moulding in dry places and in iron conduit, provided th wire is smaller than No. 6. Double braid wires should be use in all cases where the wire is larger than No. 6. Table 173 give the principal properties of rubber-covered conductors, for pres sures not exceeding 600 volts.

ıtional Electrical Code Standard, 0-600 Volts

ıstration below for key to reference letters)

	Stranded or cable		Stranded or cable						
	Double braid					Single braid		Double braid	
	Dia. mils	Lb. per 1,000 ft.	*E* Size cir. mils	*B* Insulation 64th in.	Dia. bare mils	*F* Dia. mils	Lb. per 1,000 ft.	*G* Dia. mils	Lb. per 1,000 ft.
.	......	....	250,000	6	575	845	997	929	1,047
8	......	....	300,000	6	630	902	1,173	986	1,226
6	......	....	350,000	6	681	952	1,343	1,036	1,399
4	268	42.4	400,000	6	729	1,001	1,514	1,085	1,573
2	285	53.8	450,000	6	773	1,044	1,685	1,128	1,746
0	310	70.1	500,000	6	815	1,087	1,842	1,171	1,906
9	324	80.0	550,000	7	855	1,157	2,053	1,241	2,121
8	340	96.3	600,000	7	893	1,194	2,220	1,278	2,290
6	410	149.0	650,000	7	929	1,231	2,389	1,315	2,461
5	460	184.0	700,000	7	964	1,266	2,557	1,350	2,631
4	486	218.0	750,000	7	998	1,300	2,723	1,384	2,798
3	515	260.0	800,000	7	1,031	1,333	2,891	1,417	2,968
2	588	324.0	850,000	7	1,062	1,365	3,056	1,449	3,135
1	655	412.0	900,000	7	1,093	1,395	3,223	1,479	3,304
0	697	494.0	950,000	7	1,123	1,425	3,388	1,509	3,470
0	743′	595.0	1,000,000	7	1,152	1,455	3,553	1,539	3,637
0	793	719.0	1,250,000	8	1,289	1,623	4,506	1,707	4,599
0	851	879.0	1,500,000	8	1,413	1,747	5,344	1,831	5,445
.	......	....	1,750,000	8	1,526	1,860	6,177	1,944	6,284
.	......	....	2,000,000	8	1,631	1,965	7,006	2,049	7,119

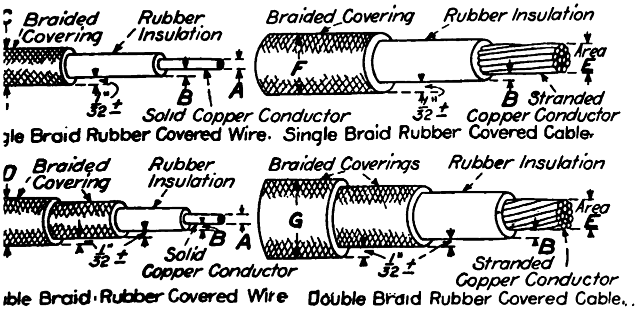


FIG. 93.—National electrical code, rubber-insulated, wire and cable (See Table 173)

175. Physical and Electrical Properties of Pure Copper Stranded Cable (*Standard Underground Cable Co.*)

Size, B. & S. gage and area cir. mils	No. of wires in strand	Dia. of wires in strand, mils	Diameter of bare cable		Approx. weight in lbs.		Approx. ft. per lb.	Approx. ft. per ohm	Approx. resistance international ohms at 68 deg. fahr.	
			Mils	In 64th of inch	Per 1,000 ft.	Per mile			Per 1,000 ft.	Per lb.
14	7	24.2	73	5	13	69	77	397	2.52	0.194
12	7	30.5	92	6	20	106	50	632	1.59	0.0795
10	7	38.5	116	8	32	169	31	1,005	0.997	0.0312
8	7	48.6	146	10	50	264	20	1,598	0.627	0.0125
6	**7**	**61.2**	**184**	**12**	**80**	**422**	**12.5**	**2,540**	**0.394**	0.00493
5	7	68.8	206	14	101	533	9.90	3,203	0.313	0.00310
4	7	77.2	232	15	127	670	7.87	4,031	0.248	0.00195
3	7	86.7	260	17	160	845	6.25	5,084	0.197	0.00123
2	7	97.4	292	19	202	1,067	4.95	6,410	0.156	0.000772
1	**19**	**66.4**	**328**	**22**	**255**	**1,346**	**3.92**	**8,083**	**0.124**	**0.000486**
1/0	19	74.5	373	24	322	1,700	3.11	10,190	0.098	0.000304
2/0	19	83.7	419	27	406	2,144	2.46	12,850	0.078	0.000192
3/0	19	94.0	470	31	512	2,704	1.95	16,210	0.062	0.000121
4/0	19	105.5	528	33	646	3,405	1.55	20,440	0.049	0.0000759
250,000	**37**	**82.2**	**575**	**37**	**764**	**4,023**	**1.34**	**24,150**	**0.041**	**0.0000550**
300,000	37	90.1	630	41	917	4,842	1.09	28,980	0.035	0.0000382
350,000	37	97.3	681	44	1,070	5,650	0.935	33,800	0.030	0.0000280
400,000	37	104.0	729	47	1,223	6,457	0.818	38,630	0.026	0.0000213
450,000	37	110.3	773	50	1,377	7,271	0.726	43,460	0.023	0.0000167
500,000	**61**	**90.5**	**815**	**53**	**1,530**	**8,078**	**0.653**	**48,290**	**0.021**	**0.0000137**
550,000	61	95.0	855	55	1,684	8,891	0.594	53,100	0.019	0.0000113
600,000	61	99.2	893	58	1,837	9,700	0.544	58,000	0.017	0.00000925
650,000	61	103.2	929	60	1,991	10,810	0.502	62,800	0.016	0.00000804
700,000	61	107.1	964	62	2,145	11,330	0.466	67,600	0.015	0.00000700
750,000	**61**	**110.9**	**998**	**64**	**2,299**	**12,140**	**0.435**	**72,400**	**0.014**	**0.00000609**
800,000	61	114.5	1,031	67	2,453	12,950	0.408	77,300	0.013	0.00000530
900,000	61	121.5	1,093	71	2,762	14,580	0.362	86,900	0.012	0.00000435
1,000,000	61	128.0	1,152	74	3,070	16,210	0.326	96,600	0.010	0.00000359
1,250,000	91	117.2	1,289	83	3,882	20,500	0.258	120,800	0.0083	0.00000214
1,500,000	**91**	**128.4**	**1,413**	**91**	**4,631**	**24,450**	**0.216**	**144,900**	**0.0069**	**0.00000149**
1,750,000	127	117.4	1,526	98	5,428	28,660	0.184	169,000	0.0059	0.00000111
2,000,000	127	125.5	1,631	105	6,200	32,740	0.161	193,200	0.0052	0.000000839

176. Properties of National Code Standard, Rubber-covered, Solid and Stranded Wire and Cable For Voltages of 600 to 1,500.

Standard Underground Cable Co.

Size		No. of wires in cond.	Diam. of wires comprising cable, mils	Thickness of rubber in inches	Diameter over all				Approx. weight per 1,000 ft., tape and braid
					Single braid		Double braid		
B. & S. gage	Cir. mils				Mils	64ths	Mils	64ths	
Solid									
14	4,107	.....	....	1/16	239	15.3	289	18.5	46
12	6,530	.....	....	1/16	256	16.4	306	19.6	58
10	10,380	.....	....	1/16	277	17.75	327	20.9	75
8	16,510	.....	....	1/16	304	19.45	354	22.6	100
6	26,250	.....	....	5/64	382	24.2	446	28.5	153
4	41,740	.....	....	5/64	425	27.2	489	31.3	212
2	66,370	.....	....	5/64	498	31.9	582	37.2	310
1	83,690	.....	....	3/32	561	35.9	645	41.25	394
1/0	105,500	.....	....	3/32	596	38.2	680	43.5	475
2/0	133,100	.....	....	3/32	636	40.65	720	46.1	595
3/0	167,800	.....	....	3/32	681	43.5	765	48.96	700
4/0	211,600	.....	....	3/32	732	46.8	816	52.2	850
Stranded									
8	16,510	7	48.6	1/16	321	20.5	371	23.75	106
6	26,250	7	61.2	5/64	404	25.8	468	30.0	160
4	41,740	7	77.2	5/64	453	29.0	517	33.1	225
2	66,370	7	97.4	5/64	532	34.1	616	39.4	320
1	83,690	19	66.4	3/32	604	38.65	688	44.0	405
1/0	105,500	19	74.5	3/32	645	41.25	729	46.6	490
2/0	133,100	19	83.7	3/32	691	44.25	775	49.6	595
3/0	167,800	19	94.0	3/32	742	47.5	826	52.8	715
4/0	211,600	19	105.5	3/32	800	51.2	884	56.5	875
....	250,000	37	82.2	7/64	878	56.2	962	61.5	1,040
....	300,000	37	90.1	7/64	933	59.7	1,017	65.2	1,220
....	350,000	37	97.3	7/64	984	63.0	1,068	68.5	1,390
...	400,000	37	104.0	7/64	1,032	66.0	1,116	71.4	1,570
...	450,000	37	110.3	7/64	1,076	68.9	1,160	74.3	1,745
....	500,000	61	90.6	7/64	1,118	71.5	1,202	76.9	1,915
...	600,000	61	99.2	1/8	1,227	78.5	1,311	83.9	2,300
...	650,000	61	103.2	1/8	1,263	80.9	1,347	86.3	2,470
...	700,000	61	107.1	1/8	1,298	83.1	1,382	88.5	2,640
....	750,000	61	110.9	1/8	1,332	85.3	1,416	90.6	2,810
....	800,000	61	114.5	1/8	1,365	87.4	1,449	92.8	2,930
....	900,000	61	121.5	1/8	1,327	91.5	1,511	96.75	3,330
....	1,000,000	61	128.0	1/8	1,486	95.2	1,570	100.5	3,670

177. Properties of Weather-proof and Slow-burning

Size, B. & S. and cir. mils	Weather-proof				Slow-burning
	Approx. wts. per 1,000 ft.		Approx. overall diameters, in.		Approx. wts. per 1,000 ft.
	Triple braid	Double braid	Triple braid	Double braid	Weather-proof white finish
			Solid wire		
0000	765	710	0.660	0.610	870
000	625	570	0.595	0.560	720
00	490	448	0.550	0.515	568
0	400	360	0.505	0.470	470
1	310	290	0.445	0.405	350
2	255	232	0.400	0.374	290
4	164	146	0.346	0.320	200
6	112	97	0.303	0.278	140
8	75	64	0.264	0.245	95
10	53	46	0.221	0.197	70
12	35	27	0.200	0.172	52
14	25	20	0.182	0.155	40
16	19	15	0.169	0.142	30
18	16	12	....	....	24
20	12	9	....	....	....
			Stranded Wire or Cable		
2,000,000	6,700	6,540	1.930	1.844	....
1,750,000	5 894	5,739	1.820	1.740	....
1,500,000	5,090	4,940	1.712	1.624	....
1,250,000	4,287	4,153	1.580	1.500	....
1,000,000	3,478	3,360	1.451	1.365	3,880
900,000	3,290	3,045	1.390	1.310	3,540
800,000	2,778	2,700	1.331	1.243	3,200
750,000	2,615	2,551	1.300	1.210	3,020
700,000	2,439	2,380	1.265	1.177	2,840
600,000	2,113	2,060	1.190	1.105	2,370
500,000	1,781	1,740	1.108	1.027	2,010
450,000	1,630	1,598	1.070	0.984	1,840
400,000	1,445	1,405	1.020	0.940	1,670
350,000	1,277	1,240	0.978	0.894	1,460
300,000	1,126	1,090	0.930	0.846	1,290
250,000	937	905	0.862	0.780	1,080
0000	806	753	0.785	0.708	910
000	655	610	0.728	0.648	745
00	515	470	0.662	0.599	590
0	420	382	0.605	0.555	485
1	328	300	0.518	0.470	360
2	267	251	0.440	0.415	300
4	173	153	0.379	0.353	205
6	117	103	0.327	0.305	145
8	75	69	0.290	0.270	97

For number of wires in strand see 183.

lid Copper Wire and Cable. (*General Electric Co.*)

Slow-burning					Size, B. & S. and cir. mils.
Approx. weights per 1,000 ft.		Approx. overall diameters, inches			
Veather-proof black finish	Under-writers	Weather-proof or white	Weather-proof or black	Under-writers	
Solid wire					
862	780	0.660	0.660	0.660	0000
710	640	0.595	0.595	0.595	000
562	510	0.550	0.550	0.550	00
462	420	0.505	0.505	0.505	0
340	330	0.445	0.445	0.445	1
280	280	0.400	0.400	0.400	2
190	180	0.346	0.346	0.346	4
127	125	0.303	0.303	0.303	6
85	90	0.264	0.264	0.264	8
60	65	0.221	0.221	0.221	10
42	40	0.200	0.200	0.200	12
30	30	0.182	0.182	0.182	14
24	22	0.169	0.169	0.169	16
19	....	....	....	....	18
....	....	....	....	....	20
Stranded Wire or Cable					
7,540	....	1.930	1.930	1.930	2,000,000
6,700	....	1.820	1.820	1.820	1,750,000
5,830	....	1.712	1.712	1.712	1,500,000
4,940	....	1.580	1.580	1.580	1,250,000
3,980	3,578	1.451	1.451	1.451	1,000,000
3,640	3,250	1.390	1.390	1.390	900,000
3,280	2,894	1.331	1.331	1.331	800,000
3,100	2,720	1.300	1.300	1.300	750,000
2,920	2,540	1.265	1.265	1.265	700,000
2,460	2,204	1.190	1.190	1.190	600,000
2,080	1,858	1.108	1.108	1.108	500,000
1,900	1,700	1.070	1.070	1.070	450,000
1,700	1,509	1.020	1.020	1.020	400,000
1,500	1,329	0.978	0.987	0.978	350,000
1,310	1,170	0.930	0.930	0.930	300,000
1,120	981	0.862	0.862	0.862	250,000
960	844	0.785	0.785	0.785	0000
785	686	0.728	0.728	0.728	000
625	550	0.662	0.662	0.662	00
510	449	0.605	0.605	0.605	0
380	360	0.518	0.518	0.518	1
335	294	0.440	0.440	0.440	2
230	196	0.379	0.379	0.379	4
165	135	0.327	0.327	0.327	6
105	94	0.290	0.290	0.290	8

178. Properties of National Code Standard, Rubber-covered, Solid and Stranded Wire and Cable For Voltages of 1,500 to 2,500.

Standard Underground Cable Co.

Size		No. of wires in cond.	Diam. of wires compris-ing cable, mils	Thick-ness of rubber in inches	Diameter over all				Approx. weight per 1,00 ft., tap and braid
					Single braid		Double braid		
B. & S. gage	Cir. mils				Mils	64ths	Mils	64ths	
				Solid					
14	4,107	.....	....	3/32	302	19.3	352	22.5	70
12	6,530	.....	....	3/32	318	20.4	368	23.55	85
10	10,380	.....	....	3/32	339	21.7	389	24.9	100
8	16,510	.....	....	3/32	380	24.3	444	28.4	130
6	26,250			3/32	414	26.5	478	30.6	175
4	41,740	.....	....	3/32	456	29.2	520	33.3	240
2	66,370	.....	....	3/32	509	32.6	573	36.65	330
1	83,690	.....	....	7/64	592	37.0	676	43.25	420
1/0	105,500	.....	....	7/64	628	40.2	712	45.5	500
2/0	133,100	.....	....	7/64	668	42.75	752	48.1	600
3/0	167,800	.....	....	7/64	712	45.5	796	50.1	725
4/0	211,600	.....	....	7/64	763	48.8	847	54.25	875
				Stranded					
8	16,510	7	48.6	3/32	398	25.5	462	29.6	140
6	26,250	7	61.2	3/32	436	27.9	500	32.0	185
4	41,740	7	77.2	3/32	504	32.25	588	37.6	250
2	66,370	7	97.4	3/32	564	36.1	648	41.5	340
1	83,690	19	66.4	7/64	635	40.6	719	46.0	435
1/0	105,500	19	74.5	7/64	676	43.25	760	48.6	520
2/0	133,100	19	83.7	7/64	721	46.1	805	51.5	620
3/0	167,800	19	94.0	7/64	773	49.5	857	54.8	745
4/0	211,600	19	105.5	7/64	831	53.2	915	58.5	905
....	250,000	37	82.2	1/8	909	58.1	993	63.5	1,080
....	300,000	37	90.1	1/8	964	61.7	1,048	67.1	1,255
....	350,000	37	97.3	1/8	1,015	65.0	1,099	70.4	1,430
....	400,000	37	104.0	1/8	1,063	68.0	1,147	73.4	1,610
....	450,000	37	110.3	1/8	1,107	70.9	1,191	76.3	1,785
....	500,000	61	90.6	1/8	1,149	73.5	1,233	78.9	1,990
....	600,000	61	99.2	9/64	1,258	80.6	1,342	85.9	2,350
....	650,000	61	103.2	9/64	1,294	82.9	1,378	88.2	2,525
....	700,000	61	107.1	9/64	1,329	85.1	1,413	90.45	2,710
....	750,000	61	110.9	9/64	1,363	87.25	1,447	92.7	2,875
....	800,000	61	114.5	9/64	1,396	89.4	1,480	94.8	3,050
....	900,000	61	121.5	9/64	1,458	93.4	1,542	98.8	3,490
....	1,000,000	61	128.0	9/64	1,517	97.25	1,601	102.4	3,730

179. Duplex or twin wires or cables (sometimes called "condu *wire"*) are shown in Fig. 94. They are used where they are t *be drawn into* conduit and should never be used except in condui *Each wire is* rubber-insulated to the thickness indicated in Tab

180 and then is served with a braid or with a tape. The two conductors are finally bound together with a tenacious braid at least $\frac{1}{32}$ in. thick for wires larger than No. 10 B. & S. gage and

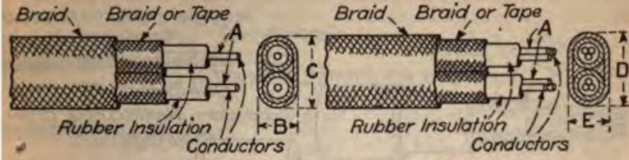


Fig. 94.—Duplex wire and cable.

$\frac{1}{64}$ in. for No. 10 B. & S. gage or less in size. This construction is considered in the N.E.C. as equivalent to that of double-braid, rubber-covered wire. Twin conductors larger than No. 0000 should not be used because of their tendency to kink.

180. National Electric Code Standard, Duplex (Flat), Two-conductor Wire and Cable, 0-600 Volts
(General Electric Co.)

A Size of each conductor B. & S. gage	Solid: Weight in lbs. per 1,000 ft.	Solid: Dimensions in inches, B × C	Stranded: Weight in lbs. per 1,000 ft.	Stranded: Dimensions in inches, D × E
8	214	0.33×0.57	214	0.35×0.61
10	162	0.30×0.52	162	0.32×0.55
12	126	0.28×0.46	126	0.29×0.48
14	100	0.26×0.42	100	0.27×0.44

181. Weather-proof wire or Cable (Fig. 95) is used for out-of-door conductors and should be supported on porcelain or glass insulators and not on knobs, cleats or rubber hooks. Weather-proof wire is not approved for inside wiring (N.E.C.) except where exposed to corrosive vapors. The so-called "weather-proof" insulation becomes a reasonably good conductor when moist. **Triple-braid** weather-proof conductors have three braids, saturated with a so-called moisture-proof compound served around them, and **double-braid** conductors have two such braids. Triple-braid conductors are approved by the N.E.C. for outside construction, but double-braid conductors are not approved at all. See Table 177 for properties.

182. Safe Current-carrying Capacity of Large Fiber-cored Cables on A.-C. Circuits.—See Fig. 96 for reference letters. Alternating current flowing in large cables has greater density on the surface of the conductor than in the center (so-called skin effect) therefore an ordinary cable will not carry as much alternating current as direct current with the same temperature rise. In order *to overcome this it is advisable,* on single-conductor cables 700,000 *cm. and larger for 60-cycle* circuits, and 1,250,000 cm. and larger for 25-cycle circuits, to make the cable with a fiber core and strand the copper around it. The weight of copper in this type of cable is the same per foot as in an ordinary cable, but owing to its annular

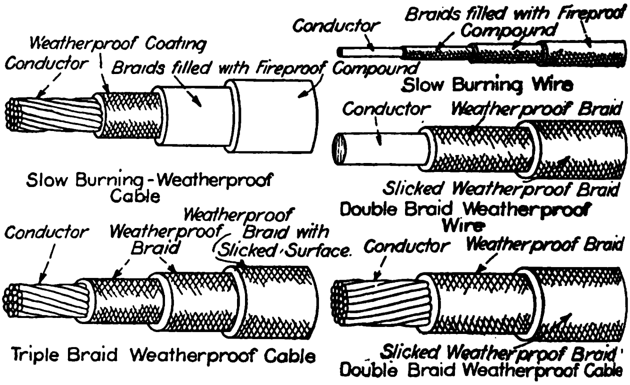


FIG. 95.—Weather-proof and slow-burning conductors.

cross-section the cable is much more efficient in carrying alternating current and also has a somewhat greater current-carrying capacity due to the larger radiating surface. These copper strands can be insulated with any desired type of insulation. (*General Electric Co.*)

182A. Fiber cord cables.

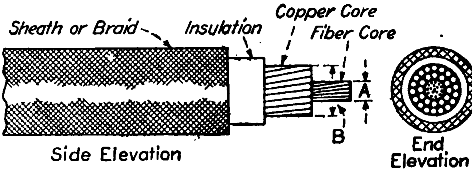


FIG. 96.—Cable with fiber core.

Size	*A* Dia. fiber core in in.	No. of wires in strand	Size wire in strand in in.	*B* Overall dia. copper core in in.	Ampere capacity	
					30 deg. cent. rise.	60 deg. cent. rise.
2,000,000	$\frac{7}{8}$	210	0.099	2.065	1,400	1,750
1,750,000	$\frac{25}{32}$	210	0.091	1.87	1,300	1,625
1,500,000	$\frac{11}{16}$	182	0.091	1.78	1,200	1,500
1,250,000	$\frac{9}{16}$	168	0.086	1.59	1,150	1,400
1,000,000	$\frac{15}{32}$	98	0.102	1.28	900	1,150
800,000	$\frac{11}{32}$	51	0.125	1.1	775	925
750,000	$\frac{10}{32}$	48	0.125	1.060	750	900
700,000	$\frac{9}{32}$	51	0.117	0.99	700	830
50,000	$\frac{1}{4}$	45	0.1056	0.890	550	660

183. Special Stranding Table for Weather-proof Slow-burning nd Bare Cables.—*General Electric Co.* The price of any weather-roof, slow-burning or bare cable depends upon the size wire used the strand. The finer the individual wires the more expensive ne cable. The following table of strands insures a minimum rice for the cable. Strands or cables from finer wires can be nanufactured.

Size B. & S. and cir. mils	No. wires in strand	Diam. of individual wires in inches	Approximate diam. of bare cable in inches	Approximate weight of copper per 1,000 ft. in lb.
8	7	0.0485	0.1455	51
6	7	0.0613	0.1839	81
5	7	0.0688	0.2064	103
4	7	0.0773	0.2319	129
3	7	0.0868	0.2604	164
2	7	0.0974	0.2922	206
1	7	0.1110	0.3330	259
0	7	0.1250	0.3750	328
00	7	0.1400	0.4190	414
000	7	0.1560	0.4700	520
0000	19	0.1056	0.5280	658
250,000	19	0.1160	0.5754	775
300,000	19	0.1270	0.6342	943
350,000	19	0.1370	0.6818	1087
400,000	37	0.1040	0.7280	1242
450,000	37	0.1110	0.7770	1415
500,000	37	0.1170	0.8154	1554
550,000	37	0.1220	0.8550	1709
600,000	37	0.1280	0.8928	1864
650,000	37	0.1330	0.9297	2020
700,000	37	0.1380	0.9648	2177
750,000	61	0.1110	0.9990	2333
800,000	61	0.1146	1.0314	2487
900,000	61	0.1216	1.0944	2813
1,000,000	61	0.1281	1.1529	3110
1,250,000	61	0.1440	1.2903	3888
1,500,000	91	0.1284	1.4124	4660
1,750,000	91	0.1390	1.5262	5435
2,000,000	127	0.1255	1.6315	6212

184. Splices in bare copper line wire can be made as indicated n Fig. 97 and should be mechanically and electrically secure efore solder is applied. There should be at least 5 turns in the eck (Fig. 97) of a splice to insure that the unsoldered splice will e as strong as the wire of which it is made. All splices in wires

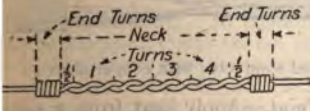


Fig. 97.—Bare copper, line wire splice.

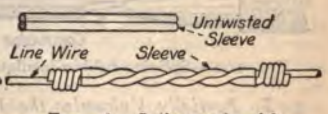


Fig. 98.—Splice made with McIntire sleeve.

or conveying electricity should be soldered in the neck. It is not lways necessary to solder the end turns. McIntire sleeves are ery satisfactory and are used to a great extent for splicing aerial ne wires. (See Fig. 98.) Solder is not necessary where sleeves are used. For further information in regard to splices in bare wire see *Electrical World*, Nov. 17, 1910, "Some Tests on Splices in Galvanized Iron Wire," By C. T. Rashman.

184A. Splices in insulated aerial line wires are made similarly to that shown in Fig. 97 except tape is served around the splice for insulation. (See Fig. 99.) If the line wire has only weather-proof insulation, friction tape is sufficient but if the inner insulation is rubber, rubber tape to the thickness of the inner insulation should be applied before the friction tape is served. All splices in wires for conveying electricity should be soldered in the neck.

185. Instructions for Making a Joint in Pure Rubber Insulated Wire (*Okonite Co.*). (See Fig. 100.) 1. *Preparing the Conductor Ends.*—Bare and clean about 1 in. of each end of the conductor; then, with a very sharp thin-bladed knife, bevel the insulation for about 1 in. as one would sharpen a lead pencil. 2. Preferably

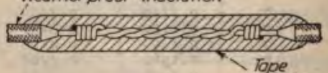


Fig. 99.—Splices and taps in insulated line wire.

make the conductor joint with a copper sleeve, sweating the latter on, being careful to clean off all surplus solder or, if the connection is made by twisting the two ends together, see that the ends do not protrude. 3. Now cover the bevels and conductor with a thin coat of a pure rubber cement and allow this to "set" (which takes about 1 min.).

4. *Insulating the Joint.*—Take a strip of $\frac{3}{4}$-in. pure rubber tape 6 to 8 in. long, and beginning at the bevel on a level with the insulation *A* in Fig. 100, wrap spirally (making sure that the turns overlap) to the other side of the joint as far as the high point of the bevel on that side, *B*. Continue to wrap to and fro until the insulation is built up slightly thicker than the regular wall. The tape must be put on under tension—say stretched to about half its width. Care must be taken to have everything perfectly clean.

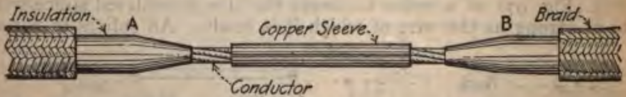


Fig. 100.—Splicing rubber-insulated conductor with copper sleeve.

5. *To Partially Vulcanize the Joint.*—Apply heat from a spirit lamp, a lighted match or the heat of the hand evenly around the joint. Do this for about 1 min. (be careful not to burn the insulation) and then wrap the joint with two layers of $\frac{3}{4}$-in. friction tape. If the wire is braided or taped, be sure that the braid or tape is cut well back so that there are no loose threads overhanging to interfere with the proper insulating of the joint.

This is the method of making a joint *properly*, and, with slight modifications, it is applicable to all sizes of conductors.

Should the friction tape become slightly set, as it sometimes does in extreme cold weather, warming will restore it perfectly.

186. Splices in Interior Wires (Fig. 101).—Not as many turns are necessary in the neck as for aerial line wires. All splices must be soldered unless made with some form of approved splicing device. Rubber tape to the thickness of the rubber insulation must be used on rubber-covered wires and friction tape must be served over the rubber to hold it in place. The so-called "Fixture Splice" (Fig. 101) is used largely by telephone men and in wiring fixtures. It can be conveniently used sometimes in splicing two wires that must be drawn taut in the splicing. A splice in wires is often made at a point between two supports, cleats, or knobs in this way. The duplex wire splice (Fig. 101) is often used by telephone men. The joints should always be "broken," that is, they should not be op-

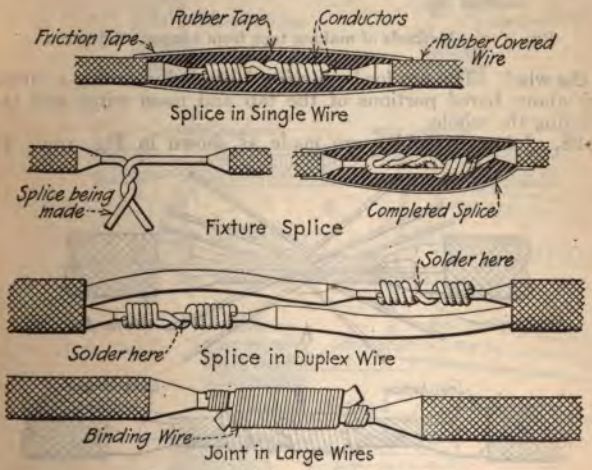


FIG. 101.—Splices in interior wires.

posite one another. In conduit work, for which duplex wire is frequently used, joints are not permissible except in junction boxes, but nevertheless they are occasionally made as indicated and pulled into conduit. Rubber and friction tape is applied to each in the same way as to the joint in a single wire and then the pair of wires should be served with friction tape. Joints should always be taped so that the insulation over the joint equals that over the rest of the conductor.

187. Taps in copper wires are made as shown in Fig. 102. The "*knotted*" *tap has the* advantage that the tap wire cannot *untwist from the main wire.* Tape should be applied as with splices. The tap for small aerial wires, Fig. 102, is made by giving the tap wire one long complete wrap around the main wire and then four short turns. The long wrap gives the joint a certain amount of flexibility which is necessary for aerial work where wires are moved

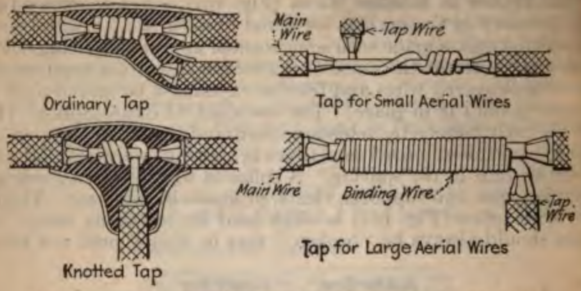


FIG. 102.—Methods of making taps from copper conductors.

by the wind. The tap for large wires is made by serving a binding wire about bared portions of the tap and main wires and then soldering the whole.

188. Joints in cables are made as shown in Fig. 103. The

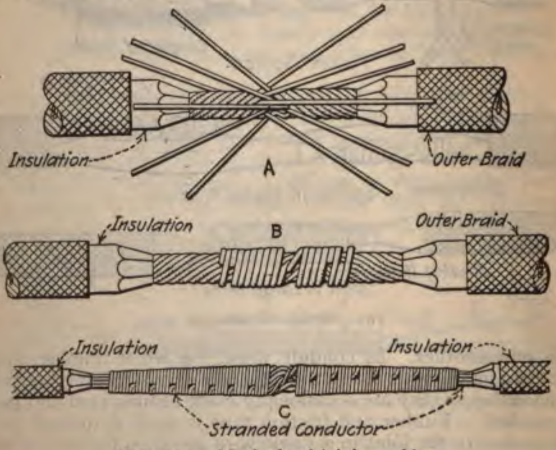


FIG. 103.—Methods of joining cables.

wires composing the cable should be spread and each pulled out *straight and the* core or a few inner wires cut away so that the splice *will not be bulky.* Then the two cable ends are abutted as shown *(Fig. 103)* and the wires are interwoven in groups of two and served along the cable. The joint is soldered by pouring, wit a ladle, molten solder through and over it, the solder pot bein meanwhile held under the joint so as to catch any solder th does not adhere. For interior work a short joint like that of *B* frequently used, but in aerial work a longer one like that of *C* preferred. For an aerial joint (*C*) a length of about 16 to 20 in. bared at the end of each cable in order to make a splice. All these joints should be thoroughly soldered.

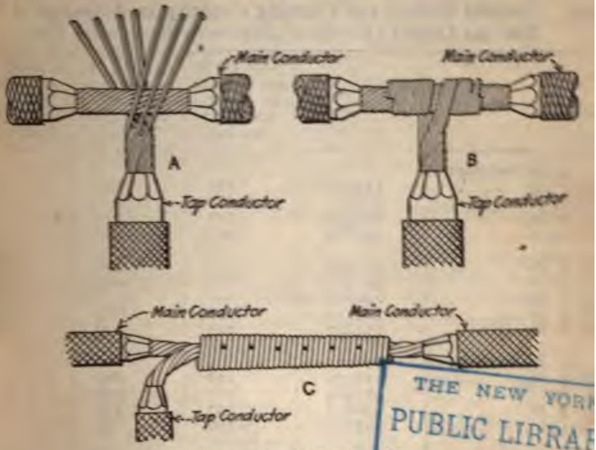


FIG. 104.—Tap joints in cables.

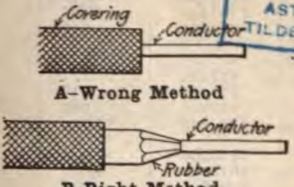


FIG. 105.—Methods of "skinning" wire.

189. Tap joints in Cables are made as suggested in Fig. 10 "*A*" shows how the tap wires are "fanned" out before bein served about the main conductor and *B* shows a completed ta joint for interior work. *C* shows a completed tap joint in a aerial cable. *Tap joints in cables can be made with a bindi wire similarly to the method of Fig.* 102.

190. ***In making any joint*** the wire ends should be scraped b *with the back of a knife blade,* sand paper or emery paper so *the solder will adhere readily.* Insulation should be cut aw shown at *B* (Fig. 105) rather than as shown at *A*. When cut as at *A* the wire is likely to be nicked and with the *B* method the tape can be served more neatly about the joint. The outer braid should be cut well back from the joint so that stray strands from it cannot be taped into the joint and, by capillary attraction, conduct moisture thereto.

191. For soldering joints the non-corrosive fluid of 201 is recommended.

192. Circular Millage and Carrying Capacity in Amperes of Flat Bus-bar Copper (*Electrical Engineer's Equipment Co.*)

	Circular mils	1,000 C. M. per ampere or 1,273 amp. per sq. in.	1,200 C. M. per ampere or 1,061 amp. per sq. in.	1,600 C. M. per ampere or 795 amp. per sq. in.
⅛ in. bar copper				
By 1 in.	159154	159	133	99
By 1½ in.	238731	239	199	149
By 2 in.	318309	318	265	199
By 2½ in.	397886	398	332	249
By 3 in.	477463	477	398	298
By 3½ in.	557040	557	464	348
By 4 in.	636618	637	531	398
By 5 in.	795772	796	663	497
By 6 in.	954927	955	796	597
¼ in. bar copper				
By 1 in.	318309	318	265	199
By 1½ in.	477463	477	398	298
By 2 in.	636618	637	531	398
By 2½ in.	795772	796	663	497
By 3 in.	954927	955	796	597
By 3½ in.	1114081	1,114	928	696
By 4 in.	1273236	1,273	1,061	796
By 5 in.	1591545	1,592	1,326	995
By 6 in.	1909854	1,910	1,592	1,194
⅜ in. bar copper				
By 1 in.	477463	477	398	298
By 1½ in.	716194	716	597	448
By 2 in.	954927	955	796	597
By 2½ in.	1193658	1,194	995	746
By 3 in.	1432390	1,432	1,194	895
By 3½ in.	1671122	1,671	1,393	1,044
By 4 in.	1909854	1,910	1,592	1,194
By 5 in.	2387317	2,387	1,989	1,492
By 6 in.	2864781	2,865	2,387	1,790
½ in. bar copper				
By 1 in.	636618	637	531	398
By 1½ in.	954927	955	796	597
By 2 in.	1273236	1,273	1,061	796
By 2½ in.	1591545	1,592	1,326	995
By 3 in.	1909854	1,910	1,592	1,194
By 3½ in.	2228163	2,228	1,857	1,393
By 4 in.	2546472	2,546	2,122	1,592
By 5 in.	3183090	3,183	2,653	1,989
By 6 in.	3819708	3,820	3,183	2,387

193. Bus-bars are usually made up of rolled copper bar from 0.25 to 0.375 in. thick and from 1 in. in width up. When more than one bar is needed to give the required current-carrying capacity the bars are separated by means of spacing blocks so as to give a maximum radiating surface. Copper bars are designed on the basis of a **current density** of about 800 to 1,000 amp. per sq. in. of cross-section. They are mounted on insulators, the type of insulator depending upon the voltage of the system. Occasionally aluminum bus-bars, employing a maximum current density of about 750 amp. per sq. in., have been installed. For medium size plants, operating at a potential of 2,300 volts, the bus-bars are made up of insulated wires, varnished cambric being preferred as the insulating material, and these are mounted on insulators attached to the framework which supports the panels. **Contact surfaces** between bus-bars should allow between 100 and 200 amp. per sq. in. of surface, and **terminals and leads** taken from the bars should allow 100 amp. per sq. in. Brass castings for **connections and terminals** have a conductivity between 12 and 18 per cent., and, therefore, it is best to use copper where large current-carrying capacity is desired.

194. Aluminum.—The weight of aluminum is 0.000,000,915 (or 91.5×10^{-8}) lb. per cir. mil-ft. or 0.000,000,808 (or 80.8×10^{-8}) lb. per sq. mil-ft. (*Standard Handbook*). See additional values giving properties of aluminum in adjacent comparative table. The following data is from the *Westinghouse Diary:*

	Copper	Aluminum
Area for equal conductivity....................	100.0	160.0
Diameter for equal conductivity..............	100.0	126.0

It will be noted from the relative diameters that an aluminum wire to be of equal conductivity to a copper wire is almost exactly two sizes larger by B. & S. Gage.

The conductivity of aluminum wire is 63 per cent. of that of copper; but an aluminum wire of equivalent conductivity will have 48 per cent. of the weight and 160 per cent. of the strength.

195. Commercial galvanized-iron wire is known in the market by the following terms: **Extra Best Best** (E.B.B.).—This is made by improved continuous processes from the very best iron. It has the best conductivity of any commercial iron wire. Its weight per mile-ohm is from 4,600 to 5,100 lbs. It is very uniform in quality, pure, tough and pliable. **Best Best** (B.B.).—This is less uniform and tough than the above (E.B.B.), but stands a good mechanical test. Its weight per mile-ohm is 5,500 to 5,800 lbs. It is largely used by telephone and telegraph companies and in railway telegraph service. **Best** (B.) is a term applied almost indiscriminately to the lower grades of iron wire for electric service. It is a harder and a less pliable wire than the two above grades. Its weight per mile-ohm is about 6,500 lbs. **Steel** is a stiff wire of high tensile strength and low conductivity. It is very ifficult to work, but is used on short lines that must be erected low cost, where conductivity is of little importance. Its weigh mile-ohm is 6,000 to 7,000 lbs.

196. Properties of Galvanized Telephone and Telegraph Wir
Based on Standard Specifications (*American Steel & Wire Co*

Size B. W. G.	Diameter in mils = d	Area in circular mils = d^2	Approximate weight in pounds		Approximate breaking strain in pounds			Resistance per mile ternational ohms) at deg.fahr.or 20 deg.ce		
			Per 1,000 ft.	Per mile	Ex. B.B.	B.B.	Steel	Ex. B.B.	B.B.	St
0	340	115,600	313	1,655	4,138	4,634	4,965	2.84	3.38	3
1	300	90,000	244	1,289	3,223	3,609	3,867	3.65	4.34	5
2	284	80,656	218	1,155	2,888	3,234	3,465	4.07	4.85	5
3	259	67,081	182	960	2,400	2,688	2,880	4.90	5.83	6
4	238	56,644	153	811	2,028	2,271	2,433	5.80	6.91	8
5	220	48,400	131	693	1,732	1,940	2,079	6.78	8.08	9
6	203	41,209	112	590	1,475	1,652	1,770	7.97	9.49	11
7	180	32,400	87	463	1,158	1,296	1,389	10.15	12.10	14
8	165	27,225	74	390	975	1,092	1,170	12.05	14.36	16
9	148	21,904	60	314	785	879	942	14.97	17.84	20
10	134	17,956	49	258	645	722	774	18.22	21.71	25
11	120	14,400	39	206	515	577	618	22.82	27.19	31
12	109	11,881	32	170	425	476	510	27.65	32.94	38
13	95	9,025	25	129	310	347	372	37.90	45.16	52
14	83	6,889	19	99	247	277	297	47.48	56.56	65
15	72	5,184	14	74	185	207	222	63.52	75.68	87
16	65	4,225	11	61	152	171	183	77.05	91.80	106

197. The so-called galvanized-steel strand (Fig. 106) is rea seven-strand cable composed of galvanized steel wires. It is us for guying and for **messenger cable** to support cables that ha not themselves much mechanical strength. It is also used **long spans in transmission lines** which (*American Steel & Wire C*

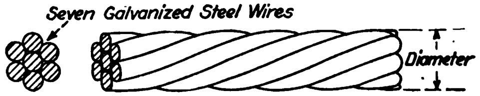


FIG. 106.—Galvanized steel strand.

cannot always be made with copper cables, because hard-dra copper has a strength of only 65,000 lbs. per square inch. Wh it is necessary to cross rivers with transmission lines, the ener may be conducted by one of the galvanized-steel cables tabulat which should be of such size and strength that it will show a saf factor of at least five. It is not necessary to suspend bare copp cables beneath a steel strand, as the steel strand itself serves as t conductor. The ordinary or Bessemer steel cable is commo used for guying and for supporting single suspension trolley wir while the other grades are commonly used for messenger wires a for long transmission-spans.

198. Galvanized Steel Strand or Cable (*American Steel & Wire Co.*)

All of these are seven-strand cables

Ordinary or Bessemer steel				Extra galvanized Siemens-Martin					Extra galvanized high-strength or crucible steel					Extra galvanized extra high or plow steel				
Diam., in.	Approx. weight per 1,000 ft., pounds	Approx. strength, pounds	List prices per 100 ft.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.
5/8	......	......	......	..	19,000	$4.35	50	10.0	..	25,000	$6.25	55	6	..	42,500	$8.75	60	4
1/2	510	8,500	$4.50	..	11,000	2.80	50	10.0	..	18,000	3.95	55	6	..	27,000	5.50	60	4
7/16	415	6,500	3.75	..	9,000	2.30	50	10.0	..	15,000	3.45	55	6	..	22,500	4.60	60	4
3/8	295	5,000	2.75	..	6,800	1.80	50	10.0	..	11,500	2.70	55	6	..	17,250	3.55	60	4
5/16	210	3,800	2.25	..	4,860	1.35	50	10.0	..	8,100	2.10	55	6	..	12,100	2.70	60	4
9/32	......	......	......	..	4,380	1.10	50	10.0	..	7,300	1.75	55	6	..	10,900	2.10	60	4
1/4	125	2,300	1.75	..	3,060	1.00	50	10.0	..	5,100	1.50	55	6	..	7,600	1.90	60	4
7/32	95	1,800	1.50	..	......	......	....	....	..	......	......	....	....	..	......	......	....	....
3/16	75	1,400	1.25	..	2,000	0.85	50	10.0	..	3,300	1.30	55	6	..	4,900	1.60	60	4
5/32	55	900	1.15	..	......	......	....	....	..	......	......	....	....	..	......	......	....	....
1/8	32	500	1.00	..	900	0.55	50	10.0	..	1,500	0.80	55	6	..	2,250	1.05	60	4
3/32	20	400	0.80	..	......	......	....	....	..	......	......	....	....	..	......	......	....	....

199. **Galvanized iron or steel wires are spliced** as shown in Fig. 97 and 5 turns are necessary in the neck of the splice to insure that the splice will be as strong as the wire. The strength of an unsoldered joint is determined by the number of turns in the neck. The end turns have but little holding power. Small **galvanized steel cables are joined** in the same way as are wires, as shown in Fig. 107. There should be 5 turns in the neck, as with wires, and a few end turns to finish off the joint. Soldering is unnecessary for guy

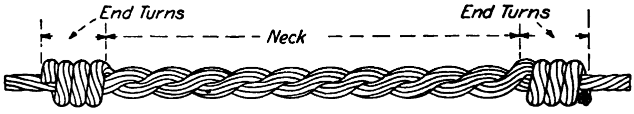


FIG. 107.—Joint in small steel cable.

wires. Larger cables can be spliced as shown in Fig. 103, or mechanical clamps can be used instead as shown in Fig. 108. Sometimes it is necessary to use several clamps, instead of one as the figure shows, in order that the joint will be as strong as the wire.

200. **Methods of Soldering Wires in Terminal Lugs.**—Where many terminal lugs are to be soldered to conductors a convenient and time-saving method of making the connections is to melt a pot of solder over a plumbers' furnace, heat the lug in the solder, pour the solder in the hole in the lug and then plunge the bared end of the conductor into it, as shown in Fig. 109. The insides of the holes of all commercial lugs are "tinned" so the solder adheres to them read-

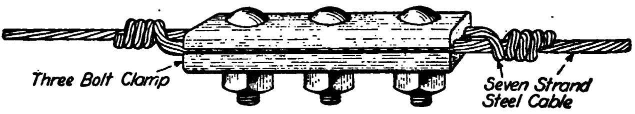


FIG. 108.—Steel cable joined with clamp.

ily, and the bared end of the conductor should also first be tinned. This may be done as follows: The end of the wire is carefully scraped with a knife or with a piece of fine sandpaper (the sandpaper is best because it cannot nick the wire) and then smeared with soldering flux and thrust into the solder pot. If a soldering stick is used the wire must be heated in the solder before the stick compound will melt and adhere. It requires but a short time to "tin" the wire end in the pot.

Immediately after the tinned end is pushed into the hole in the lug the lug should be soused with a piece of wet waste to cool it rapidly. Scrape or file off any shreds or globules of solder that adhered to the exposed surfaces of the lug and brighten it with fine sandpaper if necessary.

he insulation from the conductor ends should be cut back just enough so that it will abut against the shoulder of the lug, as gested in Fig. 110, *I*. The appearance is very unsightly and in-ates careless work if there is a gap between the shoulder and the ılation, as at *II*. If because of some mishap a connection

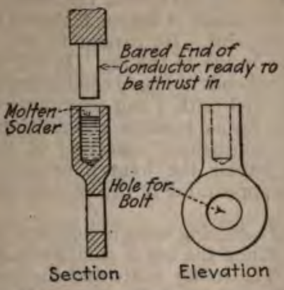
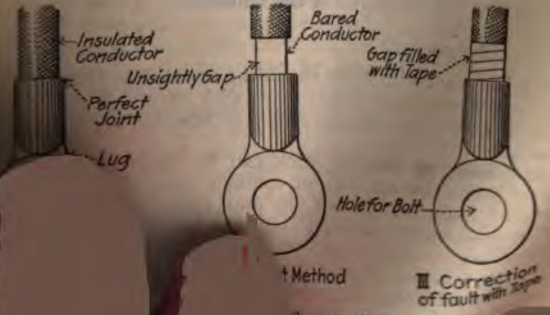


FIG. 109.—Soldering wire in lug.

ılts, having the appearance of *II*, a partial correction can be made filling the gap with servings of tape, as shown at *III*. The tape the standard $\frac{7}{8}$-in. width should be torn into strips about $\frac{1}{4}$ in. e before applying.

nly enough molten solder should be poured into the hole in the to fill it almost to the brim when the conductor is in position.



d connections.

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secure maximum mechanical strength and electrical conductivity, it is absolutely essential that the solder be maintained at the melting-point until it has thoroughly permeated the interstices of the conductor.

The wire terminal and lug should be held in the molten solder until they acquire the temperature of the solder. To prevent adhesion of solder to the outside of the lug it should first be dipped in a light oil of high flash-point. Be careful to see that no oil is permitted to reach the inside of the lug. It will be found advisable when holding the bared ends of heavy conductors in the solder pot to wrap the insulation well with a rag previously wrung out in cold water to prevent as far as possible the melting of the insulating compound and the consequent smearing of the terminal. Any such drip will not impair the joint if properly made, though it will detract from the appearance of the finished job. (*F. P. Kenny, Electrical World.*)

Another method of soldering wires in lugs is to heat the lug with a blow-torch flame. When the lug is sufficiently hot, wire solder is fed into the hole. The solder melts and the bared conductor end is then thrust into it, as above described. However, the use of a blow torch in this way should be avoided if possible, as it blackens the exposed surfaces of the lug. A cleaning with fine sandpaper is then necessary, and it requires considerable time.

201. **A soldering flux** removes and prevents the formation of an oxide during the operation of soldering, so that the solder will flow readily and unite firmly the members to be joined. For copper wires the following solution of zinc chloride is recommended by the Underwriters, and is good:

Saturated solution of zinc chloride ..	5 parts
Alcohol	4 parts
Glycerine	1 part

Solutions made with acids should be avoided as there is usually more or less corrosion in joints made with them. The commercial soldering pastes and sticks give good satisfaction in cleaning joints to be soldered.

202. **Soldering paste or stick can be made** as follows: Melt 1 lb. of tallow and add 1 lb. of common olive oil; stir in 8 oz. of powdered rosin; let this boil up and when partially cool, add, stirring constantly, ½ pint of water that has been saturated with powdered sal ammoniac. Stir constantly until cool. By adding more rosin to make it harder, it can be cast into sticks.

203. **In soldering commutator wires and connections** around electrical machines, an acid solution should never be used, because of the ensuing corrosive action. A good flux is an alcoholic solution of rosin.

204. **Soldering with Blow Torch and Iron.**—When soldering connections between wires smaller than No. 8 many wiremen use a blow torch for heating the joint. While a joint can be made in this way, it is much better to use a soldering copper for small wires. *Where a blow torch* is used the insulation on the conductors is *nearly always ignited* and burns with a thick smoke and blackens

any object on which it deposits. It is probable also that the excessive heat of the blow torch injures the adjacent insulation on the conductors. Furthermore, the blow torch is difficult to manipulate in restricted locations. A small alcohol torch is often satisfactorily used instead of a blow torch and is better adapted for the work, but it is probably not as good as a soldering iron.

In using a soldering copper it is heated in the flame of a blow torch. To solder the joint the hot tool is placed under and in close contact with it and wire solder is fed into the turns of the joint. After the solder has flowed over the entire surface of the joint the iron is removed and the joint is shaken to throw off surplus solder. There is no ignition of insulation and no sooty smoke. The soldering copper can be used in confined spaces where the use of a torch would be out of the question. Wires to be soldered must be scraped clean and bright before the tool is applied. Any of the commercial soldering pastes can be used as a flux.

205. Pointers in Blow Torch Manipulation (*W. N. Matthews & Bros. Notebook*).—Only the very best grade of gasoline (74 deg.) should be used, and it must be clean and kept in a clean can, otherwise the burner will become clogged. Never try to fill a torch from a big can. A pint or quart receptacle should be used for this purpose. If this is done, the torch can be held in one hand and filled with the other without danger of overfilling or spilling. The torch should be a little more than two-thirds full, so that there will be room for sufficient air to prevent the necessity of frequent repumping to maintain the pressure.

See that the filler plug is closed tight, to prevent the escape of air from tank. The fiber washer under the plug must be replaced when worn out. Common washing soap rubbed into threads and joints will stop all leaks. The pump should be in good working order; a few drops of lubricating oil well rubbed in will soften the pump washer. Do not turn needle valve too tight, as there is danger of enlarging the orifice of the burner. See that the burner is sufficiently heated when starting. One filling of the drip cup is generally sufficient if the flame is shielded from draft while heating the burner; if it is not, fill the cup again and light the gasoline as before. A long or yellow flame or raw gasoline shooting from the burner shows that the burner is not hot enough to properly generate gas.

Ordinarily when a gasoline torch is used, 90 per cent. of the heat is dissipated, without doing any work whatever. When performing most blow torch operations a great part of this heat may be readily saved by making a shield of sheet iron or asbestos, to direct the heat to the object to be heated.

RESISTORS

206. A cheap and good, heavy current resistor can be made by folding wire netting up and down over iron rods supported by insulators. (*Standard Handbook.*) Galvanized iron wire (No. 19 B. & S.) *netting of 1 in.* mesh and 12 in. wide has a resistance of *approximately 0.005* ohm per yard and will carry 100 amp.

207. A design for a water-cooled resistor is shown in Fig. 111. It consists of a number of pipes fitted into couplings and supplied with brass sliding bridge pieces. With all bridge pieces at the top the resistor is practically short-circuited, but when it is desired to cut out all the resistance the terminals of the rheostat should be short-circuited through the switch. With all the bridge pieces at the bottom the resistance of the circuit becomes a maximum. The pipe connections are so made that water can be circulated through the rheostat. The connections to the water mains and outlet should be made through rubber hose. The heat capacity will depend upon the amount and temperature of the water circulated.

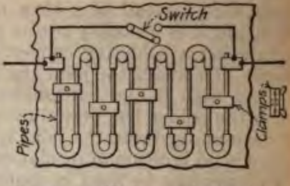


Fig. 111.—Water-cooled resistor made of pipe.

208. Rheostats made up of galvanized-iron wire mounted on wooden frames and submerged in running water are often used to absorb energy when making acceptance tests of large apparatus in the power house. In this case the power dissipated can be assumed as directly proportional to the surface of the resistor, and, therefore, the formula I $kd^{\frac{3}{2}}$ can be used with good results. Mr. P. M. Brown gives the following values of k as the results of extensive experiments:

Rheostat in barrel or tank, no flow of water.....	k = 540 to 700
Rheostat in flowing water (river or tail race)	k = 700 to 950
Rheostat in rapidly flowing water (river or tail race)	k = 950 to 1,250

A barrel should not be used to dissipate more than 5 kw. Values of $d^{\frac{3}{2}}$ can be taken from Table 215.

209. Liquid rheostats are especially adapted to the absorption of large amounts of power and are often used as an artificial load in testing dynamos or as starting rheostats for large motors starting under load. The adjustment is perfectly continuous, but unless there is a provision for short-circuiting the electrodes outside the solution it is impossible to cut out the resistance entirely. The material of which the electrodes are made is not important so long as it is a good conductor and is not attacked by the liquid. Lead or carbon plates are used with sulphuric acid, copper with copper sulphate and iron in most other cases. The current density should not exceed 1 amp. per square inch.

210. The solution in a liquid rheostat depends upon the voltage and quantity necessary to radiate the heat. Pure water is seldom used for pressures under 1,000 volts. For voltages below this sulphuric acid or some salt is added to the water to increase its conductivity. Fig. 112 shows the relative conductivity of various solutions expressed in inches between the plates with a current density of 1 amp. per square inch. Ordinary water gives a drop from 2,500 to 3,000 volts per inch gap at this current density.

211. ***The radiation* capacity of a liquid rheostat** depends upon *the volume of the* solution used and not upon the area of the surface.

is also affected by the conductivity of the material of which the nk is made; the amount of radiating surface of the tank; the temerature, pressure and dampness of the surrounding air; and the unter e.m.f. generated by chemical action (at low pressures a rge proportion of the power may be absorbed chemically without e evolution of heat). Fig. 113 is constructed from experiments ade by H. W. W. Dix and shows the allowable watts per cubic inch r different values of temperature rise.

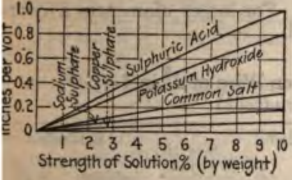


FIG. 112.—Curves showing conductivity of various solutions.

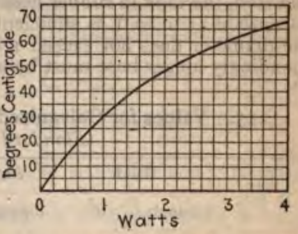


FIG. 113.—Allowable watts per cubic inch for a liquid rheostat.

As a general rule take 400 to 800 cu. in. of solution per horseower absorbed continuously. For motors, about 20 cu. in. per orse-power capacity should be allowed for starting and 60 cu. in. er horse-power for running.

212. **A good design for a liquid rheostat,** which can be easily onstructed, is shown in Fig. 114. It is arranged so as to short-cir-

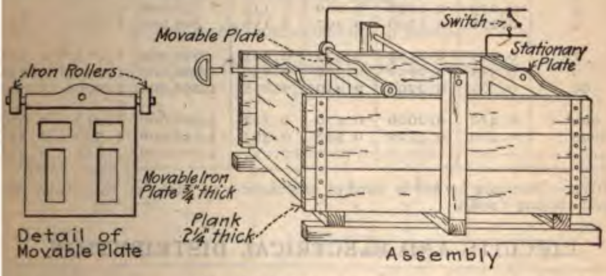


FIG. 114.—Water rheostat.

uit the electrodes with the switch when all resistance is out. The ze of the tank is determined by the size of the electrodes (roughly e area of the electrodes in square inches equals number of amperes) nd the volume of the liquid necessary to radiate the heat liberated y the absorption of the given amount of power (Fig. 112). Knowg the *size of the tank* and the voltage, the solution and materials *the electrodes and tank* can easily be chosen.

213. Water rheostats can be worked at higher densities than those given in Fig. 114 by allowing cool water to circulate through the tank. It will require $\frac{86.5}{t}$ kg. or $\frac{190}{t}$ lb. of water per hour to dissipate the heat liberated by the absorption of 1 kw. with a temperature rise of t deg. cent. This formula also applies to the cooling of metallic resistors submerged in running water.

214. Where high voltage is used the water must be conducted to and from the tank in rubber hose. For potentials up to 2,500 volts a length of 15 to 20 ft. is sufficient to prevent grounding, providing the diameter does not exceed 1 in. For larger diameters a correspondingly longer hose must be used.

215. Values for Galvanized-iron Wire of $d^{3/2}$ in $I = kd^{3/2}$.
(*Standard Handbook*)

Size B. & S.	Solid		Stranded		Size cir. mils.	Stranded	
	d-inch	$d^{3/2}$	d-inch	$d^{3/2}$		d-inch	$d^{3/2}$
20	0.0320	0.00571	....	....	250,000	0.575	0.437
18	0.0403	0.00809	....	....	300,000	0.634	0.505
16	0.0508	0.01145	....	....	350,000	0.682	0.563
14	0.0641	0.01622	0.073	0.0197	400,000	0.728	0.621
12	0.0808	0.02298	0.092	0.0278	450,000	0.777	0.685
10	0.102	0.03254	0.116	0.0394	500,000	0.815	0.736
8	0.128	0.04620	0.145	0.0555	550,000	0.855	0.791
6	0.162	0.06520	0.184	0.0788	600,000	0.893	0.844
5	0.181	0.07760	0.206	0.0940	650,000	0.930	0.896
4	0.204	0.09240	0.232	0.112	700,000	0.965	0.947
3	0.229	0.1098	0.260	0.133	750,000	0.999	0.998
2	0.258	0.1306	0.292	0.158	800,000	1.031	1.047
1	0.289	0.1555	0.332	0.911	900,000	1.094	1.145
0	0.325	0.1852	0.375	0.230	1,000,000	1.153	1.238
00	0.365	0.2203	0.419	0.271	1,250,000	1.290	1.465
000	0.410	0.2620	0.470	0.322	1,500,000	1.412	1.679
0000	0.460	0.3120	0.528	0.384	1,750,000	1.526	1.885
....	......	....	......	......	2,000,000	1.631	2.083

NOTE.—Formula $I = kd^{3/2}$ is used in calculation of wire for rheostats with forced cooling (208).

CIRCUITS AND ELECTRICAL DISTRIBUTION

216. A series circuit is one in which all components are connected in tandem as in Figs. 115 and 116. The current at every point of a series circuit is the same. Series circuits find their most important commercial application in series arc and incandescent lighting. They are seldom if ever used in this country for the transmission of power.

217. Multiple, parallel or shunt circuits are those in which the components are so arranged that the current divides between them (Figs. 116A and 117). Commercially, the distinction between multiple and series circuits is that, in series lighting circuits, the current is maintained constant and the generated e.m.f. varies with the load, whereas, with multiple circuits, the current through the

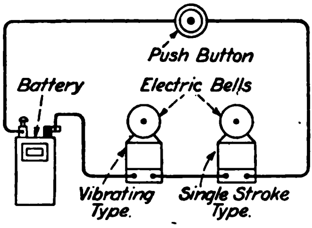


FIG. 115.—Series electric-bell circuit.

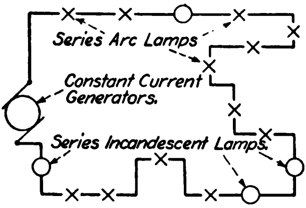


FIG. 116.—Series street-lighting circuit.

generator varies with the load and the generator e.m.f. is maintained practically constant.

218. Adding receivers in parallel on multiple circuits is really

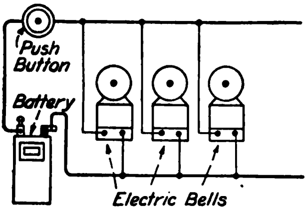


FIG. 116A.—Electric bells in parallel.

equivalent to increasing the cross-section of the imaginary conductor formed by all the receivers in parallel between the + and the − sides of the circuit.

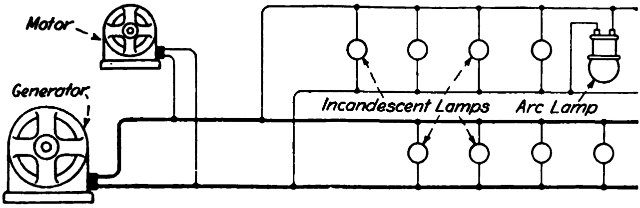


FIG. 117.—A multiple circuit for light and power.

219. The distribution of current in a multiple circuit is shown in Fig. 118. *Motors, heating* devices or other equipment requiring *electricity for their operation* could be substituted for the incandescent lamps if the proper current values were substituted for those shown. Note that the current in the main conductors decreases toward the end of the run and that the current supplied by the source—the generator—is equal to the sum of the currents

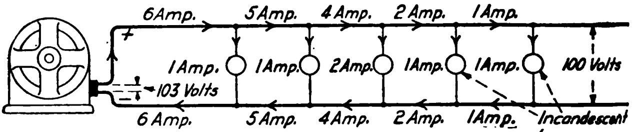


FIG. 118.—Multiple circuit currents.

required by all of the components. The voltage at the end of the run is less than that at the generator.

220. A multiple-series or parallel-series circuit consists of a number of minor circuits in series with each other and with several of

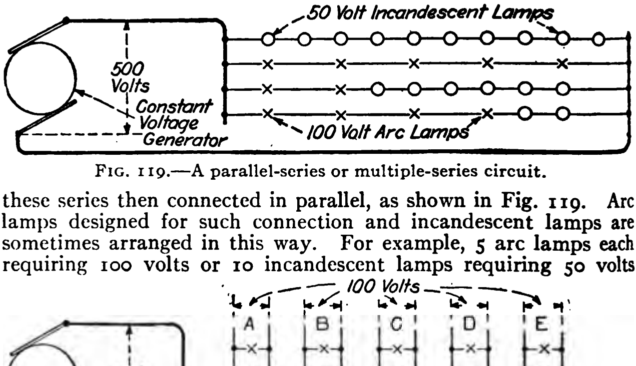


FIG. 119.—A parallel-series or multiple-series circuit.

these series then connected in parallel, as shown in Fig. 119. Arc lamps designed for such connection and incandescent lamps are sometimes arranged in this way. For example, 5 arc lamps each requiring 100 volts or 10 incandescent lamps requiring 50 volts

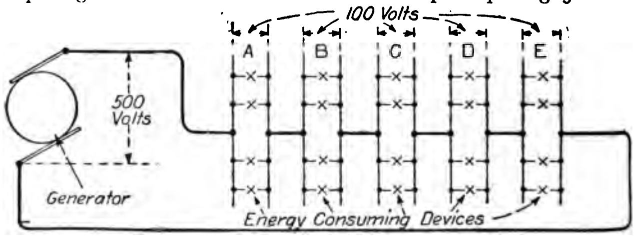


FIG. 120.—A series-parallel or series-multiple circuit.

are respectively connected in series and then these series groups are connected across a 500-volt railway circuit.

221. A series-multiple or series-parallel circuit is one wherein a number of minor circuits are first connected in parallel, and then several of the parallel-connected minor circuits are connected in series across a source of e.m.f. as in Fig. 120. This method of connection is seldom used. (There appears to be a difference of opinion as to what constitutes a "*series-multiple*" and what a "*multiple-series*" circuit. The definitions of Pars. **220** and **221** *are in accordance* with the practice of the General Electric and *Westinghouse* companies.)

222. A divided circuit (Fig. 121) is really one form of a multiple or parallel circuit. The distinction between the two sorts appears to be that, as ordinarily used, the term "divided" refers to an isolated group of a few conductors in parallel rather than to a group of a large number of conductors in parallel.

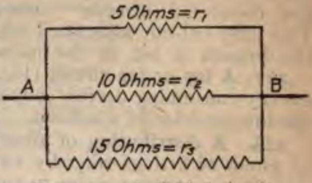


FIG. 121.—A divided circuit.

223. The joint resistance of a number of conductors in parallel can be computed with the following formula. There should be as many terms in the denominator of the formula as there are conductors in parallel:

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4}, \text{ etc.}}$$

Example—What is the joint resistance of the conductors in the divided circuit shown in Fig. 121? In other words, what is the resistance from A to B? *Solution.*—Substitute in the formula:

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}} = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{15}} = \frac{1}{\frac{6}{30} + \frac{3}{30} + \frac{2}{30}} = \frac{1}{\frac{11}{30}} = 1 \times \frac{30}{11} = 2.73 \text{ ohms.}$$

224. A feeder (or feeder circuit) is (Figs. 122 to 124) a set of conductors in a distributing system extending from the original source of energy in the installation to a distributing center and having nothing connected to it between the source and the center. The source may be a generating or a sub-station or, in the case of building or house wiring a connection to the service conductors from the street. (See Figs. 122, 123 and 124.)

225. A main. (Figs. 122 to 124.) There are really two rather distinct classes of mains thus:

(1) A main is an extension of a feeder extending from one distribution center to another distribution center having nothing connected to it between the two distribution centers. Frequently a main of this character is called a *sub-feeder*. (Fig. 122.)

(2) A main is any supply circuit to which other circuits (sub-mains or branches) connect *through automatic cut-outs*—fuses or circuit breakers—at different points along its length. Where a main is supplied by a feeder the main is usually of smaller wire than the feeder which serves it. An energy-consuming device is never connected directly to a main, a cut-out always being interposed between the device and the main.

225A. A sub-main (Fig. 122) is a subsidiary main, fed through a cut-out from a main or another sub-main, to which branches are connected through cut-outs. A sub-main is usually of smaller wire than the main or other sub-main which serves it. Ordinarily sub-mains are referred to as merely "mains." The term sub-main has not been used very extensively.

226. A branch or branch circuit (Fig. 122) is a set of conductors (feeding, through an automatic cut-out, from a distribution center, main or sub-main) to which one or more energy-consuming devices are connected directly—without the interposition of cutouts. The only cut-out associated with a branch is that through which the branch is fed at the main, sub-main or distribution center.

227. A tap or tap circuit (Fig. 122) is a circuit, serving a single energy-consuming device, connecting directly to a branch without the interposition of a cut-out.

228. A distributing or distribution center is an arrangement or group of fittings whereby two or more minor circuits are connected at a common point to another, larger circuit. A **panel box** is one form of a distribution center. (See Figs. 122 to 124.)

229. A service (or a service connection) is a set of conductors constituting an underground or an overhead connection between conductors (a **main** belonging to a public service corporation) in a thoroughfare and those of an interior or isolated wiring system. A "service" serves the wiring system with energy.

230. A loop circuit (see Fig. 125) is one wherein all receivers,

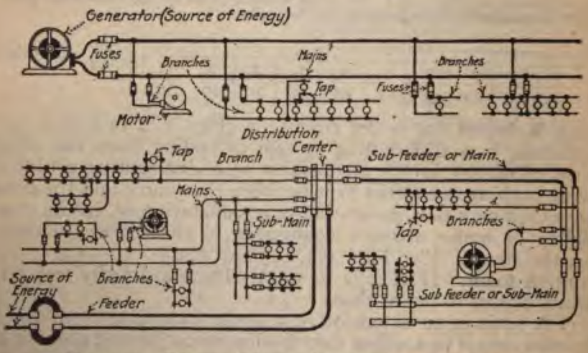


FIG. 122.—Diagram illustrating circuit nomenclature.

lamps or motors for example, are at the same electrical distance from the source of electricity. By tracing paths from one terminal back to the other through any receiver it will be found that the length of line is the same in every case. It is sometimes supposed (*Crocker's Electric Lighting*) that this arrangement of conductors must give the same pressure at all of the receivers since the sum of the distances of each receiver from the feeding points measured on the mains is constant. Actually the middle receiver (see Fig. 125) will receive a lower voltage than those at the ends as shown in the diagram. This is due to the fact that the middle receivers are supplied through the portions of the main conductors which carry heavy currents and in which the drop is greatest. For example, the drop on the mains in the case of the central receiv

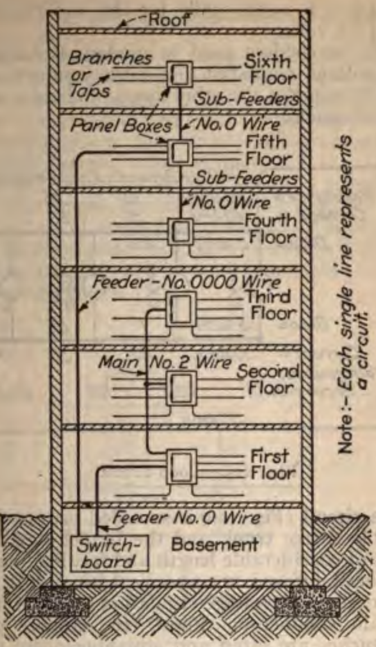


FIG. 123.—Examples of feeders, mains and branches.

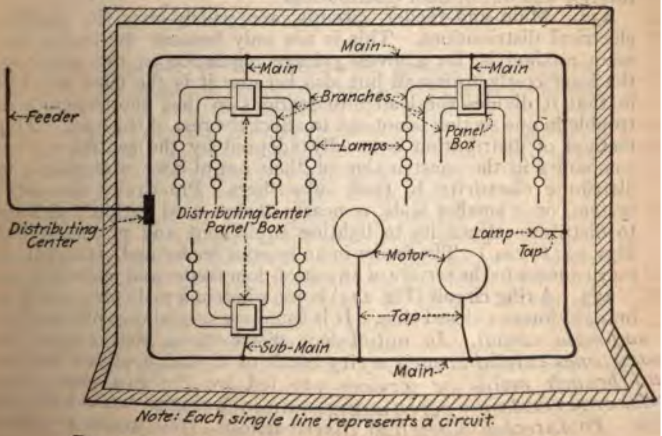


FIG. 124.—Diagram showing "closed-loop-main."

is, $2+1.5+1.5+2=7$ volts, while for the end receiver it is but $2+1.5+1+0.5=5$ volts.

Loop circuits are seldom used in modern installations. They provide close voltage regulation but more conducting material is required than for some of the other forms of circuits which provide sufficiently good results.

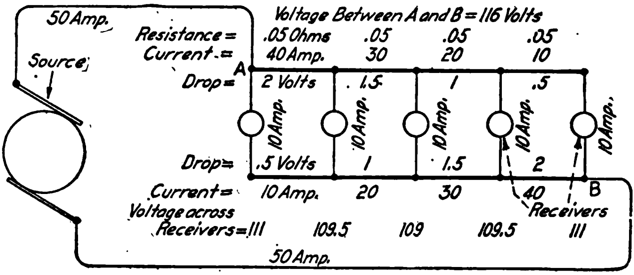


FIG. 125.—Loop circuit.

231. **A tree circuit** (Fig. 126) is so called because its main conductors resemble a tree trunk and the branch conductors limbs. Tree circuits of considerable length and feeding many receivers are usually undesirable and uneconomical because it is impossible to maintain a reasonable voltage regulation on them without using very large main conductors. Short tree circuits consisting of mains and branches are often and advantageously used in both interior and out-of-door distribution.

232. **Main-and-feeder circuits** are widely used in modern electrical distributions. This is not only because the feeder and main method is, for a given voltage regulation at the receivers, the least costly to install but also because it is the most reliable, in that it divides the load into sections so that short-circuits or trouble in one section is not apt to affect the rest of the load. This method of distribution is usually adopted by the central station companies in the construction of their out-of-door wire plants to distribute electricity to their subscribers. Practically the same system, on a smaller scale, is nearly always used within buildings to distribute electricity to lighting equipment and motors. (See Figs. 122 to 124.) The feeder in an interior feeder and main system may connect to the service of an out-of-door feeder and main system.

233. **A ring circuit** (Fig. 124) is one wherein a main (or possibly a branch) forms a closed ring. It is usually a special case of a feeder-and-main circuit. In out-of-door distributions ring mains are sometimes carried around a city block or around a certain district and branch mains or services are fed by the ring main. One feeder or several may serve a ring main each connecting at a different point. In interior electrical distributions, ring mains are seldom

used except in industrial plants, but for this service they can often be applied to advantage.

234. **The three-wire system is used because it saves copper.** (See Fig. 127.) Incandescent lamps for about 100 volts are more economical than those for higher or lower voltages. A system of any consequence operating at 110 volts would require very large conductors to maintain the line drop within reasonable limits. With the three-wire system, a low voltage, say 110, is impressed on the receivers while one twice as great, say 220, is used for transmission. Since the weight of conductors for a given loss varies inversely as the square of the voltage (see **242**) it is evident that a considerable saving is possible with the three-wire system. In this country the three-wire system is of most importance as applied to 110–220 volt lighting systems.

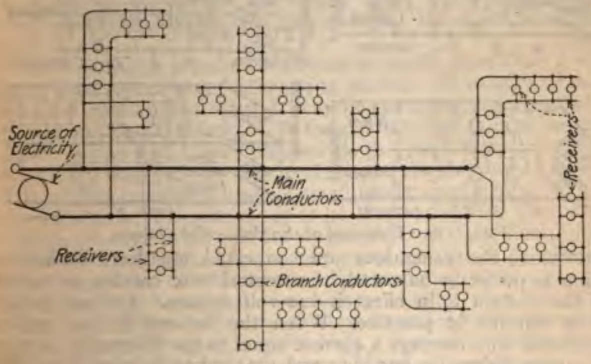


FIG. 126.—Tree circuit.

235. **The principle of the three-wire system is illustrated** in Fig. 127. Incandescent lamps for 110 volts could be connected two in series across 220 volts as shown at *I* and while each lamp would operate at 110 volts, the energy to the group would be transmitted at 220 volts and the outside conductor could, with equal loss, be one-fourth the size that would be necessary if the energy was transmitted at 110 volts. This arrangement (Fig. 127, *I*) while it would operate, is not commercially feasible because each lamp of each pair of lamps in series must be of the same size and if one lamp goes out its partner is also extinguished. These disadvantages might be partially corrected by running a third wire as at Fig. 127, *II*. Then one lamp might be turned off and the others would burn and a single lamp might be added to either side of the system between the third wire and either of the outside wires. But unless the total resistance of all of the lamps connected to one side was practically equal to that of all of the lamps connected to the other side, the voltage across one side would be higher than that across the other. On the high side the lamps

would burn bright and on the low side dim. Obviously, it is not feasible in practice to so arrange or "balance" the sides that they will have the same resistance. Hence some other method must be used in practicable three-wire systems whereby the electricity will be transmitted at, say, 220 volts and the pressure across the lamps will be, say, 110 volts.

236. Commercial three-wire systems consist (Fig. 127, *III* and *IV*) of two outer conductors, having (for lighting installations) a pressure of 220 volts impressed across them and a neutral wire so connected to sources of voltage that the pressure between it and either of the outside wires is 110 volts. In Fig. 127, *III*, generators are the sources of voltage. The neutral wire joins at the

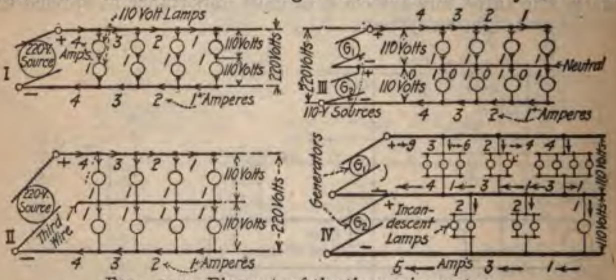


FIG. 127.—Elements of the three-wire system.

point where the generators are connected together. When the system is perfectly balanced, the neutral wire carries no current and the system is in effect a 220-volt system. Perfect balance seldom obtains in practice. When the balance is not perfect, the neutral wire conveys a current equal to the difference between the current taken by one side and that taken by the other side. Note from Fig. 127, *IV*, that the current in different parts of the neutral wire may be different and that it is not necessarily in the same direction in all parts of the neutral wire. Each incandescent lamp in Fig. 127, *IV*, is assumed to take 1 amp. and the small figures indicate the currents in different parts of the circuit.

237. The Size of the Neutral Wire of Three-wire Systems.—Where the balance is and always will be perfect no neutral wire is necessary. In out-of-door distribution systems the neutral is often one-half the size of the outer wires. For interior wiring, the neutral is frequently made the same size as the outside wires. However, a neutral conductor having two-thirds—or even one-half—the cross-sectional area of each of the outers will usually be satisfactory if it is protected in accordance with *Code* requirements. Some engineers specify thus: Where the outers are No. 6 or smaller, the neutral shall have the same area as each of the outers and where the outers are larger than No. 6 the neutral shall have two-thirds the area of each of the outers.

238. The amount of unbalance that may come on a three-wire system depends on local conditions. In ordinary three-wire lighting systems the unbalanced load seldom exceeds 10 per cen the total load. Probably 5 per cent. is a fair average for a w laid-out system. Balancer sets for interior three-wire systems are frequently specified of sufficient capacity to take care of a 10 per cent. unbalance. Sometimes the unbalance on a poorly laid out system may be 20, 30 per cent. or even more.

239. Application of Alternating Current and of Direct Current for Distribution.—The following suggestions are general and cannot be expected to apply to every special case. Where electricity is to be distributed for lighting only and not at a greater distance than about a mile from the generating station, direct current will probably be most satisfactory and economical. If many adjustable speed motors are to be served by a distribution, direct current should be used at the motors even if it is necessary to convert alternating into direct current, at the using point, with a motor generator or rotary converter. There is no satisfactory alternating current, adjustable speed motor that has the general characteristics of the direct-current shunt or compound wound motor.

Where electricity is to be distributed to points more than a mile distant from the station, alternating current will usually be most economical and satisfactory. It may be generated at a reasonably high voltage and transmitted to the points where it is to be used at that voltage and there "stepped down" with transformers to the voltage required by the receivers. Transmitting at a high voltage makes possible the use of small feeder conductors. Where many constant-speed motors are to be used, polyphase alternating current is always preferable for either short or long distribution distances because polyphase constant-speed motors are simpler and more reliable than direct current. Furthermore, alternating-current motors can be operated on higher voltages than can direct current, so it is not necessary to step down for them unless the voltage of the generator is quite high. Two-wire (single-phase) electric lighting can always be arranged from single-phase or polyphase alternating-current circuits.

Alternating current is always used where it is necessary to transform from one voltage to another without the use of moving apparatus and offers a very flexible system in this respect. But where transformers are used there are slight losses in them even when they are not loaded. An alternating-current system also has the disadvantages that its inherent voltage regulation and its efficiency are not so good as those of a direct-current system. This is particularly true if much inductive equipment, that containing coils wound on iron such as motors and arc lamps, is connected to the circuits. Despite these disadvantages experience has shown that alternating is preferable to direct current for the applications outlined above. Polyphase constant-speed motors are preferable to direct-current constant-speed motors because they are simpler, in that they have no commutator and they cost less *to maintain than do direct*-current motors. Direct current is *nearly always used in office* buildings served by isolated plants *because such loads are mainly* lighting.

240. Selection of a Frequency.—There are two frequencies *now standard in this country*, 25 cycles and 60 cycles. All other things being equal, 25 cycles would seem at first sight preferable because there is less inductive effect with it than with a higher frequency. It therefore follows that the inherent voltage regulation of a 25-cycle system is better than that of a 60-cycle system and also that the 25-cycle system is a trifle more efficient. For transmission distances of less than a few miles neither of these factors is of much consequence one way or the other. Alternating current at 25 cycles is not particularly well adapted for electric lighting because arc lamps do not operate well on it and, under some conditions, with certain generator waves, a flickering due to 25-cycle current alternations is visible in incandescent lamps. With frequencies lower than 25 the flickering is quite perceptible, while with 60 cycles no flickering is noticeable. However, some large lighting systems are successfully operated at 25 cycles. The advent of metallic filament lamps of high candle-power renders the matter of operation of multiple arc lamps of little importance and series arc lamps are now usually operated on direct current.

Several years ago a frequency of 25 cycles was often considered necessary for the operation of rotary converters but modern converters operate as well on 60 cycles as on 25.

It is often wise for an isolated plant to adopt the frequency of the local central station so that, in emergencies, energy or apparatus can be interchanged. Transformers and most other apparatus, except very slow speed motors, is as cheap or cheaper for 60 cycles as for 25 and the delivery on 60-cycle apparatus is better. A great proportion, probably over 85 per cent., of the equipment sold in this country is for 60 cycles and it is probable that the average isolated plant, central station or industrial plant which supplies electricity for light or power or for both should adopt a frequency of 60 cycles. However, where the power load is important and very slow speed motors must be used 25 cycles is adopted as it is not feasible to economically build 60-cycle motors for very slow speeds. For example, steel mills and cement plants often adopt 25 cycles.

241. Selection of a Voltage for a Distribution System.—The standard voltages for which American manufacturers build electrical apparatus are 110, 220, 440, 550, 1,100, 2,200 and higher ones, the treatment of which is not within the scope of this book. These are nominal voltages and it is seldom that apparatus is operated at exactly any one of them. It may be operated at some one voltage within a range extending from, possibly, 5 per cent. below to 5 per cent. above the nominal voltage.

Incandescent lamps for 220 volts, in the 50- to 60-watt sizes, are 10 to 15 per cent. less efficient and cost more than do corresponding 110-volt lamps. This is an inherent condition due to the relatively great length and smaller diameter of the 220-volt filament and it cannot be corrected. Steinmetz says: "The 220-volt lamp has no right to existence." It follows that a nominal voltage of 110 (an actual voltage of something between 105 and 120 volts) should be used at the terminals of incandescent lamps wher feasible. Sometimes (Fig. 128) it is desirable to use 220-v lamps where the load is largely a 220-volt motor load. In suc case the use of 220-volt lamps may be justified because of the simplicity of the method.

Branches serving incandescent lamps (Fig. 128, *II*) must always be two-wire and should be 110-volt, but the mains, even in residence wiring, are often, and profitably, three-wire because of the economy in copper of the three-wire system.

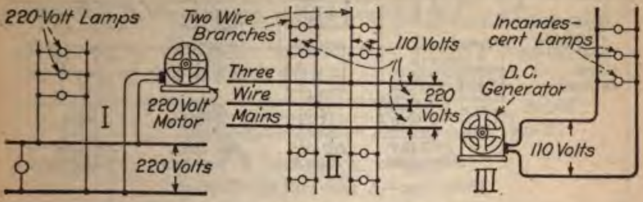


Fig. 128.—Methods of connection.

For incandescent lighting alone, in a town, industrial plant or building, for distribution distances not exceeding about 1,000 ft. a two-wire, direct-current circuit (Fig. 128, *III*) with a nominal voltage of 110 can be used with fair satisfaction. But a three-wire circuit having 220 volts across the outside wires will usually cost

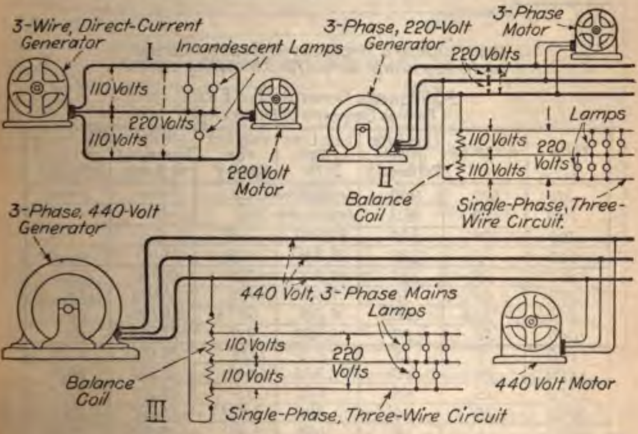


Fig. 129.—Distribution circuits.

less to install and it can be used with fair economy for distances up to possibly a mile. If the load is almost entirely lighting or adjustable speed motors, the distribution (Fig. 129, I) should be direct-current 110–220 volt, three-wire, and motors should be operated at 220 volts. But if there is a considerable constant-spe motor load, a 220-volt, three-phase distribution (Fig. 129, *II*) should, probably, be used. The motors can be operated three

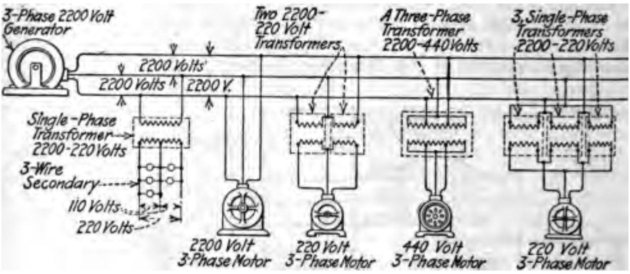
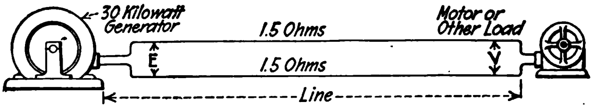


FIG. 130.—A 2200-volt distribution.

phase, and then three-wire, single-phase, 110-220-volt lightin circuits can be arranged from one or all of the phases with balanc coils. (See Fig. 129, *II*.)



Note: This table is strictly correct for direct-current and is very nearly correct for alternating-current

30 Kilowatts Generated at E Volts
(Timbie's Elements of Electricity)

Volts E	Amperes I	Line Drop in Volts R=3 Ohms IR	Line Loss in Watts I^2R	Volts Left for Motor V	Watts Transmitted to Motor	Efficiency of Line Per Cent
100	300	900	Impossible Case		—	—
200	150	450	Impossible Case		—	—
300	100	300	30,000	0	0	0
400	75	225	16.875	175	13.125	43.8
500	60	180	10,800	320	19.200	63.3
600	50	150	7,500	450	22.500	75.
800	37.5	112.5	4.219	687.5	25.780	86.
1000	30	90	2,700	910	27.300	91.
1200	25	75	1,875	1,125	28.125	93.8
1500	20	60	1,200	1,440	28.800	96.
2000	15	45	675	1,955	29.325	97.8
3000	10	30	300	2.970	29.700	99.
5000	6	18	108	4.982	29.964	99.8
10,000	3	9	27	9.991	29.973	99.9

FIG. 131.—Illustrating relation of voltage to efficiency of transmission.

Either a 440- or a 550-volt, three-phase, distribution using (F 29, *III*) 440- or 550-volt motors might profitably be used ead of the 220-volt and a saving of about three-fourths copper would result. Balance coils could be used to provide 110–220-volt, three-wire, lighting circuits. However, a voltage exceeding 300 is quite apt to kill a man that crosses it, while persons are very seldom killed on the voltages lower than 300. So, as a rule, 440 volts or greater should not be installed in any plant where the electrical apparatus cannot have expert supervision. Yet 440 or 550 volts is low enough that motors can be conveniently operated at those pressures and in practice the insulation used on

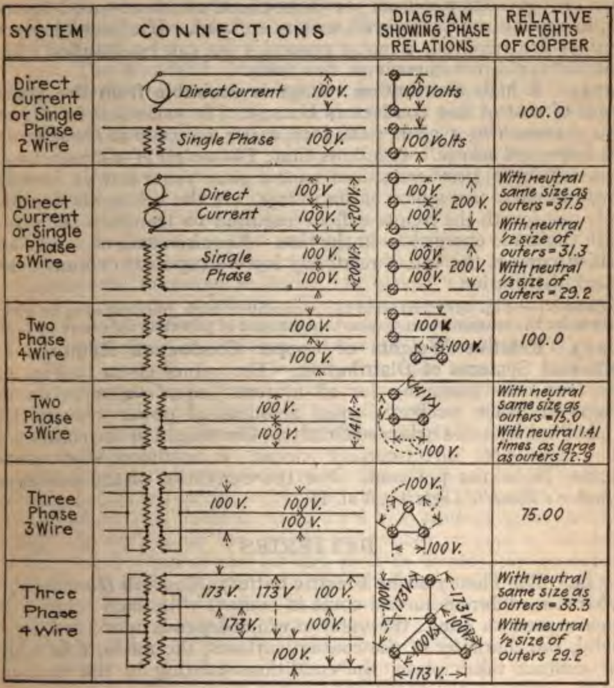


FIG. 132.—Copper economies of different distribution systems.

them is the same as for 220-volt machines. Voltages of 440 or 550 find their widest applications in industrial plants and are seldom used in central-station distributions. Direct-current voltages of 400 to 550 are now seldom used except in street railway work.

A voltage of 1,000 is practically never used in commercial work this country except for railways.

For central stations or industrial plants distributing to distance up to a few miles from the station, a nominal alternating current voltage of 2,200 is often adopted. Higher voltages, the treatment of which is not within the scope of this book, are also frequently used. (See Fig. 130.) The generators are three-phase in modern installations and each or one of the phases is used for single-phase lighting. Power service is supplied by all three phases. Transformers stepping down from 2,200, single-phase, to 110 volts single-phase or to 110-220 volts, single-phase, three-wire, are used for lighting. Three-phase transformers, stepping from 2,200 to 220, 440 or 550 volts are used for three-phase constant-speed motors or, in special cases, 2,200-volt motors are used. If adjustable-speed motors are required, a motor generator set can be installed which will deliver direct current at 220 volts.

242. **A high distribution voltage is desirable from the standpoint of cost of line conductors** because: *The power lost in a given line, transmitting a given watts load, varies inversely as the square of the impressed voltage.* It follows that: *The weight of a conductor for transmitting a given watts load with a given power loss is inversely proportional to the square of the voltage.* If the voltage is doubled, only one-fourth the copper will be required to transmit the power with the same energy loss in the line. Requirements of safety and utility compel the use of relatively low voltages for ordinary electrical distribution.

Example.—Fig. 131 illustrates the economy of high line voltages by giving values for the transmission of a certain amount of power at different voltages.

243. **Relative Weights of Copper Conductors Required for Different Systems of Distribution.**—The values given in Fig. 132 are true ones assuming for all systems: equal voltages on the lamps or other receivers, equal amounts of power transmitted, equal line losses and balanced circuits. The weight of the conductors of a two-wire, direct-current circuit is assumed, for convenience, to be 100 per cent. For the derivation of the values see *Crocker's Electric Lighting*, Vol. II.

BATTERIES

244. **The Theory of the Electric Battery** (*Standard Handbook*).—When two different metals come in contact with each other there is generated an e.m.f. the value of which depends upon the kind of metal, the character of the contact surfaces, the medium in which the contact takes place, the conditions existing in the medium, etc.

If a circuit made up of various substances and including no source of energy is closed on itself the various contact e.m.fs. will just compensate and the resultant e.m.f. of the circuit will be zero. However, if the circuit includes a source of energy as heat (thermocouple), or chemical reaction, an unbalance of e.m.f. will be produced and a current established, this current tending to reduce the e.m.f. of the source and restore the static balance of the system. *Polarization* is the action of the current in reducing the e.m.f. of the cell and it is overcome by the use of certain substances called *polarizers*.

245. The materials consumed in a battery represent a given quantity of energy. Since the internal e.m.f. is a constant, the total electrical energy output of the chemical reaction is directly proportional to the quantity of electricity produced.

246. The e.m.f. of a given cell is the contact e.m.f. and is therefore independent of the dimensions of the battery. The energy and power of the battery, however, are directly affected by the dimensions. For a given battery the energy stands in a direct ratio to the weight of active material. The power for a given number of cells in series (given e.m.f.) is determined by the area of the plates. The e.m.f., of course, depends only on the number of cells in series.

247. The standard Daniell cell has an e.m.f. which is practically 1 volt when delivering a constant current. There are many forms of Daniell cell; each of which is particularly adapted to certain service, but all having very nearly the same e.m.f. (1.07+volts). The e.m.f. is not changed appreciably by the degree of concentration of the solutions; by the temperature; by the resistance; by the purity of the zinc or copper, etc. In short, it makes a very good rough and ready standard.

A very good model is that used by the British Post-office. The jar is made with two compartments; one containing the porous cup immersed in water, in which are placed a copper plate and crystals of copper sulphate. The other compartment contains the zinc plate and the 50 per cent. saturated solution of zinc sulphate. The zinc plate is fastened so as to be just clear of the solution, and a pencil of zinc is placed in the bottom. When in use, the porous cup is placed in the second compartment, thus raising the level of the zinc solution so as to immerse the zinc. Under working conditions the e.m.f. is about 1.07 volt; when new it is about 1.079 volts.

248. The gravity type cell, which is used in telegraph work, is suitable for closed-circuit work, but should not be used for applications where it is liable to stand for a long time on open-circuit.

249. In setting up the gravity cell place the copper electrode (−) in the bottom of the jar and pour in about 3 lb. of copper sulphate crystals. Next place the zinc electrode (+) and fill with water to cover the zinc; to the water add a tablespoonful of sulphuric acid. Cover the electrolyte with a layer of pure mineral oil, which should be free from naphtha or acid and have a flash point above 400 deg. fahr. If the oil is not used the creeping can be stopped by dipping the edge of the jar in hot paraffin. When the cell is thus set up it should be short-circuited for a day or two to form zinc sulphate which will protect the zinc electrode; this preliminary run also reduces the internal resistance. The temperature of the cell should be kept above 70 deg. fahr., since the resistance increases very fast with a decrease in temperature.

The *internal resistance of the* gravity cell is ordinarily from 2 *to 3 ohms. A blue color in the* bottom of the cell denotes a good *condition, but a brown color* shows that the zinc is deteriorating. *When renewing the* copper sulphate it is best to empty the ce*nd set it up with a* completely new electrolyte. The blue lir which marks the boundary between the copper sulphate and th zinc sulphate, should stand about half way between the electrodes If it comes too close to the zinc, some of the copper sulphate ca be siphoned out or the cell can be short-circuited so as to produc more zinc sulphate. If the blue line goes too low some water an crystals of copper sulphate should be added.

250. The Fuller cell is well adapted to telephone work or an intermittent work. It can stand on open-circuit for several month at a time without any appreciable deterioration.

251. The Fuller cell is set up as follows: Mix the electrolyt by adding 6 oz. of potassium bichromate and 17 oz. of sulphuri acid to 56 oz. of soft water; pour this mixture into the glass ja Into the porous cup put one teaspoonful of mercury and tw teaspoonfuls of salt; place the cup and zinc electrode in the glas jar and fill to within 2 in. of the top with soft water. Put on th cover, insert the carbon electrode, and the cell is ready for use.

The color of the solution is orange when in working order. Th resistance varies from 0.5 to 4 ohms depending upon the conditio and dimensions of the porous cup and upon the concentration o the solution.

252. The Edison-Lalande or Edison cell is suitable for eith open or closed-circuit work. The mechanical construction of th cell is especially good. The positive pole is a plate of compress oxide of copper, the surfaces of which are reduced to metalli copper to improve the conductivity. This form of plate also act as a depolarizer. The negative pole is of pure zinc amalgamate throughout by adding mercury when the casting is made. Th electrolyte is a solution of caustic soda. The top of the solutio is covered with a heavy mineral oil to prevent the solution fro evaporating.

These cells have an initial e.m.f. of 0.95 volt, which drops t 0.70 volt when the circuit is closed. The internal resistance i very low, varying from 0.020 to 0.089 ohm, depending upon th type of cell. The Edison Manufacturing Co. have kindly sub mitted the following data:

Continuous capacity, amp......	1.5	2.5	4.0	6.0	7.0
Max. capacity, amp...........	7.49	9.53	15.51	26.68	33.35
Capacity, amp-hr.............	100	150	300	300	600
Internal resistance, ohm........	0.089	0.070	0.043	0.025	0.020

253. The Leclanché cell is adapted only to intermittent wor such as bells, telephones, etc. It is cheap and easy to maintain.

254. The Leclanché cell is set up as follows: Put 3 or 4 oz. o salammoniac in the jar; pour about one-third full of water and stir until the salammoniac is all dissolved; place the carbon elec rode in the porous cup and pack it around with manganese dioxi d crumbled carbon; then, inserting the porous cup and the ctrode into the jar, the cell is ready for use.

Practically the only attendance consists in renewing the evaporated water. The zinc is replaced when worn out. When it becomes necessary to add salammoniac the solution should be thrown out and a new one made. If the porous cell becomes clogged, soaking in warm water will improve it.

The resistance depends upon the dimensions of the electrodes, the state of the porous cup and the condition of the cell. Under proper working conditions and with a carbon-electrode having about 8 sq. in. surface, the resistance will be about 1.5 ohm.

255. **The dry cell** is a very popular form, and does not require any attendance. It is simply thrown away when exhausted. The jar, generally of zinc, forms one electrode. The carbon electrode is suspended in the center of the zinc vessel, care being taken not to allow it to touch the zinc. The zinc is protected by several thicknesses of blotting paper and the chamber filled with a mixture of carbon, manganese dioxide and sawdust (or some absorbent substance), the mixture being saturated with a solution of salammoniac. The top is sealed with wax and the whole cell slipped into a pasteboard box.

Oftentimes the life can be extended slightly by punching a hole in the top and pouring in water.

256. **A storage battery, secondary battery, or accumulator** (*Standard Handbook*) is an electrical device in which chemical action is first caused by the passage of electric current, after which the device is capable of giving off electric current by means of secondary reversed chemical action. Any voltaic couple that is reversible in its action is a storage battery. The process of storing electric energy by the passage of current from an external source, is called *charging* the battery; when the battery is giving off current, it is said to be *discharging*. A storage-battery cell has two elements, or plates, and an electrolyte. The two plates are usually made of the same material, though they may be of two different materials.

257. **The unit of capacity of any storage cell is the ampere-hour** and is generally based on the 8-hr. rate of discharge. Thus a 100 amp-hr. battery will give a continuous discharge of $12\frac{1}{2}$ amp. for 8 hr. Theoretically it should give a discharge of 25 amp. continuously for 4 hr. or 50 amp. for 2 hr. As a matter of fact, however, the ampere-hour capacity decreases with an increase of discharge rate.

258. **The capacity of a cell** is proportional to the exposed area of the plates to which the electrolyte has access, and depends [illegible] quantity of the active material on these plates.

The capacity of batteries depends, therefore, on the size [illegible] *of plates in parallel,* their character, the rate of dis- [illegible] *so on the temperature.* Taking the 8-hr. rate of dis- [illegible] *perature* of 60 deg. fahr. as standard, the capacitie[s] [illegible] American practice are from 40 to 60 amp-hr. p[illegible] square foot of *positive* plate surface (= no. of positive plates in parallel × length × breadth × 2).

260. The voltage of any storage cell depends only on the character of the electrodes, the electrolyte density and the condition of the cell, and is independent of the size of the cell.

261. The voltage of the lead sulphuric-acid cell, when being charged is from 2 to 2.5 volts, while on discharge it varies from 2.0 down to 1.7 volts. (See Fig. 133.)

262. High battery voltages are obtained by joining the required number of cells in series. Thus for 100-volt circuits, approximately 50 cells in series are required.

263. The lead storage battery of commerce is made up with electrodes having their active materials of lead peroxide and sponge lead as the positive and negative electrodes respectively, immersed in a dilute solution of sulphuric acid.

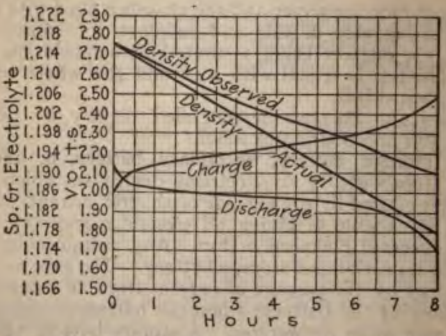


FIG. 133.—Characteristic curves of the lead storage battery.

264. There are two general types of plates, for lead storage batteries, namely, the Planté and the pasted, and numerous variations of each of these types. In the Planté type of plate the active materials are formed out of and on the lead surface of the plate itself. Pasted plates are made up by applying the active material by some mechanical process, such as mixing in a paste and spreading on the surface of a grid or plate. The pasted active material has some substance added to it to cause it to set or harden.

265. The essential differences between the Planté and the pasted plates are: For a given output Planté plates are more costly, more bulky and heavier than the equivalent pasted plates. They also are more easily injured by impurities in the electrolyte. They are, however, capable of standing more rapid charging and ...ging rates without injury. They are less liable to lose their ...terial and be injured by the accumulation of sediment ...om of the cells. They are more durable, and have ...nd in general they are a more dependable type of ...e pasted. The pasted, however, for a given outpu...

re cheap, light and occupy a smaller space. They also are not o badly damaged by impurities in the electrolyte. The efficiency f pasted batteries is lower at high current rates than the Planté ype.

Each of these types has its particular place in the art. For work such as motor-car propulsion the pasted battery is better adapted than the Planté, owing to its lightness and low cost. For power-station work the Planté battery is more suitable. There are certain classes of work for which each type is fairly well suited, uch as train-lighting, railway-signal and telephone work. In very case all the conditions, commercial as well as technical, must be considered before definitely fixing on the type which is most suitable to meet the requirements.

266. The electrolyte for lead storage batteries must be of ilute sulphuric acid made of sulphur and not from pyrites. Pyrite ontains iron, and acid made from it must necessarily contain ome iron. The presence of this metal in the electrolyte is injuri-us to the battery plates. An electrolyte need not necessarily e chemically pure, but it must be free from chlorine, nitrates, opper, mercury, arsenic, acetic acid, iron and platinum. It hould be tested by a competent chemist or supplied by some eliable company guaranteeing its character and freedom from njurious impurities. It is usually purchased of the desired spe-ific gravity, ready for use, but in cases where it is desirable to ave freight, or for other reasons, to make the electrolyte at he point of installation, either distilled water (usually purchasable rom a local ice factory) or rain water must be used to dilute he acid. *The acid should be poured into the water—never pour water into acid.* A chemical combination between the water and cid takes place, generating heat, and the solution, which becomes ot, must be allowed to cool before using and before attempting o determine its specific gravity, as the specific gravity changes markedly with the temperature of the liquid. The specific gravity equired depends on the character of the cell, its rate of discharge, nd its ampere hour capacity. The density is usually specified y the makers of the battery. Experience shows that density hould be as low as possible for satisfactory operation, but should ot be less than 1.100.

267. Rules for operation of lead storage batteries (*Standard Handbook*).

1. Be sure the ELECTROLYTE is free from injurious IMPURITIES.
2. Keep ELECTROLYTE well above tops of PLATES.
3. Maintain the SPECIFIC GRAVITY of the electrolyte at the density pecified by the manufacturers of the battery.
4. Do not let the DENSITY of the electrolyte in any cell differ from the stand-nd density more than 0.005. Thus a cell having normal density of 1.200 hould register above 1.205 and below 1.195 when fully charged. Test each ell with hydrometer once a week at least.
5. Keep CELLS CLEANED out and remove sediment when it has deposited metal near the lower edges of the plates.
6. *Be sure* SEPARATORS *are all in place* and in good order.
7. *Note any evidences of* TANK LEAKAGE and correct at once.
8. *Maintain* INSULATION *of* cells from ground and from each other.
9. *Begin* CHARGE IMMEDIATELY after the end of discharge or as soon there- *as practicable.*

10. Do not continue charge after the negative plates begin to give off gas, except the occasional "boiling" to be mentioned later.

11. Never let charging current fall below the 8-hr. rate except toward the end of charge, and

12. Stop discharge when the battery potential falls to 1.75 volts per cell with the normal current; 1.70 volts per cell discharging at the 4-hr. or 1.60 volts per cell discharging at the 1-hr. rate.

13. Watch the colors of the plates and if they begin to grow lighter treat at once for removal of sulphate.

14. Give the battery a prolonged over-charge about once a month. This over-charge should continue at about 60 per cent. of the 8-hr. rate until free gassing of the negative plates has continued for 1 hr.

15. Never let the battery temperature rise above 110 deg. fahr. and, if possible, keep below 100 deg. fahr.

16. Test each cell once a week with a cadmium electrode and a low-reading voltmeter to determine the condition of the negative plates.

17. Test the cells occasionally for drop on discharge; excessive drop indicates the presence of sulphate, and if the drop increases the amount of sulphation is also increasing.

18. When one of a series of cells is sulphated, charge it as usual in series with the others; on discharge cut the cell out, connecting the opened circuit by a heavy wire joining the two cells adjacent to the sulphated one. Be careful not to short-circuit the latter cell. When discharge is ended, remove connector and switch in the sulphated cell so that it again receives charge. Repeat this process until the cell has had its sulphate fully reduced. A double-pole, double-throw switch is conveniently used to switch the cell and the connector alternately into and out of the circuit. With it the cell may be allowed to discharge a short time before cutting out, which improves the treatment.

19. Cells which stand a considerable time unused—say as long as 45 days—should work in low density electrolyte not exceeding 1.210 specific gravity and be over-charged as directed in 18. It is better to give them a slight discharge and charge about once a week if practicable.

20. Cells which are to be idle two months or more should be taken out of commission by first fully charging and then discharging for two hours at the normal rate. Then draw off the electrolyte and fill the cells with pure water, preferably distilled. Begin discharge again at the normal rate. The cells will have to be practically short-circuited to produce this discharge in the water. When the discharge has been carried to a point at which the voltage is about 0.5 volt per cell, the water is poured out of the jars and the plates washed thoroughly by putting a hose in the jar and flowing the water over the plates. Allow the water which fills the jars at the end of the washing to remain 24 hr.; then pour out and allow the electrodes to dry. When the battery is to be used again pour in electrolyte and give a prolonged over-charge.

268. Installation of Lead Storage Batteries.—It is necessary that these cells be insulated from each other. For small glass cells make a shallow wooden box, an inch deep, having a length and breadth greater than the corresponding cell dimensions. Set this box on four glass insulators and fill it with clean sand. On this sand the cell is set. The sand affords a uniform bedding and support for the glass cell and catches and absorbs moisture which may drip down from the sides of the cell.

With lead-lined, wooden tanks, the cells themselves are set directly on glass insulators, there being four insulators under ordinary size cells and six where cells are so long as to require middle supports. It is customary now to set large cells with double insulation, that is, the cells are set on insulators, these insulators rest on a wooden framework, and the wooden framework rests in turn on a set of insulators.

The insulators used are generally of a special form, and are made of both glass and porcelain. Many years of experience have indicated that porcelain is not a proper material, as it is liable to rack and expose its porous mass so that any electrolyte spray is bsorbed into it when it ceases to be an insulator and becomes a airly good conductor.

269. **The Edison Storage Battery** (*data furnished by the Edison Storage Battery Co.*) is the result of an effort to avoid many of the disadvantages of the lead sulphuric-acid combination nd is a radical departure therefrom in every detail of construction. The positive plate consists of hollow, perforated, sheet-steel ubes filled with alternate layers of nickel hydrate and metallic ickel. The hydrate is the active material; and the metal, which s made in the form of microscopically thin flakes, is added to provide good conductivity between the walls of the tube and the emotest active material. The negative plate is made up of perorated, flat, sheet steel boxes or pockets loaded with iron oxide nd a small amount of mercury oxide, the latter also for the sake f conductivity. The grids which support these tubes and pockets re punchings of sheet steel. The cell terminals and container re likewise of steel and all metallic parts are heavily nickel plated. The electrolyte is a 21 per cent. solution of caustic potash containng also a small amount of lithium hydrate. All separators and nsulating parts are made of rubber.

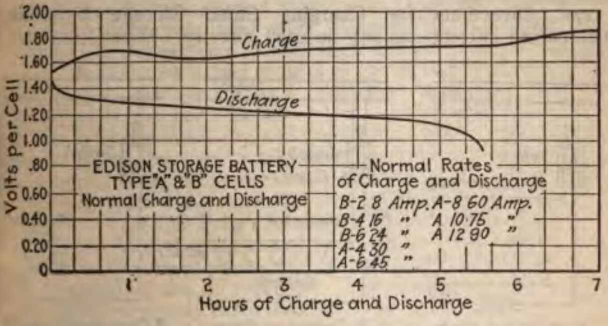


FIG. 134.—Charge and discharge curves of the Edison battery.

The current used in charging causes an oxidation of the positive late and a reduction of the negative, and these operations on ischarge are reversed. The electrolyte acts merely as a medium nd does not enter into combination with any of the active naterial as it does in the acid battery. Its specific gravity remains practically constant throughout the complete cycle of charge nd discharge. The charge and discharge curves are shown in Fig. 134.

The chief characteristics of the battery are ruggedness, due to ts solid, steel construction; low weight, because of its stronger and ighter supporting metal; long life, because of the complete reversibility *of the chemical reactions* and the absence of shedding active material; and low cost of maintenance, due to its freedom fr the diseases, such as sulphation, so commonly met with in stora battery practice, and from the necessity of internal cleaning a plate renewals. The arguments against it are high first c and high internal resistance. The importance of these must, course, be weighed with the advantages and the resultant co sidered in each proposed installation. The battery has attain its chief prominence in vehicle propulsion, but its characteristi also recommend it for many other purposes.

The attention required by this battery is of the simplest ch acter. It is chiefly important that the electrolyte be replenish from time to time with distilled water so that the plates will l entirely immersed, and that the outside of the cells be kept cle and dry, for if this is not done leakage of current will occur wi consequent corrosion of containers by electrolysis.

270. Efficiency of the Edison Storage Battery (*Standa Handbook*).—The Edison battery is not as efficient from the ener standpoint as are some of the other types, 60 per cent. being t efficiency usually attained in practice. The advantages of t cell lie largely in its mechanical construction and its freedom fro deterioration due to rough usage. It is compact and extreme light and strong.

271. Directions for Charging Small Storage Batteries.— Alternating current cannot be used directly. When this only

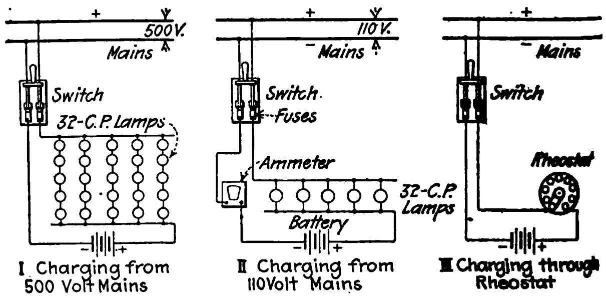


FIG. 135.—Connections for charging storage batteries.

available it must be converted to direct current by means motor-generators, rotary converters, or mercury-vapor converte Connections are shown in Fig. 135 for charging small stora batteries from direct-current mains. An ammeter in the circ is convenient but not absolutely necessary and lamps or a rheo (Fig. 135, *III*) are used to vary the current. A 16 c-p., 110-v *carbon-filament* lamp has about 220 ohms resistance and carry 0.5 ampere; a similar lamp of 32 c-p. rating has about ohms resistance and will carry 1 amp. Therefore, the charg current from 110-volt mains (Fig. 135, II) can be limited to, amp. by connecting five 32 c-p. lamps in parallel, or from volt mains (Fig. 135, *I*) by connecting in parallel five series of lamps, each series containing five 32 c-p. lamps. In both cases, two 16 c-p. lamps in parallel can be used in place of each 32 c-p. lamp. Charging current must always flow through the battery from the positive pole to the negative pole. See directions elsewhere in this section for determining polarity.

CIRCUIT CALCULATIONS

(The material on Circuit Calculation Considerations that follows was prepared by the compiler of this book and was first printed in *Electrical Review*, March 8, 1913, under the pen name of Anthony Gorman.)

272. **There are three factors that should be considered** when determining the sizes of wires for the distribution of electricity. A wire should be of such size that: (1) It will carry the electricity to the point where it will be used without an excessive drop or loss of voltage; (2) the current will not heat it to a temperature that would spoil the insulation or cause a fire (see Table 170 of *safe carrying capacities*); and (3) the cost of energy lost—the I^2R loss—due to the current overcoming the resistance will not be excessive. A conductor may satisfy one of the three conditions and may not satisfy the other two.

273. **The Voltage Drop Allowable in Lamp Circuits.**—For a 110-volt incandescent lamp load the conductors should be of such size that the pressure at the lamps can never vary more than 3 volts. Sometimes 4 and even 5 volts variation is allowed on 110-volt lamp circuits. This is not good practice. Expressed in percentages, a 1 per cent. to a 3 per cent. drop represents good practice; a 4½ per cent. drop is the upper limit. These are percentages of the receiver or normal lamp voltage. If the values above suggested are exceeded the life of the lamps may be shortened or they may burn dimly when the circuits are loaded.

274. **The Voltage Drop Allowable in Motor Circuits.**—A drop of 5 per cent. is very good practice and a 10 per cent. drop is often permitted. If motors are on the same circuits with lamps a 3 per cent. drop should not be exceeded. The question of voltage drop in conductors is closely associated with that of conductor economy. In important work particularly where the cost of energy is high, the cost of the energy lost in a conductor as well as the volts lost in it should be considered.

275. **Per cent. line drop or voltage loss** may be figured as either a percentage of the voltage required at the receiver or as a percentage of the voltage impressed by the generator or other energy source on the line. For instance, in Fig. 136, the voltage impressed on the receivers—lamps and motor—is 220. The line loss is 11 volts, hence, the pressure impressed on the line $= 220 + 11 = 231$ volts. The voltage loss as a percentage of the voltage at the *receiver* $= \frac{11}{220} = 0.05 = 5$ per cent. The voltage loss as a percentage of the voltage impressed on the line is $\frac{11}{231} = 0.048 = 4.8$

per cent. In practical work the percentage loss or drop is usually taken as a percentage of the voltage required at the receivers because this is the most convenient and direct method. In this book the term "percentage drop" refers to a percentage of the voltage required at the receivers unless otherwise noted.

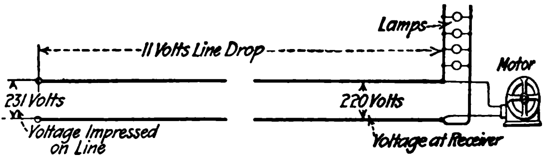


FIG. 136.—Illustrating percentage line drop.

276. To ascertain the volts drop as a percentage of the voltage impressed on the line, use the following formula:

$$V = \frac{E \times p}{100 - p} \qquad \text{(volts)}$$

wherein V = volts drop or loss in line, p = percentage drop of the voltage impressed on the line and E = voltage at the receivers.

Example.—What will be the voltage drop in a circuit where 110 volts is to be impressed on the receivers—lamps, motors or other equipment—and the allowable drop is 4 per cent. of the voltage impressed on the circuit.

Solution.—Substitute in the above formula:

$$V = \frac{E \times p}{100 - p} = \frac{110 \times 4}{100 - 4} = \frac{440}{96} = 4.58 \textbf{ volts.}$$

Table 277 gives actual line drops for different percentages of voltages impressed on the line.

277. Volts Lost at Different Per cent. (of Voltage Impressed On Circuit) Drop (*Standard Handbook*)

Per cent. drop	Voltage impressed on receivers		Per cent. drop	Voltage impressed on receivers	
	110	220		110	220
0.5	0.552	1.10	8	9.56	19.13
1	1.11	2.22	9	10.87	21.75
1.5	1.67	3.35	10	12.22	24.44
2	2.24	4.48	11	13.59	27.19
2.5	2.82	5.64	12	14.99	29.99
3	3.40	6.80	13	16.43	32.87
4	4.58	9.16	14	17.90	35.81
5	5.78	11.57	15	19.41	38.82
6	7.02	14.04	20	27.50	55.00
7	8.27	16.55	25	36.66	73.33

278. Distribution of Drop in Wiring Systems.—It is necessary in designing circuits to apportion the total allowable drop between components of a wiring system, the feeders, mains and branches. Table 279 indicates good practice for lighting circuits at

79. Distribution of Drop in 110-volt Lighting Circuits

of circuit	Proportion	4 volts total drop		3 volts total drop	
		Actual drop	Per cent. drop	Actual drop	Per cent. drop
es........	1 volt.......	1 volt..	0.91	1 volt	0.91
....	$\frac{1}{3}$ remainder.	1 volt..	0.91	$\frac{2}{3}$ volt	0.60
....	$\frac{2}{3}$ remainder.	2 volts	1.82	$1\frac{1}{3}$ volt	1.21
....	....	4 volts	3.64	3 volts	2.72

ıcandescent lamp electric lighting most of the drop should be :d to the feeders so that all of the lamps on mains and ıes served by the same feeder will burn at about the same ıcy. If most of the drop is in the mains and branches, lamps l close together but served by different mains may burn idedly different brilliancies and may attract attention and comment. Fig. 137 illustrates drop distribution.

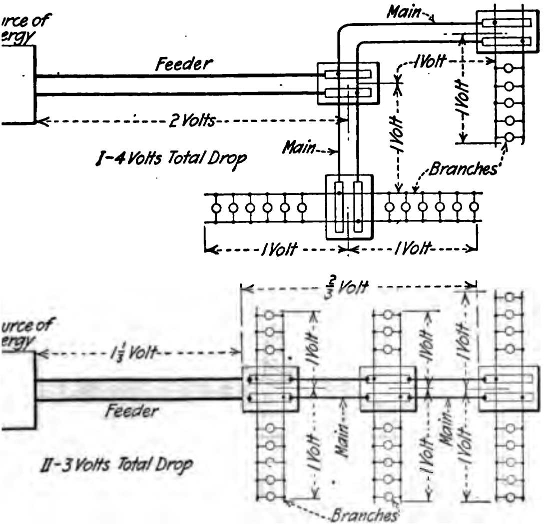


Fig. 137.—Distribution of drop in lighting circuits.

h motor circuits it is desirable to confine most of the drop mains so that a variation in the load on one motor or group ors will affect the speeds of the others as little as possible. of the drop is in the feeder, a heavy overload on one motor use a very appreciable drop in the feeder and the voltages l on all the motors, served by the feeder, would be corre spondingly decreased. The speeds of all of the motors served by the feeder would be lowered accordingly. In general, on low-voltage motor circuits, 1 volt drop can be allowed in the branches, two-thirds of the remaining allowance in the mains and one-third of the remaining allowance in the feeder. See Fig. 138 which

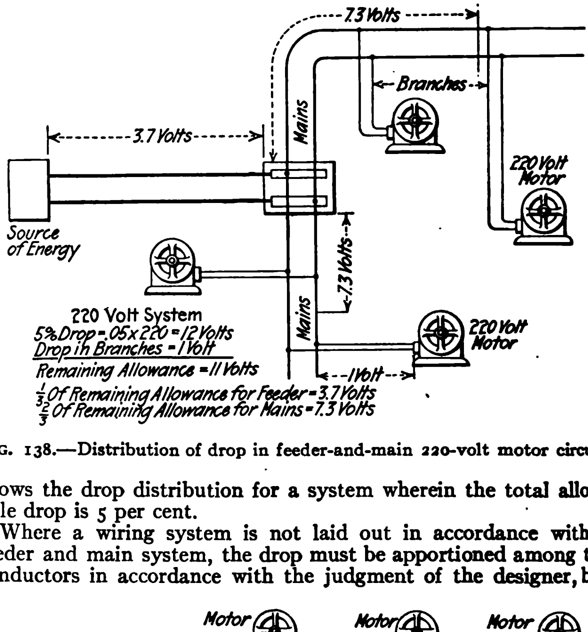


FIG. 138.—Distribution of drop in feeder-and-main 220-volt motor circuit.

shows the drop distribution for a system wherein the total allowable drop is 5 per cent.

Where a wiring system is not laid out in accordance with a feeder and main system, the drop must be apportioned among the conductors in accordance with the judgment of the designer, but

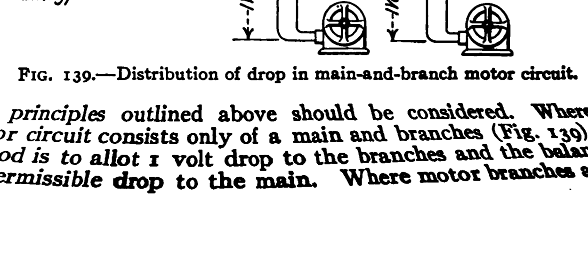


FIG. 139.—Distribution of drop in main-and-branch motor circuit.

the principles outlined above should be considered. Where a motor circuit consists only of a main and branches (Fig. 139) one method is to allot 1 volt drop to the branches and the balance of the permissible drop to the main. Where motor branches are very long the drop in them (because they must be large enough to carry full-load current without overheating) is frequently not far from 1 volt with full-load current. It may, in practice, be often assumed that it is 1 volt. Motor branches must be large enough to safely carry a current 25 per cent. greater than the full-load current because of *N.E.C.* regulations.

280. **Safe current carrying capacity** should always be considered when designing circuits. A wire may be large enough to carry a given current a given distance without undue drop, but yet so small that the current will overheat it. After a conductor size has been selected with reference to drop, Table 170 of safe current-carrying capacities should be consulted. If the wire first selected is not large enough to safely carry the current one that is large enough should be used. The matter of safe current-carrying capacity must be watched very closely in circuits that are short.

281. **The resistance of a circular mill-foot of commercial copper,** that is, a wire 1 ft. long and having an area of one cir. mil, at a temperature of 75 deg. fahr., is usually given as from 10.6 to 10.8 ohms. For wiring calculations 11 ohms is sufficiently accurate. (*Standard Handbook.*) In wiring calculations it is useless to exercise refinement, especially as the purity of the copper is unknown, the circuit lengths are often not measurable to within many per cent. of accuracy, and the difference between the successive sizes of wire available on the market, that is, the even numbered sizes, is about 60 per cent. There are other undeterminate factors.

282. **How to Proceed in Determining Wire Sizes for Circuits.**—Nearly every wiring problem involves the finding of the size wire that will carry a given current a given distance with a given drop in volts. The steps to be taken in finding the wire size in any such problem are as follows.

A. Determine the load in amperes that will come on the circuit. This ampere load value will be used in taking the wire size from a table or will be substituted for the letter *I* in a formula. See 284.

B. Find the distance to the load center of the circuit. See 285. This distance will be the actual length if the load is concentrated at the end or it will be the distance to the load center if the load is distributed. When found, this distance is used as the length of the circuit and is substituted for the letter *L* in a formula.

C. Decide what voltage drop or volts drop is allowable. See 273 and 274.

D. Determine the wire size that will give the voltage drop decided on in *C* by using one of the formulas that follow, using the values for distance and volts drop of *B* and *C*.

E. Check the wire size determined in *D* to see that it is large enough to safely carry the current by Table 170. See 280. If the size first selected is not large enough, one that is big enough to safely carry the current must be used.

F. Where economy of operation is a factor, check the size conductor as determined by *D* and *E* to be sure that the cost of the energy wasted in it in overcoming its resistance will not be excessive. See 286 and 287.

283. In determining circuit lengths from drawings or blue prints a long piece of tough paper divided (see Fig. 140) into the same measure as the drawing can be effectively used in scaling distances. Always allow for rises or drops for wall outlets. The

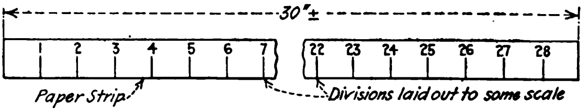


FIG. 140.—Paper scale for measuring circuit lengths.

rotometer (Fig. 141), is a convenient tool for scaling distances. The little wheel is run over the course of the circuit. The pointer indicates feet direct for drawings of certain scales. For other scales the dial reading must be multiplied by a constant to obtain actual lengths. A rotometer costs $2.00 or $3.00.

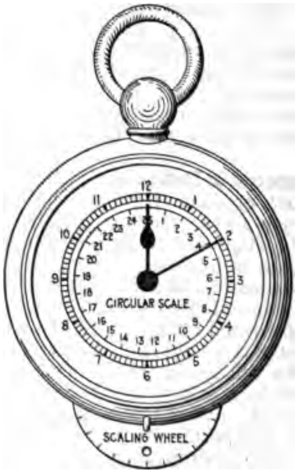


FIG. 141.—A rotometer.

284. Determination of Loads That Will Come on Conductors.—It is necessary to determine the load in amperes that will come on each conductor in a wiring system for figuring the wire sizes and so that one may be sure that the wire will safely carry the current. Where drawings are available note the ampere loads on the sheet in pencil as shown in Fig. 142. The figures opposite the receivers indicate the currents they take. The total load on each branch main and feeder is indicated within a circle. Motor branch circuits must be large enough to safely carry 25 per cent. mo than full-load current. It is convenient to note a current 25 per cent. greater than full-load current in a square near each motor branch, as in Fig. 142, so that the wire for the branch can be checked for carrying capacity. The numbers of amperes required by lamps, motors and other devices are given in tables elsewhere in this book.

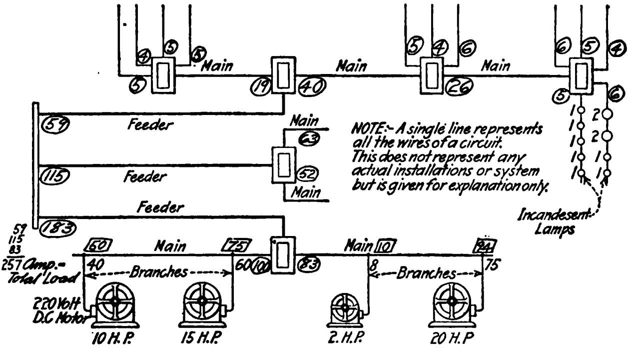


FIG. 142.—Determination of loads on conductors.

285. The location of the load center of a circuit is that point at which the total load can be assumed to be concentrated when making wiring calculations. The letter L in the wiring formulas in this book stands for the distance to the load center. The load center of a group of receivers, symmetrically arranged (Fig. 143)

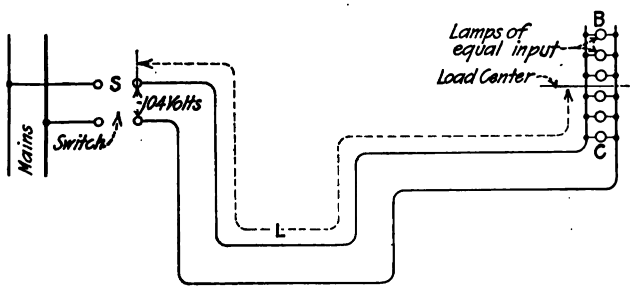


FIG. 143.—Illustrating location of load center.

and all of the same input will be in the middle of the group. Al- *ways take the distance along the circuit as* L, Fig. 143.

The distance to the load center (Fig. 143) denoted by L wo *be used for L in* the wiring formula cir. mils $= 22IL \div V$. *drop of voltage, V* in the formula, would be the drop from *switch S to the last lamp, B.* The current, I in the for would be the total current taken by all 6 lamps. If the conductors were calculated for a drop of 5 volts, the drop between S and B would be 5 volts. If 110 volts was impressed at S, the voltage at B would be $110-5=105$ volts. The other 5 lamps in the group

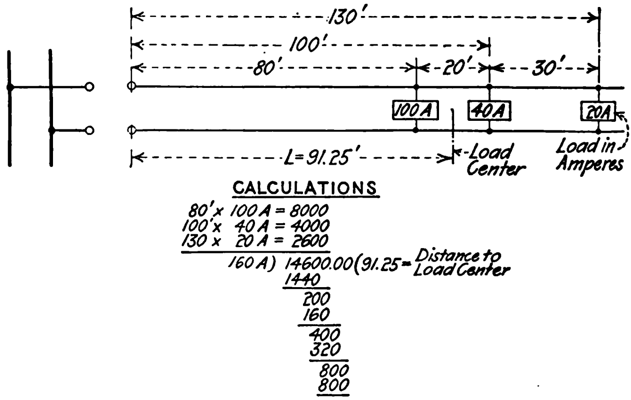


FIG. 144.—Method of computing location of load center.

would receive something greater than 105 volts, the pressure increasing slightly along the circuit toward the switch. The lamp C would receive the highest pressure of all.

The load center of a group of receivers unsymmetrically located or of unequal capacities or of both is found by: (first) multiplying

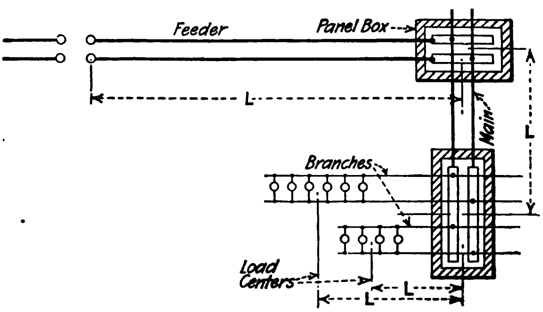


FIG. 145.—Illustrating the distance "L" to a load center.

ampere capacity of each receiver by its distance from ...nt of the circuit, (second) adding together all the ...ned, and (third) dividing this sum by the total ... See solution of example in Fig. 144.

Where no energy is taken from a circuit except at its end, the distance L for the formula is, as shown in Fig. 145, the entire length of the circuit. Always measure L along the circuit. In practice the load center is usually determined by inspection because great accuracy is not essential. A beginner should calculate a few examples until he is familiar with the principles involved.

286. For calculating direct-current two-wire circuits the following formula is used: (The material on Wiring Calculations that follows was prepared by the compiler of this book and was first printed in *Electrical Review*, June 14, 1913, under the pen name of N. V. Dunne.)

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein V = drop in volts in the circuit, I = the current in amperes in the circuit, L = the length one way or single distance of the circuit in feet and *cir. mils* is the area of the conductor in circular mils. Other forms of the formula are:

$$V = \frac{22 \times I \times L}{\text{cir. mils}} \qquad I = \frac{\text{cir. mils} \times V}{22 \times L} \qquad L = \frac{\text{cir. mils} \times V}{22 \times I}$$

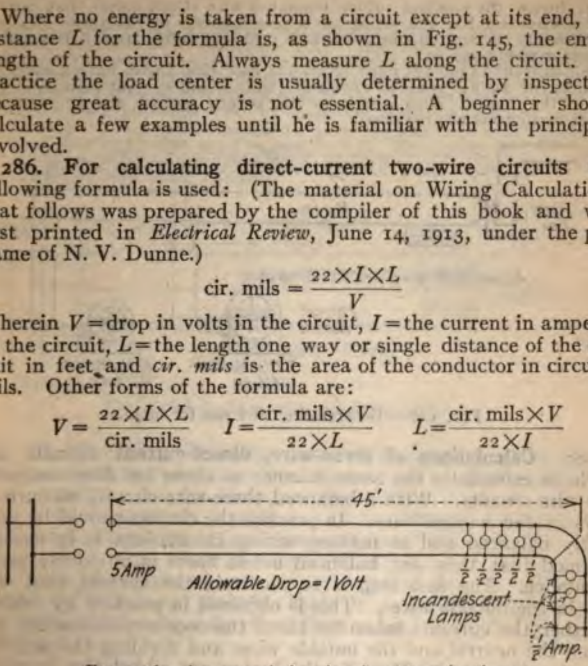


FIG. 146.—An example in wire size determination.

Example.—What size wire should be used for the branch circuit of Fig. 146? Allowable drop to the furthest lamp is 1 volt. Load consists of 10 incandescent lamps each taking ½ amp. Distance from starting point of circuit to load center is 45 ft.

Solution.—Substitute in the formula:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 5 \times 45}{1} = 4{,}950 \text{ cir. mils.}$$

Referring to Table 170, the standard size wire next larger than 4,950 cir. mils is No. 12 which has an area of 6,530 cir. mils. No. 12 wire, rubber insulated (for concealed work), safely carries, as given in the National Code column of the table, 20 amp., hence it will readily carry the 5 amp. of the circuit in question.

Example.—What size wire should be used for the 220-volt motor main of Fig. 147? The motors, so the table of motor currents (see index) shows, take approximately the currents indicated. The total load is (114 amp. + 40 amp.) 154 amp. Allowable drop is 5 per cent. or 11 volts to the furthest motor. Distance to load center is 120 ft.

Solution.—Substitute in the formula thus:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 154 \times 120}{11} = \frac{406{,}560}{11} = 36{,}960 \text{ cir. mils.}$$

Referring to Table 170, No. 4 wire, which has an area of 41,740 cir. mils, is the next largest standard size wire and would keep the drop within *the 11 volts allowed. But a No.* 4 rubber insulated wire has a safe carrying capacity of but 70 amp. The circuit under consideration carries 15 amp; hence the smallest rubber insulated wire (Code rules) that can be safely used is a No. 000 which has a safe capacity of 175 amp. No. 00, which safely carries 150 amp., could be probably safely used if the wiring inspector would pass it.

Branch leads to motors must (National Electrical Code) have a carrying capacity of 25 per cent. in excess of the full-load current ratings of the motors they serve. With a main serving several motors, the 25 per cent. excess capacity is not required.

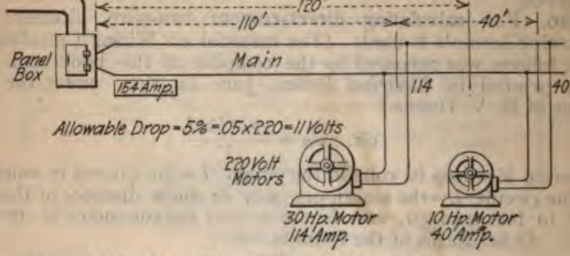


FIG. 147.—Determining wire size for main.

287. Calculations of three-wire, direct-current circuits are made in essentially the same manner as those for direct-current, two-wire circuits. With a balanced three-wire circuit, no current flows in the neutral wire. In practice the circuits should be very nearly balanced and in making wiring calculations it is usually assumed that they are balanced unless there is obviously great unbalance. The first step is to ascertain the current that will flow in the outside wires. This is obtained in practice by adding together the currents taken by all of the receivers connected between the neutral and the outside wires and dividing the sum by 2. (See Fig. 148.) Then to this value are added the currents taken by receivers, if there are any, that are connected across the outside wires. The sum is taken as the total current. The calculation is then made in the same way as for any two-wire circuit. The neutral wire is disregarded in the calculation as it is assumed that it carries no current. The neutral is frequently made smaller than the outside wires. (See Par. 237, Sect. I.)

The drop in voltage, V in the formulas, is the drop in the outside wires and is two times the drop to each receiver between neutral and outside wires. Two-wire branch circuits feeding from three-wire mains or feeders are computed in the same manner as for any two-wire circuit.

[illegible]—What size wire should be used for the three-wire main of Fig. [illegible]ble drop is 3 volts and the distance to the load center is 40 ft. [illegible]aded with two groups of receivers each taking 60 amp., [illegible] the neutral and the outside wires, and one group of re[illegible] amp. connected across the outside wires.

$$\frac{60 + 60}{2} + 20 = 80 \text{ amp.}$$ Substitute in the formula:

$$[illegible] = \frac{22 \times 80 \times 40}{3} = \frac{70{,}400}{3} = 23{,}470 \text{ cir. mils.}$$

Referring to Table 170, 23,470 cir. mils correspond most nearly to No. 6 wire which has an area of 26,250 cir. mils. This size wire would satisfy the voltage drop requirements but, for concealed wiring, rubber insulated wire must be used and rubber insulated No. 6 (see Table 170) has a safe carrying capacity of but 50 amp. The current in the circuit is 80 amp. Therefore, with rubber insulated wire No. 3 should be used which will safely carry 80 amp. The neutral wire may be made the same size as the outside wires or it may be smaller (see Par. 237, Sect. I). For exposed wiring with slow-burning or weather-proof insulation, three No. 5 wires each of which safely carries 80 amp. could be used.

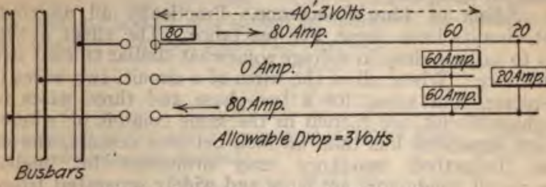


FIG. 148.—A three-wire circuit problem.

288. In calculating alternating-current circuits there are certain phenomena that must be considered that do not exist with direct-current circuits. Among these are the effects of power factor and of induction which creates reactance. Where circuits are short these effects need not always be considered, but where circuits are long they may be of considerable consequence. Capacity seldom need be considered with circuits operating at the voltages discussed in this book, namely, those of pressures below 2,200 volts. Skin effect is usually of so little consequence that it can be neglected.

There is no simple method of calculating alternating-current circuits, that takes into account the effects of power factor and reactance, that is reasonably accurate under all conditions. The methods described in following paragraphs, in which the effect of line reactance is not considered, give approximate results, but experience has shown them to be quite accurate enough for many wiring calculations. The results from these approximate formulas are usually subject to less error than other factors entering into ordinary wiring calculations. The results from the Mershon diagram method are quite accurate.

289. Large Conductors Should not be Used for Alternating-current Circuits.—If conductors are too large, the skin effect becomes so great that but a small proportion of the total area of the conductor is effective. Some engineers will use no conductor larger than 300,000 cir. mils for interior wiring, but 700,000 cir. mil conductors can be used economically for interior work if they are made upon a fiber core as described in 182. As a general proposition, conductors larger than 700,000 cir. mils are very difficult to install. If, for instance, a carrying capacity equivalent to 800,000 cir. mils is required, use two 400,000 cir. mil conductors in parallel or ... nilar equivalent arrangement.

...*er factors of the load apparatus or equipment* mus...
...*wn before alternating-current wiring calculations* c...

Wherein, I is the current in amperes in each of the four wire *kw.* = kilowatts input to load, E is the voltage across each of tl two phases and *p.f.* = the power factor of the load. The curre being known:

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein, cir. mils = area of required conductor, I = current in an peres in each of the four wires, L = the length or single distance c the circuit in feet, and V = volts drop to be allowed in the circuit.

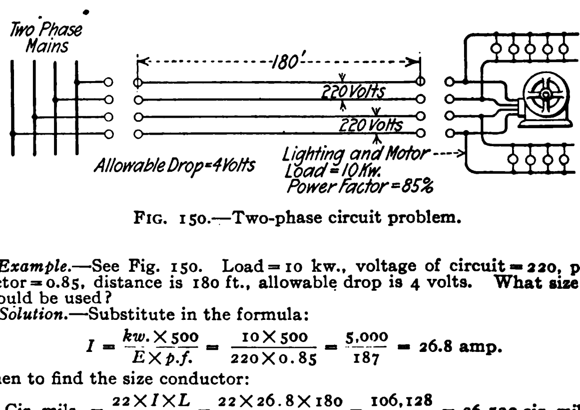


FIG. 150.—Two-phase circuit problem.

Example.—See Fig. 150. Load = 10 kw., voltage of circuit = 220, pow factor = 0.85, distance is 180 ft., allowable drop is 4 volts. What size wi should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 500}{E \times p.f.} = \frac{10 \times 500}{220 \times 0.85} = \frac{5,000}{187} = 26.8 \text{ amp.}$$

Then to find the size conductor:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 26.8 \times 180}{4} = \frac{106,128}{4} = 26,532 \text{ cir. mils.}$$

Referring to Table 170: The next larger standard size wire is No. which has an area of 33,100 cir. mils and which will safely carry, with ru ber insulation, 55 amp. and with other insulations, 80 amp. It will, ther fore, with either insulation, readily carry the 26.8 amp. in this circu Four No. 5 conductors would be used.

297. Calculation of Three-phase, Three-wire, Alternatin current Circuits where Line Reactance can be Neglected.—Th method, although not strictly accurate, can be safely used for con puting ordinary branch circuits and also for computing feede and mains where the circuits are carried in conduit or are not ve long. Where circuits are of considerable length, the method 302 should be used. If the current is not known, it must be foun using this formula:

$$I = \frac{kw. \times 1,000}{E \times p.f. \times 1.73} = \frac{kw. \times 580}{E \times p.f.}$$

Wherein, I = current in amperes in each of the three wires, E voltage between wires, *kw.* = kilowatts input to load, and *p.f.* power factor of load. The current being known, the wire size ca be calculated thus:

$$\text{cir. mils} = \frac{11 \times I \times L \times 1.73}{V} = \frac{19 \times I \times L}{V}$$

cir. mils = area for each of the three wires, I = current ›f the three wires in amperes, L = single distance or length of the circuit in feet, and V = allowable volts drop in line.

:.—See Fig. 151. Load = 10 kw., voltage of circuit = 220, power 35, distance is 180 ft., allowable drop = 4 volts. What size wire used?

.—Substitute in the formula:

$$I = \frac{kw. \times 580}{E \times p.f.} = \frac{10 \times 580}{220 \times 0.85} = \frac{5{,}800}{187} = 31 \text{ amp.}$$

ıd the conduction size:

$$= \frac{19 \times I \times L}{V} = \frac{19 \times 31 \times 180}{4} = \frac{106{,}000}{4} = 26{,}500 \text{ cir. mils.}$$

g to Table 170: The next larger standard size wire is No. 5 an area of 33,100 cir. mils. It will safely carry with rubber in-5 amp., and with other insulations 80 amp. It is therefore ample for the 31 amp. of this problem. Three No. 5 wires would be ıe circuit.

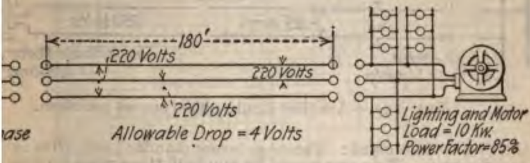


FIG. 151.—Three-phase circuit problem.

Single-phase branches from three-phase circuits are d the same as any single-phase circuit. If the two-branch rs are tapped from two of the conductors of a three-wire, ıse circuit, the voltage across the branch wires will be the hat across two of the wires of the three-phase circuit. If h is connected between one of the three wires and neutral, ge across the branch wires will be 0.58 × the three-phase etween wires. See paragraphs on the three-phase system ılternating Currents."

Calculation of Circuits where Line Reactance must be ed.—The Mershon diagram (Fig. 158) is recommended ing such calculations. Other and apparently simpler are available, but all simple methods are inaccurate under onditions and are apt to get their user into trouble unless ite familiar with the principles of alternating currents. shon diagram does not offer a direct method of ascertaining t is rather a "cut-and-try" method. The distance between d the frequency of the circuit being known, a conductor that appears to be about right is selected for trial. With n current flowing, the volts line loss in this conductor can nined with the diagram. If the volts line loss with this r is found to be excessive a different size conductor is tried. e made *until a size* conductor is found that will bring the *in the specified limit.* It is seldom that more than two *ecessary.* The method is a little tedious, but not difficult. *ate under* all ordinary conditions. See the examples

300. Calculation of Single-phase Alternating-current Cir where Line Reactance must be Considered.—The use of the M shon diagram in computing such circuits can best be explaine examples.

Example.—What size wire should be used for the branch to the 50- 60-cycle, 250-volt, single-phase induction motor of Fig. 152? The n plate current rating of the motor is 195 amp. and its full-load power fa is 85 per cent. The wires are run open and separated 4 in. Length of cuit is 600 ft. The volts line loss must not exceed 7 per cent. or 0.07×2 17.5 volts.

Solution.—To ascertain approximately what size the conductor must use the simple single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 195 \times 600}{17.5} = 147{,}000$$

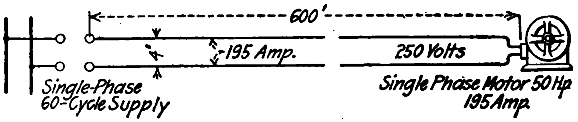


FIG. 152.—Another single-phase circuit problem.

Referring to Table 306: The next larger standard size wire is No. 00 167,800 cir. mils. This size would be ample if there were no line reacta but as it is known that there is line reactance we will select a larger ductor and find what the volts loss with it will be, using the Mershon gram (Fig. 153). Try a 250,000 cir. mil conductor.

Find the resistance and reactance drops in the line using the values f Table 306 for a 250,000 cir. mil conductor for 60 cycles and a 4 in. sep tion. From the table *resistance volts* = 0.085 and *reactance volts* = 0.1:

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1{,}000} = \frac{195 \times 0.085 \times 600}{1{,}000} = 9.9$$

$$\text{Per cent. of resistance drop} = \frac{\text{resistance drop}}{\text{receiver volts}} = \frac{9.9}{250} = 3.96 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1{,}000} = \frac{195 \times 0.139 \times 600}{1{,}000} = 16.3 \text{ vo}$$

$$\text{Per cent. of reactance drop} = \frac{\text{reactance drop}}{\text{receiver volts}} = \frac{16.3}{250} = 6.5 \text{ per cent.}$$

Refer to the Mershon diagram (Fig. 158). Follow the vertical line co sponding to the power factor, 0.85, upward until it intersects the small circle marked *O* as illustrated in Fig. 153. From this point lay off hori tally the percentage resistance drop, 3.96. From this last point lay off ' tically the percentage reactance drop, 6.5. (See Fig. 153.) This last po lies about on the 7 per cent. circle indicating that the volts line loss in t circuit with 195 amp. flowing will be 0.07 × 250 = 17.5 volts. The co tions of the example are satisfied by a 250,000 cir. mil conductor. Actua the line loss will be somewhat less than 7 per cent. as the last point does quite touch the 7 per cent. circle.

Inasmuch as this is a motor branch, the code rules require that its carrying capacity be sufficient for a 25 per cent. over-load. Therefore conductor should be capable of safely carrying 195×1.25 = 244 amp. R ferring to Table 306, a 300,000 cir. mil conductor, rubber insulated ca *would be required* to safely carry this 244 amp. In a problem in practice *would, therefore,* immediately try a 300,000 conductor for volts line lo *The preliminary* calculations were given in the above problem to illustr *the method.*

301. Calculation of Two-phase, Four-wire, Alternating-cur Circuits where Line Reactance must be Considered.—Use Mershon diagram (Fig. 158). Calculate the single-phase cir required to transmit one-half the power at the same voltage. two-phase transmission will require two such circuits.

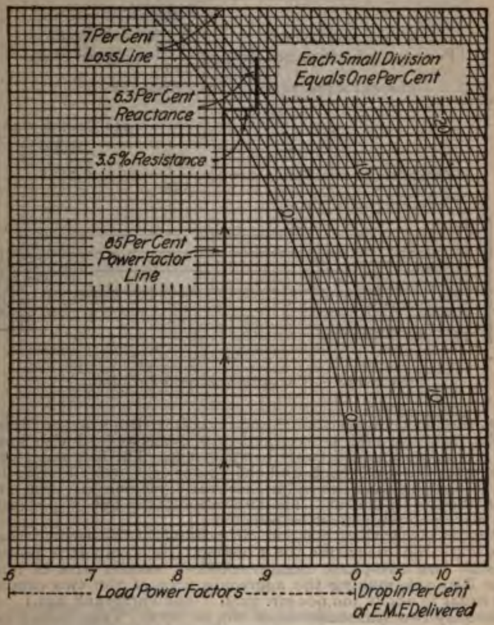


FIG. 153.—Illustrating the application of the Mershon diagram for com ing a single-phase circuit.

Example.—What size wire should be used for the two-phase circui Fig. 154? Load = 120 kw.; receiver voltage = 220; load power factor = 80 cent.; frequency = 60 cycles; length of circuit = 400 ft.; distance betw wires = 6 in. Allowable loss (voltage drop) is 5 per cent.

Solution.—Find one-half of the total load on the circuit and then proc with this one-half total load as if it were the entire load on a single-pl circuit.

$$\tfrac{1}{2}\text{ total load} = \frac{120\ kw.}{2} = \frac{120{,}000\text{ watts}}{2} = 60{,}000,\text{ watts}$$

$$\text{line current} = \frac{P}{E \times p.f.} = \frac{60{,}000}{220 \times 0.80} = \frac{60{,}000}{176} = 341\text{ amp.}$$

To ascertain approximately what size wire should be installed, use approximate single-phase formula:

$$cir.\ mils = \frac{22 \times I \times L}{V} = \frac{22 \times 341 \times 400}{12} = 250{,}066\text{ cir. mils.}$$

The next larger standard size wire is 300,000 cir. mils, which will safely carry the current 341 amp. (see Table 306) if the wires are run open. (If they are concealed—rubber insulated—at least a 500,000 cir. mil conductor must be used.)

Referring to Table 306 for a 300,000 cir. mil conductor, 6 in. separation and 60 cycles: *Resistance volts per amp.* = 0.075 and *Reactance volts per amp.* = 0.153, therefore

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1,000} = \frac{341 \times 0.075 \times 400}{1,000} = 10.23 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{10.23}{220} = 4.65 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1,000} = \frac{341 \times 0.153 \times 400}{1,000} = 20.9$$

$$\text{Per cent. of reactance drop} = \frac{20.9}{220} = 9.5 \text{ per cent.}$$

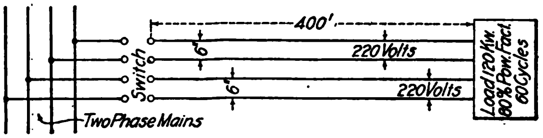


FIG. 154.—Two-phase circuit problem.

Lay out the per cent. resistance and reactance drops on the Mershon diagram (Fig. 158) for 0.80 power factor, as suggested in the single-phase problem above and as illustrated in Fig. 155. The last point on the lay out is between the 9 per cent. and the 10 per cent. volts loss circles in the diagram indicating that the volts loss with 300,000 cir. mil conductors would be about 9½ per cent. The allowable loss is but 5 per cent., so a different size conductor must be selected.

A conductor larger than 300,000 cir. mils might be selected that would bring the volts line loss within the 5 per cent. limit, but it is probably better to install two two-phase transmissions of smaller wire in multiple as shown in Fig. 156, making the aggregate area of the two conductors in multiple equal to about 300,000 cir. mils. (See Paragraph 292.)

Therefore try two transmissions of No. 00 wire. Take values for No. 00 wire from Table 306 in the manner as before, for 60 cycles and a 6 in. separation, remembering that half the former current will flow in the conductors of the subdivided transmission. Then for each two-phase, two-wire circuit the current will be ½ × 341 = 170.5 amp. Therefore:

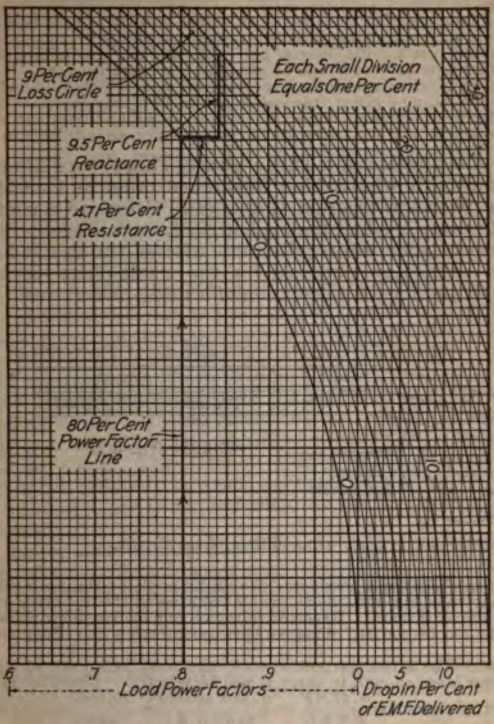
$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1,000} = \frac{170.5 \times 0.156 \times 400}{1,000} = 10.7 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{10.7}{220} = 4.8 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1,000} = \frac{170.5 \times 0.172 \times 400}{1,000} = 11.7 \text{ volts}$$

$$\text{Per cent. of reactance drop} = \frac{11.7}{220} = 5.3 \text{ per cent.}$$

Laying the per cent. resistance and per cent. reactance drops out on the Mershon diagram at 0.80 power factor it will be found that for this No



. 155.—Illustrating the application of the Mershon diagram for computing a two-phase, four-wire alternating-current circuit.

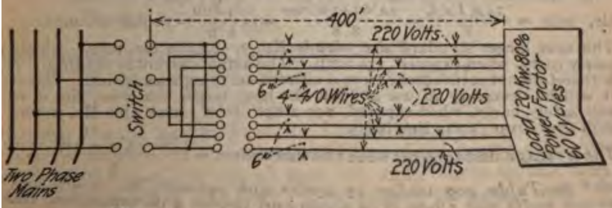


FIG. 156.—Divided two-phase circuit.

wire the per cent. volts line loss will be about 7 per cent., which is excessive.

Making another trial, considering this time two two-phase transmissions of No. 0000 wire in parallel, it will be found that the per cent. volts line loss will be about just a trifle over 5 per cent. So two two-phase circuits in parallel of No. 0000 wire would be used as shown in Fig. 156.

This is an unusually tedious problem and was selected to indicate the method of dividing a given transmission into two transmissions of smaller wire to decrease the effect of line reactance. In practice it might not be the most economical method to install the transmission as indicated in Fig. 156.

302. Calculation of a Three-phase, Three-wire Alternating-current Circuit where Line Reactance must be Considered.—Use the Mershon diagram (Fig. 158). Calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase circuit. See paragraph **300** for the calculation of a single-phase circuit.

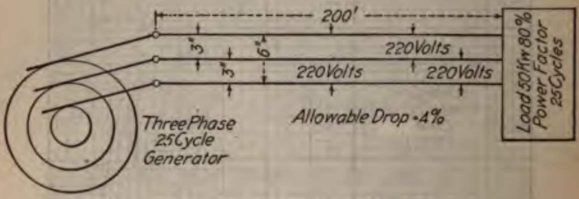


FIG. 157.—Three-phase circuit.

Example.—What size conductor should be used for the open-wire transmission shown in Fig. 157, the allowable volts loss in the line being 4 per cent. or $0.04 \times 220 = 8.8$ volts? Receiver voltage = 220; load = 50 kw.; power factor = 0.80; distance = 200 ft.; distance between wires = 3 in. Frequency is 25 cycles.

Solution.—The actual current in each wire must be known to insure that a conductor large enough to carry it will be selected. (See Par. 69.)

$$\text{actual current} = \frac{0.58 \times P}{E \times p.f.} = \frac{0.58 \times 50{,}000}{220 \times 0.8} = \frac{29{,}000}{176} = 0.165 \text{ amp.}$$

Now find one-half of the total load and proceed with this load as for a single-phase transmission which will be called the imaginary transmission.

$$\tfrac{1}{2} \text{ total load} = \frac{\text{watts}}{2} = \frac{50{,}000}{2} = 25{,}000 \text{ watts}$$

The current in the imaginary transmission would be:

$$I = \frac{P}{E \times p.f.} = \frac{25{,}000}{220 \times 0.80} = \frac{25{,}000}{176} = 142 \text{ amp. in the imaginary transmission.}$$

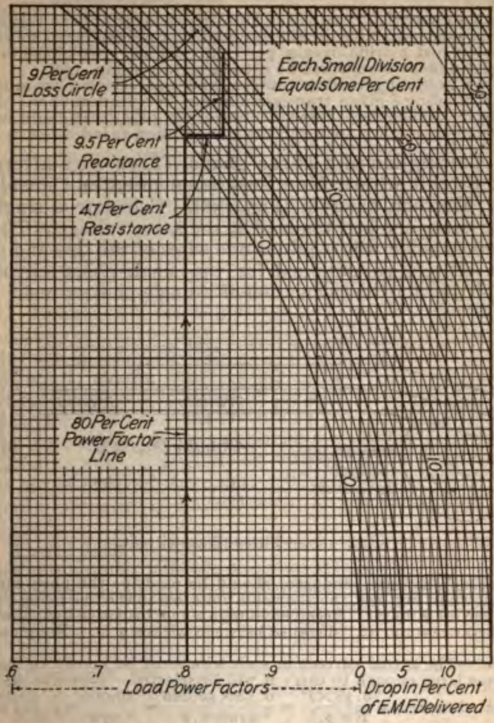
To approximate the size of wire, use the single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 142 \times 200}{8.8} = \frac{624{,}800}{8.8} = 71{,}000 \text{ cir. mils.}$$

The next larger standard size wire is No. 1—83,690 cir. mils.—which will safely carry, when exposed, 150 amp. The actual current is 165 amp. No. 1 is therefore not satisfactory from a current-carrying standpoint. Therefore, it will be necessary to use at least the next larger size wire, No. 0, which will safely carry, when exposed, 200 amp. Now check this No. 0 wire for volts line drop (volts line loss).

The average distance between the three wires $= \frac{3 \text{ in.} + 3 \text{ in.} + 6 \text{ in.}}{3} = \frac{12 \text{ in.}}{3} = 4$ in.

Refer to Table 307 under 25 cycles and opposite No. 0 wire and find: *Resistance volts per* 1,000 ft. = 0.196 and (under 4 in. separation) reactance *volts per* 1,000 *ft.* = 0.066. Then



c. 155.—Illustrating the application of the Mershon diagram for computing a two-phase, four-wire alternating-current circuit.

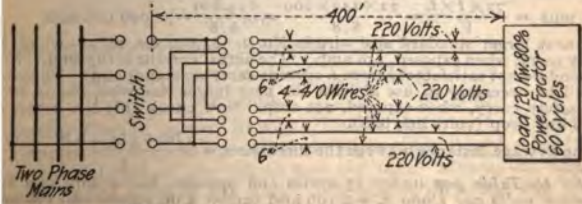


Fig. 156.—Divided two-phase circuit.

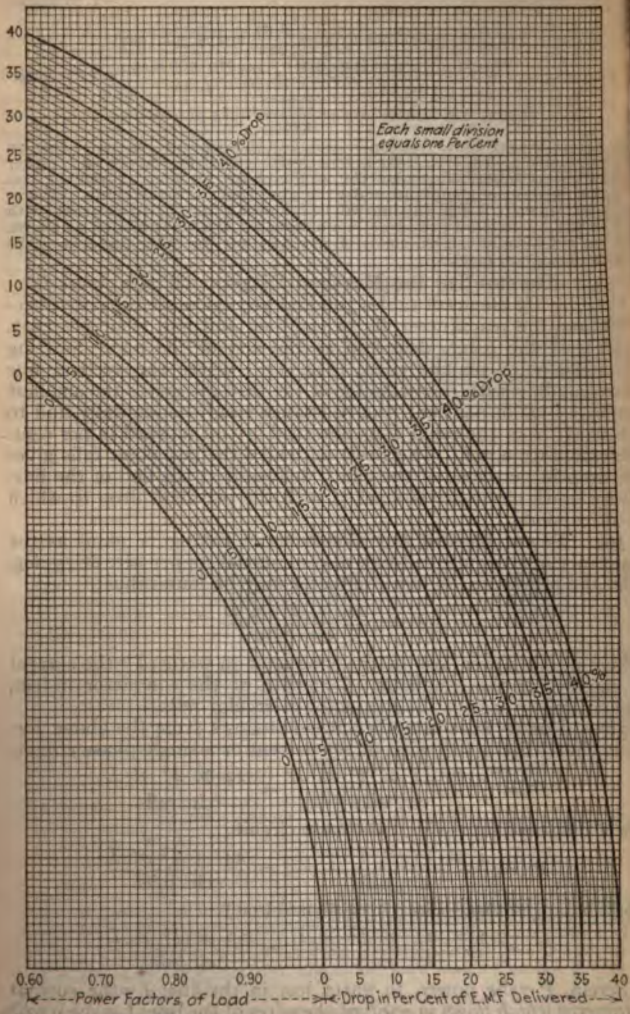


Fig. 158.—The Mershon diagram. See Par. 303 for directions as to its use and application.

Size of wire (cir. mils) and B. & S. gage	Safe carrying capacity, N.E.C. 1915 Rules: Rubber ins., amp., Table A	Safe carrying capacity, N.E.C. 1915 Rules: Other ins., amp., Table B	Resistance-volts in 1,000 ft. of copper line (2,000 ft. of wire) for 1 amp. (The values in this column are really the resistances of 2,000 ft. of conductor at 75 deg. fahr.)	[1]Frequency = 60 cycles. Reactance-volts in 1,000 ft. of line (2,000 ft. of wire) for 1 amp. at 7,200 alternations per minute (60 cycles per second) for the distance given in inches between centers of conductors. (The values in these columns are really the reactances of 2,000 ft. of conductor): ½	1	2	3	4	5	6	9	12	18	24
14– 4,107	15	20	5.06	0.138	0.178	0.218	0.220	0.233	0.244	0.252	0.271	0.284	0.302	.....
12– 6,530	20	25	3.18	0.127	0.159	0.190	0.210	0.223	0.233	0.241	0.260	0.273	0.292	.....
10–10,380	25	30	2.00	0.11[illegible]	0.14[illegible]	0.180	0.199	0.212	0.223	0.221	0.249	0.262	0.281	.....
8–16,510	35	50	1.26	0.106	0.138	0.169	0.188	0.201	0.212	0.220	0.238	0.252	0.270	0.284
6–26,250	50	70	0.790	0.095	0.127	0.158	0.178	0.190	0.210	0.209	0.228	0.241	0.260	0.272
4–41,740	70	90	0.498	0.085	0.117	0.149	0.167	0.180	0.190	0.199	0.217	0.230	0.249	0.262
2–66,370	90	125	0.312	0.074	0.106	0.138	0.156	0.169	0.180	0.188	0.206	0.220	0.238	0.252
1–83,690	100	150	0.248	0.068	0.101	0.132	0.151	0.164	0.174	0.183	0.201	0.214	0.233	0.246
0–105,500	125	200	0.196	0.063	0.095	0.127	0.145	0.159	0.169	0.177	0.196	0.209	0.228	0.241
2/0–133,100	150	225	0.156	0.057	0.090	0.121	0.140	0.153	0.164	0.172	0.190	0.204	0.222	0.236
3/0–167,800	175	275	0.122	0.052	0.085	0.116	0.135	0.148	0.158	0.167	0.185	0.199	0.217	0.230
4/0–211,600	225	325	0.098	0.046	0.079	0.111	0.130	0.143	0.153	0.161	0.180	0.193	0.212	0.225
250,000	240	350	0.085	.....	0.075	0.106	0.125	0.139	0.148	0.157	0.175	0.189	0.207	0.220
300,000	275	400	0.075	.....	0.071	0.103	0.120	0.134	0.144	0.153	0.171	0.185	0.203	0.217
350,000	300	450	0.061	.....	0.067	0.099	0.118	0.128	0.141	0.149	0.168	0.182	0.200	0.213
400,000	325	500	0.052	.....	0.064	0.096	0.114	0.127	0.138	0.146	0.165	0.178	0.197	0.209
500,000	400	600	0.042	.....	.....	0.090	0.109	0.122	0.133	0.141	0.160	0.172	0.192	0.202
600,000	450	680	0.035	.....	.....	0.087	0.106	0.118	0.128	0.137	0.155	0.169	0.187	0.200
700,000	500	760	0.030	.....	.....	0.083	0.102	0.114	0.125	0.133	0.152	0.165	0.184	0.197
800,000	550	840	0.026	.....	.....	0.080	0.099	0.112	0.122	0.130	0.148	0.162	0.181	0.194
900,000	600	920	0.024	.....	.....	0.077	0.096	0.109	0.119	0.127	0.146	0.159	0.178	0.191
1,000,000	650	1,000	0.022	.....	.....	0.075	0.094	0.106	0.117	0.125	0.144	0.158	0.176	0.188

[1] ...other frequencies the reactance will be in direct proportion to the frequency.

307. Table for Calculating Drop in Alternating-current Lines with the Mershon Diagram—25 Cycles

Size of wire (cir. mils) and B. & S. gage	Safe carrying capacity, N.E.C. 1915 Rules: Rubber ins., amp., Table A	Safe carrying capacity, N.E.C. 1915 Rules: Other ins., amp., Table B	Resistance-volts in 1,000 ft. of copper line (2,000 ft. of wire) for 1 amp. (The values in this column are really the resistances of 2,000 ft. of conductor at 75 deg. fahr.)	[1] Frequency = 25 cycles. Reactance-volts in 1,000 ft. of line (2,000 ft. of wire) for 1 amp. at 3,000 alternations per minute (25 cycles per second) for the distance given in inches between centers of conductors. (The values in these columns are really the reactances of 2,000 ft. of conductor): ½	1	2	3	4	5	6	9	12	18	24
14– 4,107	15	20	5.06	0.057	0.071	0.084	0.093	0.097	0.102	0.105	0.113	0.118	0.126	.....
12– 6,530	20	25	3.18	0.053	0.066	0.080	0.087	0.094	0.097	0.101	0.108	0.113	0.122	.....
10–10,380	25	30	2.00	0.049	0.062	0.075	0.083	0.088	0.092	0.096	0.104	0.110	0.117	.....
8–16,510	35	50	1.26	0.044	0.057	0.071	0.078	0.084	0.088	0.092	0.099	0.105	0.113	.....
6–26,250	50	70	0.790	0.040	0.053	0.066	0.074	0.079	0.084	0.087	0.095	0.100	0.108	.....
4–41,740	70	90	0.498	0.035	0.049	0.062	0.070	0.075	0.079	0.083	0.091	0.096	0.104	.....
2–66,370	90	125	0.312	0.031	0.044	0.057	0.065	0.071	0.075	0.078	0.086	0.092	0.099	.....
1–83,690	100	150	0.248	0.028	0.042	0.055	0.063	0.068	0.073	0.076	0.083	0.089	0.097	.....
0–105,500	125	200	0.196	0.026	0.040	0.053	0.061	0.066	0.070	0.073	0.082	0.087	0.095	.....
2/0–133,100	150	225	0.156	0.024	0.037	0.051	0.058	0.064	0.068	0.072	0.079	0.085	0.093	.....
3/0–167,800	175	275	0.122	0.022	0.035	0.048	0.056	0.062	0.066	0.070	0.077	0.083	0.091	.....
4/0–211,600	225	325	0.098	0.019	0.033	0.046	0.053	0.059	0.064	0.067	0.075	0.081	0.088	.....
250,000	240	350	0.085	.....	0.031	0.044	0.051	0.058	0.062	0.065	0.073	0.079	0.086	0.092
300,000	275	400	0.075	.....	0.030	0.043	0.050	0.056	0.060	0.064	0.071	0.077	0.084	0.090
350,000	300	450	0.061	.....	0.028	0.041	0.049	0.054	0.059	0.062	0.070	0.076	0.083	0.089
400,000	325	500	0.052	.....	0.027	0.040	0.048	0.053	0.057	0.061	0.069	0.075	0.082	0.087
500,000	400	600	0.042	.....	.....	0.038	0.046	0.051	0.055	0.059	0.067	0.072	0.080	0.085
600,000	450	680	0.035	.....	.....	0.036	0.044	0.049	0.053	0.057	0.065	0.070	0.078	0.083
700,000	500	760	0.030	.....	.....	0.035	0.042	0.048	0.052	0.056	0.063	0.069	0.077	0.082
800,000	550	840	0.026	.....	.....	0.033	0.041	0.047	0.050	0.054	0.062	0.068	0.075	0.081
900,000	600	920	0.024	.....	.....	0.032	0.040	0.046	0.050	0.053	0.061	0.066	0.074	0.080
1,000,000	650	1,000	0.022	.....	.....	0.031	0.039	0.044	0.049	0.052	0.060	0.065	0.073	0.079

[1] For other frequencies the reactance will be in direct proportion to the frequency.

308. The Question of Energy Loss in a Circuit should not be Slighted in Circuit Calculations (*Standard Handbook*).—It is well known that in overcoming resistance, electrical energy is wasted; and as it costs money to develop or buy electrical energy, it is evident that in any commercial system such waste must be kept to a minimum. This may be done by decreasing the resistance of the conductors or what amounts to the same thing, of increasing the size of the conductors. Inasmuch as this is also an expensive matter, care must be exercised that the additional sum added to the expenditure in copper is not so excessive as to more than counterbalance the cost of the energy continually saved. It has been laid down as a general rule that for the transmission of any given energy, the most economical conductor is one having such a resistance that the value of the energy wasted in heat annually is equal to the interest per annum on the original outlay upon the conductor.

Knowing the average amount of energy to be transmitted, it becomes an easy matter to find the average kilowatt-hours wasted in a conductor of a given resistance. The question of energy loss in conductors increases in importance as the price of the energy increases, and decreases as the price of energy decreases, so that where the energy costs or may be purchased for very little, the loss may be more than offset by the additional investment in copper necessary to avoid it. With regard to the conductors themselves, in interior wiring work, it is merely a question of the additional cost of the copper, as the price of the installation, etc., is usually about the same for any size conductor that is apt to be used. So many considerations enter into the question of the best size of wire to employ consistent with strict economy, that the matter cannot be discussed at length here. A few illustrations may suffice to show what an important bearing the question has in wiring work.

Example.—A two-wire direct-current feeder system supplies a current of 50 amp. at a distance of 200 ft. from the meter. The drop allowed is 5 per cent. and the voltage of the circuit is 110. What size of wire should be installed?

Solution.—Substituting the value given above in the cir. mil. formula, the size of wire is found to be

$$A = \frac{22 \times 50 \times 200}{110 \times 0.05} = 40{,}000 \text{ cir. mils, or a No. 4 wire.}$$

If this energy were used 10 hr. a day for 300 days, and the cost of the energy were 8 cents per kilowatt-hour, the total yearly cost would be

$$\frac{50 \times 110 \times 10 \times 300 \times 0.08}{1{,}000} = \$1{,}320.$$

Of this 5 per cent., or $66, would be lost yearly due to the drop. The cost of 400 ft., No. 4, double-braid, rubber-covered wire would be about $22.50. The interest at 5 per cent. on this $22.50 would be $1.13. Since the yearly cost of energy lost is $66.00, it would cost each year $1.13 + $66.00 = $67.13 to operate this No. 4 conductor, assuming that the use of money costs 5 per cent. a year. It is evident, since the interest charge is so much smaller than the energy cost charge, that a No. 4 conductor is not nearly large enough and that it is not by any means the most economical one for the *condition of the problem.*

Table 310 shows the total annual charges or costs for conductors of *veral sizes worked out for the* conditions of this problem, it being assumed *t, in each case, the* current of 50 amp. flows 10 hr. a day, 300 days a year *r a conductor length of* 400 ft., the energy cost being 8 cents a kw-hr. *the costs of the* conductors being those indicated. As above noted th *ge drop for the No. 4* conductor is 5 per cent. For the No. 6 conduct (which will safely carry only 46 amp. and which therefore would be too small for the 50 amp. of this problem) it will be greater than 5 per cent. For conductors larger than No. 4 the drop will be less than 5 per cent.

It is evident from Table 310 that, for the conditions of this problem and with wire at the prices assumed, a 400,000 c. m. conductor is the most economical, that is, it has the least ***total annual cost***, although a 300,000 c. m. conductor is almost as economical.

The market price of copper has a bearing on the matter of conductor economy. Where the energy cost is very low, the conductor that would be theoretically the most economical might be too small to safely carry the current. In such a case, the most economical conductor that can be used is the smallest one that has ample carrying capacity.

Example.—A two-wire feeder system 100 ft. long supplies a device requiring a current of 500 amp. The voltage of the supply is 110 and a drop of 1 per cent. is permitted. Required the size of wire (slow-burning weatherproof wire being permitted) used.

Solution.—Calculating the size of wire as in the preceding case shows that a 1,100,000-cir. mil cable is required.

If the energy in this case costs 2 cents per kilowatt-hour and the device were used 24 hr. a day and 300 days a year, what size of wire should be installed to obtain the best economy?

With the above data the yearly cost of the energy used is found to be

$$\frac{24 \times 300 \times 500 \times 110 \times 0.02}{1,000} = \$7,920.$$

If a 2,500,000-cir. mil cable be used, the drop according to the formula would be approximately 0.44 volt or 0.4 per cent. ($\frac{4}{10}$ per cent). The weight of 200 ft. of cable equivalent to 2,500,000 cir. mils would be approximately 1,900 lb., and assuming the cost to be 30 cents per pound, the copper investment would be $570. The interest on this investment at 5 per cent. would be $28.50. Now a loss of 0.4 per cent. on $7,920 would be $32 per year and since the interest on the copper investment is less than that amount, the 2,500,000-cir. mil cable should be installed. A 3,000,000-cir. mil cable would be found to be a trifle too costly. The substitution of the 2,500,000-cir. mil cable for the 1,000,000-cir. mil cable results therefore in a saving of $47 yearly. These results are figured on the ground that all other costs remain the same, which may or may not be the case. If copper were cheaper than specified, a larger cable could be substituted with a still further saving. It may readily be seen therefore that the question of drop alone should not determine the size of wire.

The preceding remarks deal with the question of energy loss from a purely financial basis. There are electrical considerations which must be taken into account in determining the maximum drop and energy loss allowable. The variation in the life and candle-power of incandescent lamps and the performance of motors and other equipment as affected by voltage and therefore energy loss should be considered.

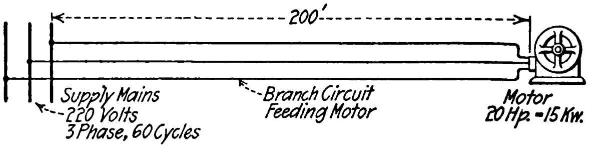


FIG. 159.—Three-phase motor circuit.

309. Use of Constants in Circuit Calculations.—Wiring and many other calculations that involve the use of several constants can be much simplified by resolving the constants into a factor which is itself a constant. It frequently occurs in central-station work that the permissible voltage drop and the power factor remain the same for many wiring computations. These and other constants can be effectively incorporated into a multiplier. An example will best explain the method.

Example.—Consider the problem suggested in Fig. 159. A three-phase 220-volt, 60-cycle, 20-h.p. motor is to be installed. It is assumed that the power factor is 70 per cent. What is the current in the line wires?

The following formula gives the current in each of the wires of a balanced three-phase circuit: $I = P \div 1.73 \times E \times p.f.$ where I is the current in amperes, P is the power transmitted in watts, 1.73 is a constant, E is the voltage of the supply circuit and $p.f.$ is the power factor of the circuit. For wiring calculations it may often be assumed that the factors 1.73, E and $p.f.$ are always of the same value in many computations. These three factors can therefore be resolved into a constant thus: $I = P \div 1.73 \times 220 \times 0.7 = 0.003,754 \times P$ watts or approximately: $I = 3.8$ kw.

It is apparent, then, that by multiplying the kilowatt capacity of the motor by the factor 3.8 the approximate full-load current in amperes flowing to the motor will result. The current for the motor of Fig. 159 will be $3.8 \times 15 = 57$ amp. Other problems may be much simplified by resolving constants into a factor.

309A. Allowable Amperes for 1-volt Drop (*National Lamp Works*)

Size wire, B. & S. or A.W.G.	Length of circuit in feet (length of wire twice as great)																	
	15	20	30	40	60	80	100	125	150	175	200	250	300	350	400	450	500	
16	8.3	6.2	4.2	3.1	2.1	1.6	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2	
14	*13*	*9.9*	*6.6*	5.0	3.3	2.5	2.0	1.6	1.3	1.1	1.0	0.8	0.7	0.6	0.5	0.4	0.4	C
12	21	*16*	*10*	*7.9*	5.3	3.9	3.1	2.5	2.1	1.8	1.6	1.3	1.1	0.9	0.8	0.7	0.6	
10	33	*24*	*17*	*13*	*8.3*	*6.3*	5.0	4.0	3.3	2.9	2.5	2.0	1.7	1.4	1.3	1.1	1.0	Not prohibited
8	53	40	*27*	*20*	*13*	*10*	*8.0*	*6.4*	5.3	4.6	4.0	3.2	2.7	2.3	2.0	1.8	1.6	
6	84	63	*42*	*32*	*21*	*16*	*13*	*10*	*8.5*	*7.2*	*6.3*	5.1	4.2	3.6	3.2	2.8	2.5	
4	134	101	*67*	*50*	*34*	*25*	*20*	*16*	*13*	*12*	*10*	*8.1*	*6.7*	5.8	5.0	4.5	4.0	
3	169	127	84	*63*	*42*	*32*	*25*	*20*	*17*	*15*	*13*	*10*	*8.5*	*7.2*	*6.3*	5.6	5.1	
2	216	160	107	*80*	*53*	*40*	*32*	*26*	*21*	*18*	*16*	*13*	*11*	*9.2*	*8.0*	*7.1*	*6.4*	
1	268	201	134	101	*67*	*50*	*40*	*32*	*27*	*23*	*20*	*16*	*13*	*12*	*10*	*9.0*	*8.1*	
0	340	254	167	128	*85*	*64*	*51*	*41*	*34*	*29*	*25*	*20*	*17*	*15*	*13*	*11*	*10*	

A Prohibited by "allowable" current-carrying capacity" rule.

B Prohibited by "660 watts per circuit" rule. (See Sec. 4, Par. **248**.)

Explanation.—Values in Section *A* of table are greater than those permitted by the *Code* (Par. **167**) in rubber-insulated copper wires of the sizes shown. Values in both Sections *A* and *B* are all such that, in any circuit operating at 110 volts or more, they will constitute a load greater than 660 watts, which is prohibited on ordinary incandescent-lamp branch circuits (Sec. 4, Par. **248**). Values in Section *C* are not prohibitive.

Example.—It is desired to install a circuit 80 ft. in length (160 ft. of wire). Reading down column headed "80," a current of 2.5 amp. causes a drop of 1 volt in an 80-ft. circuit of No. 14 wire. In an 80-ft. circuit of No. 12 wire, 3.9 amp. would cause 1 volt drop; with No. 10 wire, 6.3 amp. would cause 1 volt drop. For a current of 6 amp.—the max. current permitted on a 110-v., incandescent-lamp, branch circuit—a No. 10 wire should be used to keep the drop in this 80-ft. circuit within a 1-volt limit.

310. Table Showing Relative Economies of Conductors of Different Sizes.

(This table applies only to the first example in paragraph 308)

	No. 6 wire	No. 4 wire	250,000 c. m.	300,000 c. m.	400,000 c. m.	500,000 c. m.	600,000 c. m.	700,000 c. m.
Cost of 400 ft. of conductor	$16.80	$22.50	$102.40	$118.40	$150.40	$184.00	$218.20	$248.00
Interest on above cost at 5 per cent.	$0.84	$1.13	$5.12	$5.92	$7.52	$9.20	$10.91	$12.40
Cost of energy lost in conductor at 8 cents per kw-hr.	$101.64	$66.00	$10.56	$8.84	$6.60	$5.28	$4.49	$3.96
Total annual cost of conductor	$102.48	$67.13	$15.68	$14.76	$14.12	$14.48	$15.40	$16.36

311. Table for Three-phase Transmission (*General Electric Co.*)

(Approximate distances over which 100 kw., three-phase current, can be transmitted with different sizes of wires at different voltages, assuming an energy loss of 10 per cent. and a power factor of 85 per cent.)

American or B. & S.	Area in circular mils	Distance of transmission for various voltages at receiving end—miles				
		2,000 v	3,000 v	4,000 v	5,000 v	6,000 v
6	26,250	1.32	2.98	5.28	8.27	11.92
5	33,100	1.66	3.75	6.64	10.40	15.00
4	41,740	2.10	4.74	8.40	13.15	18.96
3	52,630	2.54	5.96	10.16	16.55	23.84
2	66,370	3.33	7.51	13.32	20.85	30.04
1	83,690	4.21	9.48	16.84	26.32	37.92
0	105,500	5.29	11.92	21.16	33.10	47.68
00	133,100	6.71	15.11	26.84	41.97	60.44
000	167,800	8.45	19.04	33.80	52.85	76.16
0000	211,600	10.62	23.92	42.48	66.42	95.68
	250 000	12.58	28.33	50.32	78.67	113.32
	500,000	25.17	56.66	100.68	157.35	226.64

Example.—What size wire is required to deliver 500 kw. at 6,000 volts a distance of 12 miles; energy loss, 10 per cent.; power factor, 85 per cent.?

Solution.—To transmit 100 kw. one would look in the 6,000-volt column for value nearest to 12 miles and use size of wire corresponding. To transmit five times this power or 500 kw., find the value corresponding most closely to $5 \times 12 = 60$ miles in the 6,000-volt column. Nearest value is 60.44 miles, which corresponds to No. 00 wire. No. 00 is the size required. To ascertain wire size to give a 5 per cent. loss—one-half the loss for which table is computed—multiply the distance of transmission by 2 before finding wire size.

SECTION II

GENERATORS AND MOTORS

PRINCIPLES, CHARACTERISTICS AND MANAGEMENT OF DIRECT-CURRENT MOTORS AND GENERATORS

1. **Direct-current generators** develop a direct or continuous e.m.f., that is, one that is always in the same direction. Commercial direct-current generators have commutators and may thereby be distinguished from alternating-current machines. The function of the commutator and the elementary ideas of generation of e.m.f. and of commutation are discussed in the First Section. See Index. Additional information in regard to commutation as applied to direct-current motors, which is in general true for direct-current generators, is given hereinafter.

2. **Excitation of Generator Fields.**—To generate an e.m.f. conductors must cut a magnetic field which in commercial machines must be relatively strong. A permanent magnet can be used for producing such a field in a generator of small output, such as a telephone magneto or a generator for sparking for an automobile; but for generators for light and power the field is produced by electro-magnets, which may be excited by the machine itself or "separately excited" from another source.

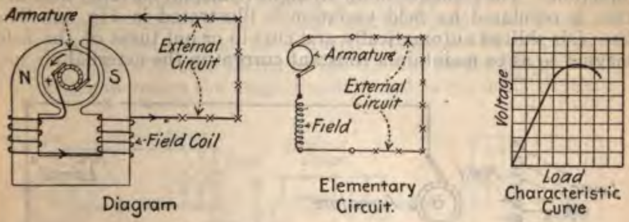


FIG. 1.—Series generator diagrams.

3. **Series-wound or constant-current generators** have their armature coils, field coils and external circuits in series with one another. (See Fig. 1.) Series generators are now used commercially only for series arc-lighting circuits and are equipped with automatic regulators to maintain the current constant irrespective of the resistance of the external circuit, *i.e.*, the number of lamps in service. The same current passes through each lamp in the series and the generator. The voltage at the brushes of a series machine is equal to (neglecting a small line loss) the voltage per lamp times the number of lamps. Thus on a circuit of 100 lamps each *requiring 50 volts* the brush pressure would be $100 \times 50 = 5{,}000$ *volts.* As shown by the curve of Fig. 1 up to a certain *maximum value with an increase in load*—resistance in this case—*the voltage of the* generator increases, tending to keep the current

constant. Automatic regulation to maintain constant current is usually effected, commercially, by either shifting the brushes or by cutting in and out portions of the field winding or by a combination of the two methods.

In Fig. 2 are shown the essentials of an arrangement for regulation by brush shifting. The course of the main current is indicated by the heavy line. When the current is at normal value the *contactor* is held midway between the contacts C_1 and C_2 by the spring. If the current increases slightly the core is pulled down into *solenoid* and brings the *contactor* with it, which makes contact with C_2. This permits a small current in shunt with the solenoid to flow through the *clutch B*, the mechanical details of which are not shown. This *clutch* pulls the *shifting rod* down and so shifts the brushes as to tend to maintain the current at a constant value. A decrease in current allows the spring to pull the *contactor* against C_1; *clutch A* operates and the brushes are shifted in the opposite direction. The principle of an arc-light (constant current) machine that is regulated by field variation is illustrated in Fig. 3. The *lever L* is shifted automatically and cuts in or out turns of the field magnet so as to maintain a constant current in the external circuit.

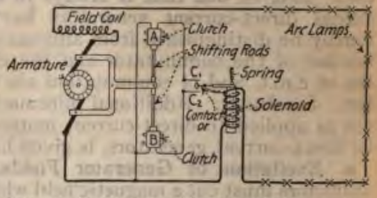


FIG. 2.—Essentials of brush-shifting mechanism for a constant-current generator.

FIG. 3.—Regulation of an arc-lamp machine by field variation.

4. Separately excited generators are used for electro-plating and for other electrolytic work where it is essential that the polarity of a machine be not reversed. Self-excited machines may change their polarities. The essential diagrams are shown in Fig. 4. The fields may be excited from any direct-current constant potential source, such as a storage battery or lighting circuit. The field magnets can be wound for any voltage because they have no electrical connection with the armature. With a *constant field excitation*, the voltage will drop slightly from no-load to *full-load* because of armature drop and armature reaction.

5. **The shunt-wound generator** is shown diagrammatically in Fig. 5. Shunt generators are now seldom used. They have been superseded by compound-wound machines. A small part of the total current, the exciting current, is shunted through the fields. The exciting current varies from possibly 5 per cent. of the total current in small machines to 1 per cent. in large ones. The exciting current is determined by the voltage at the brushes and

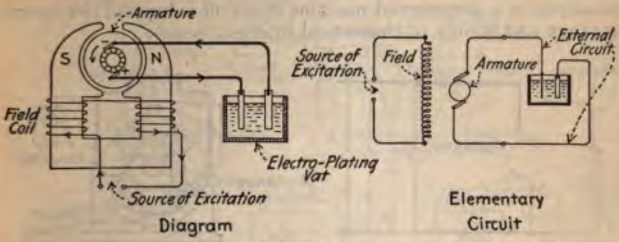


FIG. 4.—Separately excited generator diagrams.

the resistance of the field winding. Residual magnetism in the field cores permits a shunt-generator to "build up." This small amount of magnetism that is retained in the field cores induces a voltage in the armature (Timbie's *Elements of Electricity*). This voltage sends a slight current through the field coils which increases the magnetization. Thus, the induced voltage in the armature is increased. This in turn increases the current in the fields, which still further increases the magnetization, and so on, until the saturation point and normal voltage of the machine are reached. This "building up" action is the same for any self-excited generator and often requires 20 to 30 sec.

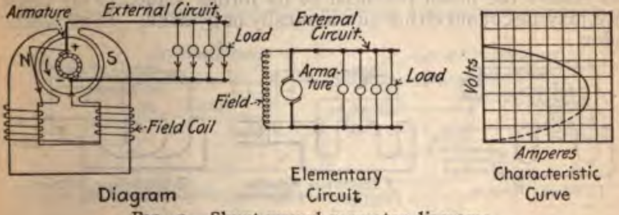


FIG. 5.—Shunt-wound generator diagrams.

If a shunt generator (Timbie) runs at constant speed, as more and more current is drawn from the generator, the voltage across the brushes falls slightly. This fall is due to the fact that it requires more and more of the generated voltage to force this increasing current through the windings of the armature. That is, the armature *IR* drop increases. This leaves a smaller part of the total e.m.f. for brush e.m.f., and then when the brush pressure falls, there is a slight decrease in the field current which is determined by the brush pressure. This causes the total e.m.f. to drop a little, which still further lowers the brush potential. These two causes combine to gradually lower the brush pressure (voltage) especially at heavy overloads. The curve in Fig. 5 shows these characteristics. For small loads the curve is nearly horizontal, but at heavy overloads it shows a decided drop. The point where the output of a commercial machine drops off is beyond the operating range and is only of theoretical interest.

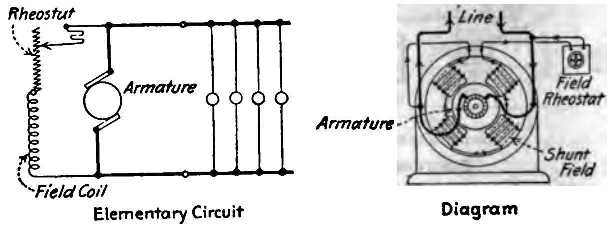


FIG. 6.—Shunt-wound generator with rheostat.

The voltage of a shunt machine may be kept fairly constant by providing extra resistance in the field circuit, see Fig. 6, which may be cut out as the brush potential falls. This will allow more current to flow through the field coils and increase the number of magnetic lines set up in the magnetic circuit. If the speed is kept constant, the armature conductors cut through the stronger magnetic field at the same speed, and thus induce a greater e.m.f. and restore the brush potential to its former value. This resistance may be cut out either automatically or by hand. See *Rheostat*, Index.

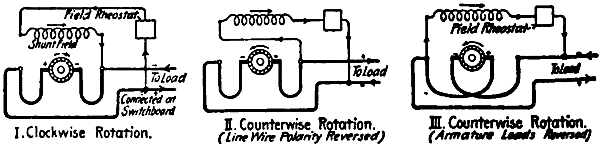


FIG. 7.—Changing rotation direction of shunt machine.

6. A shunt-wound generator gives a fairly constant voltage, even with varying loads, and can be used for incandescent lighting and other constant potential loads. These generators do not operate well in parallel, partially because the voltage of one machine may rise above that of the others and it will run them as motors. *Shunt generators* running in parallel do not "divide the load" well between themselves. They are seldom installed now, as compound-wound generators are more satisfactory for most purposes. *Shunt generators* may be bipolar (two poles) or multipolar (mo than two poles) similarly to compound-wound generators. See the following paragraphs.

7. How to reverse the direction of rotation of a shunt-wound machine is indicated in Fig. 7. Rotation is *clockwise* when, facing the commutator end of a machine, the rotation is in the direction

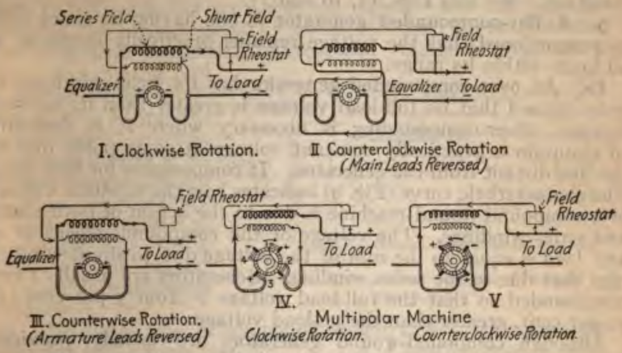


Fig. 8.—Changing rotation direction of compound machine.

of the hands of a clock. *Counter-clockwise* rotation is the reverse. It is desirable, when changing the direction of rotation, not to reverse the direction of current through the field windings. If it is reversed the magnetism developed by the windings on starting will oppose the residual magnetism and the machine may not "build-up." Connections for reversing compound machines are

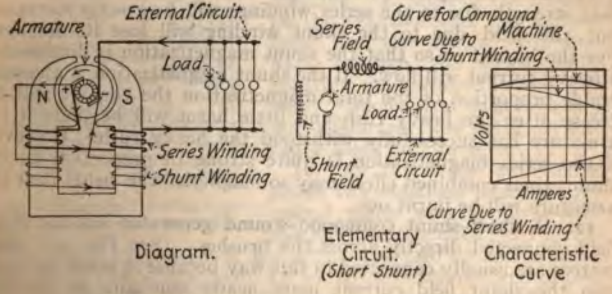


Fig. 9.—Compound-wound generator diagrams.

shown in Fig. 8. A multipolar machine can be reversed as shown *by reversing the brushes on the studs and then re-locating them in the neutral points.*

8. **The compound-wound generator** is shown diagrammatical *Fig. 9. If* a series winding be added to a shunt genera

(Fig. 5), the two windings will tend to maintain a constant voltage as the load increases. The magnetization due to the series windings increases as the line current increases, which will cause the voltage generated by the armature to rise. The drop of voltage at the brushes that occurs in a shunt generator is thus compensated for. See also Figs. 15, 16 and 17.

9. **A flat-compounded generator** is one having its series coils so proportioned that the voltage remains practically constant at all loads within its range.

10. **An over-compounded generator** has its series windings so proportioned that its full-load voltage is greater than its no-load voltage. Over-compounding is necessary where it is desirable to maintain a practically constant voltage at some point out on the line distant from the generator. It compensates for line drop. The characteristic curve (Fig. 9) indicates how the terminal voltage of a compound-wound machine is due to the action of both shunt and series windings. The voltage of the compound generator at any load is equal to the sum of the voltage due to shunt winding plus that due to the series winding. Generators are usually over-compounded so that the full-load voltage is from 5 per cent. to 10 per cent. greater than the no-load voltage.

Although compound-wound generators are usually provided with a field rheostat, it is not intended for regulating voltage as the rheostat of a shunt-wound machine is. It is provided to permit of initial adjustment of voltage and to compensate for changes of the resistance of the shunt winding caused by heating. With a compound-wound generator, the voltage having been once adjusted, the series coils automatically strengthen the magnetic field as the load increases. For direct-current power and lighting work, compound-wound generators are used almost universally.

11. **If a compound-wound generator is short-circuited** the field strength due to the series windings will be greatly increased, but the field due to the shunt winding will lose its strength. For the instant or so that the shunt magnetization is diminishing a heavy current will flow. If the shunt magnetization is a considerable proportion of the total magnetization the current will decrease after the heavy rush and little harm will be done if the armature has successfully withstood the heavy rush. However, if the series magnetization is quite strong in proportion to the shunt, their combined effect may so magnetize the fields that the armature will be burnt out.

12. **A short-shunt compound-wound generator** has its shunt field connected directly across the brushes. (See Fig. 9.) Generators are usually connected in this way because it tends to maintain the shunt field current more nearly constant on variable loads, as the drop in the series winding does not directly affect the voltage on the shunt field with this arrangement.

13. **A long shunt generator** has its shunt field winding connected across the terminals of the generator. (See Fig. 10.)

14. ***Three-wire* direct-current generators** are discussed, as *regards their application* to three-wire systems, in the first section. *See index.* They are ordinary direct-current generators with the tions and additions described below. They are usually or 125–250 volt three-wire circuits. In commercial three- ıerators (*Westinghouse Electric & Manufacturing Co.*) four ınt taps are made in the armature winding, and each pair diametrically opposite each other is connected together a balance coil. (See Fig. 11.) The middle points of the two coils (see Index) are connected together and this junction tes the neutral point to which the third or neutral wire ;ystem is connected. A constant voltage is maintained the neutral and vires which, within imits, is one-half nerator voltage. erator shaft is ex- t the commutator he collector rings. lector brushes and ılders are used in to the regular ırrent brushes and ılders.

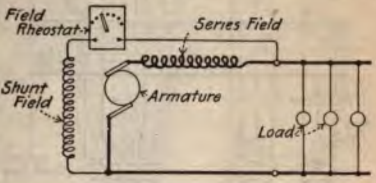
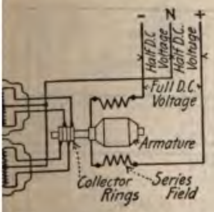


FIG. 10.—Long-shunt compound-wound generator.

The series coils of compound-wound three-wire generators ded into halves (see Fig. 12), one of which is connected to tive and one to the negative side. This is done to obtain nding on either side of the system when operating on an ced load. To understand this, consider a generator with s field in the negative side only and with most of the load positive side of the system. The current flows from the brush through the load and back along the neutral wire passing through the series field. The generator is then operating as an ordinary shunt machine. If most of the load be on the negative side, the current flows out the neutral wire and back through the series fields, boosting the voltage (on that side only). Such operation is evidently not satisfactory, and so the divided series fields are provided.



—Diagram showing con- for three-wire generator.

16. As there are two series fields, two equalizer buses are required when several three-wire machines are installed (see Fig. 12) to be operated in multiple. The two equalizers serve ibute the load equally between the machines and to pre- ıss currents due to differences in voltage on the different ırs. Because of the equalizer connections, two small l boards are supplied, one for each side of the generator. ment is also made for ammeter shunts on the terminal

ımeter shunt is mounted directly on each of the contact *the machine.* The total current output of the machine can thereby be read at the switchboard. As the shunts are at the machine, there is no chance for current to leak across between generator switchboard leads without causing a reading on the ammeters. Two ammeters must be provided for reading the current in the outside wires. It is important that the current be measured on both sides of the system, for with an ammeter in one side of the system only, it is possible for a large unmeasured current to flow in the other side with disastrous results.

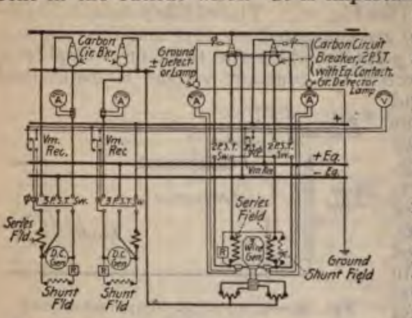


FIG. 12.—One three-wire direct-current generator, 125–250 volts, in parallel with two two-wire generators, 125 volts. Diagram of connections.

17. Wires connecting the balance coils to a three-wire generator must be short and of low resistance. Any considerable resistance in these will affect the voltage regulation. The unbalanced current flows along these connections; consequently, if they have much resistance, the resulting drop in voltage reduces the voltage on the heavily loaded side.

Switches are ordinarily not placed in the circuits connecting the four collector rings to the balance coils. When necessary, the coils may be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance-coil connections to the switchboard and back, requiring heavy leads to keep the drop low; or if heavy leads are not used, then poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them that will not be taken care of by the main circuit breakers. *Complete switchboard connection diagrams are given in Figs.* 12, 13 and 14.

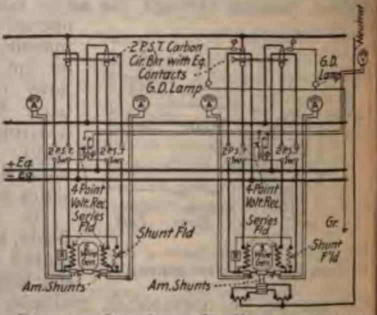
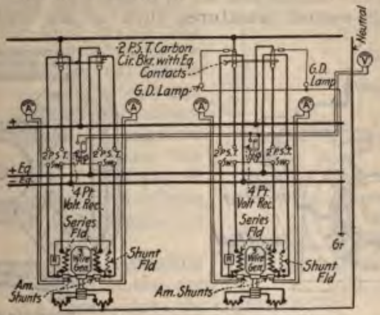


FIG. 13.—One three-wire direct-current generator, 125–250 volts, in parallel with one two-wire generator, 250 volts. Diagram of connections.

To Start a **Shunt-wound Generator.**—Note the directions concerning the oiling arrangements and bringing the machin... need. (1) See that the machine is entirely disconnec...

ɪm the external circuit. This is not always necessary, but is 'est. See that the field resistance is all in circuit. (2) Start the nature turning. (3) When the armature is up to speed, cut t field resistance until the voltage of the machine is normal or ual to that on the bus-bars. (4) Close the line switch, watching e ammeter and voltmeter and make further adjustment with e field rheostat if necessary.



. 14.—Diagram of connections of two three-wire direct-current generators operating in parallel, 125–250 volts.

19. Approximate Data on Standard, Compound-wound, Direct-current, Commutating-pole Generators

The efficiency of a generator depends on its design, and, to a tain extent, on its speed and voltage. Average values are en in the following table that are fairly representative of modern ctice.

Kilowatts capacity	Output current, amperes			Efficiency, per cent.		
	125 volts	250 volts	500 volts	½ load	¾ load	Full-load
5	40	20	10	77.0	81.0	82.5
10	80	40	20	82.0	85.0	86.0
15	120	60	30	82.5	86.5	86.5
20	160	80	40	84.0	86.5	87.5
25	200	100	50	85.0	88.0	89.0
35	280	140	70	87.0	89.0	89.5
50	400	200	835	88.0	89.5	90.5
60	480	240	120	88.5	90.5	91.0
75	600	300	150	88.5	90.5	91.0
90	720	360	180	88.5	90.5	91.0
100	800	400	200	89.0	90.5	91.0
125	1,000	500	250	90.5	91.0	91.0
150	1,200	600	300	90.5	91.3	91.5
200	1,600	800	400	91.0	91.5	92.0
300	2,400	1,200	600	91.3	91.8	92.0
400	3,200	1,600	800	91.8	92.3	92.5
500	4,000	2,000	1,000	91.8	92.2	92.5
750	6,000	3,000	1,500	92.0	92.3	92.5
000	8,000	4,000	2,000	92.5	93.0	93.5

20. Nearly all commercial direct-current generators have mo than two poles. In some of the preceding diagrams only tw were shown so that the diagrams would be simple. A two-pol machine is a bipolar machine; one having more than two poles a multipolar machine. Fig. 15 shows the connections and th direction of the magnetic flux of a four-pole machine. Diagram for machines having more poles would be similar. In multipola machines there is usually one set of brushes for each pair of pole but with series-wound armatures, such as are used for railwa

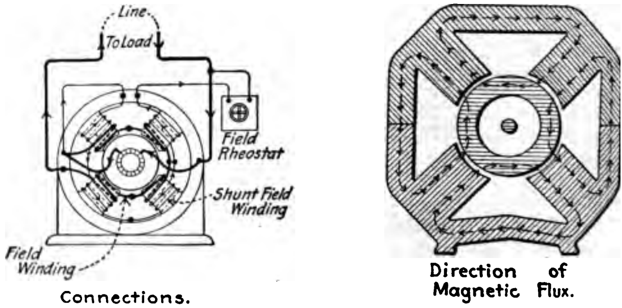


FIG. 15.—Diagrams for four-pole compound-wound generator.

motors, one set of brushes may suffice for a multipolar machine The connections of different makes of machines vary in detail an the manufacturers will always furnish complete diagrams so n attempt will be made to give them here. The directions of th field windings on generator frames are given in Fig. 16. Th directions of the windings on machines having more than fou poles are similar in general to those of the four-pole machines.

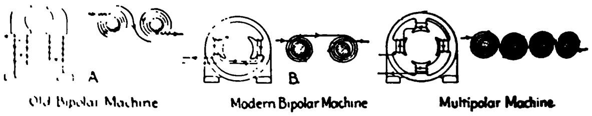


FIG. 16.—Direction of field windings on generator frames.

21. **To Start a Compound-wound Generator.**—(1) See that ther is enough oil in the bearings, that the oil rings are working, and tha all field resistance is cut in. (2) Start the prime mover slowly and permit it to come up to speed. See that the oil rings are working. (3) When machine is up to normal speed, cut out field resistanc until voltage of the machine is normal or equal to or a trifle abov that on the bus-bars. (4) Throw on the load. If three separat switches are used, as in Fig. 17, close the equalizer switch first, th *series coil line* switch second, and the other line switch third. If a *three-pole* switch is used, as in Fig. 18, all three poles are cl

ourse, closed at the same time. (5) Watch the voltmeter and mmeter and adjust the field rheostat until the machine takes its hare of the load. A machine generating the higher voltage will ake more than its share of the load and if its voltage is too high will run the other as a motor.

22. To Shut Down a Compound-wound Generator Operting in Parallel with Others.—) Reduce the load as much as ossible by throwing in resistance ith the field rheostat. (2) Throw f the load by opening the ciriit-breaker, if one is used, otherise open the main generator witches. (3) Shut down the riving machine. (4) Wipe off l oil and dirt, clean the machine nd put it in good order for the ext run.

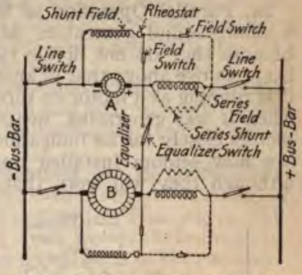


FIG. 17.—Elementary connections for parallel operation of compound-wound generators.

If the machine is operating idependently and no motors are onnected to the circuit, close the engine throttle valve and permit he engine and generator to come to rest. Turn all resistance in he field rheostat. Open the main switch. Where motors are erved they must be disconnected first. If they are not, a loaded

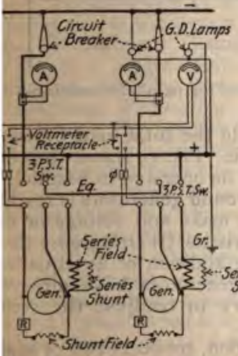


FIG. 18.—Diagram of conections of two compoundound generators to switchoard (Westinghouse).

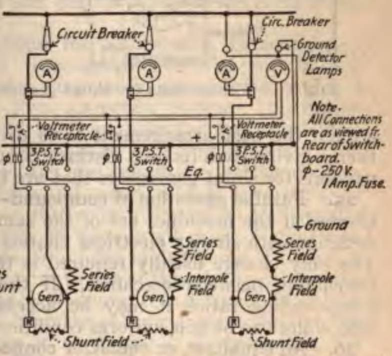


FIG. 18A.—Diagram of connections of two direct-current commutating-pole generators in parallel with one generator without commutating poles.

notor may stop when the impressed voltage decreases somewhat elow normal. Then, since its armature is not turning, it is in ect a short-circuit and may blow fuses or make other trouble.

3. To Shut Down a Shunt-wound Generator.—(1) Reduc load as much as possible by throwing in resistance with field rheostat. (2) Throw off the load by opening the circuit-breaker, if one is used, otherwise open the feeder switches and finally the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine and put it in good order for the next run.

24. **Parallel Operation of Shunt Generators.**—As suggested in 6 shunt-wound generators do not operate very well in parallel because they do not divide the load well and the voltage of one is apt to rise above that of another and drive it as a motor. When it is running as a motor its direction of rotation will be the same as when it was generating, hence the operator must watch the ammeters closely for an indication of this trouble. Shunt generators are now seldom installed and are seldom operated in parallel, although they will work that way. Where there are several in

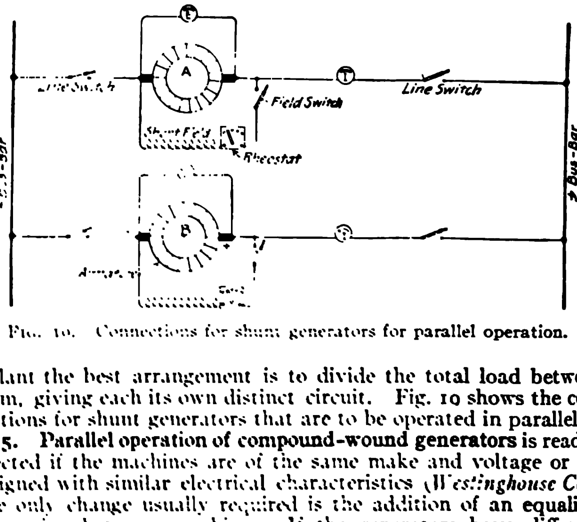


FIG. 10. Connections for shunt generators for parallel operation.

a plant the best arrangement is to divide the total load between them, giving each its own distinct circuit. Fig. 10 shows the connections for shunt generators that are to be operated in parallel.

25. **Parallel operation of compound-wound generators** is readily effected if the machines are of the same make and voltage or are designed with similar electrical characteristics (*Westinghouse Co.*). The only change usually required is the addition of an equalizer connection between machines. If the generators have different compounding ratios it may be necessary to readjust the series field shunts to obtain uniform conditions.

26. **An equalizer, or equalizer connection,** connects two or more generators operating in parallel at a point where the armature and series field leads join (see Fig. 17), thus connecting the armatures in multiple and the series coils in multiple, in order that the load will divide between the generators in proportion to their capacities. The arrangement of connections to a switchboard (*Westinghouse*) is shown in Fig. 18. Consider, for example, two compound-wound machines operating in parallel without an equalizer. If, for some reason, there is a slight increase in the speed of one machine, it would take more than its share of load. The increased current

flowing through its series field would strengthen the magnetism, raise the voltage, and cause the machine to carry a still greater amount until it carried the entire load. Where equalizers are used, the current flowing through each series coil is proportional to the resistance of the series coil circuit and is independent of the load on any machine; consequently an increase of voltage on one machine builds up the voltage of the other at the same time, so that the first machine cannot take all the load but will continue to share it in proper proportion with the other generators.

27. **Operation of a shunt and a compound dynamo in parallel** is not successful because the compound machine will take more than its share of the load unless the shunt machine field rheostat is adjusted at each change in load.

28. **Three-wire direct-current generators can be operated in multiple** (*Westinghouse Publication*) with each other and in multiple with other machines on the three-wire system (see Figs. 12, 13 and 14). When operating a three-wire, 250-volt generator in multiple with two-wire, 125-volt generators, the series fields of the two two-wire generators must be connected, one in the positive side and one in the negative side of the system, and an equalizer must be run to each machine. Similarly, when operating a three-wire, 250-volt generator in multiple with a 250-volt, two-wire generator, the series field of the 250-volt, two-wire generator must be divided and one-half connected to each outside wire. The method of doing this is to disconnect the connectors between the series field coils and reconnect these coils so that all the *N* pole fields will be in series on one side of the three-wire system and all the *S* pole fields in series on the other side of the system.

29. **Switchboard Connections for Three-wire Generators.**—Fig. 12 is a diagrammatical representation of the switchboard connections for two three-wire generators operated in multiple (*Westinghouse Publication*). Two ammeters indicate the unbalanced load. The positive lead and equalizer are controlled by a double-pole circuit-breaker; the negative lead and equalizer likewise. Note that both the positive and negative equalizer connections as well as both the positive and negative leads are run to the circuit-breakers in addition to the main switches on the switchboard. It is necessary that this be done in all cases. Otherwise, when two or more machines are running in multiple and the breaker comes out, opening the main circuit to one of them but not breaking its equalizer leads, its ammeter is left connected to the equalizer busbars and current is fed into it from the other machines through the equalizer leads, either driving it as a motor or destroying the armature winding. (See also Figs. 13 and 14.)

30. **Commutating-pole machines will run in multiple** with each other and with non-commutating-pole machines provided correct connections are made. See illustrations. The series field windings on commutating-pole machines are usually less powerful than on non-commutating-pole; and particular attention should, therefore, be paid to getting the proper drop in accordance with instructions of 32. *A connection diagram* is shown in Fig. 18, *A*.

31. ***Testing for Polarity.***—When a machine that is to operate

in parallel with others is connected to the bus-bars for the first time it should be tested for polarity. The + lead of the machine should connect to the + bus-bar and the − lead to the − bus-bar (Fig. 20, *I*). The machine to be tested should be brought up to normal voltage, but not connected to the bars. The test can be made with two lamps (Fig. 20, *II*), each lamp of the voltage of the circuit. Each is temporarily connected between a machine terminal and bus terminal of the main switch. If the lamps do not burn, the polarity of the new machine is correct, but if they burn brightly its polarity is incorrect and should be reversed. A voltmeter can be used (Fig. 20, *III*). A temporary connection is

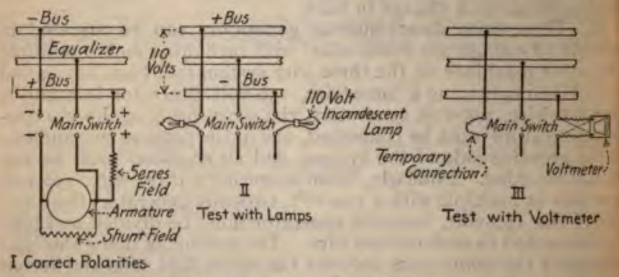


FIG. 20.—Tests for polarity.

made across one pair of outside terminals and the voltmeter is connected across the other pair. No or a small deflection indicates correct polarity. (Test with voltmeter leads one way and then reverse them, as indicated by the dotted lines.) A full-scale deflection indicates incorrect polarity. Use a voltmeter having a voltage range equal to twice the voltage on the bus-bars.

32. **To adjust the division of load between two compound-wound generators:** First adjust the series shunts of both machines so that, as nearly as possible, the voltages of both will be the same at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full-load. Then connect the machines in parallel, as suggested in Fig. 17, for trial. If upon loading, one machine takes more than its share of the load (amperes), increase the resistance of the path through its series-field coil path until the load ...es between the machines proportionally to their capacities. ... a small increase in resistance is usually needed. The increase ... be provided by inserting a longer conductor between the ...tor and the bus-bar, or iron or German-silver washers can be ...d under a connection lug. Inasmuch as (when machines ...nected in parallel) adjustment of the series coil shunt affects ...chines similarly, nothing can be accomplished through ...h adjustment.

...s **shunt for a compound generator** consists of a ...nnection across the terminals of the series field ...3) by means of which the compounding effect of the series winding may be regulated by shunting more or less of the armature current past the series coils. It may be in the form of grids, on large machines, or of ribbon resistors. In the latter case it is usually insulated and folded into small compass.

34. Connecting Leads for Compound Generators.—See that all the cables that lead from the various machines to the bus-bars are of equal resistance. This means that if the machines are at different distances from the switchboard, different sizes of wire should be used, or resistance inserted in the low-resistance leads. See **32.**

With generators of small capacity the equalizer is usually carried to the switchboard, as suggested in Fig. 18A, but with larger ones it is carried under the floor directly between the machines (Fig. 21). In some installations the positive and the equalizer switch of each machine are mounted side by side on a pedestal near the generator (Fig. 21). The difference in potential between the two switches is only that due to the small drop in the series coil. The positive bus-bar is carried along under the floor near the machines. This permits of leads of minimum length. Leads of equal lengths should be used for generators of equal capacities. If the capacities are unequal (see **32**) it may be necessary to loop the leads. (See Fig. 21.)

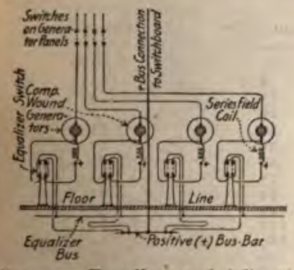


FIG. 21.—Equalizer carried directly between machines.

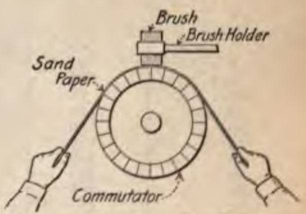


FIG. 22.—Sandpapering brushes.

35. Ammeters for compound generators should, as in Fig. 18, always be inserted in the lead not containing the compound winding. If cut in the compound winding lead the current indications will be inaccurate because current from this side of the machine can flow either through the equalizer or the compound-winding lead.

36. Brushes, their Adjustment and Care (*Westinghouse Instruction Book*).—The position of the brushes on a direct-current machine should be on or near the no-load neutral point of the commutator. This neutral point on most standard, non-commutating pole machines is in line with the center of the pole and the brushes should be set a little in advance of this neutral point. The brushes of non-commutating pole generators should be given a slight "forward lead" in the direction of rotation of the armature. Motor brushes should be set somewhat back of the neutral point, the "*backward lead*" in this case being approximately equal to the forward lead on generators. The exact position in either case is that which gives the best commutation at normal voltage for all loads. In no case should the brushes be set far enough from the neutral point to cause dangerous sparking at no-load.

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing faces. This can be most easily accomplished after the brush holders have been adjusted and the brushes inserted as follows: Lift a set of brushes sufficiently to permit a sheet of sandpaper to be inserted. Draw the sand-paper in one direction only, preferably in the direction of rotation, under the brushes (Fig. 22) being careful to keep the ends of the paper as close to the commutator surface as possible and thus avoid rounding the edges of the brushes, each set of brushes being similarly treated in turn. Start with coarse sand paper and finish with fine sand paper. If the brushes are copper plated, their edges should be slightly beveled, so that the copper does not contact with the commutator.

37. Current Taken by Direct-current Motors

Horse-power	Total amperes		
	110 volts	220 volts	500 volts
1	9	4.5	2.0
2	17	8.5	3.7
3	26	13	5.6
5	40	20	8.8
7.5	60	30	13
10	76	38	17
15	112	56	25
20	150	75	33
25	188	94	41
30	226	113	50
40	302	151	66
50	368	184	81
75	552	276	122
100	736	368	162
150	1,110	555	244
200	1,474	737	324

38. Commutating-pole Generators and Motors, Fig. 23 (*Standard Handbook*).—The principal advantage of the commutating pole construction resides in the fact that with it the commutation can be rendered practically perfect under any condition of service.

39. The object in using the commutating-pole is to produce within the armature coil under commutation an e.m.f. of the proper value and sign to reverse the current in the coil while it is yet under the brush—a result that is essential to perfect commutation. The variation in the flux distribution in the air-gap of a commercial direct-current machine of the ordinary shunt-wound type, at no-load and under full-load, is shown in Fig. 24. Consider now the value and position of the flux in the coil under the brush when the ...ine is operating at full-load. The motion of the armature ...h *this flux causes* the generation within the coil of an e.m.f., ...*sign of this* e.m.f. is such as t· tend to cause the current ...*l to continue* in the direction which it had before the coil reached the brush, and hence it opposes the desired reversal of the current before the coil leaves the brush.

There is an additional detrimental influence which tends to retard the rapid reversal of the current even when all other influences are absent. This latter influence is due to the local magnetizing effect of the current in the coil under the brush. On account of this there

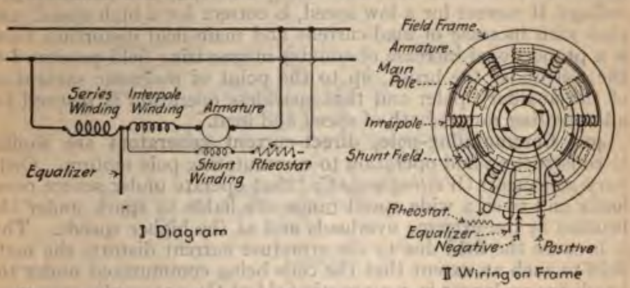


Fig. 23.—Diagram of compound-wound commutating-pole machines.

surround the conductor lines of force, the change in the value of which, with the fluctuations of the current as it tends to be reversed, generates in the coil an e.m.f. which opposes the change in the value of the current. This reactive e.m.f. is in the same direction as that due to the cutting of the flux by the coil under the brush and is likewise proportional to the speed.

It will be apparent that even were the field distortion completely neutralized, the detrimental reactive e.m.f. would yet remain.

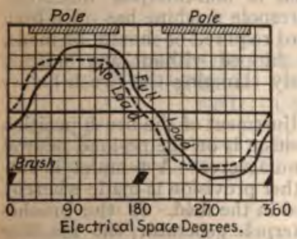


Fig. 24.—Distribution of magnetic flux at no load and at full load, without commutating poles.

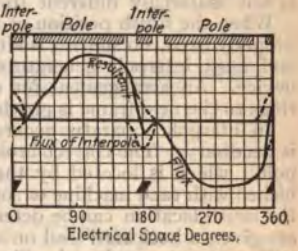


Fig. 25.—Distribution of magnetic flux at full load, with and without commutating poles.

The improved and practically perfect commutation of the commutating-pole motor is due to the fact that the flux, which is locally superposed upon the main field, not only counterbalances the undesirable *main flux cut by* the coil under the brush, but it causes *to be generated within the* coil an e.m.f. sufficient to equal and *oppose the reactive* e.m.f. just referred to. This effect will b appreciated from a study of Fig. 25, which represents the distorted flux of the motor of the usual design, as shown in Fig. 24, and indicates the results to be expected when the flux due to the auxiliary or commutating pole is given the relatively proper value.

It is worthy of note that this desirable effect is the more pronounced the weaker the main field; and that the commutation voltage, if correct for a low speed, is correct for a high speed; and that with increase of load-current and main-field distortion there is a proportional increase of counter-magnetizing field produced in the coil under the brush, up to the point of magnetic saturation of the auxiliary pole; and that sparkless operation is insured for all operating ranges both of speed and load.

40. **Commutating-pole, direct-current generators** are similar in construction and operation to commutating-pole motors. Ordinary generators (*Westinghouse Co.*) that operate under severe overloads and over a wide speed range are liable to spark under the brushes at the extreme overloads and at the higher speeds. This is because the field due to the armature current distorts the main field to such an extent that the coils being commutated under the brush are no longer in a magnetic field of the proper direction and strength. To overcome this, interpoles are placed between the main poles. (See Fig. 23.) These interpoles introduce a magnetic field of such direction and strength as to maintain the magnetic field, at the point where the coils are commutated, at the proper strength for perfect commutation. Commutating-poles are sometimes called interpoles but probably "*commutating-pole*" is the preferable term.

The winding in the interpoles is connected in series with the armature so that the strength of the corrective field is proportional to the load. The adjustment and operation of interpole generators is not materially different from that of non-interpole machines. When the brush position of an interpole machine has once been properly fixed, no shifting is afterward required or should be made, and most interpole generators are shipped without any shifting device. An arrangement for securely clamping the brush-holder rings to the field frame is provided.

In interpole apparatus accurate adjustment of the brush position is necessary. The correct brush position is on the no-load neutral point, which is located by the manufacturer. A templet is furnished with each machine or some other provision is made whereby the brush location can be determined in the field. If the brushes are given a backward lead on an interpole generator, the machine will over-compound and will not commutate properly. With a forward lead of the brushes, a generator will under-compound and will not commutate properly.

41. **The action of the magnetic flux in a commutating-pole generator** is illustrated in Fig. 26. The direction of the main field flux is shown by the dashed line. The direction of the armature magnetization is shown by the dotted lines. The direction of the flux in the interpole is shown by the full line. It is evident that the interpole flux is in a direction opposite to that of the armature flux, and as the interpole coil is more powerful in its magnetizing

action than the armature coils, the flux of the armature coils is neutralized. With a less powerful magnetizing force from the interpole than from the armature, the armature would overpower the interpole and reverse the direction of the flux, which would result in a very bad commutating condition.

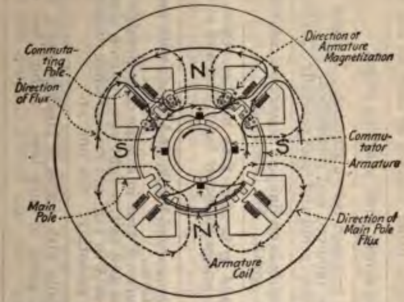


FIG. 26.—Distribution of flux in a commutating-pole generator.

42. **Commutating-pole, Three-wire Generators.**—On three-wire generators connections are so made that one-half of the interpole winding is in the positive side and the other half is in the negative side. This insures proper action of the interpoles at unbalanced load. (See Figs. 12, 13 and 14 and the text accompanying them.)

43. **To reverse the direction of rotation of a commutating-pole generator,** reverse the shunt and series fields as in an ordinary generator.

TROUBLES OF DIRECT-CURRENT MOTORS AND GENERATORS—THEIR LOCALIZATION AND CORRECTION

Table No. 44.—Pages 174 to 184 inclusive—troubles of direct-current motors and generators.

44. Direct-current Generator and Motor Defects

(From *Machinery* by special permission)

Sparking at the brushes.	Faults of	Brushes.	Not set diametrically opposite.	*A*. Should have been set properly at first, by counting bars, or by measurement on the commutator. *B*. Can be done if necessary while running; move rocker until brush on one side sparks least, then adjust other brushes so they do not spark.	1
			Not set at neutral points.	Move rocker back and forth slowly until sparking stops.	2
			Not properly trimmed.	*A*. Brushes should be properly trimmed before starting. If there are two or more brushes one may be removed and retrimmed. *B*. Clean with alcohol or ether, then grind and reset carefully. *See* lines 1, 4, 38.	3
			Not in line.	Adjust each brush until bearing is on line and square on commutator bar, bearing evenly the whole width. *See* line 13 *A*.	4
			Not in good contact.	*A*. Clean commutator of oil and grit. See that brushes touch. *B*. Adjust tension screws and springs to secure light, firm and even contact. *See* line 38 *C*.	5
		Commutator.	Rough; worn in grooves or ridges; out of round.	*A*. Grind with fine sandpaper on curved block, and polish with crocus cloth. Never use emery in any form. *B*. If too bad to grind down turn off true in a lathe or preferably in its own bearings, with a light tool and rest, a light cut; running slowly. *Note*.—Armature should have $\frac{1}{16}$ to $\frac{1}{8}$ in. end motion when running, to wear commutator evenly and smoothly. *See* line 31.	6 7
			High bars.	Set "high bar" down carefully with mallet or block of wood, then clamp tightly end nuts, or file, grind or turn true. A high bar may cause singing. *See* line 38.	8
			Low bars.	Grind or turn commutator true to the surface of the low bars.	9
			Weak magnetic field.	*A*. Broken circuit } in field coils { Repair if external. *B*. Short circuit } in field coils { Rewind if internal. *C*. Machine not properly wound, or without proper amount of iron—no remedy but to rebuild it.	10

Sparking at the brushes.	Excessive current in armature.	Genera[l]	Ground and leak from short-circuit on line.	B. Test out, locate, and repair.	
			Dead-short circuit on line.	C. *Note.*—Dead short-circuit will or should blow safety fuse. Shut down, locate fault and repair before starting again, and put in a new fuse.	
		Motor.	Excessive voltage.	D. Use proper current only, and with proper rheostat and controller and switch.	
			Excessive amperes on constant-current circuit.	E. See that controller, etc., are suitable with ample resistance.	
			Friction.	F. Reduce load on motor to its rated capacity or less. *See* 3 *B* and 35, 36.	
			Too great load on pulley.	G. See that there is no undue friction or mechanical resistance anywhere.	
	Armature faults.	Short-circuited coils.		A. Remove copper dust, solder or other metallic contact between commutator bars. B. See that clamping rings are perfectly free, and insulated from commutator bars; no copper dust, carbonized oil, etc., to cause an electrical leak. C. Test for cross connection or short-circuit, and if such is found rewind armature to correct. D. See that brush holders are perfectly insulated. No copper dust, carbon dust, oil or dust, to cause an electrical leak. *See* lines 1, 2, 60.	12
		Broken coils.		A. Bridge the break temporarily by staggering the brushes, until machine can be shut down (to save bad sparking) and then repair. B. Shut down machine if possible, and repair loose or broken connection to commutator bar. C. If coil is broken inside, rewinding is the only sure remedy. May be temporarily repaired by connecting to next coil, across mica. D. Solder commutator lugs together, or put in a "jumper," and cut out, and leave open the broken coil. Be careful not to short-circuit a good coil in doing this. *See* line 12.	13
		Cross connections.		Cross connections may have same effect as short-circuit, treat as such, *see* line 12. Each coil should test complete without cross and no ground.	14

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts.	Armature.	Overloaded.		Overload. Too many amperes, lights, or too much power being taken from machine. *See* 11, 12, 13, 14.	15
		Short-circuit.		Short-circuited. Generally dirt, etc., at commutator bars. *See* 11,12,13,14.	16
		Broken circuit.		Broken circuit. Often caused by a loose or broken band. *See* 11,12,13,14.	17
		Cross connection.		Cross connection. Often caused by a loose coil abrading on another coil or core. *See* 11, 12, 13, 14.	18
		Moisture in coils.		Dry out by gentle heat. May be done by sending a small current through, or causing machine to generate a small current itself, by running slowly.	19
		Eddy currents in core.		Iron of armature hotter than coils after a run. Faulty construction. Core should be made of finely laminated insulated sheets. No remedy but to rebuild.	20
		Friction.		Hot boxes or journals may affect armature. *See* 23, 33 below.	21
	Field coils.	Excessive current.	Shunt.	*A.* Decrease voltage at terminals by reducing speed . Increase field resistance by winding on more wire, finer wire, or putting resistance in series with fields.	22
			Series.	*B.* Decrease current through fields by shunt, removing some of field winding or rewind with coarser wire.	
				Note.—Excessive current may be from a short circuit, or from moisture in coils, causing a leakage. *See* 10, 24.	
		Eddy currents.		Pole pieces hotter than coils after short run, due to faulty construction, or fluctuating current, if latter, regulate, and steady current.	23
		Moisture in coils.		Coils show less than normal resistance, may cause short circuit or body contact to iron of dynamo. Dry out as in 19. *See also* 22 *note*.	24
	Bearings.	Not sufficient or poor oil.		*A.* See that plenty of good mineral oil, filtered clean, and free from grit, feeds; but be careful that it does not get on commutator or brush holder. *See* 12. *B.* Cylinder oil or vaseline may be used if necessary to complete run, mixed with sulphur or white lead, or hydrate of potash. Then clean up and put in good order.	25

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts.	Bearings.	Dirt or grit in bearings.	*A.* Wash out grit with oil while running, then clean up and put in order. Be careful about flooding commutator and brush holder. *B.* Remove caps and clean and polish journals and bearings perfectly, then replace. See that all parts are free and lubricate well. *C.* When shut down, if hot, then remove bearings and let them cool naturally, then clean, scrape and polish, assemble; see that all parts are free and lubricate well.	26
		Rough journals or bearings.	Smooth and polish in a lathe, removing all burrs, scratches, tool marks, etc., and rebabbitt old boxes and fit new ones.	27
		Journals too tight in bearings; bent shaft.	Slacken cap bolts, put in liners and retighten till run is over, then scrape, ream, etc., as may be needed, bend or turn true in lathe or grinder. Possibly a new box or shaft will be needed.	28 29
		Bearings out of line.	Loosen bearing bolts, line up and block, until armature is in center of pole pieces, ream out dowel and bolt holes and secure in new position.	30
		End pressure of pulley hub or shaft collars.	*A.* See that foundation is level and armature has free end motion. *B.* If there is no end motion, file or turn ends of boxes or shoulders on shaft to provide end motion. *C.* Then line up shaft and belt, so that there is no end thrust on shaft, but that the armature plays freely endways when running.	31
		Belt too tight.	*A.* Reduce load so that belt may be loosened and yet not slip. Avoid vertical belts if possible. *B.* Choose larger pulleys, wider and longer belts with slack side on top. Vibrating and flapping belts cause winking lamps.	32
		Armature out of center of pole pieces.	*A.* Bearings may be worn out and need replacing, throwing armature out of center. *See* 36. *B.* Center armature in polar space, and adjust bearings to suit. *See* 30. *C.* File out polar space to give equal space all round. *D.* Spring pole away from armature; this may be difficult or impossible in large machines.	33

Direct-current Generator and Motor Defects (*Continued*)

		Defect	Remedy	No.
Noises.		Armature or pulley out of balance.	Faulty construction, armature and pulley should have been balanced when made. May be helped by balancing on knife edges now.	34
		Armature strikes or rubs pole pieces.	*A*. Bend or press down any projecting wires, and secure with tie bands. *B*. File out pole pieces where armature strikes. *See* 30, 33.	35
		Collars or shoulders on shaft strike or rub box.	Bearings may be loose or worn out. Perhaps new bearings are needed. *See* 30, 31.	36
		Loose bolt connection or screws.	See that all bolts and screws are tight, and examine daily to keep them so.	37
		Brushes sing or hiss.	*A*. Apply stearic acid (adamantine) candle, vaseline, or cylinder oil to commutator and wipe off; only a trace should be applied. *B*. Move brushes in and out of holder to get a firm, smooth, gentle pressure, free from hum or buzz. *See* 3, 6, 7, 8, 9, 31.	38
		Flapping of belt.	Use an endless belt if possible, if a laced belt must be used, have square ends neatly laced.	39
		Slipping of belt from overload.	Tighten belt or reduce load. *See* 32.	40
		Humming of armature lugs or teeth.	*A*. Slope end of pole piece so that armature does not pass edges all at once. *B*. Decrease magnetism of field, or increase magnetic capacity of tooth.	41
Speed.	Runs too fast.	Engine fails to regulate with varying load.	Adjust governor of engine to regulate properly, from no-load to full-load, or get a better engine.	42
		Series motor, too much current, and runs away.	*A*. Series motor on constant current—(1) Put in a shunt and regulate to proper current; (2) use regulator or governor to control magnetism of field for varying load. *B*. Series motor on constant potential—(1) Insert resistance and reduce current; (2) use a proper regulator or controlling switch; (3) change to automatic speed-regulating motor.	43

Direct-current Generator and Motor Defects (*Continued*)

Speed.	Runs too fast.	Shunt motor.	Field rheostat not properly set.	*A.* Adjust field rheostat to control motor.	44
			Not proper current.	*B.* Use current of proper voltage and no other, with a proper rheostat.	
			Motor not properly proportioned.	*C.* Get a better motor, one properly designed for the work.	
	Runs too slow.	*See note below table.*		45, same as 42; 46, *see* 11 *A*; 47, short circuit in armature, *see* 12; 48 rubbing armature, *see* 35; 49, friction, *see* 3 *B*; 50, weak magnetic field, *see* 10.	
Motor.	Stop or fail to start.		Great overload. *See* 11 *F* and *G*.	Open switch, find and repair trouble. Keep switch open and rheostat "off" to see if everything is right.	51
			Excessive friction. *See* 25, 33, 35.	Shunt motor on constant potential circuit, fuse may blow or armature burn out.	52
		Circuit open.	Fuse melted or switch open.	*A.* Find and repair trouble after opening switch, then put in fuse. *See* 11 *C*.	53
			Broken wire or connection.	*B.* Open switch, find and repair trouble. *See* 13.	
			Brushes not in contact.	*C.* Open switch and adjust. *See* 5.	
			Current fails or is shut off at station.	*D.* Open switch and return starting box lever to off position, wait for current.	
			Short-circuit of field.	Test for and repair if possible. Examine insulation of binding posts and brush holders.	54
			Short-circuit of armature. Short-circuit of switch.	Poor insulation, dirt, oil, and copper, or carbon dust often result in a short-circuit.	56
	Runs backward. Wrong connections.			Connect up correctly per diagram; if no diagram is at hand, reverse connections to brushes or others until direction of rotation is satisfactory.	57

Note from line 50.—45, Engine fails to regulate. 46, Overload. 47, Short-circuit in armature. 48, Striking or rubbing of armature. 49, Friction. 50, Weak magnetic field.

Direct-current Generator and Motor Defects (*Continued*)

Dynamo or generator.	*Reversed residual magnetism.*	Reversed current through field coils. Reversed connections. Earth's magnetism. Proximity of another dynamo. Brushes not in right position. *See* 1, 2, 3.	*A.* Use current from another machine or a battery through field in proper direction to correct fault. Test polarity with a compass. *B.* If connections or winding are not known, try one way and test; if not correct reverse connections, try again and test. *C.* Connect up per diagram for desired rotation, see that connections to shunt and series coils are properly made. *See* 57. *D.* Shift brushes until they operate better. *See* 1, 2, 3.	58
	Too weak residual magnetism.		Same as 58 *A.*	59
	Short-circuit in machine.		*See* 12, 54, 56.	60
	Short-circuit in external circuit.		A lamp socket, etc., may be short-circuited or grounded, and prevent building up shunt or compound machines. Find and remedy before closing switch. *See* 54, 56.	61
	Field coils opposed to each other.		Reverse connections of one of field coils and test. Find polarity with compass; if necessary try 58 *A, C, D.* If necessary reverse connections and recharge in opposite directions.	62
	Open circuit.	Broken wire. Faulty connections. Brushes not in contact. Safety fuses melted or broken. Switch open. External circuit open.	*A.* Search out and repair. *See* 13. *B.* Search out and repair. *See* 37. *C.* Search out and repair. *See* 5. *D.* Search out and repair. *See* 53 *A.* *E.* Search out and repair. *See* 53 *D.* *F.* Search out and repair with dynamo switch open until repairs are completed.	63
	Too great load on dynamo.		Reduce load to pilot lamp on shunt and incandescent machines; after voltage is obtained close switches in succession slowly, and regulate voltage. *See* 11 *A* and 65.	64
	Too great resistance in field rheostat.		Bring up to voltage gradually with rheostat, and watch pilot lamp; regulate carefully.	65

45. Troubles of Direct-current Motors.—Much of the material under this heading is based on that in the book *Motor Troubles* by E. B. Raymond. For more-complete information relating to direct-current-motor-and-generator troubles, see the author's ELECTRICAL MACHINERY, published by the McGraw-Hill Book Company.

46. Measurement of the insulation resistance of generators will give an indication of the average condition of the insulation as regards moisture and dirt, but will not always detect weak spots (*Westinghouse Co.*). The higher the resistance, the better the general condition of the insulating material. The approximate figure of one megohm per thousand volts of rated e.m.f. when the machine is at its normal full-load temperature may be taken as indicating a fairly satisfactory condition of the armature insulation. The insulation resistance of the field will be much higher in proportion to the e.m.f. of the exciting current and will seldom give appreciable trouble. Since large armatures have much greater areas of insulation, their insulation resistance will be proportionally lower than that of small machines. Even though the material is in exactly the same condition, the insulation resistance of any machine will be much lower when hot than when cool, especially when the machine is rapidly heated.

The only feasible method of increasing the insulation resistance after the machine has been completed by its manufacturer is by "drying out." Armature winding and field coils are dried by heat;

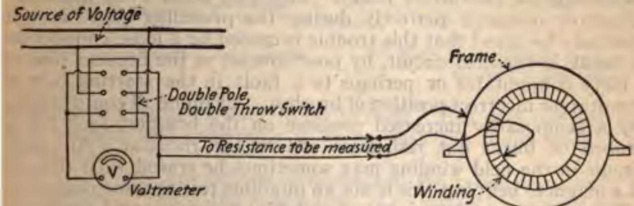


FIG. 27.—Measuring generator insulation resistance.

baking in an oven is to be preferred, but is often impracticable. They are usually heated by the passage of current. For an armature this may be done by short-circuiting the leads and running the generator with a low field charge, just sufficient to produce the proper current. (See **47**.)

Insulation resistance may be conveniently measured with a high-resistance voltmeter specially designed for the purpose as directed in the first section (see Index). Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified. A double-pole switch arranged as indicated in Fig. 27 is convenient for changing the voltmeter connections. If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

47. Drying Out a Generator or Motor.—If a generator has been exposed to dampness, before being started in regular service it should be operated with its armature short-circuited beyond the ammeters and with the field current adjusted so as to raise temperature to about 70 deg. cent. The current should then be lowered and raised by means of the field adjustment until the coils become thoroughly dry. The temperature should not be allowed to drop to that of the surrounding atmosphere, as the moisture would then again be condensed on the coils, and the machine brought to the same condition as at the start.

There is always danger of overheating the windings of a machine when drying them with current, as the inner parts, which cannot quickly dissipate the heat generated in them and which cannot be examined, may get dangerously hot, while the more exposed and more easily cooled portions are still at a comparatively moderate temperature. The temperature of the hottest part accessible should always be observed while the machine is being dried out in this way, and should not be allowed to exceed the boiling-point of water. It may require several hours or even days to thoroughly dry out a machine, especially if it is of large capacity. Large field coils dry very slowly. Insulation is more easily injured by overheating when damp than when dry.

48. When starting up, a generator may fail to excite itself (*Westinghouse Instruction Book*). This may occur even when the generator operated perfectly during the preceding run. It will generally be found that this trouble is caused by a loose connection or break in the field circuit, by poor contact at the brushes due to a dirty commutator or perhaps to a fault in the starting box or rheostat, or incorrect position of brushes. Examine all connections; try a temporarily increased pressure on the brushes; look for a broken or burnt out resistance coil in the rheostat. An open circuit in the field winding may sometimes be traced with the aid of a magneto bell; but this is not an infallible test as some magnetos will not ring through a circuit of such high resistance and reactance even though it be intact. If no open circuit is found in the starting box or in the field winding, the trouble is probably in the armature. But if it be found that nothing is wrong with the connections or the winding it may be necessary to excite the field from another generator or some other outside source.

Calling the generator we desire to excite No. 1, and the other machine from which current is to be taken No. 2, the following procedure should be followed. Open all switches and remove all brushes from generator No. 1; connect the positive brush holder of generator No. 1 with the positive brush holder of generator No. 2; also connect the negative holders of the machines together (it is desirable to complete the circuit through a switch having a fuse of about 5 amp. capacity in series). Close the switch. Where the generator in trouble connects to bus-bars fed by other generators, the same result can be effected by insulating the brushes of the machine in trouble from their commutator and closing the main switch. (See Fig. 28.) If the shunt winding of generator No. 1 is all right, its field will show considerable magnetism. If possible, reduce the voltage of generator No. 2 before opening the exciting circuit; then break the connections. If this cannot be done, throw in all the rheostat resistance of generator No. 1; then open the switch very slowly, lengthening out the arc which will be formed until it breaks.

A simple means for getting a compound-wound machine to pick up is to short-circuit it through a fuse having approximately the current capacity of the generator. (See Fig. 29.) If sufficient current to melt this fuse is not generated, it is evident that there is something wrong with the armature, either a short-circuit or an open circuit. If, however, the fuse has blown, make one more

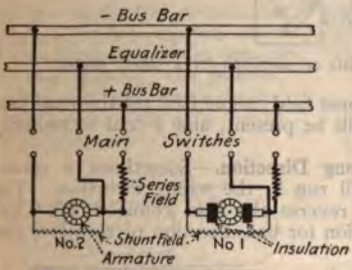


FIG. 28.—Exciting a generator.

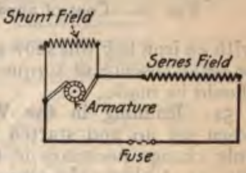


FIG. 29.—Another method of exciting a generator.

attempt to get the machine to excite itself. If it does not pick up, it is evident that something is wrong with the shunt winding or connections.

If a new machine refuses to excite and the connections seem to be all right, reverse the connections, *i.e.*, connect the wire which leads from the positive brush to the negative brush and the wire which leads from the negative brush to the positive brush. If this change of connections does no good, change back and locate the fault as previously suggested.

49. **The proper connections for a shunt motor** are as shown in Fig. 30. The field *B* is connected as shown, so that when the switch *D* is closed it becomes excited before the armature circuit through the switch *E* is closed. Thus when the motor armature has current admitted to it through switch *E* and starting resistance-box *A*, the field is already on, and the full torque of the motor is obtained. The torque of a motor is equal to the product of flux per pole, the ampere turns on the armature, and the number of poles. Hence, if the full field is not on the motor at starting, full torque will not be obtained.

50. **If a motor will not start when the starting-box is operated** *and when current is flowing in the armature, an investigation should be made to see if* the field flux is on, which can be done by

holding a piece of iron, such as a key, against the pole-piece. If the flux exists the key will be drawn strongly against the pole-piece; if there is no flux there will be practically no attraction.

51. Reversed Field-spool Connection.—There may be cases where the manufacturer has shipped a motor with one or more field spools reversed. If such is the case no torque, or, perhaps, very weak torque, will be noticed. Under such conditions a trial

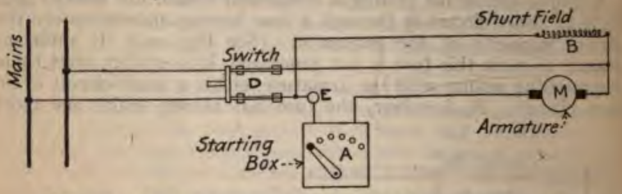


FIG. 30.—Control apparatus connections for a shunt motor.

with an iron key will show proper field magnetism, yet the weakness or total absence of torque will be present, and a trial of polarity should be made.

52. Running in the Wrong Direction.—Sometimes a motor when set up and started will run in the wrong direction. The only change necessary is to reverse the field connection. Thus Fig. 31, *I*, shows the connection for one direction of rotation and

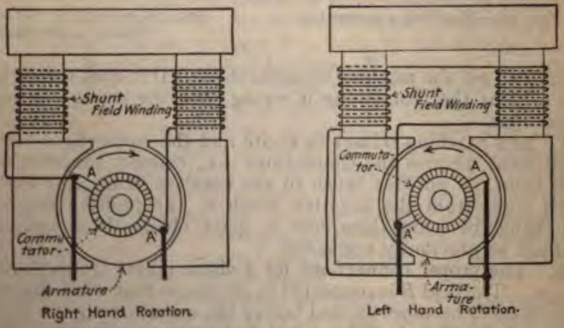


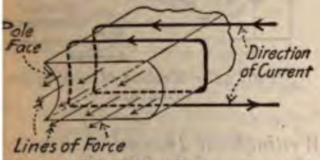
FIG. 31.—Connections for shunt-wound motors.

Fig. 31, *II*, that for the other. Note that in Fig. 31, *I*, the brushes *A* and A^1 are shifted backward against the direction of rotation. For the opposite rotation, a backward lead, as shown in Fig. 31, *II*, must be chosen.

53. Testing Polarity of Field.—This can be done in two ways: *First, by using* a compass, bringing it near the various poles and *'ing the direction* of the deflection of the needle. Since in all *'rs the poles* alternate in magnetic polarity, in one pole the agnetism coming out and the next going in, it follows that a rtain end of a compass needle will point toward one pole and ray from the next when conditions are normal. If, however, two ljacent poles show similar magnetism, the trouble is located, id the offending spool should be reversed. This should be done end for end," not by turning on the axis. The latter operation es not change the direction of magnetism, while the former does. irection of magnetism is determined by the following rule:

"Looking at the face of an electromagnet (such as the field spool a motor), a pole will be north if the current is flowing around it a direction opposite to the motion of the hands of a watch," ig. 32, and south if in the same direction as the motion of the ands of a watch. (See also the rules outlined in Sect. I of this ook.)

Another method of determining whether the magnetism of the oles is correct is to use two ordinary nails, their lengths depending pon the distance between pole-tips. The point of one nail should uch one pole-tip, the point of e other nail the other pole-tip, nd the heads of the nails should uch each other.



IG. 32.—Direction of magnetism and current about a pole.

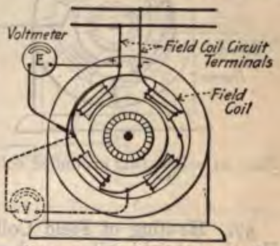


FIG. 33.—Locating field-coil troubles.

When the current flows around the field spools, the polarity etween any two poles is properly related if the nails placed as uggested stick together by the magnetism. If there is no tendency o stick, the polarity of the two poles is alike and therefore wrong.

54. **Open Field Circuit.**—If, on closing the field switch, no nagnetism is obtained by trial with an iron key, as suggested bove, there is an open circuit within one of the spools or in the rires leading to these spools. The open circuit can be located by utting out one spool at a time and allowing current to flow through he rest until the defective spool is discovered. On a two-pole notor try first one spool and then the other. For a very short ime, say, 10 min., double voltage can be carried on a spool.)n a motor having four or more poles, three spools can always be eft in circuit during the open-circuit investigations.

55. **A method of locating an open-circuited field coil** is illustrated n Fig. 33. Connect one terminal of the voltmeter to one side of he field-coil circuit and with the bared end of a wire or a contactor, uccessively *touch the junctions* of the field-coil leads around the ame. *When the open coil is bridged the voltmeter will show a l deflection.* Another way: Connect the field-coil circuit ter-

minals to a source of voltage. Connect the voltmeter successive across each coil as indicated by the dotted lines in Fig. 33. The will be no deflection on the voltmeter until the open coil is bridge when the full voltage of the circuit will be indicated.

56. A grounded field coil can be located (Fig. 34) by connecti a source of voltage to the machine terminals having first raised th brushes from the commutator, if it is a direct-current machin Connect one terminal of the voltmeter to the frame and the oth to a lead with a bared end. Tap with the bared end expos parts of the field circuit. The voltmeter deflection will be leas near the grounded coil.

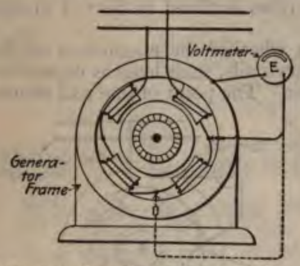


FIG. 34.—Locating grounded coil.

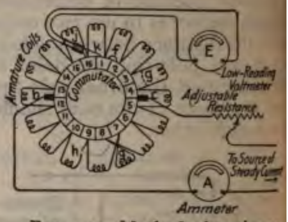


FIG. 35.—Method of testing an armature.

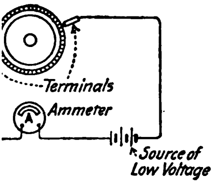
57. Heating of Field Coils (*Westinghouse Instruction Book*).— Heating of field coils may develop from any of the following causes (a) Too low speed; (b) too high voltage; (c) too great for ward or backward lead of brushes; (d) partial short-circuit o one coil; (e) overload.

58. Direct-current armatures can be tested for the commo troubles with the arrangement of Fig. 35. Terminals *b* and are clamped to the commutator at opposite sides and connecte with a source of steady current through an adjustable resistanc and an ammeter. The terminals of a low-reading voltmeter (galvanometer can often be used) are connected to two bare meta points, which are separated by an insulating block, *j*. In use, th current is adjusted to produce a convenient deflection of the volt meter when each of the points rests on an adjacent bar. Th points are moved around the commutator and bridged across th insulation between every two bars. If the voltmeter deflection i the same for every pair of bars it indicates that there is no troubl in the armature.

59. Sparking Due to Open Armature Circuit.—A cause of *sparking* commutator is an open circuit in the winding, either i the armature body or, more often, where the lead from the armat winding is soldered to the commutator. In the latter case reso ing is a ready remedy. If, however, the location of the p open circuit cannot be found, the bars can be bridged over

or itself by fastening with solder, or otherwise, a strip around the segments which indicate the break.
ication of this trouble is very apparent, for, if an open sts, the long heavy spark which accompanies it soon the mica between the two segments which are on each e break. This shows positively where to bridge over. circuit also shows itself, when the machine is running, iousness of the spark. It is unlike any other kind of or sparking, being heavy, long, and destructive in its

poor connection between a bar and coil leads will cause able deflection of the voltmeter (Fig. 35) when one of rests on the bar in trouble and the other rests on either acent bars.
open-circuited coil, as *h*, Fig. 35, will prevent the urrent through its half of the armature. There will be ion on that half of the armature until the "open" is hen the voltage of the testing circuit will be indicated.



esting for armature open-it with an ammeter.

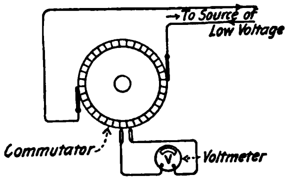


FIG. 37.—Testing for armature open-circuit with a voltmeter.

sts for Open Armature Circuits.—Another method (Fig. apply to the commutator, at two opposite points, a low ay from a battery or a dynamo with its voltage kept ce an ammeter in circuit and clean the surface of the or so that it is bright and smooth.
minal ends leading the current into and out of the com-hould be small, so that each rests only on a single seg-. 36). Note the ammeter reading and rotate the armature At the point where the open circuit exists the ammeter ll go to zero if the leads to the commutator bar have ntirely open-circuited. This is because the segment is to the winding through the commutator leads.
armature does not show the above symptoms, try con-low-reading voltmeter or a galvanometer to two adjacent while the current is passing through the armature as from some external low-voltage source (Fig. 37). Note tion. Pass from segment to segment in this manner, the *drop between the* successive pair of bars. This *he current is held* constant from the external source, *the same between* each pair of adjacent segments. If *ows a higher drop* than the others near it, a higher re-

sistance connection exists there, perhaps causing sparking biting of commutator insulation, to a less degree, to be sure, t with an actual open circuit, but enough, perhaps, to cause trouble requiring the investigation.

63. **The test for armature short-circuits,** described in preceding paragraph, is called a "bar to bar" test. It is n valuable in locating faults in armatures. It is the method to if a short-circuit from one segment to another is suspected. W the section in which the short-circuit, or partial short-circ exists comes under the contacts, a low or perhaps no deflec is shown on the galvanometer or voltmeter, thus locating the fective place. Such short-circuits, if they occur when runn owing to defective insulation, burn out the coil short-circui When the coil passes through the active field in front of the p piece, an immense current is induced in it, causing a destruc of the insulation. When this occurs the coil should be o circuited if the burning has not already short-circuited it. practical, it should be bridged over, as suggested in a prece paragraph.

64. **If two bars or a coil is short-circuited** as at *f* and *g* (35) respectively, there will be little or no voltmeter deflection w the two bars connecting to the "short-circuit" are bridged by points.

65. **A grounded armature coil** can be detected in the s manner as indicated in Fig. 34 for a field coil. Impress full age on the terminals clamped to the commutator. Ground side of the voltmeter on the shaft or spider and touch a connected to the other side to all the bars in succession. minimum deflection will obtain when the bars connecting to grounded coil are touched.

66. **Crossed coil leads** as at *g* (Fig. 35) are indicated by a t normal deflection when the points bridge the bars to which crossed coils should rightly connect. The crossing of the leads connects two coils in series, hence causes twice normal d Bridging the bars to which coil *h* connects will produce a no deflection, but it will be reversed in direction.

67. **Reversed Armature Coil.**—Instead of the armature w ing progressing uniformly around from bar to bar of the com tator, there may at some point be a coil connected in backw Such a reversed coil often causes bad sparking. One way to lo such a trouble is to pass through the armature, at opposite p on the commutator, a current. Then with a compass ex around the armature the direction of magnetism from slot to If a coil is reversed when the compass comes before it, the ne will reverse, giving a very definite indication of the improp connected coil.

68. **Heating of Armature** (*Westinghouse Instruction Book* Heating of the armature may develop from any of the follo causes: (a) Too great a load; (b) a partial short-circuit of two heating the two particular coils affected; (c) short-circuits grounds on armature or commutator.

69. **Hot Armature Coils.**—Sometimes when a new machi

tarted, local heating occurs in the armature, following the exact hape of the armature coil. This may be because, in receiving ts final turning off, the commutator bars were bridged with copper rom one segment to another by the action of the turning tool. n examination of the commutator surface will reveal this bridgng. When it is removed, satisfactory operation will ensue if the rouble has not gone too far and seriously injured the insulation f the coil.

70. Care of Commutators.—They should be kept smooth by he occasional use of No. 00 sandpaper. A small quantity of igh grade, light body oil should be used as a lubricant. The ubricant should be applied to high-voltage generators by aid of piece of cloth attached to the end of a dry stick. If the comnutator gets "out of true" it should be turned down. By using special slide rest and tool this can be done while running the ngine at a reduced speed without removing the rotating part rom the bearings. Inspect the commutator surface carefully o see that the copper has not been burned over from segment to egment in the mica and remove by a scraper any particles of coper which may be found embedded in the mica. Keep oil away rom the mica end-rings of the commutator as oily mica will soon urn out and ground the machine.

71. Process of Commutation and Correction of Glowing and Pitting.—The path of the current is as shown in Fig. 38. *A* is the arbon brush; *C*, *C'*, *C''* are the ommutator segments; *B*, *B'*, *B''* re the windings of the armature. At the position shown, coil *B* is hort-circuited by the carbon, the urrent passing into the face of he brush and out again as shown y the dotted line. This local urrent may be many times larger han the normal flow of current and is the one that causes pitting.

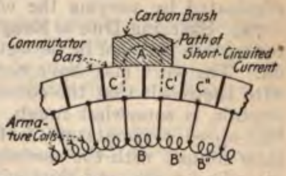


FIG. 38.—Armature coil short-circuited when commutating.

With perfect commutation, with no sparking or glowing, there should be created in the short-circuited coil under the brush, by means of the flux from that pole-tip away from which the armature s revolving, an electromotive force. This should be just large enough to reverse the current within the short-circuited coil and to render it equal to the current in the winding proper. Since on one side of the brush the current is in one direction and on the other side in the other direction, the act of commutation beneath the brush is to reverse this current and bring it up to the correct amount in the opposite direction.

With copper brushes this reversal of current must be very accurately effected. With carbon brushes there is a much smaller tendency to spark, hence they will stand a certain inexactness of commutation adjustment. Experiments indicate that the carbon can resist as much as 3 volts creating current in the wrong direction and still not spark or glow. This is the property that has aused the use of carbon brushes instead of copper on most apparatus. When, however, this potential, induced in the wron tion, rises above 3 volts during the passage of the armat underneath the brush, trouble from sparking and glowing o

This is the reason that, in a motor, the brushes are pulle ward as far as possible at no-load, so that the coil short-c by the brush may enter the fringe or flux from the pole-ti creating the proper reversal of current during the time th passing under the brush. Since adjacent poles are opp polarity, only one can provide the proper flux direction reversal. In a motor it is always the pole behind the bru thus the brush requires a backward lead. In a generator i pole ahead of the brush in the direction of rotation. Hen erators require a forward lead.

If the motor gives trouble from glowing and pitting, th is probably this induced current, and the remedy is, first, that the lead of the brushes brings them in the most satis position. If no change of lead or brush position can be which will eliminate the trouble, the width of the brush n changed. The wider the brush the longer does the coil suffe circuit, as described. Conversely the narrower the bru quicker must the current be reversed. There is, there width of brush which best satisfies both conditions.

Usually, however, where glowing occurs, the cause is too brush, and often serious trouble from this cause can be eliminated by varying the width of the brush perhaps on

72. Sparking Due to Rough Commutator.—First, the co tor surface may not be perfectly smooth after receiving its l off. The work may have been poorly done by the manuf with the result that the commutator surface, instead of be smooth, is somewhat rough. The result of this, especiall high-speed commutators, is that the brush does not mak class contact with the commutator surface. It may chatt attending noise, and thus with many motors (especially high voltage) the operation will be attended with sparking result, the commutator surface, instead of becoming brig smooth with time, becomes rough and dull or raw in app Under these conditions the brushes do not make good and, hence, the heat generated even under proper com conditions, owing to the resistance of brush contact, is m nes with consequent increase of temperature of t iddition, the friction of brush contact (whic nt of 0.2) is, with a rough commutator, muc be, which tends to increase the temperature.

g of commutator (*Westinghouse Instructio* from any of the following causes: (a) O the brushes; (c) too high brush pressure; n commutator.

nmutator.—All this (see above) trouble t is that finally the temperature will ler in the commutator will melt, perh ircuiting the winding. A comm rking, but where it is noticeabl

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... a motor the brushes are pulle
... so that the coil short-c
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... current during the time th
... adjacent poles are opp
... the proper flux direction
... always the pole behind the br
... forward lead. In a generator
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... the brush the longer does the coil suff
... the narrower the br
... be reversed. There is, ther
... both conditions.
... occurs, the cause is to
... from this cause can be
... width of the brush perhaps o

Sparking Due to Rough Commutator.—First, the co
... smooth after receiving its
... been poorly done by the manu
... the commutator surface, instead of b
... rough. The result of this, especia
... that the brush does not ma
... commutator surface. It may chat
... many motors (especially
... voltage the operation will be attended with sparkin
... the commutator surface, instead of becoming br
smooth ... becomes rough and dull or raw in app
Under these conditions the brushes do not make good
and, hence, the heat generated even under proper com
conditions, owing to the resistance of brush contact, is m
several times, with consequent increase of temperature of
mutator. In addition, the friction of brush contact (whic
give a coefficient of ... is, with a rough commutator, muc
than it should be, which tends to increase the temperature

73. **Heating of commutator** (*Westinghouse Instructio*
may develop from any of the following causes: (a) O
(b) sparking at the brushes; (c) too high brush pressure;
of lubrication on commutator.

74. **Hot Commutator.**—All this (see above) trouble i
lative. The result is that finally the temperature will r
point where the solder in the commutator will melt, perhap
circuiting or open-circuiting the winding. A commuta
stand very slight sparking, but where it is noticeable a

continued for long periods of time, trouble is liable to result. e the load is usually very light on a motor, and where full- or overload are infrequent, a smoothing of the commutator s during the light-load period which averts trouble. This reason that certain railway motors, which sometimes show ing under their normal hour rating load, give satisfaction as mmutation. The coasting of the car smooths up the imper- ble damage done by the sparking during the heavy load.

Loose Commutator Segments.—A further and more serious of sparking and commutator trouble is due to the fact that ommutator may not be "settled" when shipped by the manu- rer. A commutator is made of many parts (Fig. 39), insu-

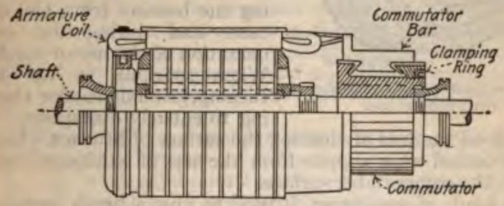


FIG. 39.—Section of direct-current motor armature.

one from another, and all bound together by mechanical ping arrangements. The segments themselves are held by a p-ring on each end, which must be insulated from them and h should hold each segment individually from any movement ive to another.

ice the clamp must touch and hold down all segments, a failure so in any case results in a loose bar, which moves relatively ie next bar and causes roughness and thus sparking, with all ttendant accumulative troubles. The roughness of commu- rs due to poor turning or to poor design is shown uniformly all the surface of the commutator on which brushes rest. ughness due to a high or loose bar is shown by local trouble the bad bar and its corresponding bars around the commu- r. The jump of the brush occurs at the high bar and is the se of the sparking. See also Pars. 77 and 78.

). **Blackening of the Commutator.**—Sparking due to a loose igh bar causes a local blackening instead of a uniform black- g, which occurs in case of poor design or poor commutator ace resulting from poor turning. Also, if the speed of the mutator is low enough, there will be a spark at the time the segment passes the brush. At ordinary speeds, or where e are several loose bars, the sparking in appearance will not different from that due to poor design or poor turning. In a case an examination of the commutator surface must be le to identify the cause.

must *be remembered* that the slightest movement of a bar, *cially with the higher* voltage and high-commutator-speed machines, may cause the trouble. A splendidly designed motor may show very poor operation, due to a commutator fault.

77. Correcting Commutator Roughness.—The proper way to correct a rough surface due to poor turning is to grind the surface with a piece of ordinary grindstone (Fig. 40). It should be cut to convenient size and held by the hand against the commutator. If possible it should be rounded out to the shape of the commutator, though the rounding is not absolutely necessary except when the surface is exceedingly irregular. A commutator can be ground on low-voltage machines without removing the brushes from the commutator and during the ordinary operation of the motor under load. When sparking is due to poor turning, grinding causes the sparking to entirely disappear. This is also a good method of cleaning the surface of brushes which have become coated with copper from the use of sandpaper in fitting them to the commutator surface.

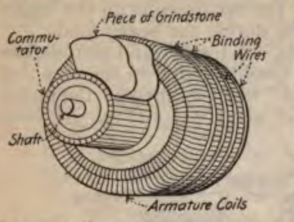


FIG. 40.—Smoothing commutator with grindstone.

Some kinds of sandpaper, if used to give a brush surface or to smooth a commutator with the brushes down, imbed in the face of the brush hard material which sticks there, cutting the commutator and thus collecting about itself copper from the commutator. An examination of the face of the brush after running a time will show these collections either in spots or all over the face of the brush. The sandstone, used as suggested, removes all this.

Where roughness and sparking are due to a loose bar, grinding will do no particular good. Then a different process for correction must be used. It consists first in tightening the clamp-rings which hold down the segments so that they touch and hold, each one preventing any relative movement of the bars. After this is done, produce a smooth surface by turning, if the bar is much displaced, or by grinding if it is but slightly displaced. The process of correcting a loose commutator therefore is as follows:

78. Loose Commutator. Clamp-rings.—First, draw the clamps of the commutator down firm, so that when the commutator is at normal temperature the clamping rings cannot be screwed down further without excessive effort. This is necessary so that all the bars may have a direct pressure from the clamp, rendering any movement, up or down, impossible. Second, after having drawn the clamps down, smooth off the surface of the commutator.

To get the clamps down firm run the motor; if roughness appears, shut down at a convenient time, and, while hot, tighten the clamping rings. If it is found that the tightening bolts can be screwed up somewhat, the machine should again be put in service for at least 4 hr., at the end of which time shut it down again and make another trial on the tightening bolts. If, now, no more can be taken up on the tightening bolts, the commutator should be surfaced, either by turning with a tool or by grinding. If the clamps are down tight and the surface of the commutator has been properly smoothed, there will be no further trouble.

79. The Slotting of Commutators (*Alan Bennett, American Machinist*, Sept. 26, 1912).—There seems to be a prevalent idea that slotting should cure all commutator troubles, irrespective of their causes. This is not true, but slotting is a cure for certain specific troubles. Where the peripheral speed of the commutator is so slow that the dirt which may collect in the slots between commutator bars will not be thrown out by centrifugal force, slotting may aggravate rather than correct commutation difficulties. See also 84.

80. The principal reason for slotting commutators is to relieve the commutators of high mica, that is, mica that projects above the surface. High mica is generally due to one of two causes: Either the mica is too hard and does not wear down at an equal rate with the copper, or the commutator does not hold the mica securely between the segments, allowing it to work out by the combined action of centrifugal force and the heating and cooling of the commutator.

It is evident that a commutator with a surface made irregular by projecting mica rotating at high speed under a brush, must impart to the brush a vibratory action, and thus impair the close contact that should exist between the brush and commutator. The result is that sparking takes place more or less violently, depending on the condition of the commutator surface and the rate of speed.

This condition generally manifests itself after the machine has been running for some time, and in many cases will account for the development of sparking which did not occur at the time of installation. Often a case of this kind is aggravated by increasing the brush tension, causing a still faster rate of wear of copper over mica, with an attendant increased heating of the commutator.

81. What is Accomplished by Slotting.—A harder brush may at times be used, with the idea of grinding off the mica and thus bringing it down to the commutator surface. Instead of curing the trouble, the commutator will, in the majority of cases, assume the raw appearance of being freshly sandpapered, instead of the glossy surface it should have, and both brush and commutator will wear rapidly.

This condition can be restored to normal and the commutator kept to a true surface by slotting, after which, with proper care and the use of proper brushes, commutator troubles will generally cease, provided the electrical design of the machine is not at fault. Even then there are cases that may be benefited to a certain extent by slotting, by reason of the good brush contact obtained. The majority of cases that show improvement are the ones in which the trouble is not inherent in the design of the machine, but is due to mechanical causes.

With a slotted commutator it is possible to use a brush of fine grain and soft texture, inasmuch as there is not the same tendency to wear away the brush as with an unslotted commutator. The commutator will then take on the much-desired polish that is generally not possible with the harder brush. The life of both brush and commutator will be increased, and friction and the consequent heating will be reduced. These advantages will effect a saving that will more than offset the cost of slotting.

82. Various Methods of Slotting.—There is a variety of slotting devices on the market. Some are designed to operate with the armature swung between the centers of a lathe; others use a special tool in a shaper, with the armature secured to its bed. Still others are used by hand with the armature resting on blocks. In all cases the full width of the mica should be removed, and the resulting slot carefully cleaned from burrs and rough edges. It is not necessary that the slotting be carried deeply in the commutator. One-sixteenth of an inch is generally considered sufficient. See also Par. **84.**

83. A slotted commutator should have proper and frequent care, as there is a chance of small particles of copper being dragged across from bar to bar, and for dirt, oil and carbon dust to accumulate in the slots and short-circuit the commutator.

84. High Mica in Commutators.—Some motors, under certain conditions, roughen up their commutators after a short term of service, although there seems to be no excessive sparking under or at the edges of the brushes. This may occur even though the commutator has been well "settled." The commutator acts as if the mica used between bars to insulate the various segments, one from another, had protruded upward, causing roughness and excessive sparking.

Actual raising of the mica is a very rare occurrence, and, if it occurs, does so at certain spots and is easily and positively identified. An actual uniform protruding of mica, all over a commutator, as described, is practically an unknown phenomenon. What actually does occur is an eating away of the copper surface of the commutator, leaving the high mica between the bars. A good machine will not spark enough to cause this condition. A poor machine will.

The phenomenon is easily identified, as the commutator surface looks raw all over instead of smooth and bright with a good brown gloss. If allowed to continue, a general roughness appears, accompanied by sparking, until finally the sparking and heating will increase so much that the machine may flash over from brush to brush, blowing the fuses or opening the circuit-breakers. The trouble is aggravated if the motor operates continuously under heavy load. If there are periods of light load, the commutator has an opportunity to be smoothed down by the brushes. This condition is appreciated by railway motor designers. A railway motor coasts a considerable portion of the time. Thus the commutator is smoothed, neutralizing the roughening occurring under load.

To remedy a roughened, high-mica commutator: (1) Use it on work where the load is somewhat intermittent; (2) replace it *altogether; or (3)* slot the commutator. Then, as there are no *[lo]nger two different* materials to wear down or to be worn away *[by] sparking,* an unequal surface will not result. The mica ne[ed] be cut down only $\frac{1}{16}$-in. and a narrow, sharp chisel will do the work satisfactorily. No trouble will result from short-circuiting in this case, since centrifugal force keeps the slots clean. Some manufacturers ship machines with slotted commutators.

85. Brush Troubles.—When there is an excessive drop in speed from no-load to full-load, the position of the brushes on the commutator should first be investigated as elsewhere suggested. No brush position that causes sparking should be chosen. The following paragraphs outline the more important brush troubles and their remedies.

86. Sparking of the brushes may be due to one of the following causes (*Westinghouse Instruction Book*). (See also Dynamo-defects Table.) (a) The machine may be overloaded; (b) the brushes may not be set exactly at the point of commutation—a position can always be found where there is no perceptible sparking, and at this point the brushes should be set and secured; (c) the brushes may be wedged in the holders; (d) the brushes may not be fitted to the circumference of the commutator; (e) the brushes may not bear on the commutator with sufficient pressure; (f) the brushes may be burnt on the ends; (g) the commutator may be rough; if so, it should be smoothed off; (h) a commutator bar may be loose or may project above the others; (i) the commutator may be dirty, oily or worn out; (j) the carbon in the brushes may be unsuitable; (k) the brushes may not be equally spaced around the periphery of the commutator; (l) some brushes may have extra pressure and may be taking more than their share of the current; (m) high mica; (n) vibration of the brushes.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator, and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken it will draw a bright spark as the break passes the brush position. This trouble can be readily located, as the insulation on each side of the disconnected bar will be more or less pitted. The commutator should run smoothly and true, with a dark, glossy surface.

87. Glowing and Pitting of Carbon Brushes.—This may be due to either of two causes, poor design or a wrong position of the brushes on the commutator. The error of design may be only in the choice of width of carbon brush used. The pitting is due to glowing. If the glowing is at the edge of the carbon it is plainly visible and easily located. It may, however, occur underneath the carbon so that only with difficulty can it be seen. Such glowing pits the carbon face by heat disintegration. With some machines three-fourths of the brush face may be eaten away and the pits may be, perhaps, $\frac{1}{4}$ in. to $\frac{1}{2}$ in. deep when discovered. A usual (incorrect) decision is that the current per sq. in. of contact is too great, the calculation being made by dividing *the line amp. by the sq. in. cross-section of either the positive or the negative brushes.* If this calculation gives a value under 45 or

50, it is certain that the cause of the trouble has not been judged correctly.

The real cause of the glowing is, to be sure, excessive current through the carbon, but this is not the line current if the calculation, as stated, shows a brush-face density below 50 amp. per square inch. It is a local current caused by the short-circuiting of two or more segments of the commutator by the brush resting upon them. The usual overlap of a carbon brush is about two segments, and while these two segments are under the brush, the armature coils connected to them are short-circuited. If the design of the machine is such that the coil so short-circuited encloses stray flux from the pole-tip, this flux will create in the short-circuited coil a current, perhaps many times larger than the brush is capable of carrying, with the result that the glowing and pitting occurs.

88. Chattering of brushes is sometimes experienced on direct-current machines. Chattering under certain conditions may become so prominent as to not only be of annoyance, but as to actually break the carbons. An examination of the commutator will reveal no roughness, the surface being, perhaps, perfectly smooth and bright. This trouble occurs principally with the type of brush holder which has a box guide for the carbon. The spring which forces the brush into contact rests on top of the carbon which has fairly free play in the box guide. Chattering usually occurs with high-speed commutators, running at 4,000 to 5,000 ft. per min., peripheral speed.

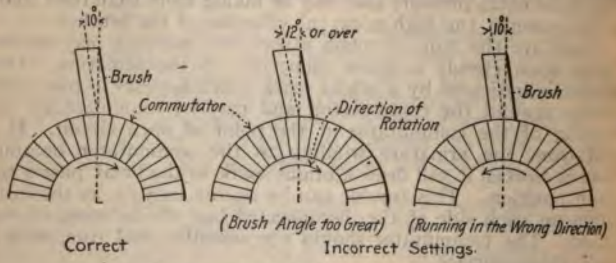


FIG. 41.—Methods of setting brushes.

Such brush holders are necessary on commutators which, like those on engine-driven machines, may run out of true on account of the shaft play in the bearings caused by the reciprocating motion of the engine. The clamped type of holder is usually free from bad chattering but rocks on a commutator that runs out, causing poor contact and perhaps sparking.

Lubricating the commutator causes the chattering to immediately disappear, but there is no commutator compound which gives a lubricating effect lasting over possibly a half hour. Thus it is not practical to lubricate often enough to prevent the chattering. *There will be no* chattering if the angle of the brush with the *radial line, passing* through the center of the carbon and the center of the commutator, is less than 10 deg. and if the carbon trails on the commutator instead of leads. Fig. 41, *I*, shows the setting which will stop all serious chattering and Fig. 41, *II* and *III*, show settings which may give trouble.

89. Low Speed.—The fault may be in the winding of the armature or field, in which case a remedy is a serious matter. On the other hand, considerable range of speed can be obtained by the choice of brush position on the commutator. Many motors will run without sparking with a range or brush shift on the commutator giving a range of speed of 15 per cent. Therefore, if the discrepancy of speed is within this amount, the brushes should be moved to counteract it. A backward shift of brush gives increased speed and a forward shift decreased speed. At any brush position, however, there must be practically no sparking. Sparking is a very serious matter, causing all sorts of trouble. A first-class motor should run at full-load within 4 per cent. (up or down) of the name-plate speed if the voltage is as specified on the name-plate. The speed at no-load should not be more than 5 per cent. higher than this, also the speed at full-load, hot, should not be over 5 per cent. greater than the speed at full-load, cold.

90. Bearing Troubles of Direct-current Motors and Generators.—See paragraphs under this same heading under "Troubles of Alternating-current Motors and Generators."

PRINCIPLES, CHARACTERISTICS AND MANAGEMENT OF ALTERNATING-CURRENT MOTORS AND GENERATORS

91. Alternating-current generators are discussed in an elementary way in the preceding section. See Index. Modern

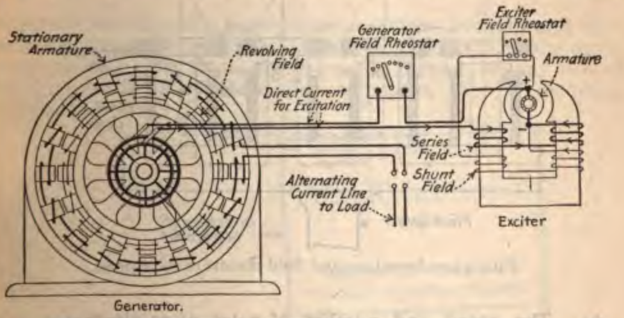


FIG. 42.—Elementary diagram of alternator and exciter.

commercial alternating-current generators usually are arranged as suggested diagrammatically in Fig. 42. Electromagnets, excited by a small direct-current generator or exciter, are mounted on a wheel-like structure which revolves within a circular stationary frame in the inner surface of which are armature coils. The revolving part is the revolving field; the stationary part is the armature. The direct current is fed to the field coils through collector rings. Armature coils are, in practice, arranged in slots in the inner circumference of the armature structure. Alternating e.m.fs. are induced in the armature by the lines of force from the field magnets cutting the armature coils. The alternating voltage can be varied, within limits, by adjusting the field rheostats.

92. There are several types of alternators or alternating-current generators. They are: (1) Revolving armature alternators wherein the armature revolves and the field magnets are stationary; (2) revolving field alternators, wherein the field magnets revolve and the armature is stationary; (3) inductor alternators, wherein both field magnets and armature are stationary and iron cores revolve between the armature core and the field-magnet poles. Modern alternators are practically all of the revolving field type because the stationary armature offers better opportunity for insulation and a high voltage is not necessary on the collector rings.

93. The electromotive force in an alternator is generated as suggested in Fig. 43. As each field coil, *D* for instance, sweeps past the armature coils the lines of force from the field coil cut the armature coils. As coil *D* passes from *A* to *C* an alternating e.m.f. represented by the curve *ABC* will be generated in the armature. It should be understood that in commercial alternators the armature coils are set in slots and differently arranged than in Fig. 43, which only illustrates a principle.

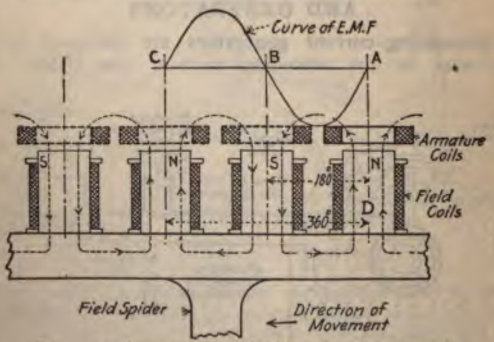


FIG. 43.—Armature and field structure developed.

94. The speed and number of poles of an alternator or an alternating-current motor determine its frequency and vice versa. *(See Table 97.)*

$$f = \frac{p \times \text{r.p.m.}}{120}; \text{ or } p = \frac{120 f}{\text{r.p.m.}}; \text{ or r.p.m.} = \frac{120 f}{p}$$

Wherein f = frequency in cycles per second, r.p.m. = revolutions per minute of rotor and p = the number of field poles.

Example.—What is the frequency of a two-pole alternator running a 3,600 r.p.m.?

Solution.—Substitute in the formula:

$$f = \frac{p \times \text{r.p.m.}}{120} = \frac{2 \times 3{,}600}{120} = \frac{7{,}200}{120} = 60 \text{ cycles per second.}$$

Example.—How many poles has a 25-cycle alternator running at 50 r.p.m.?

Solution.—Substitute in the formula:

$$p = \frac{120 f}{\text{r.p.m.}} = \frac{120 \times 25}{500} = \frac{3{,}000}{500} = 6 \text{ poles.}$$

95. Single-phase Alternators.—The circumferential distanc from the center line of one pole to the center line of the next pol of the same polarity constitutes 360 magnetic degrees. See Fi 43, which shows how a single-phase e.m.f. is generated. Fig. 4 is a diagrammatic illustration of a single-phase alternator and Fi 44 shows, diagrammatically, two different kinds of single-phas windings. Single-phase alternators are seldom made now. Th

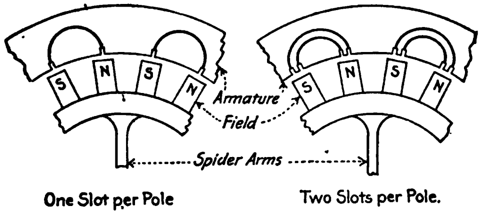


FIG. 44.—Single-phase armature windings.

manufacturers furnish three-phase machines instead and giv them a single-phase rating equal to about 70 per cent. of the three phase rating. The single-phase load is carried on any two of the three leads of the three-phase generator. See "Three-phas Alternator."

96. Approximate Performanc

220, 440, 600, 1,100, 2,200 ε

It should be understood that values will vary somew mate only and do not apply to any particular manufactu

A slow-speed machine is assumed to be one turning at 200 r.p.m. to 300 r.p.m., and a high-speed machine, on slow speed; "M" medium speed, and "H" high speed.

Kva output		Current						
		Three-phase						T
		240 volts	480 volts	600 volts	1,200 volts	2,200 volts	2,400 volts	2, vo
50	S M H	120.3	60.1	48.0	24.0	13.2	12.0	10
75	S M H	180.4	90.2	72.2	36.1	19.7	18.0	15
100	S M H	240.6	120.3	96.2	48.1	26.3	24.1	20
125	S M H	301.0	150.0	120.0	60.1	32.8	30.1	26
150	S M H	360.8	180.4	144.3	72.2	39.4	36.1	31
200	S M H	481.1	241.6	192.4	96.2	52.5	48.1	41
300	S M H	723.0	362.0	289.0	145.0	79.2	72.0	62
400	S M H	962.0	481.0	385.0	192.0	105.0	96.2	83
500	S M H	1203.0	602.0	481.0	241.0	132.0	120.0	104
600	S M H	1450.0	722.0	578.0	289.0	158.0	144.0	125
700	S M H	1690.0	841.0	673.0	337.0	184.0	168.0	146
800	S M H	1930.0	977.0	773.0	387.0	211.0	193.0	167
1,000	S M H	2406.0	1203.0	962.0	481.0	263.0	241.0	208
1,250	S M H	3000.0	1500.0	1200.0	600.0	328.0	300.0	260
1,500	S M H	3640.0	1804.0	1443.0	722.0	394.0	361.0	313
2,000	S M H	4850.0	2420.0	1924.0	962.0	526.0	481.0	41

of Alternating-current Generators
volts. Two-phase and three-phase.

speed and other conditions. Those given are general and appro

r.p.m. to 2co r.p.m.; a medium-speed machine, one turning at fr
at from 300 r.p.m. to 1,200 r.p.m. In the table, "S" indica

Current				Efficiency			Excit capaci requir
Two-phase				½ load	¾ load	Full-load	
600 volts	1,200 volts	2,200 volts	2,400 volts				
41.7	20.8	11.3	10.4	...... [1]85.5 86.6	...... [1]88.0 89.8	...... [1]89.0 90.8	...... 7. 2.
62.5	31.3	17.2	15.6	...... [1]88.0 87.1	...... [1]90.0 89.7	...... [1]91.3 90.8	...... 8. 3.
83.3	41.7	22.8	20.8	...... [1]89.0 87.7	...... [1]91.0 90.2	...... [1]92.0 91.3	...... 9. 3.
104.0	52.1	28.4	26.1	...... [1]91.0 90.1	...... [1]92.0 91.7	...... [1]92.5 92.7	...... 9. 5.
125.0	62.5	34.1	31.3	[1]90.5 [1]91.0 90.2	[1]91.7 [1]92.0 91.8	[1]92.2 [1]93.0 92.8	14. 9. 4.
166.7	83.3	45.5	41.7	[1]90.7 [1]91.0 90.1	[1]92.3 [1]93.0 92.7	[1]93.4 [1]93.5 93.5	12. 11. 6.
250.0	125.0	68.1	63.0	[1]91.0 [1]92.0 89.2	[1]93.0 [1]93.5 92.1	[1]93.5 [1]94.2 93.2	20. 15. 12.
333.0	167.0	91.0	83.3	[1]92.0 [1]92.0 90.2	[1]93.0 [1]94.0 92.3	[1]94.0 [1]94.5 93.8	23. 14. 12.
417.0	208.0	113.0	104.0	[1]92.5 91.8 90.8	[1]94.0 93.5 93.5	[1]94.5 94.4 94.5	23. 16. 13.
500.0	250.0	136.0	125.0	[1]92.5 92.4 90.0	[1]94.0 94.1 92.4	[1]94.5 94.8 93.8	28. 22. 20.
583.0	292.0	159.0	146.0	[1]93.0 91.8 90.0	[1]94.0 94.1 92.5	[1]94.6 95.0 94.0	35. 24. 20.
667.0	333.0	185.0	167.0	[1]92.8 92.1 91.5	[1]94.5 94.0 93.0	[1]95.3 95.0 94.0	32. 23. 17.
833.0	417.0	228.0	208.0	[1]93.0 92.3 92.5	[1]94.0 94.2 94.0	[1]94.8 95.0 94.6	35. 29. 25.
1040.0	520.0	384.0	260.0	[1]93.5 92.5 92.0	[1]94.5 94.6 94.2	[1]95.7 95.5 95.3	38. 30. 26.
1250.0	*625.0*	*341.0*	*313.0*	[1]93.6 92.2 93.0	[1]94.7 94.4 95.1	[1]95.4 95.5 95.9	42. 38 2
1667.0	*833.0*	*455.0*	*417.0*	[1]94.0 92.6 92.3	[1]95.0 94.8 94.7	[1]95.8 95.8 95.7	[illegible]

[1] *Engine type machines*—efficiencies do not include friction of

97. Synchronous Speeds—Alternating-current Generators and Motors

Application to Generators.—The table shows the speeds at which the rotor of an alternator which has a given number of field poles must turn to generate currents at given frequencies.

Application to Motors.—The table indicates the synchronous speed or the speed of the rotary magnetic field of an induction motor having a given number of poles and taking current at a given frequency.

The table also shows the speeds of synchronous motors having a given number of field poles and taking currents at given frequencies.

Number of poles	Revolutions per minute when frequency is											
	25	30	33⅓	40	50	60	66⅔	80	100	120	125	133⅓
2	1,500	1,800	2,000	2,400	3,000	3,600	4,000	4,800	6,000	7,200	7,500	8,000
4	750	900	1,000	1,200	1,500	1,800	2,000	2,400	3,000	3,600	3,750	4,000
6	500	600	667	800	1,000	1,200	1,333	1,600	2,000	2,400	2,500	2,667
8	375	450	500	600	750	900	1,000	1,200	1,500	1,800	1,875	2,000
10	300	360	400	480	600	720	800	960	1,200	1,440	1,500	1,600
12	250	300	333	400	500	600	667	800	1,000	1,200	1,250	1,333
14	214	257	286	343	428	514	571	686	857	1,029	1,071	1,143
16	188	225	250	300	375	450	500	600	750	900	938	1,000
18	167	200	222	267	333	400	444	533	667	800	833	889
20	150	180	200	240	300	360	400	480	600	720	750	800
22	136	164	182	217	273	327	364	436	545	655	682	720
24	125	150	167	200	250	300	333	400	500	600	625	667
26	115	138	154	185	231	280	308	370	423	554	577	615
28	107	128	143	171	214	257	286	343	429	514	536	571
30	100	120	133	160	200	240	267	320	400	480	500	533
32	94	113	125	150	188	225	250	300	375	450	487	500
36	83	100	111	133	166	200	222	266	333	400	417	444
44	79	82	91	109	136	164	182	218	273	327	341	363
48	63	75	83	100	125	150	167	200	250	300	312	333
54	56	66	74	90	111	133	148	178	222	266	278	296
60	50	60	67	80	100	120	133	160	200	240	250	266
68	44	53	59	71	88	106	118	141	176	212	221	235
72	42	50	55	67	83	100	111	133	166	200	208	222
96	31	38	42	50	64	75	82	100	125	150	156	167
100	30	36	40	48	60	72	80	96	120	120	150	160

98. Two-phase Alternator.—In a generator of the type indicated in Fig. 45 the centers of the two component coils *I* and *II* are situated 90 deg. apart and the single-phase electromotive forces generated in coils *I* and *II* by the passage of the field system past them, differ in phase by 90 deg. This property has given rise to the term quarter-phase for this type of machine, but it is more frequently called a two-phase machine. The electromotive force in coil *I* is zero when that in coil *II* is a maximum, and vice versa. The curves of electromotive force in coils *I* and *II* may be plotted as indicated in Fig. 46. Fig. 47 shows two methods of connecting the armature windings of two-phase alternators. The armature coils can be arranged in one or more slots per pole as diagrammatically suggested in Fig. 48. In commercial machines the windings are almost always arranged in more than one slot per pole. See first section for further information in regard to two-phase currents.

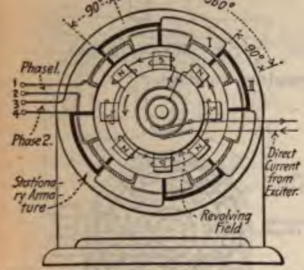


FIG. 45.—Diagram for two-phase alternator.

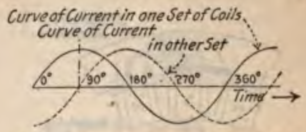


FIG. 46.—Curves of two-phase current.

99. Three-phase alternator coils are arranged as illustrated diagrammatically by coils *I*, *III* and *II* of Fig. 49, and the curves of

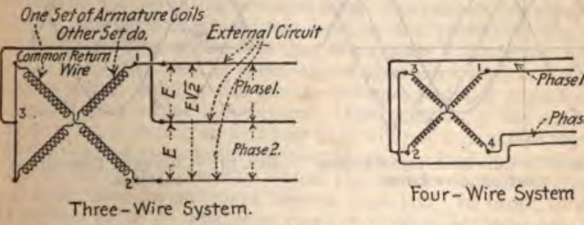
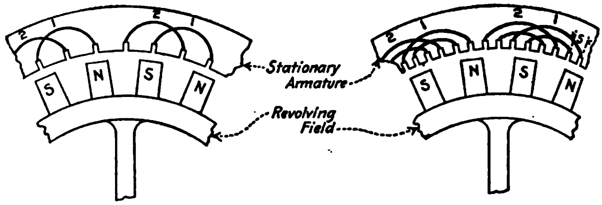


FIG. 47.—Methods of connecting two-phase generator armature windings.

instantaneous electromotive force are displaced from one another by 60 deg. as indicated in Fig. 51. This arrangement of coils is really a six-phase grouping, and in connecting the winding for three-phase, the coils of one of the phases must be connected in the reverse sense from the other two. This will give the true three-phase arrangement in which the e.m.f. curves are as in Fig. 52. These curves also represent the e.m.fs. for the winding in Fig. 50 with the three phases connected up in the same sense. H



One Slot per Pole. Two Slots per Pole.

FIG. 48.—Two-phase armature windings.

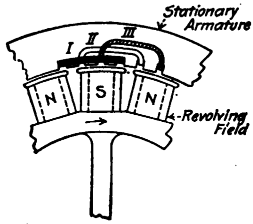


FIG. 49.—Six-phase grouping.

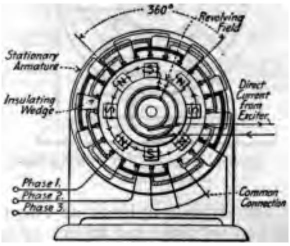


FIG. 50.—Diagram for three-phase, Y-connected alternator.

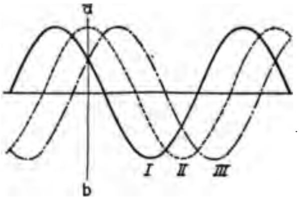


FIG. 51.—Curves of instantaneous electromotive forces.

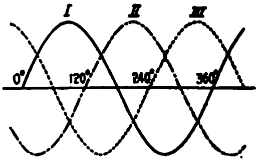
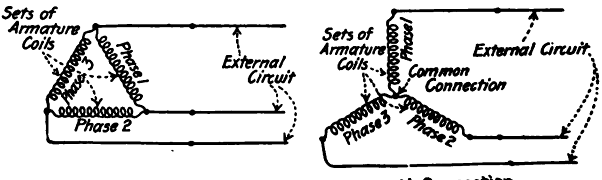


FIG. 52.—Curves of three-phase currents.



Delta (Δ) Connection Y Connection

FIG. 53.—Methods of connecting three-phase armature coils.

three coils are distributed over a double pole pitch, and the phase displacement between the e.m.fs. is 120 deg.

The two methods of connecting three-phase armature windings are shown in Fig. 53. These methods are discussed in more detail in the first section. Armature windings can be arranged in one or more slots per pole (Fig. 54). The *Y* method of connection is almost always used for three-phase generators.

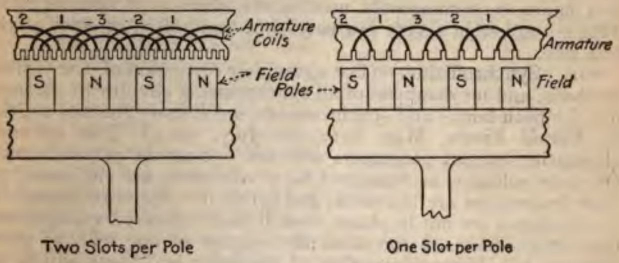


FIG. 54.—Three-phase armature windings.

100. Exciters for alternating-current generators (*Standard Handbook*) are usually compound-wound, flat-compounded, and rated at 125 or 250 volts. It is especially desirable that they be "stable," if direct-connected to the shaft of the alternators, as is sometimes done. By a stable generator is meant one that does not have an excessive rise or fall in potential with a corresponding change in speed. Standard direct-current machines of good design and of the desired rating are used where the exciters are separately driven, and separately driven exciters are preferable for most plants on account of the fact that the system is made much more flexible; any drop in the speed of the alternator does not cause a corresponding drop in the exciter voltage, and the regulation of the plant as a whole is improved. Furthermore, if the exciter is not direct-connected, an accident to it will not necessitate shutting down the generator, assuming that there is a duplicate exciter set.

In all cases it is necessary that the exciter capacity be ample and that there be sufficient reserve capacity. In order to make the exciter plant as reliable as possible, storage batteries are being installed in connection with the exciting generators in many plants in such a way that current may be furnished to the field circuits of the alternators, even though all rotating apparatus be at a standstill. As an example of the amount of reserve capacity that is sometimes installed: in the first power plant of the Niagara Falls Power Company four exciters are installed, each one having sufficient capacity to excite the entire plant, and each driven by its own turbine, fed by a separate penstock.

It is apparent that where separately driven exciters are us the prime movers should be such that the exciters may be sta independently of the current furnished by the alternators. St water-, or gas-driven units are necessary unless a storage battery or power from an external source is available for excitation of the plant when first starting up. With the bus-bars excited, motor-driven units may be operated and they are preferable in many cases. General figures for the capacity of an exciter for any machine run from 2.5 per cent. of the capacity of the alternator for moderate speeds and small sizes, to 0.5 per cent. of the alternator capacity, or a trifle less, for large, high-speed, turbine units. Two per cent. is a figure very commonly used in the absence of definite data. This is too low in a very few cases, but more often in error on the safe side.

101. **Synchronizing.**—(For a complete discussion of the various methods, and for diagrams of all synchronizing circuits in common use, for both lamps and synchroscopes, see *Electric Journal* articles by *Harold Brown*, May, 1912, and July, 1912.) Two or more alternating-current generators will not operate in parallel unless (1) their voltages, as registered by a voltmeter, are the same; (2) their frequencies are the same; and (3) their voltages in phase. If the machines are not in phase, even if their indicated voltages and their frequencies are the same the voltage of one will, at given instants, be different from that of the other and there will be an interchange of current between the machines. When two or more generators all satisfy the three above requirements they are in synchronism. Synchronizing is the operation of getting machines into synchronism. Incandescent lamps or instruments are, as described in other paragraphs used for indicating when machines are in synchronism.

102. **Synchronizing a Single-phase Circuit with Lamps.—The elementary principle** involved in determining synchronism is indicated in Fig. 55. If the voltage and frequency of generators *A* and *B* are the same and the machines are in phase, point *a* will be at the same potential at every instant as will point *a'*. Hence the lamps between *a* and *a'* will not light so long as the three conditions are satisfied. So long as the conditions are not satisfied there will be a fluctuating cross current from *a* to *a'* and a constant fluctuating of the brilliancy of the incandescent lamps. When the lamps become dark and remain so, the generators are in synchronism and may be thrown together. Had the connection at *a'* been made to the *b'* generator lead, the lamps would be bright when the generators were in synchronism, but for reasons outlined in another paragraph the connection shown which provides the "dark lamp" method of synchronizing is preferred. The second pair of lamps between b and *b'* is provided to insure against accident in case the a—a' set were broken. The same conditions occur in the a—a' set as in the b—

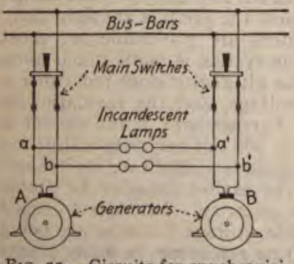


FIG. 55.—Circuits for synchronizing with lamps.

set. A voltmeter of proper rating can be substituted for the lamps.

Where the voltage generated is so high that it is not desirable to connect a sufficient number of lamps in series for it, a single lamp fed through voltage transformers can be used for synchronizing, as suggested in Fig. 56.

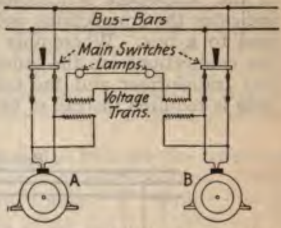


FIG. 56.—Circuits for synchronizing high-voltage circuits with lamps.

103. Phasing Out Three-phase Circuits.—Prior to connecting the leads from a polyphase generator, that is to operate in parallel with others, to the generator switch, the circuits must be "phased out." That is, the leads must be so arranged that each lead from the generator will, when the generator switch is thrown, connect to the corresponding lead of the other generator. If this is not arranged there may be considerable damage done due to an interchange of current when the two machines are paralleled. After once phasing out it is necessary to synchronize but one phase of the machine with the corresponding phase of the other machine.

Connections for phasing out three-phase circuits are shown in Fig. 57. If voltage transformers are not used the sum of the vol-

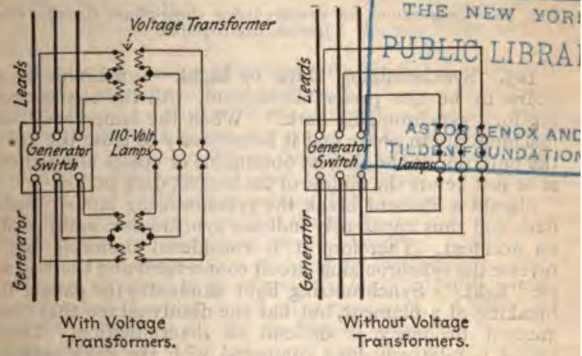


FIG. 57.—Connections for phasing out three-phase circuits.

tages of the lamps in each line should be approximately the same as the voltage of the circuits. On 440-volt circuits, two 220-volt or four 110-volt lamps should be used in each phasing-out lead.

To phase out, run the two machines at about synchronous speed. If the lamps do not all become bright and dark together, interchange any two of the main leads on one side of the switch, leaving the lamps connected to the same switch terminals, after which the la should all fluctuate together and the connections are correct. The machines are in phase when all the lamps are dark.

104. The synchronizing connections for three-phase generators are shown in Fig. 58. A synchronizing plug may be used instead of the single-pole synchronizing switch shown. The illustration indicates the connections used where machines are to be synchronized to a bus. Where only two machines are to be synchronized, the connections are the same as shown in Fig. 58, except that the bus transformer and the corresponding lamp are omitted and one plug is required instead of two.

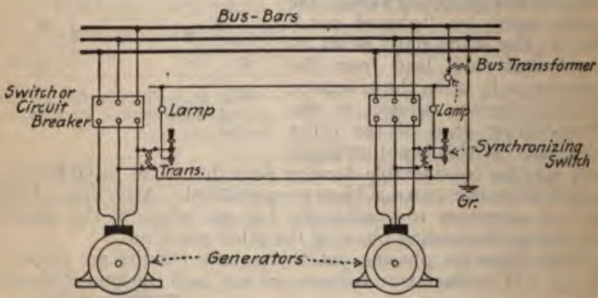


FIG. 58.—Connections for synchronizing three-phase circuits where transformers are required.

105. Synchronizing Dark or Light.—Synchronizing dark appears to be the preferable method. All the connections shown are for "synchronizing dark." When the lamps are "dark" the machines are in phase and it is necessary to close the switch when the pulsation is the slowest obtainable or ceases altogether, that is, at or just before the middle of the longest dark period.

Should a filament break the synchronizing lamps would remain dark and thus apparently indicate synchronism and possibly cause an accident. Therefore it is considered desirable by some to reverse the synchronizing circuit connections and thereby synchronize "light." Synchronizing light eliminates the danger due to the breaking of a filament, but has the disadvantage that the time of greatest brilliancy is difficult of determination. The "light" period is relatively long compared with the dark period so that synchronizing light is usually considered the more difficult and were it not that with the "synchronizing light" method the danger due to filament breakage is eliminated, the method would never be used.

The probability of a filament breaking just at the time of approaching synchronism and when the machines are not in phase is remote. If it occurs at any other time in the operation it will be noticed. As a protection against accidents due to breakage, two synchronizing lamps should always be placed in multiple.

106. **The number of lamps to use in a group to indicate synchronism** is determined by the voltage of the generators. With high voltage circuits it is not feasible to use a sufficient number of lamps, so a transformer is employed that has a voltage sufficient for a 110-volt lamp. See the diagrams. The greatest voltage impressed on the lamps is double that of the voltage transformers or generators. Thus the maximum voltage on the lamps where two 220-volt generators are being synchronized is 440 volts. The dark period may be shortened by impressing a voltage higher than their normal on the lamps. For two 220-volt machines, for example, three 110-volt lamps might be used.

107. **Synchroscopes** are instruments that indicate the difference in phase between two electromotive forces at every instant. They show whether the machine to be synchronized is running fast or slow and indicate the exact instant when the machines are in synchronism. The companies that manufacture the instruments furnish literature describing the theory involved and that gives complete circuit diagrams.

108. **While for successful parallel operation,** it is not necessary that alternating-current generators be of the same type, output, and speed, it is universally conceded that the question of wave shape is important, since if the waves are of different shapes, cross currents will always be present. Similar wave shapes are more readily obtained with machines of similar type. Satisfactory parallel operation, the previously mentioned conditions being fulfilled, consists in obtaining:

(1) Correct division of the load amongst the machines; and
(2) Freedom from hunting.

109. **Division of Load.**—Machines with similar characteristics tend to divide the common load uniformly. Such a proportional load division may be disturbed if the steam supply to the engines is defective or variable from any cause. The steam supply is regulated by the engine governors, and defects in one or more of these governors will give rise to poor load division. It is essential that the governors of all the engines shall have similar speed-regulation characteristics so that a sudden change in the load shall cause the same amount of regulation on each engine. Correct load division is therefore essentially a problem for the engine governors. It is sometimes arranged to govern all the engines from a common throttle valve, but this plan is not often employed. A more usual plan consists in running all the machines except one, with their stop valves full open and their governors fixed, so that the remaining engine may take up any variations in the common load.

Varying the voltage of an alternator running in parallel with others by adjusting its field rheostat will not vary the load on it as with a direct-current generator. To increase the energy delivered by an alternator it is necessary that the prime mover be caused to do *more work. An engine should* be given more steam or a water *wheel more water.*

110. ***Adjustment of Field*** **Current.**—When the rheostats *two alternators running in* parallel at normal speed are not adju *to give a proper excitation*, a cross current will flow betwee armatures. The intensity of this current depends only upo difference in field charges of the machines. It may vary c wide range, from a minimum of zero when both field charg normal, to more than full-load current when they differ gr The effect of this cross current is to increase the temperat the armatures and, consequently, to decrease the output generators. It is important that the rheostats be so adjus to reduce it to a minimum. This cross current registers c ammeters of both generators and usually increases both rea The sum of the ammeter readings will be a minimum when th or cross current is zero.

In general, the proper field current for a machine runn parallel with others is that which it would have if running and delivering its load at the same voltage. In order to dete the proper position of the rheostats it is necessary to mak adjustments after the alternators are paralleled, until that po is found at which the sum of the ammeter readings is a minim

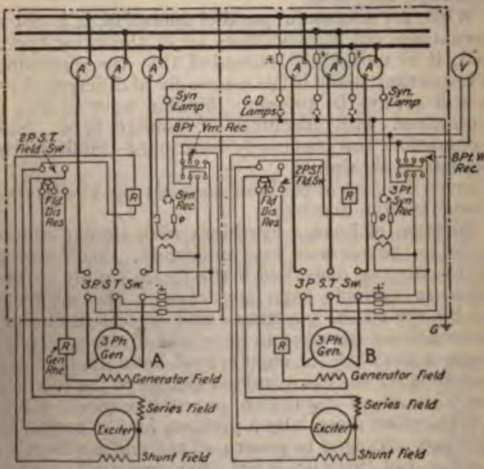


FIG. 59.—Two three-phase alternators of similar characteristics op in parallel.

To illustrate this method let us consider two similar alter *A* and *B*, Fig. 59, operating in parallel. When the generat rheostats of both are properly adjusted no cross currents wi through the armatures and the main ammeters will show readings if each machine is receiving the same amount of its prime mover. If the rheostat of A be partly cut in e its field current, a cross current, lagging in B and ill flow between the armatures, the effect of which en *A's* magnetization and weaken B's until they a imately equal. The resultant e.m.f. of the system will thereby be lowered.

On the other hand, if the rheostat of *B* be partly cut out so as to increase its field current, a cross current leading in *A* and lagging in *B* will flow between the armatures, strengthening *A's* magnetization and weakening *B's* magnetization until they are again equal. The resultant e.m.f. of the system will thereby be raised. A cross current of the same character is therefore produced by decreasing one field current or increasing the other, *i.e.*, in both cases it will lead in the first machine and lag in the second machine. The e.m.f. of the system will, however, be decreased in one case and increased in the other.

It is obvious that by simultaneously adjusting the two rheostats, the strength of the cross current may be varied considerably and the e.m.f. of the system maintained constant.

For the first trial adjustment cut in *A's* rheostat several notches and cut out *B's* the same amount, so as not to vary the e.m.f. of the system. If this reduces the sum of the main ammeter readings, continue the adjustment in the same direction until the result is a minimum. After this point is reached a further adjustment of the rheostat in either direction will increase the ammeter readings. If the first adjustment increases the sum of the ammeter readings it is being made in the wrong direction, in which case move the rheostats back to the original positions and then cut out *A's* rheostat and cut in *B's*. If both adjustments increase the sum of the ammeter readings the original positions of the rheostats are the proper ones.

In making these adjustments of the rheostats it may be found difficult to locate the exact points at which the cross current is a minimum, as it may be possible to move the rheostats over a considerable range when near the correct positions without materially changing the ammeter readings. When the adjustment is carried this far, it is close enough for practical operation. If the generators are provided with power factor meters, the same result may be obtained by adjusting all these to read the same.

111. **Hunting** (*Standard Handbook*) is a term employed to describe the oscillations of the revolving masses of the machines when they are accelerated and retarded above and below the normal average speed. If this hunting or swinging be allowed to exceed a certain amount, the regulation of the machines becomes unstable and they may break out of step. Freedom from cumulative hunting is consequently essential. The swinging action is set up primarily by variations in the rotative speed resulting from irregularity in the turning force. A perfectly uniform turning moment or turning force cannot be obtained with reciprocating engines. The irregularity in the turning moment during a revolution results from the following causes:

Defective distribution of steam in cylinders.

Short connecting rod.

Inertia of moving parts.

If one of two machines running in parallel momentarily lags behind the other, its armature receives a current which tends to the machine into phase and accelerate it so that at the instant it reaches the correct phase position its speed is a little greater than that of the other machine, which is now in turn accelerated. The machines are now alternately lagging and leading with relation to one another. In other words, hunting is set up.

Whichever engine is, for the instant, accelerating, will have its steam supply cut down by the governor. If the governor is too sensitive, it will over-govern, cutting down the steam and the speed too far. An instant later, the over-governing will be in the opposite sense, and this process will repeat itself. Similar occurrences will simultaneously be taking place on the other engine, and thus we have a case of hunting governors. By this hunting, the steam supply is rendered periodic and varies between two limits.

112. Surging is the term used in connection with the current variations during the hunting, the latter term applying to the mechanical phenomenon of periodic speed variations. The case described is an instance of hunting in the governors due to change of load and to over sensitiveness of the governors. If, however, the governors are sluggish, a time interval elapses between an accidental acceleration and its correction by the governor. This lag will, in response, tend to set up hunting.

113. Prevention of Hunting.—The variations in turning moment and angular speed may be greatly reduced by the use of a heavy flywheel, as this tends to keep the rate of revolution uniform by virtue of storing energy and giving it out again during the course of each revolution. The flywheel, however, must not have too great a moment (that is, it must not be too big) as it adds to the inertia of the moving parts and may prolong hunting if once started. Hunting may sometimes be overcome by damping the governor so that it shall not respond to small and quick variations in speed such as occur during one revolution, but shall only respond to steady and continued changes in speed. This result is obtained by fitting each governor with a suitable dash-pot so that it is rendered more sluggish and will make no alteration in the steam supply except when the force acting on the governor is continued for some length of time.

Liability to hunt may sometimes be prevented by synchronizing the engines so that the cranks on all the engines are in step, and the variations in turning moment are coincident in all the engines. This plan is sometimes effective, so far as the prevention of hunting in the generating station is concerned, but it cannot always be utilized owing to the time taken to get the cranks in step, especially as an engine must be run up in a few minutes when the load is coming on quickly. It also is apt to intensify the hunting of the apparatus in distant sub-stations.

With steam turbine-driven generators, this hunting difficulty is much more rare—practically unknown—and the use of high and uniform speeds facilitates the problem of parallel running.

The tendency of generators to hunt may be minimized by sur-unding the pole pieces of the field magnets with copper bands ich eddy currents are induced by the shifting and distort he field. These currents react on the field and oppose the s ing and thus damp the oscillations. A more suitable construction consists of a grid of copper embedded in the pole face. It is very seldom necessary to provide such "dampers" on pole pieces of generators for modern steam-engine or waterwheel drive. They are usually necessary for gas-engine driven generators.

114. To Start a Single Alternator.—(1) See that there is plenty of oil in the bearings and that the oil rings are free to turn and that all switches are open. (2) Start exciter and adjust for normal voltage. Start generator slowly. See that the oil rings are turning. (3) Permit the machine to reach normal speed. Turn the generator field rheostat so that all of its resistance is in the field circuit. Close the field switch. (4) Adjust the rheostat of the exciter for the normal exciting voltage. Slowly increase the alternator voltage to normal by cutting out the resistance of the field rheostat. (5) Close the main switch.

115. To Start an Alternator to Run in Parallel with Others.—(1) Bring the exciter and generator to speed as described in the above paragraph. Adjust the exciter voltage and close the field switch, the generator field resistance being all in. (2) Adjust the generator field resistance so that the generator voltage will be the same as the bus-bar voltage. (3) Synchronize, as outlined in one of the above paragraphs. Close the main switch. (4) Adjust the field rheostat until cross currents are a minimum and adjust the governors of the prime movers so that the load will be properly distributed between the operating units in proportion to their capacities.

116. To Cut Out a Generator Which is Running in Parallel with Others (*Westinghouse Instruction Book*).—(1) Preferably cut down the driving power until it is just sufficient to run the generator empty. This will reduce the load on the generator. (2) Adjust the resistance in the field circuit until the armature current is a minimum. (3) Open the main switch. It is usually sufficient, however, to simply disconnect the machine from the bus-bars, thereby throwing all the load on the remaining machine without having made any previous adjustment of the load or of the field current.

Caution.—The field circuit of a generator to be disconnected from the bus-bars must not be opened before the main switch has been opened for, if the field circuit be opened first, a heavy current will flow between the armatures.

117. The principle of operation of the induction motor is illustrated in Fig. 60, which indicates diagrammatically a two-phase revolving field generator and a two-phase induction motor having a rotor that is simply a bar of iron. The induction motor depends for its operation on a rotating magnetic field. There is no electrical connection between the revolving and stationary parts of an induction motor.

Windings of the types shown in the illustration are not used in commercial machines, but the general theory involved is the same as with commercial windings. The revolving field (see illustration) of the generator, in turning in the direction shown by the arrow, generates a two-phase current which is transmitted to the r

The current, in conductors of one phase, magnetizes poles *A* and *B* and that in the other phase the poles *C* and *D*. The winding is so arranged that a current entering at *A* will produce a south pole at *A* and a north pole at *B*. At the instant shown at *I*, the motor poles *A* and *B* are magnetized while poles *C* and *D* are not, because it is a property of a two-phase circuit that when the current in one of the phases is at a maximum value, the current in the other phase is at a zero value. Hence, the bar iron rotor will assume the vertical position shown.

At another later instant, represented at *II*, the currents in both of the phases are equal and in the same direction; the motor poles will be magnetized as shown and the rotor will be drawn into the position indicated. At the instant illustrated at *III*, because of the properties of two-phase currents, there is no current in the phase the conductors of which are wound on poles *A* and *B*, but the current in the phase the conductors of which magnetize poles *C* and *D*, is a maximum. Hence the rotor is now drawn into a horizontal position. Similar action occurs during successive instants and the rotor will be caused to rotate in the same direction within the motor frame so long as the two-phase current is applied to the motor terminals. Considering it in one way, the rotating magnetic field rotates within the motor frame and drags the rotor around with it.

The magnetic attraction or drag exerted on the rotor in a simple motor built as illustrated would be pulsating in effect, hence the torque exerted by such a motor would not be uniform.

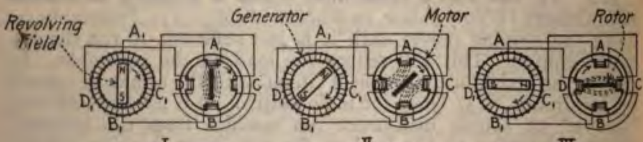


FIG. 60.—Illustrating the principle of the induction motor.

118. Commercial induction motors operate because of the principles outlined in 117, but their construction is considerably different from that shown in Fig. 60. In commercial induction motors the stator or primary winding is distributed over the entire inner surface of that portion of the stator structure which is of laminated iron and which conducts the magnetic flux. The rotor consists of a laminated iron cylinder which has a winding of insulated wire or of copper rods or bars embedded in slots uniformly spaced around the periphery of the core. Where bars or rods are used they are short-circuited at both ends by heavy copper conductors forming a completely short-circuited rotor.

In the commercial induction motor the magnetic field of the rotor which reacts on the magnetic field of the stator is produced by currents in the rotor conductors. These currents are generate by the rotor conductors being cut by the lines of force of the rotating field which was described in a preceding paragraph. Consider a polyphase induction motor with its rotor at rest. Now connect a source of the proper polyphase current to the motor terminals thereby energizing the stator winding. A rotating magnetic field will be produced by the stator winding. As this magnetic field swings around within the stator structure it will cut the copper bars imbedded in the surface of the rotor. Currents will thereby be induced in the bars and these currents will generate magnetic fields around and within the rotor. Due to the interaction between the rotor and stator magnetic fields, rotation of the rotor will be produced.

It is therefore evident that the turning speed (revolutions per minute) of the rotor can never be quite equal to that of the rotating magnetic field as there must always be a sufficient difference in speed or "slip" that the rotor conductors will be cut by the lines of force of the rotating field. Obviously, if the rotor speed were the same as that of the revolving field, no lines of force could be cut by rotor conductors and there would not be sufficient magnetic interaction between the stator and rotor fields to produce rotation of the rotor and pull a load.

The intensity of the current induced in the rotor and therefore the torque is determined by the amount of "slip" between the rotor and the rotating magnetic field. The greater the torque required, the greater will be the slip.

119. General Characteristics of Polyphase Squirrel-cage Induction Motors.—Their speed is practically constant at all loads. Hence they are used for constant-speed service where starting and reversing are infrequent. The starting torque is relatively small and a large starting current 2 to 6 times full-load current, depending on the design of the motor, is drawn from the line if the motor must start full-load torque.

Simple and rugged construction is a feature of these motors, the bearings being the only parts subject to wear. Since there are no sliding electrical contacts there can be no sparking and the motors are therefore particularly suitable for operation in places where there are inflammable gases or dust.

If the resistance of the rotor be increased the motors can be built, in the smaller capacities, for high starting torque, rapid acceleration, and frequent starting. Motors built thus can be profitably used for operating punches, shears and the like, where simplicity of control is desirable, as with them a large drop in speed produces but a slight increase in torque, permitting the stored energy in the flywheel to be delivered to the machine when a heavy load occurs. In this respect such an induction motor resembles a compound-wound direct-current motor.

If the torque *imposed on* any induction motor reaches 2 to 4 *times full-load torque* the motor will stop or "pull out." (See Par. *126.*)

The output and torque of an induction motor varies as the square *of the applied voltage,* hence it is desirable to maintain the voltag[e] *normal value.*

120. Approximate Data on
220, 440 and 2,200 volts,[1]

The values given are general and approximate, but are fairly represen-

H.p.	Poles	Synchronous speed		Approx. full-load slip, per cent.		Approximate full-load speed		[2]Starting current for full-load torque
		25 cycles	60 cycles	25 cycles	60 cycles	25 cycles	60 cycles	
½	4	750	1,800	8	6	690	1,700	2.7-3
1	4	750	1,800	8	6	690	1,700	2.7-3
1½	6	500	1,200	8	7	460	1,120	2.7-3
2	4	750	1,800	8	6	690	1,700	2.7-3
2	**6**	**500**	**1,200**	**8**	**7**	**460**	**1,120**	**2.7-3**
3	4	750	1,800	8	6	690	1,700	2.7-3
3	6	500	1,200	8	7	460	1,120	2.7-3
4	8	375	900	8	6	345	850	2.7-3
5	4	750	1,800	8	6	690	1,700	2.7-3
5	**6**	**500**	**1,200**	**8**	**7**	**460**	**1,120**	**2.7-3**
5½	8	375	900	8	6	345	850	2.7-3
7½	4	750	1,800	7	4	700	1,720	2.7-3
7½	6	500	1,200	7	5	465	1,135	2.7-3
7½	8	375	900	7	6	349	850	2.7-3
10	**6**	**500**	**1,200**	**7**	**5**	**465**	**1,135**	**2.7-3**
10	8	375	900	7	6	349	850	2.7-3
12	10	300	720	6	6	282	680	2.7-3
15	6	500	1,200	6	5	470	1,135	2.7-3
15	10	300	720	6	6	282	680	2.7-3
20	**6**	**500**	**1,200**	**6**	**5**	**470**	**1,135**	**2.7-3**
20	8	375	900	6	6	353	850	2.7-3
25	6	500	1,200	6	5	470	1,135	2.7-3
25	12	250	600	5	6	237	565	2.7-3
30	8	375	900	5	6	355	850	2.7-3
35	**8**	**375**	**900**	**5**	**6**	**355**	**850**	**2.7-3**
35	12	250	600	5	6	237	565	2.7-3
40	8	375	900	4	6	360	850	2.7-3
50	8	375	900	4	6	360	850	2.7-3
75	10	300	720	4	6	288	680	3-3.5
75	**14**	**214**	**514**	**4**	**4**	**205**	**495**	**3-3.5**
100	10	300	720	4	4	288	690	3-3.5
110	16	....	450	....	4	......	430	3-3.5
150	12	....	600	....	4	......	575	3-3.5
150	16	....	450	....	3	......	435	3.5
200	12	....	600	....	4	......	575	3.5

[1] 2,200-volt motors are seldom if ever made for capacities of less than 20 to 30 h.p.
[2] Starting current for full-load torque in terms of full-load current.
[3] Starting torque in terms of full-load torque.

121. Characteristics of Polyphase Induction Motors Having Wound Rotors and Internal Starting Resistance.—Motors of this type of the ordinary design give about 1½ times full-load torque with approximately 1½ times full-load current, making them suitable for use on lighting circuits and for other applications where a minimum starting current is desirable. In general, motors of this type are not built in capacities exceeding 200 h.p. because of the mechanical difficulties encountered in arranging the intern[al] resistance.

Standard Induction Motors

two-phase and three-phase.

tative of what may be expected from commercial induction motors.

[3]Starting torque at rated voltage	[4]Pull out torque	[5]Efficiency, per cent.				Power factor, per cent.				H.p.
		½ load	¾ load	Full-load	1¼ load	½ load	¾ load	Full-load	1¼ load	
1.3	2.3	65	70	72	73	52	63	70	72	½
1.3	2.3	74	77	77	76	60	72	80	83	1
1.3	2.3	82	84	84	83	60	72	78	80	1½
1.2	2.3	82	84	85	85	64	75	80	83	2
1.3	**2.3**	**82**	**84**	**84**	**83**	**60**	**72**	**78**	**80**	**2**
1.3	2.3	82	85	85	84	74	83	86	88	3
1.3	2.3	81	83	84	84	65	75	81	83	3
1.5	2.5	82	85	85	84	74	83	86	88	4
1.5	2.5	83	85	85	84	78	85	88	89	5
1.3	**2.5**	**84**	**86**	**86**	**85**	**78**	**84**	**86**	**87**	**5**
1.5	2.5	82	85	85	84	74	83	86	88	5½
2	3	83	85	85	84	79	88	90	92	7½
1.5	2.5	83	85	84	84	73	82	85	87	7½
1.5	2.5	83	85	85	85	70	78	83	85	7½
1.5	**2.5**	**85**	**86**	**85**	**84**	**80**	**86**	**89**	**90**	**10**
1.5	2.5	84	86	85	84	75	82	86	88	10
1.5	2.5	85	86.5	86	86	70	80	85	88	12
1.5	2.5	85	86	86	85	79	86	89	90	15
1.5	2.5	85	86.5	86	86	70	80	85	88	15
1.5	**2.5**	**87**	**88**	**87.5**	**87**	**82**	**89**	**91**	**90**	**20**
1.5	2.5	84	85	85	85	71	81	85	87	20
1.5	2.5	86	87	87	86	82	89	91	91	25
1.5	2.5	86	87	87	87	64	75	81	83	25
1.5	2.5	86	86.5	86	85	72	82	86	88	30
1.5	**2.5**	**87**	**88**	**88**	**87**	**72**	**82**	**86**	**88**	**35**
1.5	2.5	86	87	87	86	75	83	85	86	35
1.5	2.5	87	88	87	86	76	84	89	90	40
1.75	2.75	87	88	88	88	78	86	89	90	50
1.75	2.75	86	87.5	87	86.5	76	84	88	90	75
1.75	**2.75**	**86**	**88**	**89**	**89**	**74**	**83**	**87.5**	**89**	**75**
1.75	3	89	90	90	90	83	89	91	91	100
1.75	3	87	89	92	91	85	91	92	91	110
1.75	3	89	90	90	89	82	89	91	90	150
1.5	2.5	87	89	89	88	80	87	89	90	150
1.5	**2.5**	**91**	**92.5**	**92**	**91**	**85**	**91**	**92**	**91**	**200**

[4] Pull-out torque in terms of full-load current.

[5] Efficiencies of 25-cycle motors slightly lower than those of 60-cycle motors due to their lower speeds.

Compared with the squirrel cage motor, one with a wound rotor and internal resistance will develop a greater starting torque per ampere, but it should not be used for applications wherein there is great inertia or excessive static friction. If used for such applications full starting current may be required for a considerable period before the apparatus attains full speed. Since the capacity of the internal resistance is small, excessive temperatures may result and cause trouble.

122. Approximate Amperes per Terminal for Altern current Induction Motors

Horse-power	Single-phase 110 volts	Single-phase 220 volts	Single-phase 440 volts	Two-phase (four wire) 110 volts	Two-phase (four wire) 220 volts	Two-phase (four wire) 440 volts	Three-phase (three wi 110 volts	Three-phase 220 volts	Three-phase 440 volts	Three-phase 550 volts	1100
0.5	6.6	3.4	1.8	3.3	1.7	0.9	3.7	1.8	1	.....	..
1	14	7	3.5	6.4	3.2	1.6	7.4	3.7	1.9	.....	..
2	24	12	6	11	5.7	2.9	13	6.6	3.3	2.5	..
3	34	17	8.5	16	8.1	4.1	19	9.3	4.7	3.5	..
5	52	26	13	26	13	6.5	30	15	7.5	6	..
7.5	74	37	18.5	38	19	9.5	44	22	11	9	..
10	94	47	23.5	44	22	11	50	25	12.5	11	..
15	....	....	....	66	33	16.5	76	38	19	16	..
20	....	....	....	88	44	22	102	51	25.5	22	..
25	....	....	....	111	55	28	129	64	32	25	..
30	....	....	....	134	67	33.5	154	77	38.5	32	
40	....	....	....	178	89	44.5	204	107	53.5	44	
50	....	....	....	204	102	51	236	118	59	52	
75	....	....	....	308	154	77	356	178	89	77	
100	....	....	....	408	204	102	472	236	118	100	
150	....	....	....	616	308	154	710	355	178	147	
200	....	....	....	818	409	204	940	470	235	192	
250	....	....	....	.....	510	250	.....	590	290	237	I
300	....	....	....	.....	600	300	.....	700	350	285	I

123. Characteristics of Polyphase Slip-ring or Wound Induction Motors Having External Starting Resistance.— motors have insulated wire or bar windings on the rotor a provided with collector rings whereby an external resistance connected in the rotor circuit. The speed of the motor varied by varying the amount of external resistance in the circuit. These motors are used in moderate and large cap for nearly all variable speed applications. They are als for constant speed applications where the starting current m low.

The motors operate with characteristics similar to th direct-current motors having resistance in the armature When the external resistance is short-circuited, the motors become squirrel cage machines and operate with the characte of such machines.

124. Characteristic Curves of the Induction Motor.—The of Fig. 61 are fairly typical of the average commercial ind motor. It will be noted that the normal rating of the m taken at such a point that both the power factor and the effi re the highest possible. The motor could be so design her the power factor or the efficiency, but not both, ter than shown at normal load, but the design of an r is a compromise between the leading factors re the best efficiency and power factor obtainable with suitable overload and starting characteristics. Fig. 62 shows the curves of the same motor running single-phase.

125. **The torque curves of an induction motor with a wound rotor,** from rest to synchronism, running both three-phase and single-phase with resistance and without resistance, are shown in Fig. 63. Curve *A* shows the torque from rest to synchronism without resistance in the rotor circuit. If resistance is inserted, curve *B*

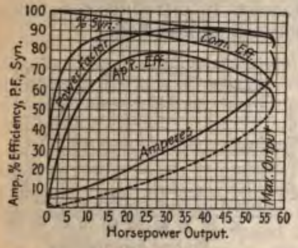


FIG. 61.—Typical performance curves of a 20-h.p., three-phase induction motor.

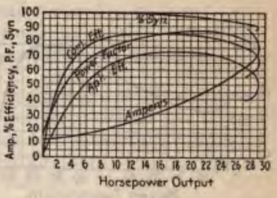


FIG. 62.—Performance curves of the motor shown in Fig. 63, when running single-phase.

is obtained and the starting torque is 440 lb. against 170 lb. without resistance. Curve *C* indicates the torque where too much resistance is used in the rotor. Curve *E* illustrates the torque single-phase, which is zero at starting. An induction motor starts as shown on curve *B* until it reaches the point *F*, when the resistance is cut out and the motor adjusts itself to its operating position at *G*. Thus, if the torque required of the motor for which the curve is shown,

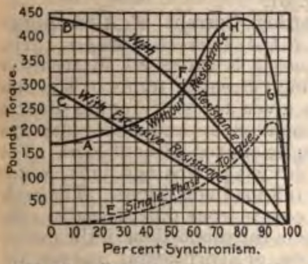


FIG. 63.—Torque curves of a 30-h.p. induction motor.

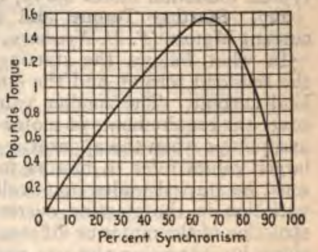


FIG. 64.—Torque curves of a 1-h.p., three-phase induction motor, running single phase.

is greater than 440 lb., shown at *H*, the motor will break down and come to rest. With the resistance in the rotor, a starting torque of 440 lb. is available, but this load cannot be brought up to normal speed. The motor can only bring the torque represented by the point *F*, in other words 290 lb., up to normal speed.

In Fig. 64 it will be noted that the torque of a three-phase motor running single-phase at starting is zero, rising to a maximum and reaching zero at synchronism. This means that an induction motor never runs at synchronous speed. The three-phase motor, Fig. 65, starts with a reasonable torque, reaches its maximum output and goes to zero again at synchronism.

Figs. 65 and 66 show the torque curves of squirrel cage motors without resistance in the rotor circuit. With resistance inserted in the armature, the torque is greater at starting and less later. This is the reason that it is advantageous to introduce resistance at starting and cut it out as synchronism is approached.

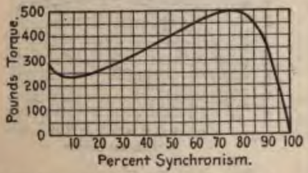


FIG. 65.—Torque curves of a 20-h.p., three-phase induction motor.

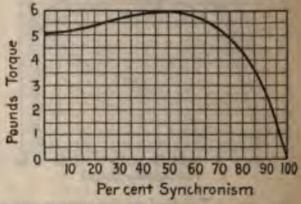


FIG. 66.—Torque curve of a 1-h.p., three-phase induction motor.

126. The Pull-out Torque of an Induction Motor.—All induction motors will "pull out" at some certain torque if they are overloaded. The "pull-out" limit—the maximum torque that can be developed—is that point at which further increase in torque will cause the motor speed to decrease rapidly and then to stop. This point is usually at between 2 and 4 times the full-load rated torque, depending on the design and the capacity of the motor. See the typical induction motor curve, Fig. 61.

127. Starting Torque and Starting Current of Alternating-current Motors (*F. D. Newbury, N.E.L.A. Convention Paper*, 1911). —In what follows the starting torque is expressed in terms of the full-load torque, and the starting current in terms of the full-load current. The smaller values given for synchronous motors cover the requirements of motor-generator sets and air compressors and pumps when the apparatus can be started without load. The larger values refer to motors for driving pumps and fans, which must be started under practically full-load conditions. The wide variation in the starting current comes from differences in construction of the motor or differences in the proportions of the motor, since, by increasing the size and cost of synchronous motors, the starting performances can be materially improved.

SINGLE-PHASE INDUCTION MOTORS, WITH CLUTCH, SPLIT-PHASE STARTER.—Starting torque, 1 to $1\frac{1}{4}$, starting current, $4\frac{1}{2}$ to 6.

SINGLE-PHASE INDUCTION MOTORS, WITHOUT CLUTCH, SPLIT-*PHASE STARTER*.—Starting torque, 2; starting current, $3\frac{1}{2}$ to $4\frac{1}{2}$.

POLYPHASE INDUCTION MOTORS, CAGE-WOUND TYPE, AUTO-*TRANSFORMER* STARTER.—Starting torque, 2; starting current, *to 8.*

POLYPHASE INDUCTION MOTORS, WOUND-ROTOR TYPE, STEP-BY-STEP RESISTANCE STARTER.—Starting torque, 1; starting current, $1\frac{1}{4}$. Starting torque, 2; starting current, $2\frac{1}{2}$.

SYNCHRONOUS MOTORS, AUTO-TRANSFORMER STARTER.—Starting torque, 0.3 to 0.5; starting current, $1\frac{1}{2}$ to $2\frac{1}{2}$. Starting torque, 0.7 to 1; starting current, 4 to 8.

ROTARY CONVERTERS, AUTO-TRANSFORMER STARTER.—Starting torque, 0.2; starting current, $1\frac{1}{2}$. Starting torque, sufficient to start itself.

128. **Speed Regulation of Induction Motors. Slip.**—The speed regulation is the percentage drop in speed between no-load and full-load based on the maximum speed; it is usually called the "slip." The "slip" at full-load is usually about 5 to 7 per cent. At other loads it is approximately proportional to the load, therefore, at twice full-load the drop in speed will be approximately 10 to 15 per cent.

129. **The slip of an induction motor** is the ratio of the difference between the rotating magnetic-field speed (revolutions per minute or angular velocity) and the rotor speed to the rotating magnetic-field speed. The speed of the rotating magnetic field is equivalent to the synchronous speed of the machine (see table of synchronous speeds elsewhere in this section) which is determined by the frequency of the current and the number of poles of the machine. Then:

$$\text{Slip} = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}}$$

When there is no load on a motor the slip is very small, that is, the rotor speed is practically equal to the synchronous speed. Slip varies with the design of the motor and may vary from 4.0 to 8.5 per cent. at full-load in motors of from 1 to 75 h.p. of ordinary design.

Example.—What is the slip at full-load of a 4-pole, 60-cycle induction motor which has a full-load speed of 1,700 r.p.m.

Solution.—From Table 97 or Formula 94 the speed of the rotating field or the synchronous speed of a 4-pole, 60-cycle motor is 1,800 r.p.m. Then substituting in the above formula:

$$\text{Slip} = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}} = \frac{1{,}800 - 1{,}700}{1{,}800} = \frac{100}{1{,}800} = 5.5\%$$

Therefore the slip is 5.5 per cent. The voltage of the motor or whether it is single-phase, two-phase, or three-phase are not factors in the problem.

130. **The Induction Motor Inherently a Constant-speed Motor. The Regenerative Feature.**—A characteristic of the induction motor is that it tends to rotate at a definite synchronous speed irrespective of whether the motor is driving or being driven, providing there is no starting resistance in the rotor circuit. For instance, when a load is being lowered and the motor is connected to a source of energy, it acts as an alternating-current generator, the descending load furnishing the driving power. The motor delivers energy to the line. When load is being raised the motor absorbs energy from the line. *This returning of energy to the line by a motor is termed regeneration.* Consider an installation where cars loaded with ore are lowered down a slope on a railroad and the empty cars are hoisted back. The motor delivers about as muc

power to the line when lowering as it consumes when h
with the result that practically no energy is consumed in op
the system. The proof of this is that the watt-hour me
such an installation runs backward about as much as i
forward.

Another interesting example is a balanced passenger
wherein the passenger cars run over varying grades and
times one is loaded, at other times the other is loaded. Th
when equipped with induction motors connected to a so
energy, run at a practically uniform speed without the use of b
whether the load overhauls the motor or not. This charac
will not obtain if starting resistance is left in the rotor c
for then the motor will slow down in case it is delivering
to the cars and will operate at an over-speed if the cars are d
ing power to the motor. (*Practical Engineer.*)

131. To Reverse the Direction of Rotation of a Polypha duction Motor.—For a two-phase, four-wire motor, inter the connections of the two leads of either phase. For a two- three-wire motor, interchange the two outside leads. For a phase motor, interchange the connections of any two motor

132. A single-phase induction motor, when its rotor revolving, has no starting torque. After the rotor com revolving there is a certain interaction of magnetic fields w there is exerted a continuous turning effort. While such a

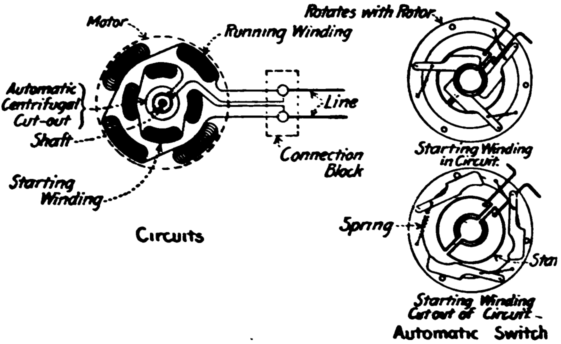


FIG. 67.—Single-phase motor diagram.

can be started by hand by giving the rotor a twist, the mos
mon method of starting is by the so-called split-phase m
With this method the circuit supplying the motor is divid
two circuits and one is arranged in some way so as to hav
siderably more inductance than the other. Each circuit s
a winding.

These windings are called the starting and running w
The current in the starting winding differs in phase by
90 deg. from that in the running winding because of

uctance in the starting circuit. The starting winding is ar-
ged at practically 90 electrical degrees from the running wind-
. This latter winding in the motor shown in Fig. 67 consists
a greater number of turns of larger wire, well distributed over
stator, while the starting winding consists of fewer turns and
considerably smaller wire. In this motor the starting winding
lf is designed so that it has more inductance than the running
ding. In some motors, an inductance coil, carried in the base
the motor, is connected in series with the starting winding to
vide the necessary inductance.

'he running winding remains in the circuit at all times of motor
ration, while the starting one only remains in circuit until the
tor has reached synchronous speed or nearly so. When the
ed is reached at which the starting winding should be cut out,
automatic centrifugal switch (see illustration) operates and
ns the "starting" circuit and the motor continues to operate
ly by virtue of the "running" winding and circuit.

33. **Phase Splitting and Repulsion Starting of Single-phase uction Motors.**—In the former method two windings are used
the stator of the motor; one of these is the working winding,
other the starting winding (see **132**). In some cases an ex-
ial starting box is employed to secure the necessary phase
erence in the current, in others the reactance is part of the
ondary winding itself.

Vhere a single-phase induction motor is started by the "re-
sion" method (see **135**) the rotor is similar to the armature
a direct-current motor, being provided with form wound coils
a commutator. There are two sets of brushes, bearing on
commutator, these sets being short-circuited upon each other.
: stator is supplied with single-phase current, and there is no
trical connection between the stator and the rotor. The
rents in the stator set up a flux which reacts on the rotor, re-
ing the successive coils and thereby causing rotary motion.
en the motor approaches synchronous speed a centrifugal
ice of some description short-circuits the commutator bars
lifts the brushes, transforming the motor into the induction
e with practically a squirrel cage rotor.

34. **The Starting Torque, Starting Current and Speed Regu- on of Single-phase Induction Motors.**—The single-phase in-
tion motor, with phase-splitting starting device, is suitable for
chines in which the starting torque is not over 150 per cent.
full-load torque. Almost invariably some type of clutch is
d which allows the motor to attain nearly synchronous speed
ore picking up the load. The starting current with 150 per
t. of full-load torque is approximately 250 per cent. of full-load
rent, and the maximum torque is from 150 to 200 per cent. of
full-load torque. The speed regulation from no-load to full-
l is good, being better than in the multiphase motor. In gen-
however, the efficiency, power factor and maximum torque
ot as good as in corresponding multiphase motors. They
ited only for driving machinery where the starting torque
d is light. The single-phase induction motor, with th

repulsion method of starting, has a starting torque of from 2 to 2½ times full-load torque, with 2 to 2½ times full-load current. (*A. B. Morrison, Power*, March 4, 1913.)

135. **The condenser-compensator method of starting single-phase induction motors** is shown in Fig. 68. Two terminals of the stator winding, which is practically of the standard three-phase construction, are connected to the supply mains. The third terminal of the stator winding is connected to the line through an auto-transformer. The main to which it is connected is determined by the direction of rotation desired. A condenser is also connected across the transformer to provide capacity. Then when the motor has reached synchronous speed the starting winding can be cut out by opening the switch and the motor then operates upon running winding only.

136. **The compensated repulsion single-phase motor** is one in which the line current passes through the stator and also through the rotor by means of two sets of brushes bearing on the commutator. There is also a second set of brushes set at an angle to the first which are short-circuited on themselves. This motor differs from the straight repulsion type in that it contains two additional sets of brushes and the stator and rotor are in electrical contact.

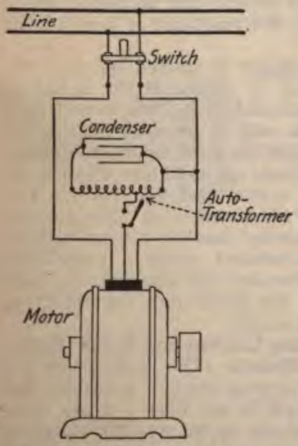


FIG. 68.—A single-phase, self-starting induction motor with a condenser starting arrangement.

137. **The compensated repulsion motor has a starting torque** of 2½ to 3 times full-load torque with approximately twice full-load current, and the maximum torque is from 3 to 3½ times full-load torque. The power factor is very high at all loads, but the efficiency is lower than in the induction motor. This type of motor is well adapted for loads where heavy starting torque is required with sudden overloads. It has the disadvantages of having a commutator and is somewhat more noisy than the induction motor after the latter is up to speed. (*A. B. Morrison, Jr., Power*, March 4, 1913.)

138. **If a variable-speed single-phase motor is required,** some form of compensated repulsion motor is generally used. The behavior of the motor is very similar to that of the variable-speed wound-rotor multiphase-induction motor with resistance in series with the rotor. It is consequently, owing to its unstable speed characteristics, suited only to such applications as require a steady horse-power at given speeds. Its characteristics as regards starting torque, etc., are unchanged when used for variable speed. The resistance is inserted in series with the brushes which

normally short-circuited and the insertion of additional resistance decreases the speed. By the insertion of resistance in series with the brushes carrying the line current it is also possible to raise the speed of the motor slightly above synchronism.

139. Approximate Data on Single-phase Induction Motors, 110 to 440 Volts (*Electric Motors, Crocker and Arendt*).—The synchronous or no-load speed of any induction motor is determined by the number of its poles and the frequency. See **94.** Very small single-phase motors, such as fan motors, may not show performances as good as those tabulated below. Pull-out or "break-down" torque as tabulated is in terms of rated full-load torque.

Horse-power	No. of poles	Per cent. slip	Pull-out torque	Per cent. power factor at given loads				Per cent. efficiency at given loads				Synchronous speed at 60 cycles
				½	¾	Full	1¼	½	¾	Full	1¼	
½	4	6.0	1.5	46	58	66	68	53	60	63	60	1,800
1	4	4.0	1.6	55	59	73	75	60	63	68	62	1,800
2	4	2.5	1.8	56	65	77	76	71	75	78	77	1,800
5	4	2.5	1.8	78	83	86	86	71	76	77	76	1,800
10	4	2.5	1.8	75	81	84	83	75	79	80	79	1,800
20	6	2.0	1.9	78	80	86	87	85	88	86	85	1,200
30	8	2.0	1.9	68	80	85	84	77	81	83	82	900
50	4	2.3	2.0	91	94	93	91	82	84	86	86	1,800

140. Synchronous motors (*Carl D. Knight, Practical Engineer*, June 1, 1912).—Generally speaking, any modern alternating-current generator will operate with more or less satisfaction as a synchronous motor, and unless special operating features must be provided for, the two are often identical in construction.

There are two advantages of the synchronous motor, namely: it operates at a constant speed at all loads, provided the driving alternator runs at a constant speed, and its power factor is at all times under the control of the attendant; it can be used to correct low power factor of the system that feeds it in addition to driving a mechanical load, provided it has sufficient capacity.

The latter characteristic is often of considerable importance. It is well known that the power factor of the induction motor, even under full-load conditions, is seldom greater than 95 per cent., and it often falls as low as 50 or 60 per cent. at light load. The result is that an alternating-current generator driving a considerable number of induction motors ordinarily operates at a comparatively low power factor. If this alternator is loaded to its full kilowatt capacity at such a low power factor, overheating will result.

If the alternator is not loaded beyond its normal current capacity *it operates at a low energy* load but with the same heating losses *as at full-load,* on account of the reduced power factor. The ad-*vantage of the synchronous* motor on such a system is, that by *proper adjustment of its* field current it may be made to draw from *the line a current* which is leading with respect to the voltage and which will neutralize the lagging current taken by the induction motors. The current in the alternating-current generator can thereby be brought into phase with the voltage and the generator will operate under its normal conditions. When used in this manner as a compensator for lagging current, the synchronous motor must be of larger size than required by its power output, on account of the excess current which it draws from the line.

141. A synchronous condenser is a synchronous motor that operates to correct power factor only and does not pull any mechanical load.

142. Disadvantages of the Synchronous Motor.—To offset its advantages, the synchronous motor has disadvantages which ordinarily limit its application to relatively large capacities, and to installations where it can be used as a compensator for lagging current. The chief disadvantage is that the motor has small starting torque even at full-load current. The motor also requires a supply of direct current for its field excitation.

143. The Uses of Synchronous Motors (*Standard Handbook*).—Due to the fact that synchronous motors require more care than induction motors, are not self-exciting and are started with some difficulty, synchronous motors are seldom employed where induction motors can be used. Where an induction motor would be objectionable on account of the large lagging wattless currents which affect the voltage regulation, a synchronous motor may be used to advantage. It is also used as a "synchronous condenser" in connection with induction motor loads for power factor correction as noted above.

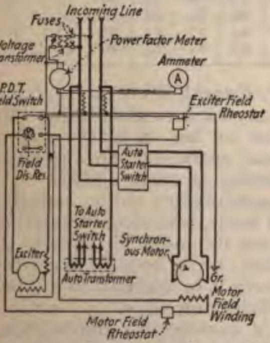


Fig. 69.—Connections for a self-starting synchronous motor.

144. The steps in starting a synchronous motor are about as follows:

(1) See that motor is clean, that bearings are well supplied with oil, and that oil rings are free to turn.

(2) See that all switches are open.

(3) Close the double-throw field switch, cutting in the field rheostat with its resistance all in.

(4) Close the main-line switch (if any) in the circuit and throw in the double-throw switch, throwing it in the starting position. The motor should start and speed up to synchronism in from 30 to 60 sec.

(5) When motor is up to speed, throw field switch over to the other (running) position with rheostat all in.

(6) Throw double-throw main switch over to running position, putting motor on full line voltage.

(7) Adjust field rheostat for minimum armature current.

Fig. 69 shows the method of connecting a three-phase, se tarting synchronous motor to its exciter. This diagram sh a double-throw switch in the field circuit. This switch, however, may (where the exciter is connected to the same shaft as the synchronous motor) be single-throw and the field connected direct through the exciter armature with the rheostat in the circuit. The field is thus short-circuited at standstill and is gradually charged as the motor speeds up.

145. **Starting Synchronous Motors.**—Practically any polyphase synchronous motor may be started by applying full-load voltage to the armature, leaving the field open until the motor has reached its normal speed. Such a procedure would require, however, 2 or more times the full-load current of the machine. Since the power taken by a synchronous motor starting in this manner is of very low power factor, the line disturbances might be considerable. Starting at full line voltage is also liable to induce in the field windings an excessively high voltage, often resulting in breaking down the insulation.

To limit the starting current to a reasonable value, auto starters or compensators are often used. These are similar and used in exactly the same manner as the starting compensators used with induction motors. When starting with a compensator the field-winding circuit is opened by a switch provided for the purpose or the field circuit may be closed through a resistance until the motor has attained its normal speed.

This arrangement does not provide a great starting torque, and in most modern synchronous motors the revolving field of the motor is provided with a special auxiliary winding similar to the winding on the rotor of a squirrel cage induction motor. It has been possible to construct motors having nearly 30 per cent. of full-load torque at approximately $1\frac{1}{2}$ times full-load current. Beside improving the starting torque this squirrel cage winding also has a tendency to reduce the hunting or pumping effect which is sometimes encountered in the operation of synchronous motors.

Where the motor to be started is comparable with the size of the generator which drives it, it is often necessary to connect a small induction motor to the synchronous motor to bring it up to speed. When approximately normal speed has been reached the synchronous motor is thrown on the line as before, and the field closed immediately.

When a large starting torque is required, as, for example, in driving a considerable amount of shafting, it is often impractical to start the load and the motor from rest simultaneously. In such instances it is customary to install a friction clutch or similar device between the motor and its load, so that the motor may attain its normal speed before any load is imposed upon it.

Occasional installations are encountered where the motor is the only load on the driving generator. In such cases it is possible to connect the synchronous motor to the line before starting the alternator. On starting the alternator, both will come up to speed together.

Cases have been known in which the motor was a small part of the load on the driving alternator, that is, the alternator was larger compared with the motor, when an auto starter was used to raise the voltage at start instead of to reduce it. This method gives a fairly good torque, but requires large current, and the operator must be certain that the motor windings will not be damaged before trying such a method.

In cases where it is desired to use an alternating-current generator as a motor and no compensator is available, water rheostats can be used to good advantage, one being placed in series with each phase. They are short-circuited when the motor has attained normal speed. (*Practical Engineer.*)

TROUBLES OF ALTERNATING-CURRENT MOTORS AND GENERATORS, THEIR LOCALIZATION AND CORRECTION

146. Troubles of Alternating-current Machinery.—Much of the material under this heading is based on that in the book *Motor Troubles*, by E. B. Raymond. For further data relating to alternating-current-machinery troubles and their correction see the author's ELECTRICAL MACHINERY, published by the McGraw-Hill Book Company.

147. Induction Motor Troubles (*H. M. Nichols, Power and the Engineer*).—The author asserts that the unsatisfactory operation of an induction motor may be due to either external or internal conditions. The voltage or the frequency may be wrong, or there may be an overload on the machine. Low voltage is the most frequent cause of trouble. The starting current sometimes amounts to twice the running current, with the result that the voltage is particularly low at starting. The best remedy for this disorder is larger transformers and larger motor leads, one or both. The troubles that occur most frequently within the motor itself are caused by faulty insulation, and by uneven air gap due to the springing of the motor shaft or to excessive wear in the bearings. If a wound-rotor machine refuses to start, the trouble may be due to an open circuit in the rotor winding. A short-circuited coil in the motor will make its existence known by local heating in the latter. Most motors designed to employ a starting resistance will not start at all if the resistance be left out of the secondary circuit.

148. Troubles of Alternating-current Generators (*Westinghouse Instruction Book*).—The following causes may prevent alternating-current generators from developing their normal e.m.f.:

The speed of the generator may be below normal.

The switchboard instruments may be incorrect and the voltage may be higher than that indicated, or the current may be greater than is shown by the readings.

The voltage of the exciter may be low because its speed is below normal, or its series field reversed, or part of its shunt field reversed or short-circuited.

The brushes of the exciter may be incorrectly set.

A part of the field rheostat or other unnecessary resistance may be in the field circuit.

The power factor of the load may be abnormally low.

149. Causes of Shutdowns of Induction Motors.—Sometimes there is trouble from blowing fuses. Or possibly, and more serious, the fuses do not blow and the motor, perhaps humming loudly, comes to a standstill. Under these conditions, the current may be 10 times normal, so that the heating effect, being increased as the square of the current or 100 fold, causes the machine to burn out its insulation.

Since the torque or turning power of an induction motor is proportional to the square of the applied voltage (one-half voltage produces only one-quarter torque), it is evident that lowering the voltage has a decided effect upon the ability of the motor to carry load, and may be the cause of its stopping. Another cause may be that the load on the motor is more than equal to its maximum output.

The bearings may have become worn, so that the air-gap (which ordinarily is not much over 0.040 in. and on small motors as small as 0.015 in.) has been gradually reduced at the lower side of the rotor to practically zero. The rotor commences to rub on the stator. The friction soon becomes so great that it is more than the motor can carry. The result is that it shuts down.

A shut-down may be due to bearings introducing excessive friction. Hot bearings, in turn, may be due to excess of belt tension, dirt in the oil, oil rings not turning, or to improper alignment of the motor to the machine that it drives. Hence, under such conditions, it should be ascertained whether the voltage has been normal, whether the air-gap is such that the armature is free from the field, and whether the load imposed upon the motor is more than that for which it was designed. In any installation a system should be arranged whereby an inspector will examine the gap, bearings, etc., periodically.

Rarely, shutting down may be due to the working out of the starting switch, which may be located within the armature. Such a switch is operated by a lever engaging a collar which bears on contacts which, as they move inward, cut out the resistance in series with the rotor winding and located within it.

If the short-circuiting brushes work back, introducing resistance into the armature circuit while the machine is trying to carry load, it will at once slow down in speed and probably stop, usually burning out the starting resistance. Of course, this can occur only from faulty construction. The remedy is to fit the brushes properly, so that they will not work out. It is well to inspect them at the time of air-gap inspection.

150. Low Torque while Starting Induction Motors.—Although the circuit to the motor be closed, sometimes it does not start. The same general laws of voltage, etc., apply to the motor at starting as when running. Hence, the points mentioned under "Shut-downs" should be investigated and if necessary corrected. *The resistance, which is* frequently inserted in the armature, may *be short-circuited, thus* giving a low starting torque. Unless *starting compensator is* used for starting, it is necessary, in ord*to obtain a proper starting* torque with a reasonable current, *a resistance be inserted* in the rotor circuit. The resistanc only limits the current, which would, with the motor standing still, be large, but it causes the current of the armature to assume a more effective phase relation, so that with the same current a far larger torque is obtained. A partial or complete short-circuit of the resistance partially or wholly ruins the starting torque.

151. Low Maximum Output of Induction Motors.—The maximum load which a motor can carry may be less than desired, or less than the name plate indicates. If the voltage, air-gap, load, etc., are right, it may be possible that a mistake has been made in connections. It is then easiest to return the motor to the factory, but if immediate operation is essential, the armature connections can easily be changed so as to give a large increase in output. To ascertain what to do, remove the bracket on the side of the motor which covers the connections between the coils. Each motor has a certain number of poles. Pick out one phase, and find out how many groups of coils are connected up. From this, the number of poles can be determined. A better way is to calculate this from the speed of the motor and the frequency of the circuit on which it is running. See 94.

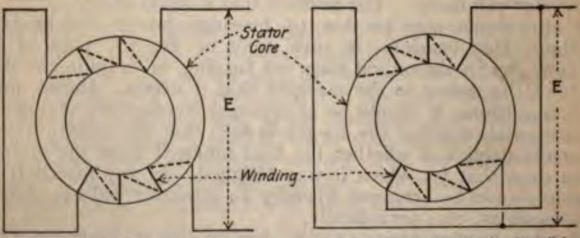


FIG. 70.—Connections of induction-motor coils.

From an examination of the connections it can be easily determined whether the poles in any place are connected in series or in multiple, or in series-multiple. Thus, in a motor, the connections may be as shown in Fig. 70, *I*, which shows the windings of one phase of a four-pole motor. If the connections be changed to those in Fig. 70, *II*, each coil will then receive double its former voltage and the motor will give four times the output. Before making a change in connections such as that indicated here one must ascertain to a certainty that the increased current that will result will not injure the windings.

It should be borne in mind, however, that this makes the motor less efficient, increasing the exciting current, and thus lowering the power factor. If conditions demand it, this method may be followed. The temperature under the new conditions should be carefully watched to see that there is not undue heating. The only change in connections that can be used for quarter-phase motors is of the type of the one just described.

With three-phase motors the poles can be grouped not only as previously suggested, but a variation of connections from delta to star, or the reverse, can be made. A delta-connected, two-pole motor is shown in Fig. 71, *I*, where the three phases are indicated by the letters, *A*, *B* and *C*. Any one of these phases may have poles connected in either series or multiple. In a delta connection with the coils spaced 120 deg. apart, as shown in Fig. 71, *I*, each phase has the line voltage *E*.

In the star connection the phases are joined as in Fig. 71, *II*. In this case, as in Fig. 71, *I*, each phase may have poles in series or in multiple. In the case of Fig. 71, *II*, each coil has a voltage of $0.58 \times E$.

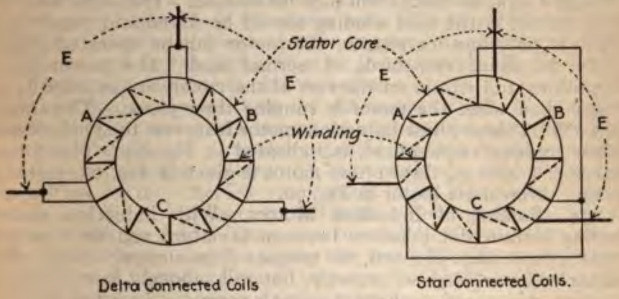


FIG. 71.—Three-phase motor coil connections.

152. Winding Faults of Induction Motors.—When a new induction motor is received, it sometimes happens that in attempting to operate the machine, although it will start, the currents are excessive and unbalanced, undue heating appears or a peculiar noise is emitted and accompanied possibly by dimming of the lights on the same circuit and the lowering of speed with perhaps actual shut-down of other induction motors thereon. If, after examination, there is found to be no difficulty with the air gap, belt tension, starting resistance or bearings, the probabilities are that the coils of the motor have been wrongly connected or that the winding has been damaged during transportation. Certain indications of these conditions are shown by instrument readings. The winding faults in a three-phase motor may be:

1. One coil of the rotor may be open-circuited. The armature or rotor may have a defective winding just as may the field. A coil-wound rotor construction is used only when a starting resistance is used. When a compensator is used no starting resistance is required, and the winding consists simply of bars connected at the ends by a ring.

2. Two coils or phases of the armature may be open-circuited.

3. Armature may be connected properly but field coil or phase may be reversed.

4. *Part of field may be short-circuited.*

5. *One phase of field may be open-circuited.*

The symptoms shown for certain of these trouble conditions are indicated in the following data from actual tests on a 5-h.p., six-pole, 1,200 r.p.m., 60-cycle induction motor.

153. **With an open circuit in field or stator in a three-phase** motor, current would flow only in two legs. There would be no current in the other leg and the motor would not start from rest with all switches closed. However, a three-phase motor or a two-phase motor will run and do work single-phase if it is assisted in starting. The starting torque is zero, but as the speed increased the torque increases.

With a small motor, giving a pull on the belt will introduce enough torque so that it will pick up its load. Therefore while an open circuit in the field winding should be found and repaired, if there is not time for repairs, the motor can be operated single-phase to about two-thirds of normal load. The power factor conditions and effects on the rest of the circuit are practically no worse than when the motor is running three-phase. The torque of a 1-h.p., three-phase induction motor from rest to synchronism, when running single-phase, is indicated in Fig. 64. The torque curve of a 20-h.p., three-phase motor is given in Fig. 65, and of a 1-h.p., three-phase motor in Fig. 66.

154. **Balking of Induction Motors.**—With induction motors having certain slot relations between armature and field, at one certain percentage of speed, the torque will go almost to zero. The motor will start its load properly, but will suddenly lose its torque at some slow speed, perhaps one-tenth normal. Such trouble may be caused by a magnetic locking effect of the teeth of the armature with the poles of the field. This phenomenon, with ordinary measuring instruments and facilities cannot easily be measured. But with special torque measuring instruments the peculiar synchronous locking can be measured and exactly located. If all other investigations show no cause of weak torque during the rise of the speed from rest to synchronism, the relation between the number of poles and slots in the rotor may account for the trouble. This is an unusual condition, but on squirrel cage motors it has existed. There is no remedy but a change in design, so that the manufacturer must take action for correction.

155. **Squirrel Cage Armature or Rotor Troubles.**—Unusual operation due to reversals of phase, phases open-circuited, and other causes, occur with squirrel-cage armatures as well as with wound armatures. Poor soldering of the armature bars may be the cause. Sometimes a solder flux may be used that will insure proper operation for a while, but time will develop poor electrical contacts due to chemical action at the joints. If the resistance of all of the squirrel cage joints are uniformly high, the effect is simply like that of an armature having a high resistance, which causes a lowering of the speed and local heating at the joints. If some of the joints are perfect, but some bad, the motor may not have the ability to come up to speed and there will be unbalanced currents.

156. **Effects of Unbalanced Voltages on Induction Motors.**—The maximum output of a polyphase induction motor m...

naterially decreased if the voltages impressed on the differen phases are unequal. On a three-phase system, the three voltage between the legs 1–2, 2–3 and 1–3 should be approximately equa Also on a two-phase the voltage 1–2 should equal 3–4. If thes voltages, impressed on the induction motor, are not equal th maximum output of the motor as well as the current in the variou legs is proportionately affected.

For example, with a two-phase motor, if the voltages in the tw legs differ by 20 per cent., a condition sometimes met in norma practice, the output of the motor may be reduced 25 per cent Then, instead of being able to give its maximum output of, say 150 per cent. for a few moments, it will give but 112 per cent The varying loads which the motor may have to carry may shu it down. In cases of low maximum output, the relative voltage on the various legs should always be investigated. If they vary the trouble may be due to this variation.

In addition to the effect on the maximum output, the unequa distribution of current in a two-phase motor under such condition may be quite serious. Consider a specific case of a 15-h.p., six-pole 1,200-r.p.m., 220-volt motor, with the voltage on one leg 220 an the voltage on the other leg 180; current in leg No. 1 was 60 amp and in leg No. 2 35 amp. at full-load. The normal current a full-load was 35 amp. Thus the fuse might blow in the phas carrying the high current, causing the motor to run single-phase If an attempt is made to start the motor the blown fuse not bein noticed, there would be no starting torque.

Consider the specific case of a six-pole, 10-h.p., 1,200-r.p.m 160-volt, three-phase motor. The motor on normal voltage, a full-load, took 110 amp. in each leg. With unbalanced voltage of 161, 196 and 168, only full-load could be carried, althoug the average of these voltages is such that it might be assume that 25 per cent. overload should be carried.

157. Induction Motor Starting Compensator Troubles.—Some times a mistake is made in the connections to the compensator so that full voltage is used at starting and the lesser voltage afte throwing over the switch. Then the motor at starting take excessive current, and, since the maximum output is in proportio to the square of the voltage, the motor capacity is much reduce when it is apparently running on the operating position. Suc action, therefore, can usually be accounted for by a wrong connec tion in the compensator. Sometimes a motor connected to compensator takes more current at starting than it should, unde which conditions a lower tap should be tried. Compensators ar usually supplied with various taps and the one should be selecte which produces the least disturbance on the line, giving at th same time the desired starting torque on the motor.

When a motor, having been connected to a compensator, wi not start, the cause may be entirely in the compensator. T *compensator may have become open-circuited, due to a f within. The switch may have become deranged, so that it not close, or a connection within the compensator may ecome loosened. Possibly,* when a motor will not start connected to a compensator just installed, a secondary coil may be "bucked" against another secondary coil within the compensator so that no voltage is produced by the compensator at the motor. This results in no particular heating and in no apparent phenomenon which would account for the motor not starting. An ammeter in the motor leads will indicate the absence of current, or a voltmeter will indicate the absence of voltage.

158. Induction Motor Collector Ring Troubles.—It is essential that the contact of the brushes on the collector rings be good, else the contact resistance will be so great as to slow the motor down and to cause heating of the collector itself. This effect is particularly noticeable when carbon brushes are used. The contact resistance of a carbon brush under normal operation pressure and carrying its usual density of current (40 amp. per square inch) is 0.04 ohm per square inch. Thus, under normal conditions, the drop is 0.04×40, which equals 1.6 volts. If the contact is only one-quarter the surface, this drop would be 6.4 volts, and might materially affect the speed of the motor. Thus, if the speed is below synchronous speed more than it should be (normally it should not be over 4 per cent. below), an investigation of the fit of the brush upon the collector may show up the trouble.

If copper brushes are used, this trouble is much less liable to occur, since the drop of voltage, due to contact resistance when running at normal density (150 amp. per square inch), is only one-tenth that of carbon. The same trouble may occur due to the pigtail, which is usually used with carbon brushes, making poor contact with the carbon, which gives the same effect as a poor contact with the collector itself.

159. Hunting of Induction Motors.—In very rare cases an induction motor will hunt and cause much trouble. The phenomenon appears as a speed variation of 1 or 2 per cent. each side of the normal speed, with a period of vibration depending upon the conditions. It may be anywhere from 10 to 500 swings a minute.

This rare phenomenon of induction motors depends upon the drop in the line between the generator operating the induction motor and the motor itself, and upon the design and slot relations of field and armature. It will cease if the line resistance be cut out between the motor and the generator. If this is not possible, it can sometimes be stopped on a three-phase motor by changing from delta- to Y-connection, or possibly the grouping of the poles may be changed. In any case, the flux in the motor is altered.

The period of hunting has nothing whatever to do with the hunting of the generator. Hunting of a motor may occur even though the generator speed is exactly uniform. This action is entirely distinct from a variation of the uniformity of the speed of the generator due to the engine driving, which lack of uniformity is repeated by the motor itself. It is more vicious and usually results in a gradual increase of amplitude of swing until the motor finally gets swinging so badly that it finally breaks down and stops entirely. Ordinarily, the manufacturer is responsible, but a change of connections will often cure the trouble and keep the apparatus in operation until a permanent correction can be effected.

160. Improper End Play in Induction Motors.—Induction motors are so designed that the revolving parts will play endwise in the bearing; $\frac{1}{16}$ in. or so. If in setting up the machine the bearings so limit this end action that the rotor does not lie exactly in the middle of the stator, there is a strong magnetic pull tending to center the rotor. If the bearings will not permit this centering, the thrust collars must take the extra thrust which, in an induction motor, is considerable. If in addition to the magnetic thrust the belt pull is such as to also draw in the same direction, the trouble is increased. The end force may be such as to heat the bearing excessively and to cause cutting, soon rendering the motor inoperative.

In case of trouble with bearings, the end play should be tested by pushing against the shaft with a small piece of wood, placed on the shaft center. With the machine operating under normal conditions there should be no particular difficulty in pushing the shaft first one way from one side, and then the other way from the other side. If it is found that the revolving part is hugging closely against one side, the trouble can be corrected either by pressing the spider along the shaft in a direction toward which the hugging is occurring, or by driving the tops of the lamination teeth in the same direction. With a wooden wedge, the tops of the teeth can often be without any difficulty driven over $\frac{1}{8}$ to $\frac{3}{16}$ in. This movement will usually correct the trouble. Driving the teeth of the stator $\frac{1}{8}$ in. or so in the opposite direction to that of the end thrust will usually accomplish the same result. It is best to choose the teeth (stator or rotor) which are most easily driven over. The thin long ones move easier than do the short broad ones.

161. Oil Leakage of Induction Motors.—Sometimes a bearing will permit oil to be drawn out, perhaps a very little at a time. Ultimately enough will accumulate to show on the outside or on the windings of the machine. While a motor will run for a period with its windings wet with ordinary lubricating oil without being apparently injured, insulation soaked with oil will deteriorate and eventually fail.

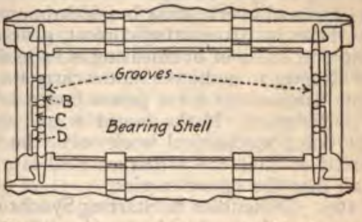


Fig. 72.—Grooves to prevent oil leakage.

One of the principal causes is a suction of the oil due to the drafts of air from the rotor, and one of the best methods of stopping the trouble, under ordinary conditions, is to cut grooves as shown in Fig. 72 at *B* and *D*. These grooves on a 50-h.p. motor *may be* $\frac{1}{8}$ *in.* deep and $\frac{3}{16}$ in. wide. Each groove *has three holes drilled* through the bearing shell to convey the oil *collected by the grooves* into the oil well. These grooves are just s *effective with a split* as with a solid bearing. It is impossible ere *to go into the various* causes of oil leakage. The grooves a ggested *are a general* remedy and cover many cases.

162. General Summary of Synchronous-Motor Troubles.—Failure of a synchronous motor to start is often due to faulty connections in the auxiliary apparatus. These should be carefully inspected for open circuits or poor connections. An open circuit in one phase of the motor itself, or a short-circuit will prevent the motor from starting. Most synchronous motors are provided with an ammeter in each phase, so that the last two causes can be determined from their indications—no current in one phase in case of an open circuit, and excessive current in case of a short-circuit. Either condition will usually be accompanied by a decided buzzing noise, and in case of a short-circuited coil, it will often be quickly burned out. The effect of a short-circuit is sometimes caused by two grounds on the machine.

Starting troubles should never be assumed until a trial has been made to start the motor light, that is, with no load except its own friction. It may be that the starting load is too great for the motor.

If the motor starts but fails to develop sufficient torque to carry its load when the field circuit has been closed, the trouble will usually be found in the field circuit. First, determine whether or not the exciter is giving its normal voltage. Assuming the exciter voltage to be correct, the trouble will probably be due to one of the following causes. (1) Open circuit in the field winding or rheostat or (2) short-circuit or reversal of one or more of the field spools. Open circuit can often be located by inspection or by use of the magneto.

The majority of field troubles are caused by excessive induced voltage at start, or by the field circuit being broken. This excessive voltage may break down the insulation between field winding and frame or between turns on any one field spool, thus short-circuiting one or more turns, or it may even burn the field conductor off, causing an open circuit.

Causes of overheating in synchronous motors are about the same as those in alternating-current generators. Probably the most common cause of overheating is excessive armature current due to an attempt to make the motor carry its rated load, and at the same time compensate for a power factor lower than that for which it was designed. If the motor is not correcting low power factor, but doing mechanical work only, the field current should be adjusted so that the armature field is a minimum for the average load that the motor carries.

163. Difficulties in Starting Synchronous Motors.—A synchronous motor is weaker in starting than is an induction motor. In general, however, a synchronous motor will start itself and perhaps a very light load. Starting requires no field current as the flux which tends to start the motor is not the flux that operates it when it is up to speed. In starting, the field current is lagging, and a lagging current tends to pull down the voltage on the supply circuit, hence tends to lower the applied voltage. The starting torque, as in an induction motor, is proportional to the square of the applied voltage. For example, if the voltage is halved, the starting effort is quartered. When a synchronous motor will no start, it may be because the voltage on the line has been pulled down below the value necessary for starting.

In general, at least half voltage is required to start a synchronous motor. Difficulty in starting may also be caused by an open circuit in one of the lines to the motor. Assume the motor to be three-phase. If one of the lines is open the motor becomes single-phase, and no single-phase synchronous motor, as such, is self starting. The motor will, therefore, not start, and will soon get hot. The same condition is true of a two-phase motor, if one of the phases is open-circuited.

Difficulty in starting may be due to a rather slight increase in static friction. It may be that the bearings are too tight, perhaps from cutting during the previous run. Excessive belt tension, in case the synchronous motor is belted to its load, or any cause which increases starting friction will probably give trouble. Difficulty in starting may be due to field excitation being on the motor. After excitation exceeds one-quarter normal value, the starting torque is influenced. With full field on, most synchronous motors will not start at all. If the proper voltage is applied to a motor, and the circuits are all closed except the field circuit and the friction is a minimum, and still the motor will not start, the fault is probably with the manufacturer. Pole pieces often receive extra starting windings or conducting bridges are provided between the pole pieces to assist in starting. Possibly the manufacturer in shipping may have omitted these devices. In such cases one must refer to the factory.

Usually compensators are used for starting synchronous motors. If there is a reversed phase in a compensator, or, if the windings of the armature of the synchronous motor are connected incorrectly, there will be little starting torque. Incorrect connection can be located by noting the unbalanced entering currents. Readings to determine this unbalancing should be taken with the armature revolving slowly. The revolving can be effected by any mechanical means. While the motor is standing still, even with correct connections, the armature currents of the three phases usually differ somewhat. This is due to the position of the poles in relation to the armature, but when revolving slowly, the currents should average up. If the rotor cannot be revolved mechanically, similar points on each phase of the armature must be found. Then when the rotor is set successively at these points the currents at each setting should be the same. Each phase when located in a certain specific position as related to a pole, should, with right connections, take a certain specific current. With wrong connections, the currents will not be the same.

164. Open Circuit in the Field of a Synchronous Motor.—If in the operation of a synchronous motor the field current breaks for any reason, *the armature current will largely increase, causing either a shut-down or excessive heat. It becomes important, therefore, in synchronous motors to have the field circuit permanently established.*

165. Short-circuit in an Armature Coil of a Synchronous Motor.—*A short-circuit in an armature coil of a synchronous mo*

16

burns it out completely, charring it down to the bare copper. When this occurs, the symptoms are so evident that there is no difficulty in identifying the trouble. Such a coil may under ordinary circumstances be cut out and operation continued. In an induction motor, the current in the short-circuited coil rises only to a certain value, but heats it many times more than normal. It is not necessarily burned out immediately, and perhaps it may not be burned out at all.

166. **Hunting of Synchronous Motors.**—Synchronous motors, served by certain primary sources of energy, tend to "hunt." The periodicity of the swinging is determined by properties of the armature and the circuit. It may reach a certain magnitude and there stick, or the swinging may increase until finally the motor breaks down altogether. This trouble usually occurs on long lines having considerable resistance between the source of energy and the synchronous motor. Sometimes it occurs under the most favorable conditions. Irregular rotation of a prime mover, such as a single-cylinder steam engine, is often responsible for the trouble. The usual remedy is to apply to the poles, bridges of copper or brass in which currents are induced by the wavering of the armature. These currents tend to stop the motion. Different companies use different forms of bridges. When hunting or pulsating occurs, and the motor is not already equipped with bridges, it is best to consult the manufacturer. In general, the weaker the field on a synchronous motor, the less the pulsation. Sometimes pulsation may be so reduced that no trouble results by simply running with a somewhat weaker field current.

167. **Improper Armature Connections in Synchronous Motors.**—This trouble usually manifests itself by unbalanced entering currents and by a negligible or very low starting torque. The circuits should be traced out and the connections remade until the three entering currents for three-phase, or the two entering currents for two-phase, are approximately equal. These currents will not be equal even with correct connection when the armature is standing still.

168. **Polarity of Synchronous Motors.**—Since the winding of a synchronous motor armature is in series all the way around the circumference and under all of the poles, except in exceedingly rare cases, the trouble from a reversed pole is much less serious than with an induction motor or direct-current machine. With a reversed pole everything operates fairly well. The only trouble is that the fields require more current than they should because of the pole that is opposing the field. If, therefore, excessive field current is required for minimum input to a motor, it is a good plan to test the polarity of all the spools with a compass.

169. **Bearing troubles of synchronous motors** are similar to those of induction motors. A difference is that, with a synchronous motor, the air-gap between the revolving element and the poles is relatively large, so that the wearing of the bearing, which throws the armature out of center, is not so serious as with an induction motor. End play should be treated the same as with an induction motor.

170. Bearing Troubles of Motors and Generators.—Modern generators and motors have self-oiling bearings. They should be filled to such a height that the rings will carry sufficient oil upon the shaft. If the bearings are too full, oil will be thrown out along the shaft. Watch the bearings carefully from the time the machine is first started until the bearings are warmed up, then note the oil level. The expansion of the oil due to heat and foaming raises the level considerably during that time. The oil should be renewed about once in six months, or oftener if it becomes dirty or causes the bearings to heat.

The bearings must be kept clean and free from dirt. They should be examined frequently to see that the oil supply is properly maintained and that the oil rings do not stick. Use only the best quality of oil. New oil should be run through a strainer if it appears to contain any foreign substances. If the oil is used a second time it should first be filtered and, if warm, allowed to cool. If a bearing becomes hot, first feed heavy lubricant copiously, loosen the nuts on the bearing cap, and then, if the machine is belt connected, slacken the belt. If no relief is afforded by these means, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze." Renew the oil supply before starting again. A new machine should always be run at a slow speed for an hour or so in order to see that it operates properly. The bearings should be inspected at regular intervals to insure that they always remain in good condition. The higher the speed, the more care should be taken in this regard.

A warm bearing or "hot box" is probably due to one of the following causes: (1) Excessive belt tension. (2) Failure of the oil rings to revolve with the shaft. (3) Rough bearing surface. (4) Improper lining up of bearings or fitting of the journal boxes.

STARTING AND CONTROLLING DEVICES FOR MOTORS

171. The National Code rules require that each motor and its starter be protected by fuses or a circuit-breaker and controlled by a switch which must plainly indicate whether on or off. The switch and cut-out (fuses or circuit-breaker) are preferably located near the motor and in plain sight of it. All wiring should be neat and workmanlike and the wires should be run in conduit wherever possible.

172. Speed Control of Direct-current Electric Motors. Rheostats (*The Electric Controller & Mfg. Company*).—A direct-current motor of any capacity, when its armature is at rest, offers a very low resistance to the flow of current and an excessive and perhaps destructive current would flow through it if it were connected directly across the supply mains while at rest. Consider a motor adapted to a normal full-load current of 100 amp. and having a resistance of 0.25 ohm; if this motor were connected across a 250-volt circuit a current of 1,000 amp. would flow through its armature—in other words, it would be overloaded 900 per cent. with consequent danger to its windings and also to the driven mach

In the case of the same motor, with a rheostat having a resistance of 2.25 ohms inserted in the motor circuit, at the time of starting the total resistance to the flow of current would be the resistance of the motor (0.25 ohm) plus the resistance of the rheostat (2.25 ohms), or a total of 2.5 ohms. Under these conditions exactly full-load current, or 100 amp., would flow through the motor, and neither the motor nor the driven machine would be overstrained in starting. This indicates the necessity of a rheostat for limiting the flow of current in starting the motor from rest.

An electric motor is simply an inverted generator or dynamo, consequently when its armature begins to revolve a voltage is generated within its windings just as a voltage is generated in the windings of a generator when driven by a prime-mover. This voltage generated within the moving armature of a motor opposes the voltage of the circuit from which the motor is supplied, and hence is known as a "counter-electromotive force." The net voltage tending to force current through the armature of a motor when the motor is running is, therefore, the line voltage minus the counter-electromotive force.

In the case of the motor above cited, when the armature reaches such a speed that a voltage of 125 is generated within its windings, the effective voltage will be 250 minus 125, or 125 volts, and, therefore, the resistance of the rheostat may be reduced to 1 ohm without the full-load current of the motor being exceeded. As the armature further increases its speed, the resistance of the rheostat may be further reduced until, when the motor has almost reached full speed, all of the rheostat may be cut out, and the counter-electromotive force generated by the motor will almost equal the voltage supplied by the line so that an excessive current cannot flow through the armature.

In practice, a rheostat is provided for starting a direct-current electric motor. The conductor providing the resistance is divided into sections and is so arranged that the entire length or maximum resistance of the rheostat is in circuit with the motor at the instant of starting and that the effective length of the conductor, and hence its resistance, may be reduced as the motor comes up to speed.

In cutting out the resistance of a starting rheostat care must be used not to cut it out too rapidly. If the resistance is cut out more rapidly than the armature can speed up, a sufficient counter-electromotive force will not be generated to properly oppose the flow of current, and the motor will be overloaded.

173. **Rheostatic Controller.**—If all the resistance of the starting rheostat (see above paragraph) is not cut out, the motor will operate at reduced voltage, and hence at less than normal speed. A rheostat so arranged that all or a portion of its resistance may be left in a motor circuit to secure reduced speeds is called a "rheostatic controller." Such rheostatic controllers are used for controlling series and compound-wound motors driving cranes and similar machinery requiring variable speed under the control of operator.

*4. *In a series-wound motor the speed varies inversely as th* —*the lighter the load the higher the speed.* A series-wou motor of any size, when supplied with full voltage under no-load, or a very light load, will "run away" just as will a steam engine without a governor when given an open throttle.

For a given load, a series-wound motor with its rheostat in series draws the same current irrespective of the speed and for a given load the speed varies directly as the voltage. The speed at a given load may be varied by varying the resistance in the motor circuit; in the meantime if the load on the motor be constant the current drawn from the line will be constant regardless of the speed.

175. **Shunting the Field of a Series Motor.**—The above statements relate to the use of a rheostat in series with a series-wound motor. If a resistance or rheostat be placed in parallel with the field of a series-wound motor the speed will be increased instead of decreased at a given load. This is known as shunting the field of the motor. This shunt would never be applied till the motor has been brought up to normal full speed by cutting out the starting resistance. With a "shunted field" a motor drives a load at a speed higher than normal and therefore requires a correspondingly increased current.

176. **Shunted Armature Connection of a Series Motor.**—If a resistance is placed in parallel with the armature of a series motor, the motor will operate at less than normal speed when all the starting resistance has been cut out. This connection is known as a "shunted armature connection" and is useful where a low speed is desired at light loads and is particularly useful in some cases where the load becomes a negative one, that is, where the load tends to overhaul the motor, as in lowering a heavy weight.

177. **Speed Control of Shunt-wound Motors.**—A shunt-wound motor, unlike a series motor, when supplied with full voltage, maintains practically a constant speed regardless of variations in load within the limits of its capacity. It automatically acts like a steam engine having a very efficient governor. The speed of a shunt-wound motor may be decreased below normal by a rheostatic controller in series with its armature and may be increased above normal by means of a rheostat in series with its field winding. The latter rheostat is known as a "field rheostat," and, to be effective, must have a high resistance owing to the small current which flows through the shunt field winding.

178. **Speed Control of Compound-wound Motors.**—A compound-wound motor is a hybrid between a series and shunt-wound motor and its characteristics are likewise of a hybrid nature. A compound-wound motor will not "run away" under no-load as will a series motor, but its speed decreases as the load increases, though not so rapidly as is the case with a series-wound motor. The characteristics of the compound-wound motor render it particularly valuable in cases where the load is subject to wide variation. It will give a strong torque in starting and driving heavy loads and at the same time will not race dangerously when the load is suddenly relieved.

The speed of a compound-wound motor may be reduced below normal by means of a rheostat in the circuit of its armature. The speed may be increased above normal by shunting and even short circuiting the series field winding, and may be still further increased by means of a field rheostat in series with the shunt field winding.

179. **In starting a direct-current motor** (see Fig. 73), close the line switch and move the operating arm of the rheostat step by step over the contacts, waiting a few seconds on each contact for the motor speed to accelerate. If this process is performed too quickly the motor may be injured by excessive current; if too slowly, the rheostat may be injured. If the motor fails to start on the first step, move promptly to the second step and if necessary to the third, but no farther. If no start is made when the third step is reached, open the line switch at once, allow the starter handle to return to the off position, and look for faulty connections, overload, etc. The time of starting a motor with full-load torque should not, as a general thing, exceed 15 sec. for rheostats for motors of 5 h.p. and lesser output, and 30 sec. for those of greater output.

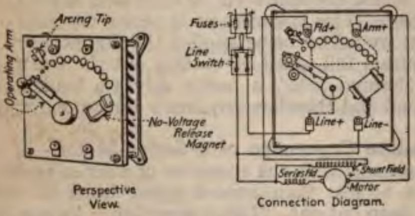


FIG. 73.—Direct-current motor starting rheostat.

180. **In stopping a direct-current motor,** open the line switch. The arm will return automatically to the off position. Never force the operating arm of any automatic-starting rheostat back to the off position.

181. **Starting rheostats for shunt-, compound- and series-wound direct-current motors** vary somewhat in detail, design, and method of connection with the ideas of the different manufacturers. The rheostat shown in Fig. 73 is fairly typical of those for starting motors of outputs up to 120 h.p.

182. **The low-voltage release device on a starting rheostat** consists of a spring, which tends to return the operating arm to the off position, and an electromagnet, which, under conditions of normal voltage, holds the operating arm in the running position. The coil of this magnet is regularly connected across the circuit with a protecting resistance in series, but can be connected in series with the shunt field of the motor if specially required. If the voltage drops below a predetermined value, the arm is released and returned by the spring to the off position.

183. **Arcing Devices on Starting Rheostats.**—Arcing tips consisting of pivoted fingers are sometimes mounted near the point where the circuit is opened. In passing to the off position, a lug on the end of the arm strikes and deflects the tip, which is in electrical connection with the first stationary contact; the current is diverted to the tip, which snaps back when released and opens the circuit very quickly, thus rupturing the arc. Blow-out coils can be mounted behind the first contact and will disrupt any arc formed opening the circuit.

184. Overload Release Device on Starting Rheostats.—'his device, which is not illustrated, includes an electromagnet, which, in case of overload, attracts its armature and forces an insuating wedge between two contacts, separating them and thereby pening the circuit of he low-voltage release nagnet. The operatng arm returns immeliately to the off posiion. With some derices, the attraction of he armature forces two contacts closed which laces a short-circuit round the low-voltage elease magnet thereby le-energizing it and ermitting the operatng arm to return to he off position. It should be noted that the National Code rules require the use of fuses or circuit-breakers with each rheostat even though it be equipped with an overload release of this nature.

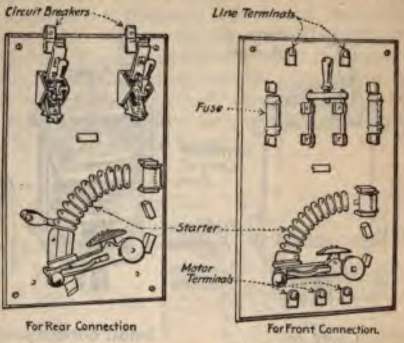
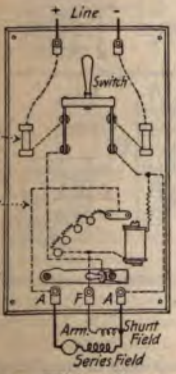


FIG. 74.—Direct-current motor starting panels.

185. Starting panels for direct-current motors are shown in Figs. 74 and 75. Panels, of which the illustrations are typical, are very desirable in that they concentrate all of the apparatus for the motor's control at one point and greatly simplify the wiring. Where such a panel is used it is merely necessary to run the two line wires to the line terminals of the panel and the three leads between the motor and the panel and the installation is ready for operation. The designs of different manufacturers vary in details. The panels can be obtained for either front or rear connection and with circuit-breakers or fuses for overload protection. Which is preferable is determined by the characteristics of the installation in question.



IG. 75.—Wiring diagram of typical starting panel.

The advantages and disadvantages of protection of each type may be summed thus: (1) Fuses have a time element that circuit-breakers do not have; that is, fuses will not open an overloaded circuit as quickly as circuit-breakers. For this reason fuses may be preferable for motors hat are liable to very brief overloads, especially where expert pervision of electrical apparatus is maintained, as in large mills d factories. A supply of extra fuses must be kept available. here there are many fuse replacements the cost of fuse renewals

The field resistance is cut in and out by a rotating arm passing contact buttons in all but the largest controllers for which a d is used. Arc shields between drum segments and blow-out are provided where necessary. The controllers can be arra to provide dynamic braking. Speed ranges of from 1 to possibly, 1 to 6 are usually provided.

187. Operation of Rotary or Machine-tool Type Controller (See Figs. 69, 77 and 78.) Continuous movement of the opera handle in either direction first starts the motor in the correspon direction of rotation, then cuts out the starting resistance, finally cuts in the field resistance until the desired running spe reached. The handle should be moved over the starting not in not over 15 sec. for motors of possibly 10 h.p. capacity an not over 30 sec. for larger motors. The starting resistance sh not be used for speed control.

For a quick stop when operating with weakened field, move handle quickly to the first running notch, hold it there moment and then move it to the off position; the application of full strength when the speed is high causes dynamic braking, checking the speed quickly and without shock. For a very q emergency stop, the handle can be moved to the first rever notch after checking the speed by dynamic braking, but this op tion causes severe mechanical and electrical stresses; this rever should never be carried beyond the first notch. When the m is to be at rest for any length of time, open the line switch.

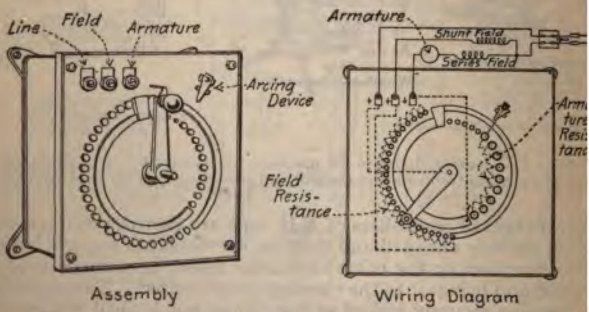


FIG. 79.—Non-automatic starting and speed-adjusting rheostat.

188. A non-automatic starting and speed-adjusting rheo for direct-current motors is shown in Fig. 79. This device no low-voltage or overload protection hence is suitable only applications where skilled attendance is available. The opera arm makes contact as it is revolved between the circular and the resistance contact buttons. There are a number of fi ntrol steps, hence close speed adjustment over a consider ge can be obtained. The contact buttons of the inner circ nent are connected to the starting resistor and the contac

:er circle are connected with the running resistor. A read- the following paragraph describing the operation of the will render clear the principles involved.

Operation of a Non-automatic Starting and Speed-adjust- ɛostat.—(Fig. 79.) To start the motor, close the line switch or breaker and move the operating arm of the rheostat over the g buttons to the first running position (the point where the r contacts overlap). A motor starting with full-load torque be brought to this point in approximately 15 sec. Further ient of the operating arm increases the motor speed by field . The motor can be operated continuously with the arm field contact button, but with rheostats of this design must allowed to run on arting button. To ne motor, open the witch or circuit- r and move the ıt arm to the off n. The latter ient must not be en, since this rheo- ıas no automatic s. To protect the in case of failure of wer supply and its uent return after ıtor has stopped, a ltage release cir- eaker should be :d in series with heostat. *The rheo- ndle must be in the ition* before the cir- eaker is closed. *ghouse Electric & acturing Company.)*

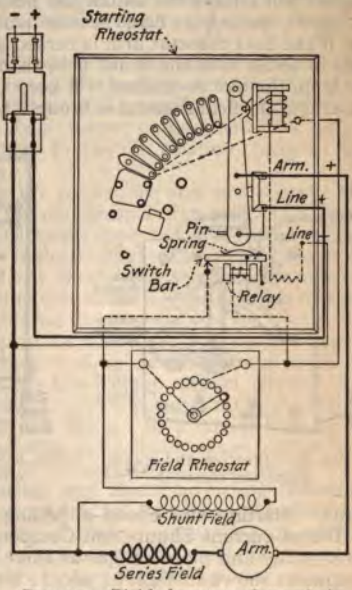


FIG. 80.—Field rheostat relay switch.

. **Field relay** :s are required separate rheostats :d for starting and ling the speeds of . This is required National Code rule to prevent the possibility of starting ɔr with weakened field. The switch, shown in Fig. 80, :d under the starter handle accomplishes this function by ircuiting the field rheostat during acceleration so that the must always start with full field regardless of the position ield rheostat arm. The switch shown, or a similar one, can lied to ordinary starting and speed-regulating rheostats ıerally should be mounted on the rheostat at the factory of ı that furnishes it.

eld relay switch shown consists of a small electro-magnet, a pivoted switch bar, and a stationary contact. The switch bar is normally held away from the contact by a helical spring. The magnet coil, switch bar, and contact are in series with a circuit that parallels the field rheostat.

When the operating arm of the starting rheostat is moved to the first step, a pin on its hub presses the relay switch bar against its stationary contact, thus short-circuiting the field rheostat. As the arm is turned the pin on the starter hub soon releases the relay switch bar; but the relay electro-magnet, energized when the contacts close, holds this bar temporarily in place. The winding of the relay electro-magnet is so proportioned that if there is little or no resistance in series with the motor shunt field, the relay magnet will release the switch bar before the motor is brought to full speed, leaving the field rheostat available for speed adjustment. But if the field rheostat arm is turned so that there is more resistance in series with the shunt field than would be safe to insert in one step, the electro-magnet will keep the relay switch closed until the arm of the field rheostat is brought back toward the off position.

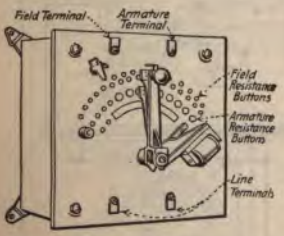


FIG. 81.—Starting and speed-adjusting rheostat.

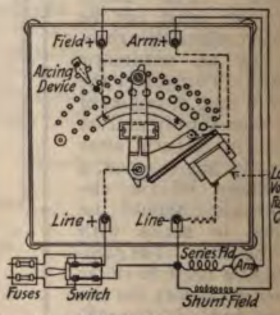


FIG. 82.—Wiring diagram for starting and speed-adjusting rheostat.

191. Starting and Speed-adjusting (Field Control) Rheostats for Direct-current Shunt- and Compound-wound Motors.—There are as many and more designs as there are manufacturers, but the equipment shown in Figs. 81 and 82 is typical and can be used for starting and regulating speed in non-reversing services where speed adjustment by field control is desirable. The apparatus is so arranged that the motor is always started with full field strength. In case of failure of the voltage, the field control resistance is automatically short-circuited and the motor is disconnected from the line.

The rheostat consists of a face plate carrying the contacts, operating arms, and safety devices, mounted in connection with two resistors. One is for starting and one is for adjusting the field strength. The face plate carries three rows of stationary contacts. The upper row is connected with the field adjusting resistor, the second row with the starting resistor; and the lower row contains a long curved segment for short-circuiting the field resistance in starting. A contact for short-circuiting the armature resistance when the arm is in the running position is sometimes provided.

The face plate supports two arms, an operating arm and a short-circuiting arm, pivoted to the same hub and arranged so that they cannot pass each other. The operating arm carries the handle and two contact fingers, one for the starting contacts and the other for the field contacts. The short-circuiting arm has a contact finger which slides over the contact bar, short-circuiting the field resistance in starting, and the armature resistance while running. In some designs this arm also carries laminated copper brushes which short-circuit the starting resistance when the arm reaches the running position. A spring tends to return the short-circuiting arm to the off position.

Under conditions of normal operation the short-circuiting arm is held in the running position against the force of the spring by an electro-magnet connected across the line in series with a protecting resistance. If the voltage falls below a predetermined point, the arm is released and returns to the off position, carrying the operating arm with it.

Rheostats for this service are frequently arranged so that the circuit is opened between a lug on the operating arm and a small pivoted finger with a centering spring mounted near the first starting contact and connected to it electrically. The current is always broken abruptly no matter how slowly the arm may be moved. Blow-out coils are sometimes mounted on the rear of the face plate to disrupt any arc that may form.

An overload release device can be mounted on all but the largest rheostats of this type. It consists of an electro-magnet which, in event of an overload, opens the low-voltage magnet circuit, thus releasing the short-circuiting arm. The tripping point is adjustable. The National Code rules require the use of a circuit breaker or fuses with a rheostat equipped with an overload release of this character. (*Westinghouse Electric & Manufacturing Company.*)

192. **Operation of a Starting and Speed-adjusting Rheostat.**—(Figs. 81 and 82.) The motor is started by moving the operating arm to the running position, stopping a few seconds on each starting contact to permit the speed to accelerate. The retaining magnet holds the short-circuiting arm in the running position where it short-circuits the starting resistor. The operating arm is then moved back over the field-resistance contacts until the desired speed is reached. For motors starting with full-load torque, the time of acceleration should be from 15 sec. to 30 sec., depending upon the capacity of the motor. To stop the motor, open the line switch. Both arms then return to the off position automatically.

193. **Armature control speed regulators** (Fig. 83) are used for speed reduction with shunt, compound or series motors in non-reversing service where the torque required decreases with the speed but remains constant at any given speed as with fans, blowers and centrifugal pumps. They can also be used for applications where the torque is independent of the speed, as with job

printing presses. However, this method of speed control is not suitable for such applications where there is operation for long periods at reduced speed, since such operation is not economical. It is not possible, where the torque varies, to obtain constant speed with these controllers.

In the regulator shown the low-voltage release consists of an electro-magnet enclosed in an iron shell, a sector on the pivot end of the operating arm, and a strong spring which tends to return the arm to the off position. The magnet is mounted directly below the pivot of the arm and its coil is connected in shunt across the line in series with a protecting resistance. When the magnet is energized its plunger rises and forces a steel ball into one of a series of depressions in the sector on the arm with sufficient force to hold the arm

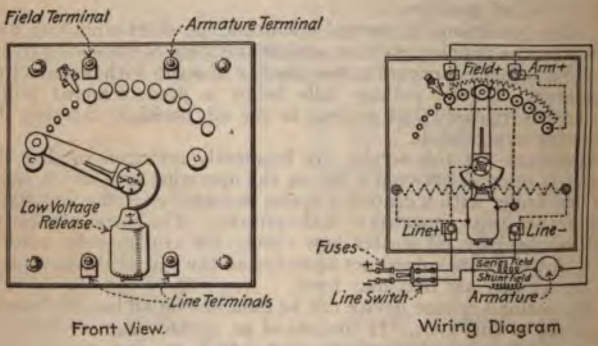


FIG. 83.—Armature control speed regulator.

against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned. When the voltage fails, the magnet plunger falls and the spring throws the operating arm to the off position. An overload release, similar to that described in another paragraph, which operates by opening the low-voltage coil circuit, is sometimes furnished on regulators of this type. Standard commercial rheostats of this type are designed to give about 50 per cent. speed reduction on the first notch. See the following paragraph on operation for further information.

194. Operation of Armature Control Speed Regulators.—(Fig. 83.) Continuous motion of the operating arm starts the motor and brings it gradually to maximum speed. Moving the arm over the first few contact buttons increases the shunt field strength if the motor is shunt or compound. The movement over the succeeding buttons cuts out armature resistance and permits the motor to speed up.

195. ***Objections to Armature Control*** (Crocker and Arendts, *Electric Motors*). (a) *Bulk of Rheostat*.—This may not be very objectionable if only a few motors are so controlled, but for a number the extra space becomes a factor, and in many cases it is difficult to find sufficient room near the motor.

(b) *Inefficiency of the System.*—The same amount of power is supplied at all speeds, but at low speeds only a small part of it is converted into useful work, the balance being wasted in the rheostat as heat.

(c) *Poor Speed Regulation with Varying Loads.*—Since the impressed voltage at the armature terminals is equal to the line voltage minus the resistance drop in the rheostat ($V_t = V - I_aR_x$), any change in the current drawn by the motor produces a change in the terminal voltage, the counter e.m.f., and therefore the speed.

196. Crane controllers for direct-current series and compound-wound motors are usually arranged somewhat as indicated in Fig. 84. The switching device consists of a disc of soapstone or other fire-proof insulating material carrying stationary contact pieces and a pivoted switch arm carrying four contactors. Blow-out coils are usually provided to effectively rupture the arcs that form when the contactors pass from one contact piece to the next. The resistors may be contained in the controller base, as in small controllers, or may be arranged for separate mounting as in large ones. In Fig. 84 the fine lines within the circle are shading lines which merely indicate that the circle is a soap stone disc. Only the heavy lines within the circle represent electrical connections. Fig. 85 shows two typical controllers.

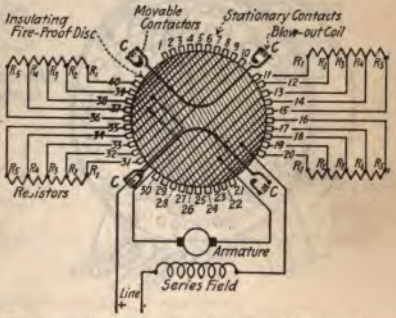


FIG. 84.—Connections of a 16-point crane controller connected to a series motor.

Movement of the controller handle in either direction past the off position starts the motor in the corresponding direction of rotation. At each step a section of resistance is short-circuited. At the full-speed positions all the resistance is short-circuited. Stops prevent over-running past the full-speed positions. Direct-current crane controllers increase or decrease the amount of resistance in series with the motor and thereby control its speed.

197. Dynamic braking of direct-current motors is effected by allowing a motor to be temporarily driven as a generator by its load. The mechanical energy of the moving machinery or descending load is thus converted into electrical energy and then into heat which is dissipated in resistance. The result is that the speed of the motor is promptly retarded. The amount of braking action can be adjusted *by varying* the current flowing in the motor *armature.*

A load exercising an active torque on the motor armature, suc as an elevator car, cannot be brought to a full stop by this methoc since with the decreasing armature speed the braking action als decreases. For final stopping, some form of mechanical brak which acts automatically, is therefore necessary.

Dynamic braking is used in connection with motors for elevator hoists, cranes, coal and ore handling machinery, railway cars, etc It is employed for reducing the motor speed just before a stop, a in elevator service; or for controlling the speed of moving objects as in lowering crane loads, retarding the speed of the cars descendin grades, etc.

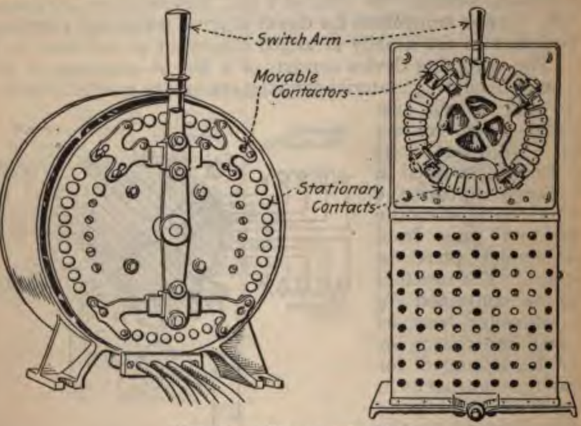


FIG. 85.—Crane controllers.

198. The principal advantages of dynamic braking are th practical absence of all wear and tear on the apparatus, convenienc of application, and ease, accuracy, and certainty of control. Ir dynamic braking with a properly selected motor, active deteriora tion is limited to the controller contacts, which can be arranged fo quick, easy, and inexpensive renewal. No special or additiona apparatus is required for braking except the resistance which ca be placed wherever convenient within a reasonable distance fron the motor. The braking effect can be adjusted with great accurac over a wide range by varying the armature current or the fiel strength by means of suitable resistance.

In some instances, notably with railroads, dynamic brakin actually returns energy to the circuit; but in industrial service th energy generated is usually dissipated by resistance. In electri cars, during the winter months this dynamic braking current is i many cases run through heaters for warming the cars.

199. Heating with Dynamic Braking.—The most importar limitation to the use of dynamic braking is the heating of the motc the generated currents. For simple stopping duty this actic is insignificant as it lasts only a few seconds; but with speed cont in lowering a load by dynamic braking, the generated current m flow for an extended length of time and the heating may be cons erable, especially as it is added to the heating of the machine wh operated as a motor. This additional heating effect due to t braking current must be considered in selecting the motor.

200. Dynamic-braking Connections.—Fig. 86 shows by sim diagrams some of the possible connections. Diagram *I* shows t armature of a shunt motor short-circuited through a brake resi ance, the field remaining across the line. Diagram *II* shows t

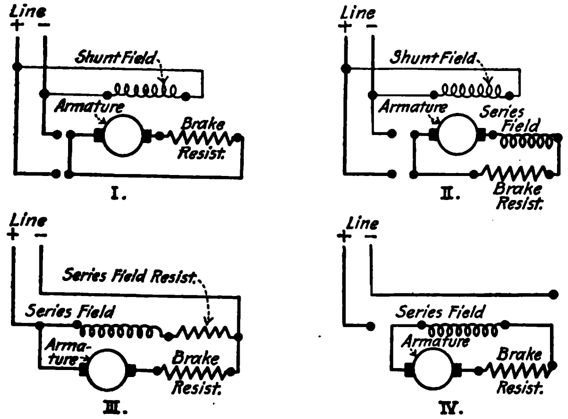


FIG. 86.—Dynamic braking connections.

armature of a compound motor short-circuited through the ser field and a brake resistance, the shunt field remaining across t line. Diagram *III* shows the armature of a series motor sho circuited through the series field, a protecting resistance for t field, and a brake resistance—the field and its resistance being series across the line. Diagram *IV* shows the armature and ser field of a series motor short-circuited through a brake resistan all of which are entirely disconnected from the line.

By cutting out the series field in diagram *II* the braking eff can be diminished, the connections then being as in *I*. The c nections shown in diagram *III* are generally preferable for ser motors during the first part of the braking operation, in order insure building up as a generator. As soon as the generator acti has begun, the connections can be changed to those shown in d gram *IV*. In each of the cases shown by the four diagrams t braking effect can be increased by short-circuiting sections of brake resistance and thus increasing the armature current.

201. The methods of starting **induction motors** may be as follows:

(1) By Connecting Directly to the Line.—This method i

narily used only for small motors—those of less than 10 h.p. output—because on starting the motor takes an excessive current and th voltage regulation will be disturbed unless there is ample generatin capacity and the conductors are of a generous cross-section.

(2) *By Inserting Internal Resistance in the Rotor Circuit.*—Thi method is used only with wound rotor machines. The resistanc is cut in or out of the circuit by the operation of a switch on th motor shaft so arranged that the handle of the switch is stationar when the rotor is turning.

(3) *By Introducing External Resistance in the Rotor Circuit.*—This method can be used only with a wound-rotor machine havin collector rings upon which brushes bear that connect with the re sistance. The resistance is cut in or out of the rotor circuit by a controller somewhat similar to the ordinary direct-current moto controller.

(4) *By Using a Transformer having Low-voltage Taps.*—A low voltage can be impressed on the motor at starting by connectin it with a suitable switch to the low-voltage taps.

(5) *With a Starting Compensator or Auto-transformer.*—Thi is the usual method for motors of ordinary capacity and is simila to the transformer method in that low voltage from the compen sator taps are impressed on the motor at starting.

(6) *By Connecting the Armature Coils in Star for Starting and in Delta for Running.*—This method is described in detail in a followin paragraph.

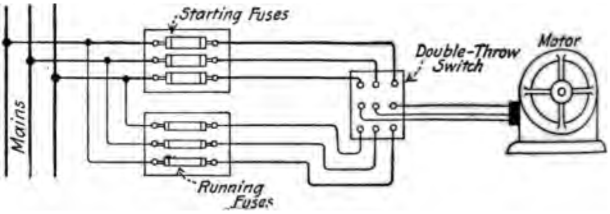


FIG. 87.—Starting small motor by throwing directly on the line.

202. A small induction motor can be started by throwing i directly on the line. (Fig. 87.) This method is, as a general thing not used for motors of capacities exceeding 5 h.p. Two sets of fuses should be provided, one for starting and one for running with a double-throw switch to connect the motor to either set. A switch having a spring so arranged that the blades will not re main in the starting position unless manually held there should be used. The starting current of an induction motor thrown directly on the line will be something between three and eight times the full-load running current. If only one set of fuses is used for a polyphase motor and they are of sufficient capacity to carry the starting current, one fuse may open but the motor will continue to operate on one phase, drawing a current considerably abo ormal. The probable result is a burnt-out motor.

203. Self-contained starters for wound-rotor induction motors of relatively small capacity (Figs. 88 and 89) can be purchased. The resistors for these are mounted within the enclosing case that carries the switching mechanism that increases or decreases the amount of effective resistance in the rotor circuit. As a rule, the resistors in these starters are designed only for starting service,

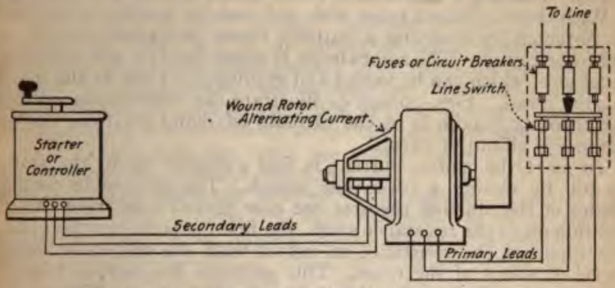


FIG. 88.—Connections of starter to wound rotor motor.

hence they can be used only where starts are infrequent and starting conditions are not severe. They are not usually designed for speed control for which service drum-type controllers with externally mounted resistances are used.

In the usual designs a set of resistors is connected with each phase of the motor (Fig. 90) secondary and all three are interconnected in star by the frame of the starter which is grounded, protecting the operator against shocks.

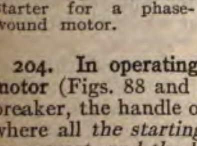


FIG. 89.—Enclosed starter for a phase-wound motor.

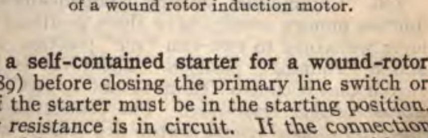


FIG. 90.—Method of varying rotor resistance of a wound rotor induction motor.

204. In operating a self-contained starter for a wound-rotor motor (Figs. 88 and 89) before closing the primary line switch or breaker, the handle of the starter must be in the starting position, where all the starting resistance is in circuit. If the connections are correct, and the load is not too great, the motor should start as soon as the line switch is closed; on failure to start, open the primary circuit, and examine the load conditions and the connections. With some starters the handle may have to be advance slightly beyond the starting position before the motor starts. As the motor speed accelerates the starter handle should be moved gradually to the running position, bringing the motor to full speed within the time which is usually specified by the manufacturer of the starter. In the running position all starting resistance is, in starters of most designs, short-circuited.

205. Starting a Coil-wound Rotor Motor (*Southern Electrician*) —With the coil-wound rotor, high and variable starting torque can be obtained by inserting a variable ohmic resistance directly in the rotor circuit. The rotor circuit is connected to a non-inductive resistance, which can be varied and gradually cut out as the motor attains speed. Figs. 90 and 91 illustrate the connections. When the rheostat handle is in the extreme left-hand position, the resistance is all out of circuit.

To start the motor, current is first switched on to the stator circuit by closing a triple-pole switch. The three-pole contact blades of the starting rheostat are now moved over from the off position on to the resistance studs, the first contacts of which place the whole of the resistance in circuit with the respective three-phase windings of the rotor. This prevents the current induced in the rotor windings by the stator circuit from reaching an excessive amount. The switch handle on being further rotated in a right-handed direction gradually cuts out the resistance until all the resistance is out of circuit. In this position the rotor windings are short-circuited.

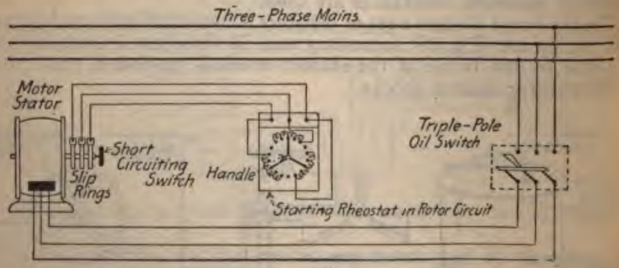


FIG. 91.—Starting arrangement for three-phase coil-wound rotor motor.

206. Commercial starting compensators for squirrel cage induction motors usually have three positions at which the starting lever will come to rest—an "off" position, a "starting" position, and a "running" position. The lever is so arranged that the switch that it controls cannot come to rest in any other positions unless forcibly restrained. The connections of a two-phase and of a three-phase compensator are shown in connection with the material on auto-transformers in Sect. V, *Transformers*. Connection arrangements for compensators of other types are shown on pages adjacent hereto.

In starting compensators, as usually arranged, when in the "o position the switch is open and the motor and auto-transformer are entirely disconnected from the source of energy. When in the "starting" position, the source of energy is directly connected by the switch to the auto-transformer terminals and the low voltage taps of the auto-transformer are connected to the motor. Usually there are no fuses inserted in the starting leads at the compensator.

When thrown to the "running" position the switch connects the motor through fuses to the source of energy and the auto-transformer is entirely disconnected from the source of energy. The fuses provided in the running leads are for the protection of the motor against overload while it is in normal operation. The fuses protecting the tap circuit to the compensator where the tap circuit branches from the main are usually depended upon to protect the motor while it is starting.

207. Starting With and Without Compensators.—The starting current taken by a squirrel cage induction motor at the instant of starting is equal to the applied electro-motive force divided by the impedance of the motor. Only the duration of this current, and not its value, is affected by the torque against which the motor is required to start. The effect of starting without and with a compensator is illustrated by diagrams *I* and *II* in Fig. 92. In this diagram, motor *I* is thrown directly on a 100-volt line. The impedance of the motor is 5.77 ohms per phase, the starting torque 10 lb. at 1 ft. radius and the current taken 10 amp. In diagram *II* a compensator is inserted, stepping down the line pressure from 100 to 50 volts. This reduces the starting current of motor one-half and the starting torque becomes one-quarter

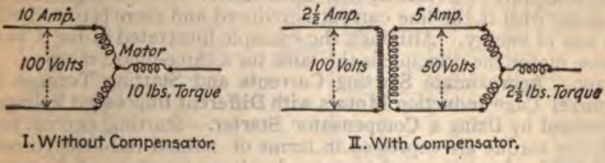


FIG. 92.—Starting with and without compensator.

its previous value or $2\frac{1}{2}$ lb. at 1 ft. radius. The current in the line is reduced inversely as the ratio of transformation in the compensator and becomes $2\frac{1}{2}$ amp.

Thus when a compensator is used the starting torque of the motor can be reduced to approximately the value required by the load and the current taken from the line correspondingly decreased. Where a compensator is not used an increase of rotor resistance results in a proportional increase in the starting torque of the motor with a very slight decrease in the starting current drawn rom the line. Where a compensator is used with a motor having high-resistance rotor the voltage can be reduced to a lower value n would be required with a low-resistance rotor for the same ting torque. Standard compensators are provided with severa from which various combinations can be obtained.

208. Comparison of Auto-transformer and Resistance for Decreasing Voltage for Starting Squirrel Cage Motors.—The motor in Fig. 93 is supposed to require 100 amp. to start it; that is, to provide the energy necessary to produce the necessary starting torque. At *I*, where an auto-transformer is used to lower the

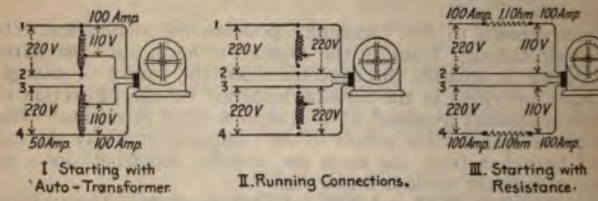


FIG. 93.—Starting with resistance and with compensator.

voltage to 110, a current of 100 amp. is produced in the motor primary with a current in the line of 50 amp. This condition is due to the transformer action of the auto-transformer. At *II* the running connections are shown wherein the auto-transformer is entirely disconnected from the circuit. At *III* are illustrated the conditions that would obtain were the voltage lowered for starting by inserting resistance in series with the line. Obviously 100 amp. must flow in all portions of the line even though the resistance of 1.1 ohm reduces the line voltage of 220 to a voltage of 110 which is impressed on the motor. There is a loss of energy in the resistance. Evidently the auto-starter method is preferable because with it the line current is reduced and there is practically no loss of energy. Although the example illustrated is for a two-phase motor the principle is the same for a three-phase motor.

209. Approximate Starting Currents and Starting Torques of Squirrel Cage Induction Motors with Different Impressed Voltages Obtained by Using a Compensator Starter.—Starting current and starting torque are expressed in terms of normal full-load current and full-load torque, and impressed voltage is expressed in terms of normal voltage:

Voltage impressed on motor, per cent.	Starting current taken from line, per cent.	Starting torque, per cent.
40	112	32
60	250	72
80	450	128
100	700	200

210. Taps of a Starting Compensator (*Southern Electrician*).—Compensators are usually shipped by their manufacturers connected to the auto-transformer tap giving the lowest torque. If the motor *will not start* its load with this tap connected the next higher *voltage tap* should be tried, and so on, until the tap is found that *provides the* required torque.

Compensators for use with motors of 15 h.p. and under sometimes have three taps giving voltages of 40 per cent., 60 per cent. and 80 per cent. of full-line impressed voltage. For motors above 15 h.p., four taps are frequently provided giving 40, 58, 70 and 85 per cent. of full-line voltage. The proper tap for giving the maximum starting torque without causing an inconvenient voltage disturbance in the supply circuit, can best be ascertained by experiment.

One make of compensator has for motors of from 5 to 18 h.p., taps starting the motor at 50, 65 and 80 per cent. of the full impressed line voltage, with respective line currents equal to 25, 42 and 65 per cent. of the current that would be taken by the motor if no compensator were used. For motors larger than 18 h.p., compensator-voltage taps are provided giving voltages equal to 40, 58, 70 and 85 per cent. of the full impressed line voltage, and respective currents approximately equal to 16, 34, 50 and 72 per cent. of the current that would be taken by the motor if it were started directly from the supply line.

211. Starting compensators for motors of high-voltage or large current capacity are arranged with the switches separate from the auto-transformer (Fig. 94). The equipment usually consists of one double-throw or two interlocked single-throw oil switches

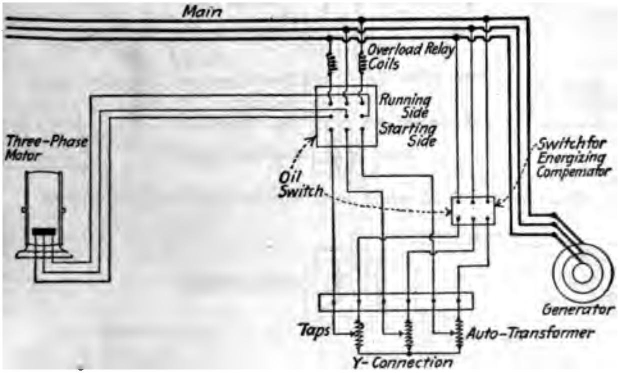


FIG. 94.—Starting compensator with separate switches, and auto-transformer for high-voltage or large capacity motor.

for the motor and a single-throw oil switch for energizing the auto-transformer. In the running leads to the motor may be inserted overload relays which will open the oil switches in case of over-draught of current. The oil switches are usually mounted on a switchboard panel while the auto-transformer may or may not be mounted on the panel. The construction indicated in the oth compensator diagrams is used by certain manufacturers for mot f capacities up to and including 550 volts when the normal c nt does not exceed 300 amp. per phase and for motors of f

1,040 to 2,500 volts with currents not greater than 125 amp. per phase. Where motors take greater normal currents or are of higher voltage the arrangement of Fig. 94 is applied.

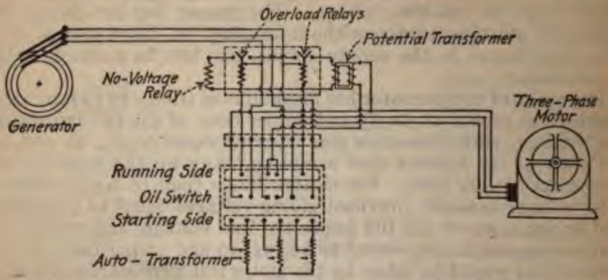


FIG. 95.—Potential transformer for no-voltage relay of high-voltage motor.

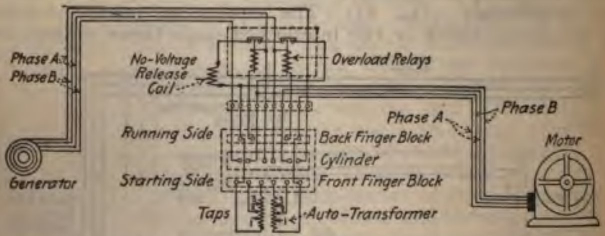


FIG. 96.—Overload relays on a two-phase starting compensator.

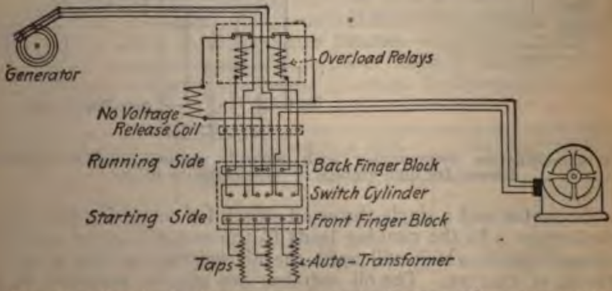


FIG. 97.—Overload release coils on a three-phase starting compensator.

212. **When no-voltage release compensator starters are use[d] [fo]r *high-voltage* motors** a small voltage transformer is usua[lly arra]nged as in Fig. 95 to energize the no-voltage coil. This

ment is used by certain manufacturers for compensators, the no-voltage release attachment, for voltages of from 1,040 oo. The secondary of the former furnishes 110 volts hich the no-voltage relay und.

. Overload release coils mpensators are arranged tially as shown in Figs. d 97. When there is an oad on either phase the plunger of the overload is drawn up which opens o-voltage release coil cir- This de-energizes the no-ge release coil and the ensator circuit is auto-ally opened as described e paragraph on the no-ge release. The overload are usually arranged so they can be adjusted to te at different currents s a circuit breaker can be ted. An inverse-time-nt feature is usually in-rated whereby the relay perate almost instantly on heavy overloads but will perate until a certain in- of time has elapsed (the of the interval being ap-nately inversely propor- to the amount of overload) on lesser overloads. It will be from the diagrams that fuses are not necessary where the

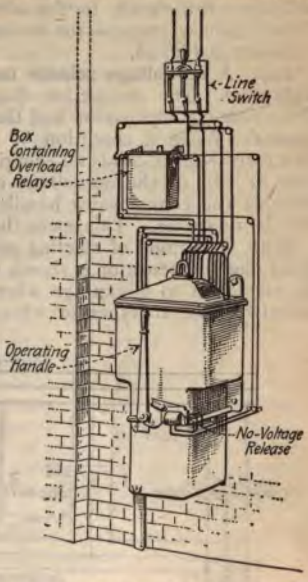


FIG. 98.—Installation of an auto-starter equipped with no-voltage and overload release attachments.

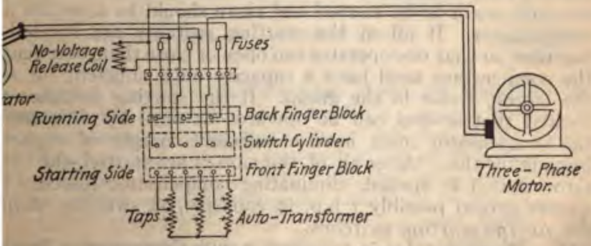


FIG. 99.—Starting compensator with no-voltage release.

l relays are used. A decided advantage of the overload that they can be adjusted to protect a motor again running single-phase. If one phase opens, sufficient additional current will be drawn through the others to operate a relay which will open the circuit to the compensator. An installation of a Westinghouse compensator having no-voltage and overload relays is shown in Fig. 98.

214. A no-voltage release can be provided on starting compensators. The connection diagram is shown in Fig. 99 for a three-phase compensator and that for a two-phase compensator is similar. When a condition of no-voltage exists on the line, the *no-voltage release coil* is de-energized which permits the iron armature or core of the no-voltage coil to drop, which automatically releases the compensator handle which is returned to the off position by its spring. This opens the circuit through the compensator.

215. A method of starting several polyphase induction motors from one compensator is shown in Fig. 100. This can frequently be employed to advantage where there are a number of motors situated close together or where a number of motors must be

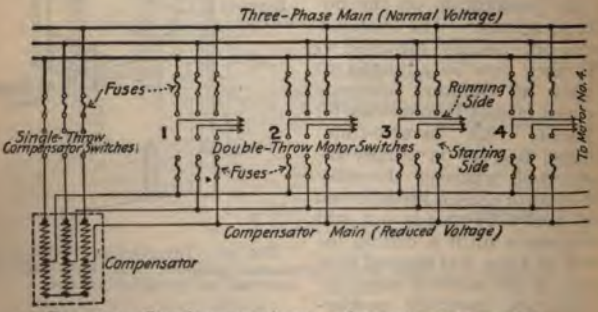


FIG. 100.—Starting several motors from one compensator.

started from one location. A double-throw switch is necessary for each motor to be started and there should be a switch for the compensator. If all of the starting switches are located close together, so that one operator can open or close them consecutively, the compensator need have a capacity only sufficient for serving the largest motor in the group. If the starting switches are so located that several can be operated at once by different men, the compensator must have a sufficient margin of capacity to provide for this. After all of the motors are started the compensator switch is opened, eliminating compensator losses. Where motors exceed possibly 7 h.p. in capacity, oil switches should be used for the starting switches.

216. Fuses for Use in Connection with Compensator Starters.—*National Code* standard fuses carried in holders mounted on slate ...ses are usually used for compensators for voltages up to 60... For voltages of from 1,040 to 2,500, if fuses are used, t... ...ion type is preferable. A table of fuse sizes for induct...

motors is given elsewhere in this book, but where not otherwise specified fuses of a capacity corresponding to 1¼ times the full-load current of the motor are supplied.

217. **The delta-star method of starting three-phase, squirrel cage induction motors** is sometimes used (Fig. 101). The stator-coil terminals are brought out from the frame and connected to a double-throw switch as shown. In starting, the coils are connected in star and the current is $\frac{1}{1.73}$ or 0.58 of what it would be with the coils connected in delta. After the rotor has attained full speed the switch is thrown to the running position, which connects the coils in delta and normal voltage is thereby impressed on them. Motors must be specially constructed for this method of starting as it is not extensively used by the principal manufacturers.

218. **Speed Control of Polyphase Motors** (*B. G. Lamme*).—The speed of polyphase motors can be controlled by a number of different methods, of which the following are the most important. I. Adjusting the resistance of the secondary circuit. II. Adjusting the primary voltage. III. Using two motor primaries, one of which is capable of being rotated. IV. Changing the number of motor poles. V. Operating two or more motors connected in cascade. VI. Adjusting the frequency of the primary current. VII. Changing the number of phases of the secondary windings.

The results obtained by the use of these various methods differ widely, so that in selecting a variable speed alternating-current motor careful consideration must be given to the characteristics of the method of control in order to determine its suitability for the service. In many cases a combination of methods is required in order to produce the desired speed changes.

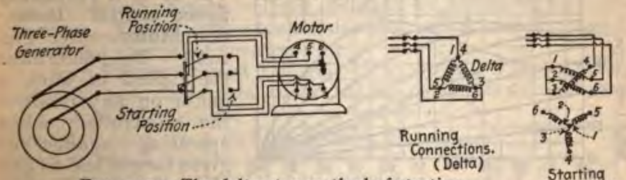


FIG. 101.—The delta-star method of starting.

219. **Speed Control of a Polyphase Motor by Adjusting the Resistance of the Secondary Circuit.**—With constant torque, the speed of the motor increases regularly as each step of the resistor is short-circuited and remains constant on any given notch. But with varying torque the motor speed varies also; that is, an alternating-current motor when operating with auxiliary resistance in the rotor circuit is properly classified as a *varying speed motor*. *This method of speed control is, therefore, not suitable for service requiring several constant speeds with varying torque, such as machine-tool work, etc.*

Speed control by means of adjustable secondary resistance i however, very useful where constant speeds are not essential, for example, in operating cranes, hoists, elevators, and dredges, and also for service in which the torque remains constant at each speed, as in driving fans, blowers, and centrifugal pumps. In service where reduced speeds are required only occasionally and where small speed variation is not objectionable, this method of control can also be used to good advantage. On account of energy loss in the resistors, the efficiency is reduced when operating at reduced speeds, this reduction being greatest at the slowest speeds. The circuits are essentially the same as for starting by varying resistance in the rotor circuit, as shown in Figs. 90 and 91.

220. With secondary speed control the rotor usually has a Y-connected winding to which is connected, in series in each phase, an external resistance, Figs. 90 and 91. By moving the adjustable arm the amount of resistance in series in each phase can be varied from a maximum to zero and the speed varied from the highest speed to the lowest speed. This form of control is in general preferable to the primary control method and is used where a large number of speeds is required and it is not necessary for the motor to run at any considerable period at reduced speed.

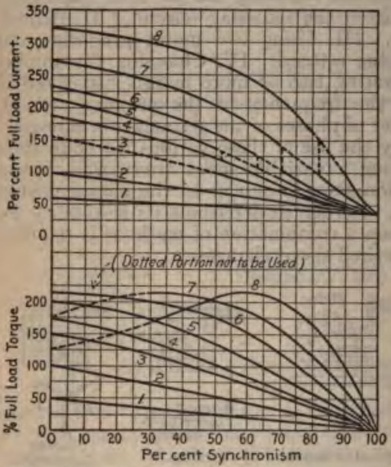


FIG. 102.—Typical current, torque, and speed curves for an induction motor with secondary speed control.

221. Speed-torque Curves of a Secondary Speed-control Induction Motor.—(See Fig. 102.) To determine the speed of such a motor on any point of the controller when operating against a given torque and to find the current taken at that speed and torque, refer to curves which show the speed, torque and current for phase-wound variable speed motors. Those of Fig. 102 are typical of ordinary capacities. For any given torque, follow along the abscissa corresponding to this value to its point of intersection with the torque curve for that particular notch of controller. Then follow up the ordinate until it intersects the current curve corresponding to the same controller notch and the value so obtained is the current taken by the motor.

Example.—Suppose it is desired to determine the current taken on various points of the controller when starting a 25-h.p. 220-volt motor bringing it from rest to full speed against full-load torque—the first point (Fig. 102) at which more than full-load torque can be obtained is the third notch and following the line upward to the current curve we see that the current taken is 150 per cent. full-load current. This value drops until about 45 per cent. synchronous speed is reached, when in order to hold up the torque it is necessary to throw to the fourth notch.

The current rises correspondingly to 130 per cent. full-load, then drops until 53 per cent. synchronous speed is reached. Then the controller must be moved to the fifth notch, thence it drops until 65 per cent. synchronous speed is reached, etc.

The dotted line indicates the variation in current.

222. Speed Control of a Polyphase Motor by Adjusting the Primary Voltage.—(Fig. 103.) Adjusting the primary voltage of a motor causes speed changes that are similar to those produced by adjusting the resistance of the motor secondary. The voltage variations can be obtained by means of adjustable resistors, auto-transformers, or choke coils in series with the primary.

This method has the disadvantages of poor speed regulation, low efficiency, and unsatisfactory control, especially when the pri-

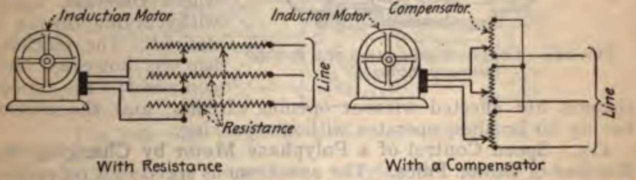


FIG. 103.—Methods of varying the voltage impressed on an induction-motor.

mary voltage is high; it is not in general commercial use. Squirrel cage induction motors are, however, almost invariably started with reduced primary voltage obtained by means of auto-transformers. Fig. 104 indicates the external appearance of a variable-resistance starter for such service.

223. Primary Speed Control.—(Fig. 103.) Where a compensator is used, contactors, connected by conductors to the stator, are arranged to slide over the compensator taps, in a manner similar to that in which the lever arm slides over the segments of a rheostat, and thereby vary the voltage impressed on the rotor. The speed regulation of a motor controlled by this method is very poor and the power factor and efficiency decrease with the speed. Where a resistance is used for varying the voltage impressed on the stator, the regulation and efficiency of the machine are not as good as when a compensator is used.

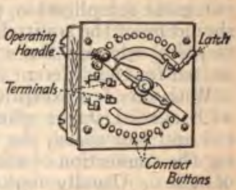


FIG. 104.—Primary resistance starter for a squirrel cage motor.

224. Speed Control of a Polyphase Motor with a Double Primary Arrangement.—The double primary motor resembles an ordinary squirrel cage induction motor in construction except that primary is divided vertically into halves, each with separate and windings. One-half can be rotated around the rotor by means of a worm-screw and rack device. Fig. 105 shows this construction. When the two halves of the primary are placed so that like poles are in line, the rotor windings are subjected to maximum magnetic flux from the primary, and the motor will run with minimum slip and therefore at its maximum speed. By turning the movable half of the primary, the flux acting on each rotor bar is gradually reduced, causing increased slip and a corresponding reduction of the motor speed for a given torque.

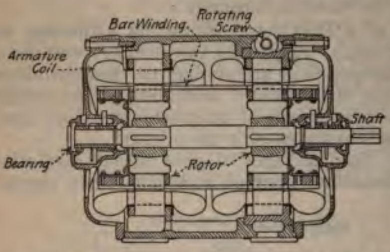


FIG. 105.—Longitudinal section of a double primary motor.

This operation is equivalent to varying the primary voltage and therefore cannot be used with advantage where constant speed with varying torque is desired. The mechanism is, however, self contained; the speed changes are effected without opening circuits; and the motor, having no brushes, operates without sparking.

225. Speed Control of a Polyphase Motor by Changing the Number of Motor Poles.—The synchronous speed of a polyphase motor is inversely proportional to the number of its poles. Thus on a 60-cycle circuit a two-pole induction motor has a synchronous speed of approximately 3,600 r.p.m., a four-pole motor 1,800 r.p.m., an eight-pole motor 900 r.p.m., etc. It is therefore possible to alter the speed of a motor by changing the number of its poles.

This can be accomplished by using two or more separate primary windings, each having a different number of poles, or by using a single winding which can be connected so as to form different numbers of poles. In general only two speeds are possible without great complication, the preferable ratio being 1 : 2. The rotor should be of the squirrel cage type as this is adapted to any number of poles, whereas the windings of a wound rotor must be reconnected for the different speeds.

With very few exceptions these motors are squirrel cage machines with special stator windings. They are designed to operate at full and half speed, the different speeds being obtained by changing the connection of the coils so as to halve or double the number of poles. Usually motors with the lower speed other than half speed require more complicated connections and necessitate bringing out a large number of leads from the motor. The motors can be designed for three or four speeds, but such will require two distinct stator windings. Obviously these motors are very special and their use is not advocated except when absolutely necessary.

The efficiency is approximately the same at each speed and the *power factor which* is lower at full speed than that of the normal motor *is reduced very greatly* at the lower speed. Also the put is proportional to the speed, while the percentage slip remain approximately the same for each speed, and the starting torque per ampere varies approximately inversely as the speed.

226. Speed control of polyphase motors by operating two or more motors connected in cascade offers, under some conditions of service, the most convenient and economical method of speed variation. In this arrangement all the rotors are mounted on one shaft or the several shafts are rigidly connected. The primary of the first motor is connected to the line, its secondary, which must be of the phase-wound slip-ring type, to the primary of the second motor and so on. The secondary of the last motor can be either of the squirrel cage or of the phase-wound type. In practice more than two motors are rarely used. The arrangement is shown in Fig. 106.

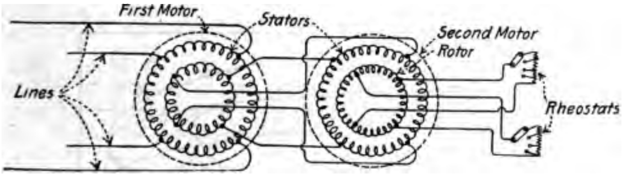


FIG. 106.—Two polyphase motors connected in cascade.

Speed changes are obtained by varying the connections of the motors, the following combinations being possible with two motors. Each motor can be operated separately at its normal speed with its primary connected to the line, the other motor running idle; the motors can be connected in cascade so that the rotors tend to start in the same direction (direct concatenation); or the motors can be connected so that the rotors tend to start in opposite directions (differential concatenation). If the first motor has 12 poles and the second 4, the following synchronous speeds can be obtained on a 25-cycle circuit.

(1) Motor *II* (4 poles) running single, 750 r.p.m.; (2) motors in differential concatenation (equivalent of 8 poles), 375 r.p.m.; (3) motor *I* (12 poles) running single, 250 r.p.m.; (4) motors in direct concatenation (equivalent of 16 poles), 187.5 r.p.m. By the use of adjustable resistance in the secondary circuits, changes from one speed to the next can be made with uniform gradations.

A great number of speed combinations are possible by the use of this method; the control is simple and safe, as few leads are required and main circuits are not opened for most of the speeds. The rotors can be made with smaller diameters than is possible with other multispeed motors, hence the flywheel effect is reduced to a minimum. In general, a cascade set is applicable where speed changes must be frequently made with high horse-power output and primary voltage, and where the speed ratios are other than 1:2.

227. *Speed Control of a Polyphase Motor by Adjusting Frequency of the Primary Current.*—Since the synchronous of an induction motor is equal to the alternations of the supply circuit divided by the number of poles in each circuit, a change in speed can be effected by changing the frequency of the circuit.

Fig. 107 shows the speed-torque and other curves of a motor when operated at 7,200, 3,600, 1,800, and 720 alternations per minute, or at 100, 50, 25, and 10 per cent. of the normal alternations. The speed-torque curves corresponding to the above alternations are *a*, *b*, *c*, and *d*. The current curves are *A*, *B*, *C*, and *D*. This figure shows that for the rated torque *T*, the current is practically constant for all speeds, but the electro-motive force varies with the alternations. Consequently, the apparent power supplied, represented by the product of the current by electro-motive force, varies with the speed of the motor, and is practically proportionate to the power developed.

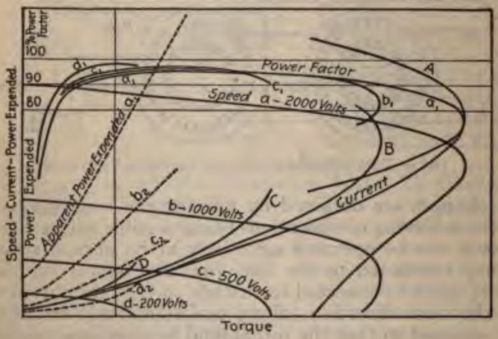


FIG. 107.—Performance curves of a polyphase induction motor with different applied frequencies and different applied electromotive forces.

In a few cases, where only one motor is operated, the generator speed can be varied. If the generator is driven by a water-wheel, its speed can be varied over a wide range, and the motor speed will also vary. If the generator field is held at practically constant strength, then the motor speed can be varied from zero to a maximum at constant torque with a practically constant current.

Another method of accomplishing this result is by the use of a frequency changer. Fig. 108 shows the arrangement. *B* and *C* are induction motors of the ordinary type; *A* is a direct-current motor directly connected to the rotor of *B*. *C* is the driving motor and *B* the frequency changer. The primary of *B* is connected to …e line, its secondary to the primary of *C*. The frequency of the …ent delivered to *C* depends on the relation of the speed of the … *B* to the synchronous speed of B; the slower the rotation of …tor the higher the frequency delivered to C and the higher …d of *C*. The speed of the rotor B is controlled by adjust…ld of motor *A*. Motor *B* must be practically the same si…

s C; but motor A can generally be relatively smaller, the exact ize depending on the maximum and minimum frequency and the ower required for motor C.

This method can be applied with special advantage where direct-urrent motor drive is not desirable.

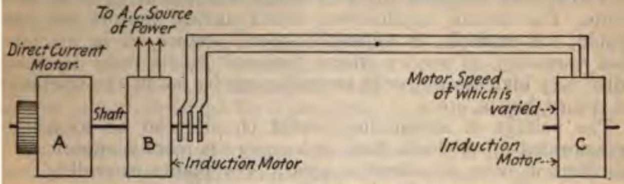
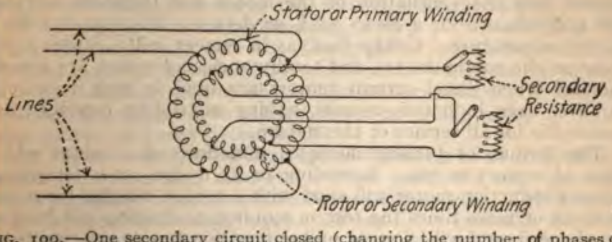


FIG. 108.—Speed adjustment by changing frequency.

228. Speed Control of a Polyphase Motor by Changing the Number of Phases of the Secondary Winding.—Phase-wound notors have in almost all cases secondaries with three-phase windngs. If only one of the secondary circuits is closed the motor will un at about half speed, with very low power factor and poor eficiency. This method of speed adjustment (Fig. 109) is frequently ised in experimental work, but has no extensive commercial pplications.



IG. 109.—One secondary circuit closed (changing the number of phases of the secondary winding).

THE APPLICATION OF ELECTRIC MOTORS

229. Comparative Cost of Line-shaft and Individual Motor Drive for Machine Tools (*Amer. Mach.*, Sept. 26, 1912).—The nost economical motor will compare favorably in first cost with ne-shaft drive. Its first cost does not exceed by much that of nstalling line shafting, countershafting and belts. The difference paid for in two or three years when so small an item as the power ved in friction of overhead mechanical transmission equipment one is considered. The saving in production will pay for the ference in a very short time.

30. Direct-current Versus Alternating-current Motors.—ther alternating-current or direct-current motors shall b used is usually determined by the kind of energy available. If a new power plant is to be installed, however, the operating conditions may sometimes affect the choice of current. Even in this case the characteristics of the new plant should agree with those of the nearest central station in order to obtain break-down service and to operate economically with central-station energy on reduced loads. For certain applications, direct-current motors are preferable; for example, in adjustable-speed service, as in machine tool operation, in service where frequent starts must be made with very high torque, or in reversing service, as in the operation of cranes, hoists, etc.

The voltage of alternating-current circuits can be so readily transformed up or down that such energy is more economical for distribution over considerable areas. For plants extending over a considerable area or distributing energy to distances, say, of one-fourth mile or more, alternating current is nearly always more economical. In order to utilize alternating-current for distribution when direct-current motors are preferable, the installation of rotary converters or motor generators for changing from the one kind of current to the other is sometimes warranted.

The question of protecting motors from dust and refuse sometimes determines the system that must be employed. When there is any possibility of injury from the accumulation of dirt or dust in motors, semi-enclosing or totally enclosing covers are essential on all motors having sliding contacts. Totally enclosing covers stop the ventilation of the motor and therefore increase the temperature for a given load, or decrease the capacity for a given temperature. Gritty dust, as in cement mills, causes rapid wear on the commutators, and totally enclosing covers are recommended when direct-current motors are used in such locations. Squirrel cage induction motors, having no sliding contacts, are preferable for all service of this nature.

The torque, or turning moment, sometimes determines which class of motors to use. According to its design, an alternating-current induction motor will start with a torque ranging from one to three or more times the torque required to develop full-load at rated speed, and will stop, or pull out, with a torque ranging from two to four times its full-load torque. Higher relative starting torque can be obtained by the use of larger alternating-current motors, but in some cases the more practical way is to employ direct-current motors.

231. Speed Classifications of Electric Motors.—The electric motor may assume practically an infinite number of different forms and can be applied to an almost unlimited number of uses. Each motor, however, possesses certain inherent speed characteristics by means of which it can be classified in one of several groups. The following classification is that which was adopted by the American Association of Electric Motor Manufacturers, January, 1909:

(a) *Constant-speed Motors.*—In which the speed is either constant or does not materially vary, such as synchronous motors, induction motors with small slip, ordinary direct-current shunt-wound motors and direct-current compound-wound motors no-load speed of which is not more than 20 per cent. higher tha the full-load speed.

(b) *Multispeed Motors.*—Two-speed, three-speed, etc., motoı which can be operated at any one of several distinct speeds, thes speeds being practically independent of the load, such as direcı current motors with two armature windings and induction motoı with primary windings capable of being grouped so as to forı different numbers of poles.

(c) *Adjustable-speed Motors.*—(1) Shunt-wound motors in whic the speed can be varied gradually over a considerable range, bı when once adjusted remains practically unaffected by the loac such as motors designed for a considerable range of speed by fiel variation.

(2) Compound-wound motors in which the speed can be varie gradually over a considerable range as in (1), and when once ac justed varies with the load similar to compound-wound constanı speed motors or varying-speed motors, depending upon the peı centage of compounding.

(d) *Varying-speed Motors.*—Motors in which the speed varie with the load, decreasing when the load increases, such as serie motors and heavily compounded motors. Examples of heavil compounded motors are those designed for bending roll and mi service, in which a shunt winding is provided only to limit the lighı load operating speed.

232. Determining the Speed Required of a Motor for a Give Application (*Earl D. Jackson, Engineering Magazine,* Septembe 1911).—Ascertain accurately the desired speed or speeds of th machine to be driven, and the maximum horse-power as well as th average horse-power required. The speed or speeds of the drive machine may be ascertained by tests with an experimental motoı or from data furnished by the builder of the machine. Often ir dividual motor drive is to replace steam or group drive, in whic cases speeds are easily determined.

233. The horse-power required of the motor (*Earl D. Jackson*) should be determined accurately. The purchaser may rent a experimental motor and ascertain the power required. This is prob ably the most satisfactory way. Group drive generally require that this be done, as the amount of power required for a group c machines is problematical. Note that from the input to the tes motor, as measured with a wattmeter, or with a voltmeter an ammeter, should be subtracted the test-motor losses, as the motc to be purchased is rated on horse-power output or brake-horse power. Money spent in the accurate determination of the powe required is wisely expended.

Machine-tool builders, and motor manufacturers, are ofte requested to supply the information as to how large a motor shoul be. The machine-tool builder often overestimates the horse power required to be on the safe side. The result is that the moto run at one-*quarter to one-half* load at greatly reduced efficien *The electrical losses, and interest* and depreciation on the unne *sary extra investment* may amount to considerable in a *nstallation.*

234. Open Versus Enclosed Motors.—The metal covers of closed motors reduce the efficiency and capacity of the motor by preventing free circulation of air around the active elements of the motor. Working conditions usually determine whether it is possible to use the open motor, which is, of course, the desirable practice, or whether the presence of excessive dust renders it necessary to enclose the moving parts of the motor partially or completely. The partially or semi-enclosed motor should not be placed in a concealed position because it will then be neglected. Perforated covers and wire screens clog up by dust and dirt, and a semi-enclosed motor becomes, virtually, a totally enclosed motor with a semi-enclosed rating and consequent trouble.

235. Application of Vertical Motors.—Vertical motors are recommended only when the nature of the drive renders it apparent that they possess great advantages over motors of the standard or horizontal type. Vertical motors are, in general, inclined to be troublesome and require greater attention. They are not generally kept in stock. The motor and repair parts must be replaced from factory stock and a delay in shipment usually results.

236. The rating of motors is determined by the continuity of operation, which must accordingly be considered in making a selection. The heating of the machine due to the passage of electric current through it largely determines the rating. If too great a load is imposed the motor will become excessively hot and the insulation will probably be injured. Obviously, a motor can be rated higher for intermittent service than for continuous service; conversely, a motor rated for intermittent service must not be used at the same rating for continuous service. In any service a motor can nearly always deliver more than its standard continuous rated output for short periods only, with intervening periods of rest. This fact is often overlooked, and motors larger than necessary are accordingly selected.

237. Factors Affecting the Selection of Small Motors (*Westinghouse Publication*). *Alternating-current, Single-phase Motors.*—Single-phase motors should be selected with starting torque that will bring the machine promptly up to speed. Allowance must be made for reduced voltage of circuits, since the starting torque varies as the square of the voltage. On account of too small wiring or insufficient transformer capacity, the voltage of many such circuits drops considerably at times. While the motor is starting, the voltage may drop to possibly 80 per cent. of its rated value at which the starting torque of the motor is only approximately 64 per cent. of the torque at full voltage. For these reasons, motors to drive machines from the ordinary lighting circuits should be selected for the worst probable starting conditions. Under especially severe starting conditions, centrifugal clutches are advisable on single-phase motors. The clutch operates automatically after the motor has attained nearly full speed, thus minimizing both the amount and the duration of the starting current.

The maximum turning effort, or torque, while the motor is running must also be ample for the worst load conditions to which the machine will probably be subjected, and with voltage at least 10 per cent. below rated voltage.

Direct-current Motors.—The operating characteristics of direct-current motors depend very largely on the field windings. The following comparison applies to shunt- compound- and series-wound motors of the same rating and efficiency, hence the same rated full-load current input. *Shunt-wound motors* take starting current in direct proportion to the starting effort or torque required, and the speed while operating remains practically constant at all loads. Such motors are most generally applicable unless the starting conditions are too severe.

Compound-wound motors will develop higher starting and maximum torques with the same current input than shunt-wound motors, but the speed while operating varies more widely with the load. They should be applied where high starting effort with low current is desired, and where some change of speed with load is not objectionable. Also on circuits with fluctuating voltage the series field winding of such motors helps to steady the current and speed.

Series-wound motors develop higher starting and maximum torques with a given current input than either shunt or compound motors; but while operating, the speed varies widely with the load, increasing to a dangerously high speed at no-load. Series motors are applicable where very heavy torque must be developed, either while starting or operating, and where varying speed with varying load is not objectionable. Series motors must not be belted or applied where the load may become very light, since if the belt should come off, or the load be removed in any other way, the speed would become excessive.

238. The standard direct-current motor voltage practically standardized for factory use is 220 volts. This voltage is both economically and operatively superior for direct-current motor systems to that of 110 volts sometimes employed.

239. Types of Direct-current Motors for Different Speed Requirements (*Engineering Magazine*, September, 1911)

Requirement	Type of motor
Approximately constant speed, no-load to full-load.	Shunt motor. Shunt-commutating pole motor.
Semi-constant speed, no-load to full-load.	Compound motor.
Adjustable speed, remaining approximately constant for one adjustment, no-load to full-load.	Shunt motor, with adjustable field resistance. Shunt-commutating pole motor with adjustable field resistance.
Adjustable speed, semi-constant for one adjustment, no-load to full-load.	Compound motor, with adjustable shunt field resistance.
Varying speed, varying with the load.	Series motor. Series-commutating pole motor.

240. Characteristics of Direct-current Motors and Their Fitness for Different Applications.—This subject is treated, in addition to the matter in the following paragraphs, in several paragraphs in this section starting with **249**.

241. Induction-motor Applications (*A. M Dudley, Electric Journal*, July, 1908)

Squirrel cage		Phase-wound	
Constant speed	Variable speed	Constant speed	Variable speed
1. Motor-generator sets.	1. Starting motors.	1. Flour mills.	1. Hoists and winches.
2. Pumps.........	2. Crane motors.	2. Paper, machinery, pulp grinders, beaters.	2. Cranes.
3. Blowers........	3. Fly-wheel service, punches, shears, etc.	3. Belt conveyors.	3. Elevators.
4. Line-shaft drive.	4. Sugar centrifugals.	4. Wood planers.	4. Fly-wheel motor-generator sets.
5. Cement machinery.	5. Laundry extractors.	5. Air compressors.	5. Steel-mill machinery charging machines, hoists.
6. Wood-working machinery (except planers).	6. Brake motors.	6. Line shafting..	6. Coal and ore unloaders.
7. Cotton-mill machinery.	7. Cross-head motors.	7. Driving wheel lathes.	7. Dredging machinery.
8. Paper machinery, calendars, Jordan engines.	8. Valve motors.	....	8. Shovels.
9. Concrete mixers.	....	....	9. Mine haulage.

242. Squirrel Cage Induction-motor Applications for Constant-speed Service (*A. M. Dudley, Elec. Jour.*, July, 1908). *Motor-generator Sets.*—Small starting torque is required and good speed regulation, which characteristics are preeminently met by a squirrel cage motor with very low resistance in the secondary rings. A fair specification on a large set is that it shall start on 30 to 40 per cent. of full voltage, and draw current not in excess of $1\frac{1}{4}$ times full-load current.

Pumps.—With a centrifugal pump, decreasing the head pumped against increases the load on the motor. This type of pump will raise considerably more than four-thirds the amount of water 30 ft. that it will 40 ft., with the result that the motor is overloaded if it is designed for 40 ft. head. In this the centrifugal pump is exactly opposite to the plunger or reciprocating pump, which, being positive in its action, increases its load with increase of head and vice versa. (In some modern types of centrifugal pump the load decreases with decrease of head after reaching the maximum load corresponding to the head for which the pump is designed.

Blowers.—*Rotary blowers*, except positive blowers, have a characteristic similar to centrifugal pumps, in that the load varies with the amount of air delivered and becomes less as the pressure against which the blower is working increases. That is to say, the maximum load which could be put on a motor driving a blower of this nature would be to take away all delivery pipes and let the blower exhaust into the open air.

Line Shafting.—Squirrel cage motors are used very successfully for driving line shafting where the idle belts are run on loose pulleys, in this way keeping down the starting torque.

Cement Mills.—The possibility of entirely covering the bearings and the absence of all moving contacts make the squirrel cage motor successful where the more complicated construction and moving contact surfaces of the wound secondary motor or the direct-current machine are damaged by accumulation of dust. In starting up a tube mill it must be rotated through nearly 90 per cent. before the charge of pebbles and cement begins to roll. This makes the starting condition severe and a motor should have a starting torque of not less than twice full-load torque to do the work.

Wood-working Machinery.—On account of high friction and great inertia, the starting torque is sometimes so high and of so long duration (30 sec. to 1 min.) that it is sometimes better to apply a wound secondary motor.

Paper Machinery.—If calendars are driven with a constant-speed motor, it is necessary to make some provision either by mechanical speed-changing devices or a small auxiliary motor for securing a slow threading speed.

243. **Squirrel Cage Variable Speed Motor Applications.**—These motors in general have high-resistance end rings, high slip and high starting torque. The torque increases automatically as the speed decreases. In these general respects they resemble a direct-current series motor and are in fact fitted for the same class of work, with the added advantage that they have a limiting speed and cannot run away under light load.

Flywheel Service.—In driving tools which are used with fly-wheels, such as punches, shears, straightening rolls and the like, the usefulness of high slip comes in, as if the fly-wheel is to give up its energy, it is obliged to slow down in speed when the load comes on. A motor with good regulation and low slip would try to run at constant speed, carrying the flywheel and load as well, but the motor in question "lies down" and allows the flywheel to carry the peak load, speeding up again when the peak has passed.

In sugar centrifugals is an application where the sole purpose of the motor is to accelerate the load to full speed, in say 30 sec., where it is allowed to run 1 min. and then shut down to repeat the cycle a minute later. The centrifugal consists of a cylindrical basket with perforated walls and mounted around a vertical shaft as an axis. The same principle is used in laundry extractors where the wet linen is placed in a similarly perforated basket and the water whirled out by centrifugal force.

244. Applications of **Constant-speed Motors with Phase-wound Secondaries.**—There are classes of service which require a heavy starting torque combined with close speed regulation after the motor is up to speed. These requirements are exactly satisfied by a motor with a phase-wound secondary. The secondary winding itself has a very low resistance, which results in a small "slip," high running efficiency, power factor and good regulation when the secondary is short-circuited. The insertion of external resistance enables the motor to develop maximum torque at the start with a moderate starting current.

Flour Mills.—The number of line shafts, belts and gears in flour mills makes a very heavy starting condition and the nature of the product and its quality demand absolute speed within a few revolutions per minute. The best solution is the phase-wound rotor.

Other Examples.—There is another class of machinery which is not so exacting about regulation but which has the same feature of heavy starting and runs continuously after once up to speed. Under this head come most of the applications of this type of motor. They are, paper-pulp grinders, which, on account of the inertia of the grindstones, are hard to start; pulp beaters, belt conveyors, which may be required to start when full of coal; rock or cement crushers; air compressors, which have a high starting friction because of the construction and the number of parts; line shafting where the belts run for the most part on the working pulleys and are therefore heavy to start. Under the best possible conditions, if line shafting is employed, the loss of power from this source alone, due to friction, is 25 per cent. to 30 per cent. and may run up to 40 or 50 per cent. This is a strong argument for individual drive of machines wherever practicable.

245. Application of Motors with Phase-wound Secondaries for Variable-speed Service.—The application, which is typical of this class, is found in hoist and crane service. Motors for this work are designed for intermittent operation and given a nominal rating based upon the horse-power which they will develop for ½ hr. with a temperature rise of 40 deg. cent. They never operate for as long a period as 30 min. continuously and they are called upon at times to develop a torque greatly in excess of their nominal rating. For these reasons motors of this class should never be applied on a horse-power basis, but always on a torque basis. Since torque is the main consideration and the service is intermittent these motors are usually wound for the maximum torque which they will develop and given a nominal rating based upon one-third to one-half of this torque. Double-drum hoists, hoisting in balance, and large mine haulage propositions in general require a motor rated on a different basis. For this service the motor should have the necessary maximum torque, and be able to develop for about two or three hours, with a safe rise in temperature, a horse-power equivalent to the square root of the mean square requirement of the hoisting cycle. These are only general rules and the most careful consideration should be given in each individual case to secure a motor which will perform the work satisfactorily.

Coal and Ore Unloading Machinery. Dredges. Power-shovels.—...g to the complication of the cycle of operation there is ...

ılty in providing a motor for this apparatus than in the case plain hoist. Usually the number of cycles per hour given is aximum which the apparatus can develop and in practice it ıot be possible to operate at so high a speed. This in itself newhat of a factor of safety, though it is not one that can be upon, as the test for acceptance is ordinarily made at the act number of operations per hour.

e most impressive application of motors of this class, and ıps in the operation of any electrical apparatus, is the fly- l motor-generator set for hoisting or heavy reversing roll ce in steel mills. Service of this nature is extremely fluctu- in its requirements, having very great peaks one instant and st nothing the next.

246. Operating Speeds of Various Machine Tools

circular (wood)	9,000 ft. per min. at rim
band (wood)	4,000 ft. per min. at rim
band (hot iron and steel)	200–300 ft. per min. at rim
stones	800 ft. per min. at rim
y wheels	5,000 ft. per min. at rim
(for wrought iron)	12 ft. per min. outer edge
(for cast-iron)	8 ft. per min. outer edge
ıg cutters (for brass)	120 ft. per min. outer edge
ıg cutters (for cast-iron)	60 ft. per min. outer edge
ıg cutters (for wrought iron)	50 ft. per min. outer edge
ıg cutters (wrought steel)	35 ft. per min. outer edge
cutting (gun metal, etc.)	30 ft. per min. at circum.
cutting (steel)	8 ft. per min. at circum.
g (cast-iron)	10 ft. per min. at circum.
ıg (wood)	1,500 ft. per min. at circum.
ıg (brass)	70 ft. per min. at circum.
ıg (gun-metal)	30 ft. per min. at circum.
ıg (steel)	25 ft. per min. at circum.
ıg (wrought iron)	30 ft. per min. at circum.
ıg (cast-iron)	20 ft. per min. at circum.

247. Size of Motors to Drive Machine Tools

Machine	Size	H.p. of motor
ıe lathes, 14 to 48 in. swing	Light duty	2 to 7½
	Heavy duty	5 to 20
:al boring rolls	20 in.	5
	100 in.	15
	16 ft.	30
l drills	4 to 10 ft.	3 to 7½
ht drills	15 to 50 ft.	½ to 3
ıg machines	Small	3
	Large	15
rs	24×24 in.	5 to 7½
	56×56 in.	15 to 25
	14×12 ft.	75 main motor; 12 rail motor
ırs	14 to 36 in.	3 to 7½
rs	10 to 30 in.	3 to 15
saws	1 to 3 ft.	2 to 10
ers	....	5 to 15

3. Motor-driven Wood-working Machinery.—Alternating- *nt, squirrel cage,* constant-speed induction motors form the *suitable drive* for the majority of wood-working machines.

In some few machines, as in "hogs" for reducing slabs to kindling, high flywheel effect makes starting difficult, and motors with phase-wound rotors and external resistance are preferable. For machines requiring adjustable speed, such as certain types of wood lathes, direct-current shunt-wound motors give the best results because of the greater range of speeds possible.

249. Individual Motor Drive and Group Drive for Wood-working Machinery.—Individual motor drive should be used for single machines that are operated more or less irregularly but at their full capacity. This applies to most wood-working machines. Group drive is satisfactory for machines used frequently but not simultaneously. Thus an emery wheel, knife grinder, carving machine, cabinet saw and disc sander can all be run by one motor, which can have a capacity of considerably less than the aggregate rating of the machines it is used to drive.

250. Size Motors Required to Drive Wood-working Tools

Machine	Size	Motor h.p.
Jointers	Small	2
	Large	5 to 7½
Inside molders	8×4	15
	15×6	20 to 30
Outside molders	4×4	5
	8×4	10
	14×5	20
Mortising machines		3 to 5
Planers, matchers, and molders	9×6	30
	30×12	40
Surfacers	Small, slow feed	5
	Large, rapid feed	30
Belt sanders		3 to 5
Column sanders		3
Disc sanders		3
Drum sanders	16-in. drum	3
	42-in. drum	10
	60-in. drum	20
	80-in. drum	30
	102-in. drum	40
Spindle sanders		3
Band saws	Small	3
	Large	20
Band re-saws	8×24	15
	28×36	40
Circular saws, single cut off	14 in.	3
	36 in.	5
	60 in.	60
Circular rip saw	14 in.	10
	36 in.	15
Timber sizers		30 to 50
Tenonizing machines	Small	3 to 5
	Large	10 to 15

251. Motor-driven Pumps (*Westinghouse Diary*).—Either direct-current or alternating-current motors are satisfactory. (See 254.) For most cases shunt-wound direct-current and squirrel ’ge alternating-current motors are suitable; but when the start- r conditions are severe, as when the pump must be started agains ill discharge pipe, compound-wound direct-current and phas ed alternating-current motors are preferable.

252. Power Required for Printing Machinery
(W. O. Webber, "Power")

		h. p.
	30 in. by 52 in., 2 rev., No. 8 Cottrell press, 19 impressions per min.	1.19
	27 in. by 41 in., No. 20 Adams press, 16 impressions per min.	0.68
	32 in. by 54 in., Huber perfecting press	2.44
	43 in. by 64 in., Huber perfecting press, automatic feed	5.55
	27 in. by 41 in., No. 4 Adams job press	0.43
	26 in. by 40 in., No. 2 Adams job press	0.34
	32 in. by 54 in., No. 1 Potter cylinder roller press	0.50
	26 in., No. 1 Hoe perfecting press	5.41
	Web paper-wetting machine	0.52
Newspaper presses	One 10-page web perfecting press, 12,000 per hr.	15.39
	One 10-page web perfecting press, 24,000 per hr.	31.00
	One 12-page web perfecting press, 12,000 per hr.	20.45
	One 12-page web perfecting press, 24,000 per hr.	29.56
	One 32-page web perfecting press, 12,000 per hr.	28.73
Calico printing machin'y, 100 yard goods per min.	One 19-cylinder, soaper and dryer, full, 110 r.p.m.	3.97
	One cutting machine, full, 65 r.p.m.	2.77
	One set drying cans to cutting machine, full, 110 r.p.m.	2.33
	One back starcher, 3 wide machines, full, 115 r.p.m.	4.24
	One indigo skying machine, 5 vats all working full, 64 r.p.m.	4.78
	One 40-in., 5-roll calender, working full, 234 r.p.m.	9.80
	One single-color printing machine	10.60

253. Power Required to Drive Printing Presses
(Walter Scott and Co. specifications[1])

	Mach. No.	Size of bed in.	Imp. per hour	Rev. of shaft per imp.	h.p. motor
Class C, newspaper drum cylinder.	5	29 × 42	2,000	5	2
	6	33 × 47	1,800	5	2.5
	7	37 × 51	1,600	5	3
Class D, job news drum cylinder.	1	17 × 22	2,800	4	1.5
	3	24 × 29	2,400	5.09	2
	4	26 × 34	2,200	5.07	2.5
	5	29 × 42	2,000	5	2.5
	6	32 × 47	1,800	4.96	3
Class E, high-speed drum	2	20 × 25	3,600	6	2
	3	23 × 31	3,200	6.52	2.5
	4	26 × 36	2,850	7.56	3
	5	29 × 42	2,600	8.08	3.5
2-roller two rev. high-speed.	4	26 × 36	2,800	6.8	2.5
	5	29 × 42	2,600	7	3
4-roller two rev. high-speed.	4	27.5×36	2,600	7.4	3
	5	30.5×42	2,400	7.8	3.5
	6	35 ×46	2,200	8.06	4
	7	38 ×48	2,100	8.43	4.5
	8	41.5×52	2,000	8.81	5
	9	45 ×56	1,900	9.37	5.5
	10	48.5×62	1,800	9.75	6
	11	50 ×66	1,700	9.75	6

[1] Walter Scott and Co. recommend 1 h.p. more than is called for in each case, as this gives a liberal margin for coolness in running and reserve power for special work.

254. *Power Required for Pumping.*—The size of motor required for operating a pump can be roughly determined by the following formula:

$$h.p. = \frac{g.p.m. \times H}{2{,}000}$$

where *g.p.m.* is the gallons pumped per minute, and *H* is the total vertical lift in feet. This formula neglects friction head and assumes an efficiency of about 50 per cent. for the pumping unit. The following formula is exact for fresh water:

$$\text{h.p.} = \frac{g.p.m. \times (H+F)}{3,960 \times E}$$

where *F* is the friction head and *E* the efficiency of the pump expressed in hundredths. For sea water, the result should be multiplied by 1.026.

INSTALLATION OF MOTORS AND GENERATORS

255. Brief of Underwriters' Rules Covering the Installation of Generators (*Factory Mutual Fire Insurance Co's. Handbook*).—Generators should be located in clean, dry places, away from combustible materials; and a light location rather than a dark one is always preferable. It is not desirable to place them in the work-rooms of a plant where combustible material abounds, as in the ordinary textile mill, though they may sometimes be so located if properly cut off from the main room by a dust-tight plank partition. A location suitable for a first-class steam engine is none too good for a generator.

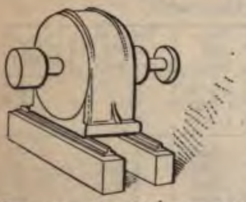


FIG. 110.—Machine mounted on two timbers.

A solid foundation is necessary for smooth running. Where a generator or motor must be mounted on timbers, two parallel timbers, as shown in Fig. 110, are preferable to a four-sided framework, which encloses a place under the machine that is difficult to keep clean.

256. Brief of Underwriters' Rules Covering Dynamo Wiring (*Wiring Rules of the Factory Mutual Fire Insurance Companies*).—Since there is generally a considerable number of wires brought close together in this room, particularly in the vicinity of the switchboard, the use of a "slow-burning" insulation is of great importance. As automatic sprinkler protection is not always advisable in dynamo rooms, the necessity for reducing as far as possible the chances of a fire at this point is at once evident. The desirability of fireproof construction throughout the dynamo room is especially emphasized.

Special care should be exercised in rigidly supporting and thoroughly insulating the wires from generator to switchboard, as the main cutouts are usually on the switchboard and a short-circuit between these wires would, therefore, be likely to burn out the armature.

257. Brief of Underwriters' Rules Covering the Installation of Motors (*Factory Mutual Fire Insurance Co's. Handbook*).—The use of voltages above 550 in rooms where manufacturing processes are being carried on will be approved only when every practicable safeguard has been provided. Plans for such installations should be submitted to the Inspection Department before work on them is begun.

Direct-current motors and alternating-current motors with brushes should be so located or enclosed, especially in dusty or linty places, that inflammable material or flyings cannot accumulate around them and become ignited by serious sparking at the brushes. Similar protection should also be provided in wet places, as most electrical machinery is injured by continued exposure to moisture.

Alternating-current induction motors of the type without brushes can be safely located in almost any part of a textile plant without being enclosed, being generally no more dangerous than any other piece of machinery running at the same speed.

For light work, direct-current motors which have all of the working parts enclosed in an iron case are on the market, and these "enclosed" motors may be treated in the same way as induction motors without brushes.

Where an enclosure around the whole motor is provided, it should include the starting rheostat or auto-starter, as well as the main switch and fuses or circuit-breaker, and should, if possible, be of such a size as will permit the attendant to enter it and easily get at any part of the apparatus. It should preferably be made largely of glass, so as to keep the motor in full view of the attendants, thus promoting cleanliness and making it possible to quickly discover any derangement. It should also be thoroughly ventilated, in order to prevent undue heating of the electrical machinery.

Where the use of a motor is permitted in a dusty or linty place without being enclosed, or if the enclosure provided for it is too small to include anything else, the rheostat or auto-starter and the main switch and fuses or circuit-breaker should be placed in a dust-tight cabinet of approved construction. Similarly, in wet places, these accessories should be protected from moisture in a cabinet which is thoroughly water-tight.

258. **Commonwealth Edison Company Rules for Motor Wiring** (*Commonwealth Edison Co. Handbook*).—Wiring for motors should be so arranged that the current used for power purposes may be metered separately from that used for lighting. Wiring for elevators should also be arranged so that current used on elevators may be metered separately from that used for other power. All motors larger than 1 h.p. must be wound for 220 volts, and it is preferred that motors of $\frac{3}{4}$ h.p. and larger be so wound.

No motors larger than 5 h.p. will be supplied on single-phase system, except by special permission, given by the Inspection Department of the Company in each case. Motors of 5 h.p. and larger will be supplied on the three-phase system at 60 cycles, 220 volts, where three-phase current is available. No motor will be connected which requires more than three times full-load current in starting without load.

259. **Foundations are necessary** (*Practical Electricity*) to support and maintain in alignment generators and other electrical machines of any considerable size. Foundations are made of masonry. Brick or stone set in mortar (preferably cement mortar) will do, but *concrete is almost* universally used because it is usually *the cheaper. A 1 : 3 : 6 (1* part cement, 3 parts crushed stone or *gravel and 6 parts sand by* bulk) or even a 1 : 3 : 7 mixture of con-

crete will give excellent results. Brick or stone for foundations can be set in a 1 part cement and 3 parts sand mortar.

260. The size of a foundation is determined by the size of the machine supported and by the stresses imposed by the machine. The area of base of any foundation must be great enough that its weight and the weight of the machine supported will not cause it to sink into the soil. The bearing power of soils is given in Table **260A.** Where a machine is not subjected to any external forces, that is, where it is self-contained, the only requirement of the foundation (provided the machine is not one that vibrates excessively) is to keep it from sinking into the ground and the lightest possible foundation that will do this will be satisfactory. Therefore motor-generators and rotary converters do not require heavy foundations. Machines that are driven by or drive external apparatus require foundations heavy enough to resist the tendency of the external apparatus to tip or to displace the foundation. No rule can be given for determining the proper weight for a foundation, in such a case. However, with a solid foundation, it is usually true that if the foundation is large enough to include all of the foundation bolts of the machine and to extend to good bottom, it will be sufficiently heavy. Experience is required to enable one to design the lightest possible foundation that will do, so it is well for the beginner to be sure that his foundation is heavy enough.

260A. Bearing Power of Soils (*Standard Handbook*)

Soil	Tons per sq. ft.	Remarks
Good solid natural earth	4	New York building laws.
Pure clay, 15 ft. thick, no admixture of foreign substances except gravel	1.75	Chicago building ordinances.
Dry sand, 15 ft. thick, no admixture of foreign substances	2	Chicago building ordinances.
Clay and sand mixed	1.5	Chicago building ordinances.
Hard rock on native bed	250	Richey.
Ledge rock	36	Richey.
Hard-pan	8	Richey.
Gravel	5	Richey.
Clean sand	4	Richey.
Dry clay	3	Richey.
Wet clay	2	Richey.
Loam	1	Richey.

260B. Foundations for machinery should be entirely separate from those of the building (*Standard Handbook*). Not only must the foundations be stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair-felt, mineral wool and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from 2 to 3 ft. deeper and 2 or 3 ft. wider on all sides than the foundation, and the sand, or whatever material used, occupies this extra space.

260C. A templet (Fig. 111) giving the location of all bolts to be used in holding the machine in place should be furnished, and the bolts may be run inside of iron pipes having an internal diameter a little greater than the diameter of the bolt. This allows some play to the bolt and is found very convenient for the final alignment of the machine. (See Fig. 112.) The bolts are sometimes cast in solid. Templets for foundation bolts can be made from ⅞-in. boards. The bolts are supported in the templet while the concrete is being formed. See Fig. 111 for an example of a simple templet.

261. Foundation bolts are usually mild steel rods, threaded for nuts on both ends, of such diameter that they will readily pass through the holes in the machine bed-plates. For small machines, ordinary machine bolts will do. Bolts should always extend nearly to the bottom of the foundation. (See Fig. 112.)

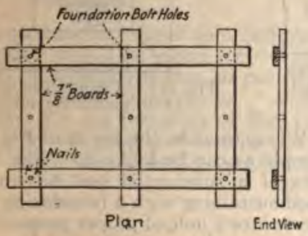


FIG. 111.—Simple foundation templet.

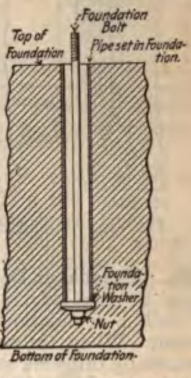
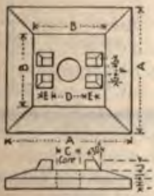


FIG. 112.—Bolt set in foundation.

262. Foundation washers are used on the lower ends of the bolts to retain them in the foundation. (See Fig. 112.) Ordinary round building washers, pieces of steel plate with holes punched in their centers, pieces of angle iron or old rails are sometimes used for foundation washers. But the form of cast-iron washer shown in Fig. 113 is better.



Size of Bolt	Weight	A	B	C	D	E	F	G	H	I	J
⅞"	8 lbs.	6	3½	1⅛	1⅝	½	⅜	⅜	⅜	⅜	½
1"	15	8	4¼	1⅜	1⅜	½	½	⅜	⅝	⅜	½
1¼"	30	10	4½	1⅝	2⅛	⅝	¾	½	⅝	⅝	½
1½"	45	12	5¼	1⅞	2½	¾	⅞	½	⅞	⅝	½
1¾	60	14	5½	2⅛	2⅞	1	1	⅝	1	½	½
2"	100	16	6	2⅜	3¼	1⅛	1	⅝	1⅛	⅞	½
2¼"	135	18	7	2⅝	3⅝	1¼	1⅛	¾	1¼	¾	½
2½	154	20	9	2⅞	4	1¼	1⅛	1	1	1	½

FIG. 113.—Dimensions of foundation washers.

263. Foundation pockets are provided in foundations where it is thought desirable to have the bolts removable. A pocket is a hole in the *side of a foundation* arranged so that the nut on the lower end *of a foundation bolt* can be reached. (See Fig. 114.) Ordinarily foundations are not pocketed. The bolts are cast in solid. If bolts are removable it is not necessary to raise the bed-plate of a machine up over them to mount it. The bed-plate is shifted into position and then the bolts are dropped in. Washers similar to that of Fig. 115, which have a pocket for the nut, are preferable for pocketed foundations.

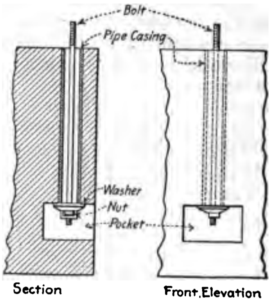


FIG. 114.—Foundation pocket.

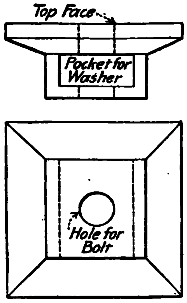


FIG. 115.—Foundation washer with pocket for nut.

264. **Foundation Design.**—Where feasible, the design of Fig. 116 should be used, which is as simple as can be laid out. The form for such a foundation consists of a substantial box having no bottom. Where the earth is self-sustaining such a foundation can be made by throwing the concrete into a hole of proper proportions (Fig. 117). The sides of the hole constitute the form. Founda-

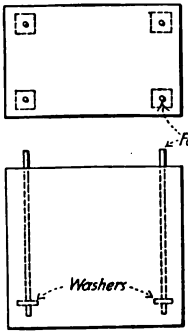


FIG. 116.—Simple foundation.

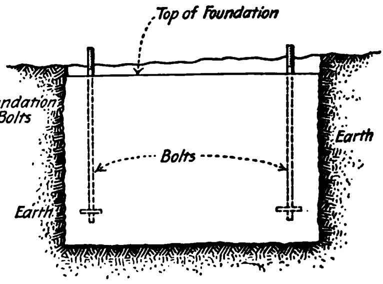


FIG. 117.—Foundation cast without forms.

tions of this type can be used for machines that have solid bed-plates, that is, for bed-plates through which air for ventilating the machine is not expected to rise. Where such a foundation, if cast solid, would be unnecessarily heavy, it can be hollowed out as suggested in Fig. 118.

Where considerable area of base is required, a solid foundation can be made, as suggested in Fig. 119, with an extended footing. The footing may consist of one or more steps. No step should be less than 8 in. thick. The "rise" and "width" of each step should be about equal. It is necessary sometimes to thus extend the base to maintain the pressure on the soil within a safe value.

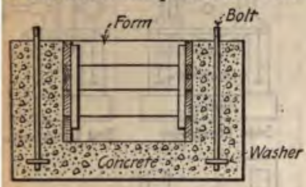


FIG. 118.—Hollowed out foundation.

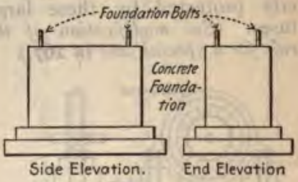


FIG. 119.—Foundation with extended footing.

Where machines have open bed-plates similar to that of Fig. 120 provision should be made for "ventilation" of the machine. It should be arranged so that air can rise all about it and keep it cool. Fig. 121 shows one type of "ventilated" foundation which is designed for the bed-plate of Fig. 120. A foundation for a large engine-driven generator can be made as suggested in Fig. 122. This design affords ample ventilation. A machine with an open

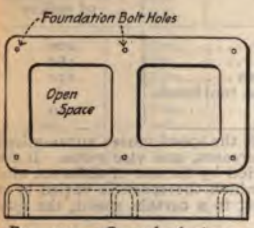


FIG. 120.—Open bed-plate.

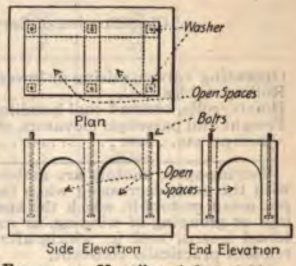


FIG. 121.—Ventilated foundation.

bed-plate can be supported on foundation columns as indicated in Fig. 123, a design used for water-wheel generators, but probably a design similar to that of Fig. 121 is better, in that it provides a support under the entire bed-plate. Undrained pits under machines should be avoided because they collect dirt and oil. A machine not exceeding 50 kw-amp. in capacity may be supported by a framework of timber. Other types of machines require heavier foundations and should be secured by foundation bolts set with a templet as above indicated. A drawing or blue-print of the generator base or bed-plate, will be furnished by the manufacturer of the machine on application.

265. *Underwriters' Rules Specifying Sizes of Wires for Motor Leads.*—A conductor carrying the current of only one motor must be designed to carry a current at least 25 per cent. greater than that for which the motor is rated. Where the wires under this rule would be over-fused in order to provide for the starting current, as in the case of many of the alternating-current motors, the wires must be of such size as to be properly protected by these larger fuses. (*See modification of this rule for a special case in* **267.**)

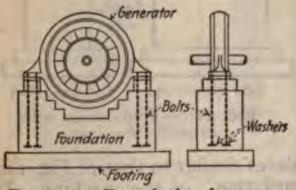


FIG. 122.—Foundation for an engine-driven generator.

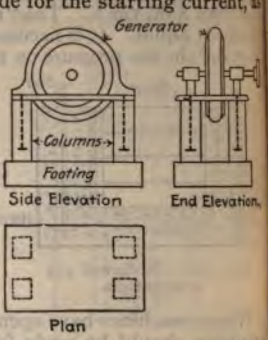


FIG. 123.—Machine supported on columns.

The current used in determining the size of a conductor carrying the current of only one varying-speed alternating-current motor must be the percentage of the 30-minute current rating of the motor as given in the following table:

Classification of Services.	* Percentage of current rating of motor
Operating valves, raising or lowering rolls.	200
Rolling tables.	180
Hoists, rolls, ore and coal handling machines	150
Freight and passenger elevators, shop cranes, tool heads, pumps, etc.	120

Varying-speed motors are motors in which the speed varies automatically with the load, decreasing when the load increases, and vice versa. It does not mean motors in which the speed is varied by the use of different windings or grouping of winding, or motors in which the speed is varied by external means, and in which, after adjusting to a certain speed, the speed remains practically constant.

266. Wiring Table for Direct-current Motors.—The values that are here tabulated represent experience of an employee of an Underwriting Department. Table based on average efficiencies quoted by several motor manufacturers. Table is compiled on the basis of installing conductors of 25 per cent. greater carrying capacity than required for the normal full-load running current of the motors. Commercial sizes of fuses, switches, etc., have been used even though they are of slightly greater capacity than that indicated necessary by the calculations.

Where two or more motors are supplied from one service or from the same feeder, the size of service or feeder may be determined by adding together the approximate full-load currents of the different motors as given in table, and basing the conductor size on this total current.

Wiring Table for Direct-current Motors (*continued*)

Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
110	2.4	4	5	14
220	1.2	3	5	14
500	0.5	1	5	14
110	4.8	6	10	14
220	2.4	4	5	14
500	1.0	2	5	14
110	8.4	12	15	14
220	4.3	6	10	14
500	1.8	3	5	14
110	17.0	25	25	10
220	8.5	12	15	14
500	3.7	5	5	14
110	20.0	25	25	10
220	10.0	15	15	12
500	4.4	6	10	14
110	24.0	30	30	8
220	12.0	15	25	12
500	5.3	8	10	14
110	28.0	35	35	8
220	14.0	20	25	12
500	6.0	8	10	14
110	40.0	50	50	6
220	20.0	25	25	10
500	8.8	12	15	14
110	60.0	75	75	3
220	30.0	40	50	6
500	13.5	18	25	12
110	80.0	100	100	1
220	40.0	50	50	6
500	17.5	25	25	10
110	120.0	150	150	00
220	60.0	75	75	3
500	26.3	35	35	8
110	154.0	200	200	0000
220	77.0	100	100	1
500	34.0	45	50	6
110	192.5	250	250	300,000
220	96.3	125	150	0
500	42.4	60	75	3
110	232.0	300	300	350,000
220	116.0	150	150	00
500	50.8	70	75	3
110	270.0	350	400	500,000
220	135.0	175	200	000
500	59.2	75	75	3

data applies to voltages of from 100 to 125 volts, 220-volt da' volts and 500-volt data to 500 to 600 volts.

266. Wiring Table for Direct-current Motors (*continued*)

Horse-power	Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
	110	310.0	400	400	500,000
40	220	155.0	200	200	200,000
	500	67.8	90	100	1
	110	377.0	500	500	700,000
50	220	188.5	250	250	300,000
	500	83.0	110	150	0
	110	452.0	600	600	900,000
60	220	226.0	300	300	350,000
	500	99.5	125	150	0
	110	528.0	660	700	1,100,000
70	220	264.0	350	300	500,000
	500	116.0	150	150	00
	110	568.0	710	800	1,200,000
75	220	284.0	375	400	500,000
	500	124.0	150	150	00
	110	604.0	755	800	1,300,000
80	220	302.0	375	400	500,000
	500	133.0	175	200	000
	110	680.0	850	1,000	1,500,000
90	220	340.0	450	500	600,000
	500	149.0	200	200	200,000
100	110	746.0	950	1,000	1,800,000
	220	373.0	500	500	700,000
	500	164.0	225	250	0000
	110	934.0	1,170	1,200	2,105,500
125	220	467.0	600	600	900,000
	500	205.0	275	300	300,000
	110	1,106.0	1,390	1,500	2,400,000
150	220	553.0	700	800	1,200,000
	500	245.0	325	400	400,000

[1] See note at bottom of preceding page.

267. Determining Sizes of Wire and of Fuses for Induction Motors.—*The* 1915 *National Electrical Code* rules applying to this class of wiring are substantially as follows: Rule 23e—"*Where rubber-covered conductor carries the current of only one A. C. motor of a type requiring large starting current, it may be protected in accordance with Table B* (*other insulations than rubber*) *of No.* 18." Rule 68h—"*Fuses must be so constructed that with the surrounding atmosphere at a temperature of* 75 *deg. fahr.* (24 *deg. cent.*) *they will carry indefinitely a current* 10 *per cent. greater than that at which they are rated, and at a current* 25 *per cent. greater than the rating at which they will open the circuit without reaching a temperature which will injure the fuse tube or terminals of the fuse block. With a current* 50 *per cent. greater than the rating and at room temperature of* 75 *deg. fahr.* (24 *deg. cent.*) *the fuses starting cold must blow within the time specified as follo*

0-30 *amp.*, 1 *min.*; 31-60 *amp.*, 2 *min.*; 61-100 *amp.*, 4 *min.*; 101-200 *amp.*, 6 *min.*; 201-400 *amp.*, 12 *min.*; 401-600 *amp.*, 15 *min.*

An induction motor designed to meet the best condition of normal operation should have as low an impedance as practicable, but a motor thus designed necessarily takes a very large current in starting, this current being inversely proportional to the impedance. This starting current, therefore, varies with the load the motor must start. The average condition found in practice is 100 per cent. load. With 100 per cent. load the starting current will be about four times normal current when a starting compensator is used and very close to five times normal current when the motor is thrown directly on the line. (See Fig. 124.) These curves show that this starting current does not last over 10 sec.

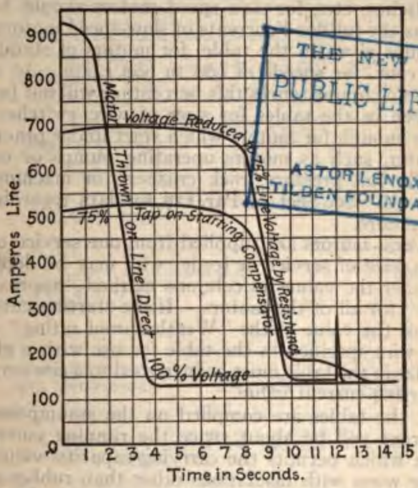


Fig. 124.—Starting currents taken by a 100-h.p., 440-volt induction motor loaded to its normal rating.

It will be found by computing the size of wire for any run of ordinary length, that the starting fuses necessitate that a larger wire be used than would be required to carry the full running current of the motor. This is still the case even when advantage is taken of Rule 23*e*, which allows rubber-covered wire to be fused to the carrying capacities given in *Table B* for wires with insulations other than rubber. However, further advantage may be taken of Rule 68*h*.

It will be found, by reference to the starting curves (Fig. 124), that *the fuses will carry* 50 per cent. over their normal rated capacity *for a greater length of* time than the duration of the starting curren *From the foregoing* it will therefore be evident that the size of w *for any induction* motor may be computed by selecting a line fus a capacity equal to two-thirds of the starting current and selecting a size of wire having the carrying capacity nearest to the rating of the fuse, using the carrying capacity given in *Table B* of the *National Electrical Code.*

There seems to be no rule regarding the fusing of weatherproof wire which makes any concession for this class of insulation, but, owing to the fact that weatherproof wire is never installed in conduit and therefore radiates effectively, it would seem to be permissible to make the same reduction from *Table B* as is made between *Tables A* and *B*.

268. The tables on alternating-current motor wiring (270 to 273) are for installations where motors do not start under full-load. The wire sizes shown are those that should be used for the branch circuit, from the main or distribution center, to the motor. Sizes of wires, switches, etc., for slow-speed motors should be larger in proportion, as the full-load currents of slow-speed motors are larger than the values given in the table, for motors of standard speed. Add 12 per cent. for speeds of 900 to 600 r.p.m. In some cases and under some circumstances this percentage will not be sufficient.

Values given in the tables for sizes of wire, switches and fuses are not large enough for motors which start under practically full-load or greater, such as motors operating pumps or compressors starting under full pressure, rock crushers, or machinery having heavy flywheels. See **Sect. II, Par. 127, for** data regarding starting currents of motors.

Where several motors are supplied from one service or from the same feeders, size of service or feeder wire may be determined by adding together the values in columns marked "approximate full-load current" for all of the motors. If the starting current of one motor exceeds the value of the "Weatherproof rating" of the rubber-covered wire specified in the table for use with a given horsepower, the size in the table must be increased to a size corresponding with the starting-current value.

Note that the tables are compiled on the assumption that the starting current will be about twice the running current. Code rule No. 23*e* which permits the carrying-capacity value normally allowable for wires with insulations other than rubber to be used for rubber-insulated alternating-current motor leads, determines the conductor sizes tabulated. Voltage drop is not considered in the tables.

269. The factors to be considered when designing a motor-drive for a machine are: (*Abstracted from article by A. G. Popcke, American Machinist,* Oct. 3, 1912.) The space available; the surrounding conditions; the nature of the load; the speed of the shaft where power is to be applied; the speed of the motor used; the method of connecting the motor mechanically: (*a*) Direct connected; (*b*) belted; (*c*) geared; (*d*) connected by chain drive.

270. Three-phase Induction Motor Branch Circuits, 110, 220 and 440 Volts—Fuse, Switch and Wire Sizes
(All frequencies and standard speeds. See Par. 268 for limitations)

Horse-power	110 volts: Approximate full-load current, amp.	110 volts: [1] Size wire, American or B. & S. gage	110 volts: [1] Size of switch, amp.	110 volts: [2] Size of starting fuses, amp.	110 volts: [3] Size of running fuses, amp.	220 volts: Approximate full-load current, amp.	220 volts: [1] Size wire, American or B. & S. gage	220 volts: [1] Size of switch, amp.	220 volts: [2] Size of starting fuses, amp.	220 volts: [3] Size of running fuses, amp.	440 volts: Approximate full-load current, amp.	440 volts: [1] Size wire, American or B. & S. gage	440 volts: [1] Size of switch, amp.	440 volts: [2] Size of starting fuses, amp.	440 volts: [3] Size of running fuses, amp.
1	7	14	15	15	9	4	14	10	8	5	2	14	15	4	3
2	13	10	35	30	20	7	14	15	15	9	3	14	15	6	4
3	19	8	50	40	25	9	14	25	20	12	5	14	15	10	7
5	30	6	75	60	40	15	10	35	30	20	8	14	25	20	10
7½	44	4	100	90	55	22	8	50	45	30	11	12	25	25	15
10	51	2	150	110	64	26	6	75	55	35	13	10	35	30	20
15	76	0	200	175	95	38	5	100	75	50	19	8	50	40	25
20	102	00	250	225	150	51	2	150	110	65	26	6	75	55	35
25	129	000	300	275	175	64	0	200	175	80	32	6	75	65	40
30	154	0000	400	325	200	77	0	200	175	100	39	5	100	80	50
35	175	250,000	400	350	225	88	0	200	200	110	44	4	100	90	55
40	210	350,000	500	450	275	107	00	250	225	150	54	2	150	110	70
50	246	500,000	600	600	325	123	000	250	250	175	62	2	150	125	78
75	350	700,000	800	750	450	186	300,000	400	375	250	93	0	200	200	120
100	472	1,000,000	1,000	950	600	243	400,000	500	500	325	122	000	250	250	175
150	710	1,700,000	1,500	1,450	900	362	700,000	800	750	450	181	300,000	375	375	225
200	940	....	2,000	2,000	1,200	480	1,000,000	1,000	1,000	600	240	400,000	500	500	300

...ing fuses so selected as to pass 200 per cent. full-load current. [2] Running fuses so selected as to pass 125 per cent. full-
[3] Switches and wire so selected as to safely carry current passed by starting fuses. See Par. 268.

271. Protection, Switches and Wire for Induction Motors—Three-phase, Three-wire, 2,200 Volts, 60 Cycles

(Underwriter's Equitable Rating Bureau, Portland, Oregon. *Electrical Review*, June 15, 1912)

Horse-power	Speed	Approximate full-load current	Size of wire, B. & S. gage	Size of oil switch in amp.	Size of starting protection, amp.	Size of running protection, amp.
15	1,800	3.7	14	60	10	5
	1,200	3.9	14	60	10	5
20	1,200	5.4	14	60	15	10
	900	5.8	14	60	15	10
25	1,200	6.5	14	60	20	10
	720	7.2	14	60	20	10
35	1,200	8.9	12	60	25	15
	720	9.8	12	60	30	15
50	900	13.7	10	60	40	20
	514	14.3	10	60	40	20
75	900	19.0	8	60	60	25
	514	20.7	8	60	60	30
100	720	24.4	6	100	75	35
	450	27.2	6	100	80	40
150	720	36.8	4	100	110	50
	450	40.9	2	200	125	60
200	600	50.0	2	200	150	75
	400	54.5	2	200	150	75

272. Single-phase Induction Motor Branch Circuits, 110 and 220 Volts—Fuse, Switch and Wire Sizes

(All frequencies, standard speeds. See Par. 268 for limitations)

Horse-power	110 volts					220 volts				
	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.
1	16	8	35	35	20	8	14	25	20	10
2	24	8	50	50	30	12	12	25	25	15
3	34	6	75	70	45	17	8	35	35	25
4	44	4	100	90	55	22	8	50	45	30
5	54	2	150	110	70	27	6	75	60	35
7½	80	0	200	175	100	40	5	100	80	50
10	106	00	250	225	125	53	2	150	110	70

[1] *Switches and wire so selected as to safely carry current passed by starting fuses.* [2] *Starting fuses so selected as to pass 200 per cent. full-load current.* [3] *Running fuses so selected as to pass 125 per cent. full-load current.* S **268.**

273. Two-phase, Four-wire Induction Motor Branch Circuits, 110 and 220 Volts—Fuse, Switch and Wire Sizes

(Standard speeds and frequencies. See Par. **268** for limitations)

	110 volts					220 volts				
Horse-power	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuse, amp.	[3] Size of running fuse, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuse, amp.	[3] Size of running fuse, amp.
1	6	14	15	12	8	4	14	10	8	5
2	11	12	25	25	15	6	14	15	12	8
3	16	8	35	35	20	8	14	25	20	10
4	18	8	50	40	25	9	14	25	20	12
5	26	6	75	55	35	13	10	35	30	20
7½	38	5	100	80	50	19	8	50	40	25
10	44	4	100	90	55	22	8	50	50	30
15	66	1	150	150	85	33	6	75	70	45
20	88	0	200	200	110	44	4	100	90	55
25	111	00	250	225	150	55	2	150	110	70
30	134	000	300	275	175	67	1	150	150	84
35	147	200,000	300	300	200	79	0	200	175	100
40	178	300,000	400	375	225	89	0	200	200	120
50	204	350,000	500	450	275	102	00	250	225	150
75	308	600,000	800	650	375	154	0000	400	325	200
100	408	900,000	1,000	850	550	204	300,000	400	400	275
150	616	....	.....	.....	800	308	600,000	800	650	400

[1] Switches and wire so selected as to safely carry current passed by starting fuses. [2] Starting fuses so selected as to pass 200 per cent. full-load current. [3] Running fuses so selected as to pass 125 per cent. full-load current. See Par. **268.**

274. The space available is the first consideration that determines the location of a motor. In many cases it is impossible to conveniently connect a motor to accommodate the requirements of a machine. In these cases, the motor must be connected to a countershaft in a way similar to that shown in Fig. 125, or the motor can be mounted on the ceiling, on a post or girder near the machine. Belt or chain drive must be used in such cases.

A convenient location is sometimes found for a motor, but the presence of water, oil and grease or small chips renders it undesirable. Inclosed motors can be used to overcome the difficulty. The use of a semi-inclosed motor will often insure protection. If an open motor is used in such cases, it is usually placed on the ceiling, a pedestal or a near-by column or girder, a belt or chain connection being used. (A. G. Popcke, *American Machinist*, Oct. 3, 1912.)

Mechanical difficulties in finding a location for a motor can often be overcome, oil and water avoided, and compact units obtained by the *addition of a countershaft* at the base of a machine to which *the motor is geared.* Figs. 126 and 127 show the back view and *side views of such an installation.* Note the convenient location *of the starting switch.*

The nature of the work of metal-working machinery is usual such that gears can be used wherever the motor can be placed on a machine. Machines such as punches, shears and headers, where heavy loads of short duration occur, are equipped with flywheels, which help to take up the shock; for this reason motors can be geared to this type of machine. When applying a motor to a header or any machine where a large flywheel is used, and the machine is not adapted to gearing, an easy way to apply a motor is to belt it to the flywheel.

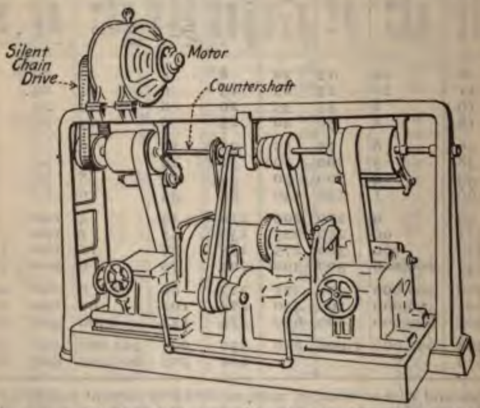


FIG. 125.—Motor driving countershaft with a silent chain.

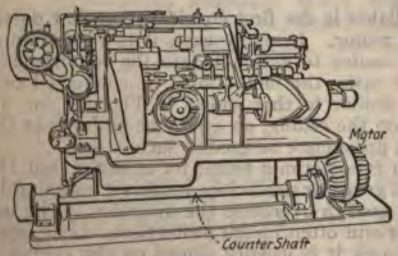


FIG. 126.—Back view showing countershaft at base.

FIG. 127.—Countershaft geared to motor.

275. The speeds of the shaft on the machine to which power is applied *is the principal factor which determines the speed of the motor to be connected.* These speeds vary with the type of machine. On forging machines using large flywheels they are as low as 5[illegible] 60 r.p.m.; on machine tools, such as lathes, drills, millers, etc. average between 200 and 300 r.p.m. Speeds as high as 1,[illegible] to 2,000 r.p.m. occur on grinders and wood-working machine: The method of taking care of these will be explained later.

276. Modern practice is to standardize the speeds of motor: This practice has been promoted by the extensive use of alternatin current. Since 60 cycles is used in the majority of alternating current systems, the standard speeds of direct-current motors ar approximately the same as the speeds of 60-cycle, alternating current motors.

The speeds obtainable with the 60-cycle motors mostly used ar 1,700 to 1,800; 1,100 to 1,200; 850 to 900; 650 to 720, and 550 to 6c r.p.m. The higher speed given in each case is the synchronou speed at which the motor runs when not loaded. The speed de creases from 5 to 7 per cent. as the motor is loaded.

On 25-cycle circuits the speeds of motors most frequently use are 700 to 750; 550 to 600, and 350 to 375 r.p.m. The speeds o direct-current motors are given in the second column of Table 28(A reference thereto will show the relation to the speeds of the alter nating-current motors just given.

277. Mechanical Connections.—Motors can be either direc connected, belted, geared or connected to machines by chain driv Direct connection with a flexible or rigid coupling can be use only where the speed of the shaft to which power is applied is th same as the motor speed. Belts, gears or chains must be use in all other cases.

278. Belt Drive of Motored Machines.—This is the mos convenient method in the majority of cases and is the least exper sive. It is, therefore, used more than the other two methods. Th factors to be considered when applying a belt drive are: Spee reduction; pulley sizes; belt speeds; motor speed; distance betwee pulley centers; arc of contact; size of belt; use of idle pulleys; moun ing of the motor.

279. Considerations in Obtaining Speed Reduction With a Be Drive.—The speed reduction is the ratio of the speed of the motc to the speed of the shaft where power is applied. Obtaining th required speed reduction involves the size of the motor pulley machine pulley and belt speed. The sizes of the pulleys used o motors have been standardized according to ratings, *i.e.*, horse power and speed of motor. These are given in Table 280, colum 3. This fixes standard practice for belt speeds (see Table 28(column 7).

As the diameter of a motor pulley is reduced, the strains on th motor bearings and shaft are increased. A minimum pulley i therefore, specified by motor manufacturers for each motor ratin (see Table 280, column 5). The maximum diameter of the pulle on a motor is required only where speeds higher than the motc speed are required (grinders and wood-working machines). Th maximum diameter is, in nearly all cases, limited by the belt speec which should not exceed 5,000 ft. per minute. In some cases, wi *small motors especially, the size and location of the motor such that the diameter of the motor limits the diameter of largest pulley.*

280. Standard Motor Ratings Showing the Standard and Minimum Pulleys Used in Each Case, Also Belt Speed with Standard Pulley

1	2	3	4	5	6	7	8
H.p.	R.p.m. D. C. motors	Standard pulley		Minimum pulley		Belt speed standard pulley, ft. per min.	Leather belt
		Dia.	Face	Dia.	Face		
1	1,700	3½	2½	3	1¾	1,560	Single
2	1,700	3½	3	3	3	1,560	Single
	1,200	4	3	3	3	1,250	Single
	850	4	4	3½	4	890	Single
3	1,800	4	3	3	3	1,890	Single
	1,150	4	3	3½	4	1,200	Single
	850	5	4½	4	4½	1,110	Single
5	1,800	4	4	3½	4	1,890	Single
	1,200	5	4½	4	4½	1,570	Single
	850	6	5	4½	5	1,340	Single
7½	1,700	5	4½	4	4½	2,220	Single
	1,150	6	5	4½	5	1,800	Single
	975	7	6	5	6	1,790	Single
	850	7	6	5	6	1,560	Single
	650	8	7	6	7	1,360	Single
10	1,700	6	5	4½	5	2,670	Single
	1,300	7	6	5	6	2,380	Single
	1,150	7	6	5	6	2,100	Single
	850	8	7	6	7	1,780	Single
	730	8	7	6	7½	1,530	Single
	600	9	8	6½	9	1,410	Single
15	1,700	7	6	5	6	3,100	Single
	1,250	8	7	6	7	2,620	Single
	1,100	8	7	6	7½	2,300	Single
	825	9	8	6½	9	1,940	Single
	675	10	9	7	8	1,770	Single
	600	11	10	7½	9½	1,730	Single
20	1,700	8	7	6	7	3,560	Single
	1,100	9	8	6½	9	2,600	Single
	900	10	9	7	8	2,360	Single
	750	11	10	7½	9½	2,160	Single
	650	11	10	8	9½	1,870	Single
25	1,400	9	8	6½	9	3,330	Single
	1,100	10	9	7	8	2,800	Single
	950	11	10	7½	9½	2,730	Single
	825	11	10	8	9½	2,370	Single
	600	12	12	9	10½	1,880	Double
30	1,700	9	8	6½	9	4,000	Single
	1,150	11	10	7½	9½	3,330	Single
	975	11	10	8	9½	2,800	Single
	725	12	12	9	10½	2,280	Double
	600	13	12	10	11	2,040	Double
35	1,700	10	9	7	8	4,450	Single
	1,150	11	10	8	9½	3,330	Single
	850	12	12	9	10½	2,670	Double
	675	13	12	10	11	2,300	Double
40	1,700	11	10	7½	9½	4,900	Double
	950	12	12	9	10½	3,000	Single
	775	13	12	10	11	2,640	Double
	600	14	12	12	13	2,200	Double
50	1,700	11	10	8	9½	4,900	Double
	975	13	12	10	11	3,320	Double
	750	14	12	12	13	2,750	Double
	565	16	13	12½	15	2,360	Double

ɪ. Belt speed is figured as follows:

$$\text{speed (feet per minute)} = \frac{\left(\begin{array}{c}3.14 \times \text{diam. of motor pulley} \\ \text{(inches)} \times \text{r.p.m. of motor}\end{array}\right)}{12}$$

2. The success of a belted motor application depends largely the arc of contact. The distance between centers of motor y and machine pulley, as well as the speed reduction, determine rc of contact on the smallest pulley, usually the motor pulley. ors can be furnished with idler-pulley attachments, Fig. 128, these are applied to advantage where it is necessary to overcome all arc of contact.

ɪ28.—Idler pulley attachment o increase arc of contact.

FIG. 129.—Back-geared motor suitable for extremely low speeds.

3. When necessary to obtain extremely low speeds back- ed motors should be used. (Fig. 129.) A good standard for k-geared motor gives a speed reduction of 6 to 1 between arma- and countershaft speed. Usually, if the required reduction in l exceeds 6 to 1, a back-geared motor should be used.

ample.—If the reduction is 12 to 1 between the motor speed and the ine speed, a back-geared motor with a 6 to 1 speed reduction should be and the further reduction 2 to 1 obtained by means of a pulley on the ershaft of the back-geared motor.

is poor practice in the majority of cases to use back-geared rs having an initial speed of 1,700-1,800 r.p.m. In applica- requiring from 10 to 20 h.p., 1,200-r.p.m. back-geared motors ld be used; above this 900-r.p.m. or 720-r.p.m. back-geared rs should be used.

4. The pulleys furnished with motors make provision for roper width of the belt. Table 280 shows whether a single uble belt should be used. The width of the belt should be one narrower than the pulley face on pulleys up to 12-in. face; e that it should be two inches narrower than the pulley face.

5. The cost of a motor of given horse-power increases as the l speed decreases. For instance, the cost of a 10-h.p. motor at r.p.m. is approximately the same as a 5-h.p. motor at 600 . *The cost increases in the same proportion as the square f the torque figured* at 1-ft. radius. This quantity is figured ans *of the following formula:*

$$\text{Torque at 1-ft. radius} = \frac{5{,}250 \times \text{h.p.}}{\text{r.p.m.}}$$

Example.—A 7½-h.p. motor at 1,150 r.p.m., ready for belting, costs approximately $180, and a 7½-h.p. motor at 650 r.p.m. costs approximately $235. The torques are

$$\frac{5,250 \times 7\frac{1}{2}}{1,150} = 34.2 \text{ and } \frac{5,250 \times 7\frac{1}{2}}{650} = 60.5$$

The square roots of these are 5.85 and 7.8, respectively.

The ratio of these square roots is

$$\frac{7.8}{5.85} = 1.33$$

The ratio of prices is

$$\frac{235}{180} = 1.31$$

These two ratios check closely.

From a cost point of view, therefore, as high a speed motor as possible should be used, but a pulley diameter smaller than the minimum specified should not be used.

286. Belting Motors.—There are two general cases to be considered when belting motors; these are: (1) Where the dimensions of the machine pulley is fixed, as when belting to a flywheel. In this case the motor pulley must satisfy the requirements of the machine. Care must be taken not to use a pulley of a diameter smaller than the minimum specified. The arc of contact of the motor pulley must also be carefully considered, for the speed reduction is usually large.

(2) Where the machine pulley can be chosen to suit the standard motor pulley. Tables 289 and 288 were devised to aid in selecting the proper speed of motor and size of pulleys. Table 289 gives the machine speed at the left column and the motor speeds at the top of the table. The figures in the body of the table are the speed reductions for any combination of machine and motor speed indicated.

287. Determining the Arc of Belt Contact.—Before deciding upon any belt drive the arc of contact of the belt with the smaller pulley should be carefully checked. In machine-tool work, on applications where belts are used, the distance between centers is usually between 3 and 5 ft. Motor pulleys range in diameter from 3 to 12 in. and the arc of contact is usually considered when the ratio of reduction is between 3 and 6.

Table 288 gives the arc of contact when the size of the motor pulley, ratio of reduction and the distance between pulley centers are known.

Example.—Refer to Table 288. The motor pulley is 6 in., the ratio of reduction is 4 and the distance between centers is 5 ft.

Solution.—The table shows the arc of contact as 162 deg.

Table 291 shows the effect of the arc of contact on the transmitting power of the belt. The decrease with decreased arc of contact is expressed by a percentage which the power transmitted at a given arc of contact is of the power transmitted at 180 deg. Thus if the arc of contact is 140 deg., only 78 per cent. of the power figured by the belt formula given in a following paragraph, based on a 180-deg. arc of contact, can be transmitted.

To transmit the required power the pulley and belt width must be increased or an idler pulley must be used to increase the arc of contact.

Example.—Illustrating the application of Tables **280**, **289** and **288**. The peed of the machine is 185 r.p.m.; the horse-power required is 7½; the disance between centers is 5 ft. What motor speed and what pulleys should e used for the belt drive?

Solution.—Refer to Table **289**. This shows that for 150 to 200 r.p.m. a 20-r.p.m. motor should be used.

Refer to Table **288**. A 7½-h.p., 650-r.p.m. motor has an 8×7-in. standard ulley and a 6×7-in. minimum pulley.

The speed reduction with this motor is

$$\frac{650}{185} = 3.5$$

Refer to Table **288**. The arc of contact for a ratio of reduction of 3.5 average of 3 to 4), distance between centers of 5 ft. and 8-in. motor pulley, s 160 deg. (average of 164 and 157), and with a 6-in. motor pulley is 165 deg. average of 162 and 168). Either will give successful service. The machine ulley would be, with an 8-in. motor pulley, 3.5×8 = 28 in. and with a 6-in. notor pulley, 3.5×6 = 21 in.

The face in either case will be 7 in. and a single 6-in. leather belt should e used. The combination of 8-in. motor pulley and 28-in. machine pulley s preferred because the motor pulley is standard.

The above example covers a case where the machine pulley can e selected at will. In cases where a motor is to be belted to a lywheel or to a pulley which cannot be easily changed, the proedure is as explained in the following.

Example.—The size of the machine pulley (flywheel) is 72 in.; the speed f the pulley is 100 r.p.m.; the horse-power required is 15, and the distance etween centers is 6 ft. What motor speed and motor pulley should be used?

Solution.—Consider a reduction of 6 : 1 belted directly. The motor speed nust be 600. The size of the motor pulley

$$\frac{\text{machine pulley}}{\text{ratio of reduction}} = \frac{72}{6} = 12 \text{ in.}$$

Table **280** shows that a 12-in. pulley can be used with a 15-h.p., 600-r.p.m. notor. It is 1 in. greater than the standard pulley diameter. Table **288** hows that for a 12-in. motor pulley, a ratio of reduction of 6, and 6 ft. listance between centers, the arc of contact is outside the limits of the able and very small (less than 120 deg.).

288. Arcs of Belt Contact for Different Ratios of Reduction, Distances Between Centers and Pulley Diameters

Ratio of reduction	Distance between centers, feet	Diameter of motor pulley, inches									
		3	4	5	6	7	8	9	10	11	12
3	3	170	166	163	160	157	153	150	147	145	141
	4	173	170	167	165	163	161	158	156	155	151
	5	175	172	170	168	167	164	162	161	160	157
4	3	165	160	155	150	145	142	156	132	126	122
	4	168	165	162	158	154	152	148	144	140	137
	5	172	168	166	162	159	157	155	151	148	146
5	3	160	153	148	142	134	128	122	....	....	....
	4	165	161	157	152	146	142	138	....	....	....
	5	168	164	162	157	153	150	146	....	....	....
6	3	153	147	139	131	122	.....	.....	....	....	....
	4	161	156	150	144	138	.....	.....	....	....	....
	5	164	161	156	152	146	.....	.....	....	....	....

289. Relation of Machine and Motor Speeds and Recommendations for Belt Drive

B = Motor belted direct. **Bbg** = Back-geared motor belted. Bbg = 1.33, etc., the number indicates reduction from countershaft speed if a back-geared motor with a 6 to 1 reduction is used. The heavy-faced type indicates the motor speed recommended for most cases.

Speed of driven machine	Approximate motor speed 1,800	1,200	900	720	600
1,500	1.2 B	...	...	...	...
1,000	1.8 B	1.5 B	...	...	...
800	2.2 B	1.5 B	1.12 B	...	...
600	3.0 B	2.0 B	1.5 B	1.2 B	1.2 B
500	3.6 B	2.4 B	1.8 B	1.44 B	1.2 B
400	4.5 B	3.0 B	2.25 B	1.8 B	1.5 B
350	5.13 B	3.4 B	2.52 B	2.06 B	1.7 B
300	6.0 B	4.0 B	3.0 B	2.4 B	2.0 B
250	7.2	4.8 B	3.6 B	2.9 B	2.4 B
200	9.0	6.0 B	4.5 B	3.6 B	3.0 B
150	12.0	8.0 Bbg 1.33	6.0 B	4.8 B	4.0 B
100	18.0	12.0 Bbg 2.0	9.0 Bbg 1.5	7.2 Bbg 1.2	6.0 B
90	20.0	13.4 Bbg 2.23	10.0 Bbg 1.67	8.0 Bbg 1.33	6.7 Bbg 1.11
80	22.5	15.0 Bbg 2.5	11.3 Bbg 1.88	9.0 Bbg 1.5	7.5 Bbg 1.25
70	25.3	17.1 Bbg 2.85	12.9 Bbg 2.15	10.2 Bbg 1.7	8.6 Bbg 1.43
60	30.0	20.0 Bbg 3.33	15.0 Bbg 2.5	12.0 Bbg 2.0	10.0 Bbg 1.67
50	36.0	24.0 Bbg 4.0	18.0 Bbg 3.0	14.4 Bbg 2.4	12.0 Bbg 2.0

290. Obtaining a Successful Belt Drive.—A successful drive can be obtained for the application of **287** by using a 12×10-in. pulley on the motor and employing an idler pulley. It is not customary for motor manufacturers to supply idler attachments on motors so large. In such cases an idler pulley attachment is more successful if mounted on a foundation, floor or bracket on the machine driven.

The use of a back-geared motor in a case like this is awkward because the pulley on the motor countershaft must be of large diameter. If a back-geared 1,200-r.p.m. motor were used, the countershaft speed being 200 r.p.m., a 36-in. pulley would be required on the motor countershaft, making an awkward looking drive, as this pulley would be larger than the motor.

291. Relation of Arc of Contact to Power Transmitted by Belting

Arc of contact in Degrees	Per cent. of power transmitted[1]
180	100
170	94
160	89
150	83
140	78
130	72
120	67

[1] Based on power transmitted with 180 deg. arc of contact.

292. General Rules Covering the Installation of Belting.—If possible, the lower side of the belt should be the driving side. The distance between pulley centers should be great enough to allow some sag in the upper side of the belt, or an idler pulley should be used to increase the arc of contact. The following general rules are from *Kent's Mechanical Engineers' Pocket-book.*

"1. Narrow belts over small pulleys, 15 ft. between pulley centers, the loose side of the belt having a sag of 1½ to 2 in.

2. Medium-width belts on larger pulleys, 20 to 25 ft. between pulley centers, with a sag of 2½ to 4 in.

3. Main belts on very large pulleys, 25 to 30 ft. between centers, with a sag of 4 to 5 in."

If the distance is too long the belt will flap unsteadily, resulting in unnecessary wear of both the belt and the bearings; if too short, the severe tension required to prevent slipping will cause rapid wear of bearings and may cause them to overheat.

The foregoing distances represent good safe practice for long life of belt and bearings. Shorter distances are frequently used but necessitate tighter belts, or the use of wider pulleys and belts, or larger pulleys and higher belt speeds. Very short belts can be made to work satisfactorily by the aid of idler pulleys, which increase the arc of contact.

It is not desirable that the slope of the belt direction be over 45 *deg. from horizontal;* the belt should never run vertical, *if possible to avoid it, since* the advantage of sag to increase the arc of contact is then lost. The pulley should be a little wider than the belt.

Belts should be run with the least tension required to prevent slipping or flapping. The slack side should have a gently undulating motion. Lateral movement of the belt on the pulley indicates poor pulley alignment or unequal stretching of the edges of the belt. Belt joints should be as smooth as possible, and a lapped joint should always trail, never lead over the pulley. Belts should be kept clean and dry; if any belt dressing is applied let it be very sparingly.

293. Minimum Distance between Pulley Centers.—A rule that has given satisfaction in practice is this. The distance between the pulley centers should not be less than 3 times the sum of the diameters of the pulleys. A better drive will result if the distance is 4 or 5 times the sum of the diameters.

294. Horse-power of Belting.—The ability of a belt to transmit power depends upon (1) the safe working effective tension allowable for the belting, (2) the arc of contact of the belt with the smaller pulley, and (3) the speed of the belt. The rule and formulas given herein are based on the assumption that the arc of contact on the smaller pulley is 180 deg. or one-half the circumference. If it is less than this, one of the correction factors given in **291** should be applied.

The effective tension is not the tension in either the loose or the tight side of the belt, but is the difference between the tensions in these two sides. It is due to the effective tension that power is transmitted by the belt. "Effective tension" is sometimes called "working tension."

It is evident that the horse-power rating of a belt is a rather flexible thing and depends entirely on how great an effective tension is considered allowable. With a heavy tension a small belt will transmit a great amount of power for a short period but will soon stretch, cease to transmit its load, and become worthless. The values given for effective tension in the accompanying tables have been proven by experiment to be ones that will provide belts of reasonably long life without excessive first cost.

295. Safe Working Effective Tension Per Inch Width for Endless Leather Belts (*Page Belting Company*).—These values apply only to belts that can be cemented at the joints by skilled workmen and thereby be made endless. For rough and ready work, for belts having their ends held together with ordinary laces or fasteners, use the belting tables given elsewhere.

Kind of belt	Approx. thickness	Working tension
Single	$\frac{3}{16}$ in.	66 lb.
Single	$\frac{1}{4}$ in.	86 lb.
Light double	$\frac{17}{64}$ in.	90 lb.
Heavy double	$\frac{19}{64}$ in.	96 lb.
Heavy double	$\frac{20}{64}$ in.	100 lb.
Heavy double	$\frac{24}{64}$ in.	120 lb.
Heavy double	$\frac{26}{64}$ in.	130 lb.

296. To Find the Horse-power a Belt of Known Dimensions will Transmit.—Multiply the safe effective working tension of the *belt per inch width* (take this from Table **295**) by the width of the *belt in inches,* and multiply this product by the speed of the b in feet per minute, and divide the result by 33,000. The quotient will be the number of horse-power the belt is capable of transmitting. (See the table of approximate values, **299**.)

Or, expressing this rule as a formula and combining all of the constants into one factor:

$$\text{h.p.} = \frac{W \times D \times T \times \text{r.p.m.}}{126{,}500}$$

Wherein: h.p. = horse-power belt will transmit, W = width of belt in inches, T = safe effective working tension in pounds per inch width of belt, from **295**, D is the diameter of either pulley in inches, r.p.m. = the revolutions per minute of the same pulley.

Example.—What horse-power will the light double leather belt in Fig. 130 transmit? Width = 6 in., and belt is driving a pulley 15 in. in diameter at 100 r.p.m.

Solution Using the Rule.—Safe effective working tension of light double belt is, from **295**, 90 lb. per inch width.

$$\text{Speed of belt in feet per minute} = \frac{100 \text{ r.p.m.} \times 15 \text{ in. diam.} \times 3.1416}{12 \text{ in.}} = 392.7 \text{ ft. per min.}$$

$$\text{Then: } \frac{90 \text{ lb.} \times 6 \text{ in.} \times 392.7 \text{ ft. per min.}}{33{,}000} = 6 \text{ h.p.}$$

Or solving with the formula:

$$\text{h.p.} = \frac{W \times D \times T \times \text{r.p.m.}}{126{,}500} = \frac{6 \times 15 \times 90 \times 100}{126{,}500} = \frac{810{,}000}{126{,}500} = 6 \text{ h.p.}$$

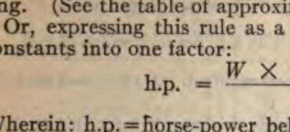


FIG. 130.—Example in finding horse-power of belting.

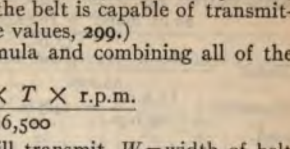


FIG. 131.—Example in finding size belt required.

297. To Find the Width of a Belt Required to Transmit a Given Horse-power.—Read the preceding paragraph. Multiply the safe effective working tension (Table **295**) per inch width by the speed of the belt in feet per minute, and divide the product by 33,000. The quotient is the horse-power a belt 1 in. wide will transmit, provided it is in contact with at least 180 deg. or one-half the pulley circumference.

Having found the amount of power for a belt 1 in. wide, divide the whole number of horse-power given by the horse-power transmitted by a belt 1 in. wide and the quotient will be the width of the belt required.

Or expressing this as a formula using the same notation as in **296**:

$$W = \frac{126{,}500 \times \text{h.p.}}{D \times T \times \text{r.p.m.}}$$

Example.—What width single thickness leather belt should be used [to] drive the machine of Fig. 131. Diameter of driven pulley is 20 in. Spe[ed] ... 00 r.p.m.

Solution.—Safe effective working tension of single thickness belt per inch width is, from 295, 66 lb. First find the speed in feet per minute thus:

$$\frac{20 \text{ in. diam.} \times 100 \text{ r.p.m.} \times 3.14}{12 \text{ in.}} = 523 \text{ ft. per min.}$$

Then: $$\frac{66 \text{ lb.} \times 523 \text{ ft. per min.}}{33{,}000} = 1.05 \text{ h.p. per inch width of belt.}$$

Therefore $\frac{15 \text{ h.p.}}{1.05 \text{ h.p.}} = 14.3$ in. wide belt required. A 15-in. belt must be used.

In practice instead of using a 15-in. single thickness belt for this application a heavier or double belt would be used whereby the belt width could be decreased accordingly.

Solving the same problem using the formula:

$$W = \frac{126{,}500 \times \text{h.p.}}{D \times T \times \text{r.p.m.}} = \frac{126{,}500 \times 15}{20 \times 66 \times 100} = \frac{1{,}897{,}500}{132{,}000} = 14.3 \text{ in.}$$

A 15-in. wide belt must be used because standard belting increases in width by 1-in. increments.

298. Horse-power Transmitted by Canvas Belt (*Page Belting Company*).—Horse-power transmitted by 4-ply canvas belt = 1 h.p. for each inch wide for each 800 ft. of belt speed per minute.

6-ply belts transmit 50 per cent. more.
8-ply belts transmit 75 per cent. more than 4-ply.
10-ply belts transmit 100 per cent. more than 4-ply.
12-ply belts transmit 125 per cent. more than 4-ply.

Comparison

4-ply = single leather or 3-ply rubber.
6-ply = light double leather or 4- and 5-ply rubber.
8-ply = double leather or 6- or 7-ply rubber.
10-ply = heavy double leather or 8-ply rubber.

299. Tables of Safe Horse-power of Belting (*Page Belting Company*).—The following tables will be found useful for quickly and safely determining the amount of power that belting will transmit. It is always wise to leave a wide margin between what a belt must do and what it can do and such a margin is provided by the values in the table.

Horse-power for single leather

Width of belt	Belt speed, ft. per minute									
	600	1,200	1,800	2,400	3,000	3,600	4,200	4,800	5,400	6,000
1 in.	1	2	3	4	5	6	7	8	9	10
2 in.	2	4	6	8	10	12	14	16	18	20
3 in.	3	6	9	12	15	18	21	24	27	30
4 in.	4	8	12	16	20	24	28	32	36	40
5 in.	5	10	15	20	25	30	35	40	45	50
6 in.	6	12	18	24	30	36	42	48	54	60
8 in.	8	16	24	32	40	48	56	64	72	80
9 in.	9	18	27	36	45	54	63	72	81	90
10 in.	10	20	30	40	50	60	70	80	90	100
12 in.	12	24	36	48	60	72	84	96	108	120
14 in.	14	28	42	56	70	84	98	112	126	140
16 in.	16	32	48	64	80	96	112	128	144	160

Horse-power for double leather

Width of belt	Belt speed, ft. per minute										
	400	800	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,000	5,000
4 in......	4	8	12	16	20	24	28	32	36	40	50
6 in......	6	12	18	24	30	36	42	48	54	60	75
8 in......	8	16	24	32	40	48	56	64	72	80	100
10 in......	10	20	30	40	50	60	70	80	90	100	125
12 in......	12	24	36	48	60	72	84	96	108	120	150
16 in......	16	32	48	64	80	96	112	128	144	160	200
20 in......	20	40	60	80	100	120	140	160	180	200	250
24 in......	24	48	72	96	120	144	168	192	216	240	300
30 in......	30	60	90	120	150	180	210	240	270	300	370
36 in......	36	72	108	144	180	216	252	288	334	370	450
40 in......	40	80	120	160	200	240	280	320	360	400	500

The previous rules given for figuring horse-power are more accurate than the tables, and will show that a belt can transmit more than the tables specify. The tables allow a margin of safety for the belts being laced or otherwise fastened but not "made endless," and also for a relatively small "arc of contact" on pulleys.

300. **To find the speed of a belt in feet per minute,** multiply the circumference of either pulley, in feet, by its number of revolutions per minute. To obtain the circumference, multiply the diameter by 3.14 or, roughly, by $3\frac{1}{7}$.

301. **Minimum Diameter of Pulleys for Long Life of Heavy Belts** (*Westinghouse Diary*)

For double belts .... 12 in.
For double belts extra flexible .... 10 in.
For double 3-ply belts .... 18 in.

302. **The ratio of diameter of two pulleys,** one a driver and the other driven, should not be greater than 6 to 1 for ordinary drives. That is, the diameter of the large pulley should not be more than 6 times greater than the diameter of the small one. A preferable ratio is 4 or 5 to 1.

303. **Maximum Speeds for Belts.**—Roughly, belt speeds should not exceed 1 mile (5,280 ft.) per minute. This speed is given when the diameter of either pulley in inches multiplied by its r.p.m. equals 20,000 (D×r.p.m.=20,000).

304. **Rule for Finding Length of Belts.**—When it is not feasible to measure with the tapeline the length required, the following rule, which gives a very accurate result when the pulleys are of the same diameter and an approximately accurate result when the pulleys are of different diameters, can be used:

Add the diameters of the two pulleys (*D* and *d*, Fig. 132) together, divide the result by 2 and multiply the quotient by $3\frac{1}{7}$; add the product to twice the distance (*L*) between the centers of the shafts and the result is the length required. All values should be expressed either in feet or in inches. Expressed as a formula, using the notation of Fig. 132, the rule becomes:

$$\text{Length of belt} = [(D+d)1.57]+2L$$

Example.—What is the length of the belt required for the two pulley Fig. 133. Diameters of pulleys are 16 in. and 18 in. Distance betw centers is 10 ft. or 120 in.

Solution.—Substitute in the formula:

Length of belt $= [(18 + 16)1.57] + 2 \times 120 = (34 \times 1.57) + 240 = 293.4$ in

$\frac{293.4}{12} = 24.4$ ft.

If one pulley is considerably larger than the other a little ex allowance should be made, because the distance between the poi of tangency of the belt on the two pulleys is somewhat greater tl the exact distance between the centers of the shafts.

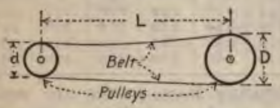


FIG. 132.—Notation for belt length formula.

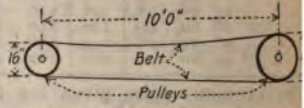


FIG. 133.—Example in finding belt length.

305. Rule for Measuring Belts in the Roll.—Add to the ameter of the roll in inches the diameter of the hole in the cer of the roll. Multiply this sum by the number of coils in the and multiply this product by 1.32. The three figures on the indicate the number of feet in the roll.

Example.—Roll of 5 in. single leather belt measures $37\frac{5}{8}$ in. outside ameter; hole is $4\frac{5}{8}$ in. in diameter; number of coils in roll is 84. How is the belt?

Solution.—Using the above rule:

$37\frac{5}{8} + 4\frac{5}{8} = 42\frac{1}{4} \times 84 = 3{,}549 \times 1.32 = 4{,}684.68.$

Taking the first three figures on the left: The roll contains $468\frac{1}{2}$ ft. actual measurement the roll is found to contain 469 ft.—(*Page Be Company.*)

306. Ox-leather belts give the best results under ordinary ditions. No other belts will stand the shifter or shipper; co belts are weakened when wet; rubber belts are rotted when o but leather will stand wet and dryness, cold and heat, and la long time even when oil saturated.—(*Scientific American.*)

307. Splicing Belts (*Page Belting Company*).—Where poss the ends of the belt should be fastened together by splicing cementing. If belts are to be laced or fastened otherwise than cement, cut off the ends perfectly true using a try-square. Pu the holes exactly opposite one another in the two ends as in 134. The grain side of the belt should be run next to the pu and the belt should be run off of, not against, the laps. Undo edly, exclusive of cementing, lacing is the best method for faste belt ends together, as the lacing is as flexible as the belt and noiselessly over the pulleys. The best lacing is the cheap Cheap lacing is very expensive in the long run.

Use a small lace so that the holes will be small. For belts to $2\frac{1}{4}$ in. wide, use $\frac{1}{4}$-in. lacing; $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in. use $\frac{5}{16}$-in. lac 5 in. to 12 in. use $\frac{3}{8}$-in. lacing. For wider belts use wider lacin *proportion.* Avoid thick lacing. Light, strong lacing is the b

In punching a belt for lacing it is desirable to use an oval p *the longer diameter* of the punch lying parallel with the len e belt, so that a minimum amount of leather across the belt ill be cut out. There should be in each end of the belt two rows holes, placed zigzag. Make the holes the smallest possible at will admit the lace. In a 2-in. belt there should be 3 holes in ch end; in a 2½-in. belt, 4 holes; in a 3-in. belt, 5 holes; in a 4-in.

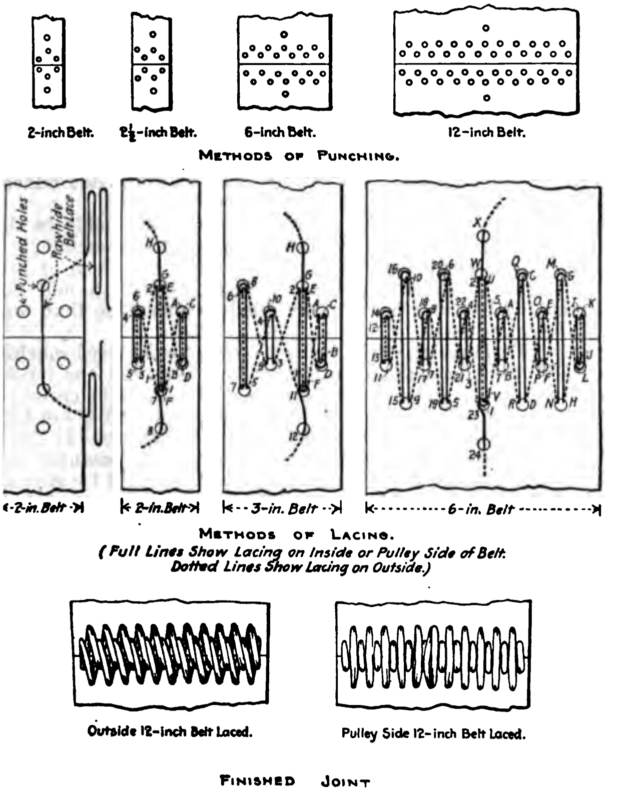


Fig. 134.—Method of lacing belts.

lt, 7 holes; in a 5-in. belt, 9 holes; in a 6-in. belt, 11 holes; in an n., belt, 15 holes; in a 10-in. belt, 19 holes; in a 12-in. belt, 23 les.

The center of no hole should come nearer to the side of the belt an ⅜ of an inch nor nearer the end than ⅞ of an inch. The second v should be at least 1¾ in. from the end. On wide belts thes ances should be even a little greater.

gin to lace in the center of the belt, and take much care keep the ends exactly in line, and to lace both sides with equ tightness. The lacing positively must not be crossed on the sid of the belt that runs next to the pulley.

308. In putting on new belts, a common rule is to draw the up and stretch them ⅛ in. for every foot in length of belt.

The strongest part of belt leather is near the flesh side, abou one-third the way through from that side. It is, therefore, desi able to run the grain (hair) side on the pulley, in order that th strongest part of the belt may be subject to the least wear. Th flesh side is not as liable to crack as is the grain side when the be is old; hence it is better to crimp the grain than to stretch i Leather belts run with the grain side to the pulley will drive 30 pe cent. more than if run with the flesh side. The belt, as well a the pulley, adheres best when smooth, and the grain side adhere best because it is smoother.

309. A belt adheres much better, and is less liable to sli when run at a high speed than at a low speed. Therefore, it better to gear a mill with small pulleys, and run them at hig velocity, than with large pulleys, and run slower. A mill thu geared costs less and has a much neater appearance than wit large, heavy pulleys.

310. Belt Troubles.—The belt on any belt-connected machin should be tight enough to run without slipping, but the tensio should not be too great or the bearings will heat. The crowns o driving and driven pulleys should be alike as "wobbling" of belt is sometimes caused by pulleys having unlike crowns. If this i caused by bad joints, they should be broken and cemented ove again. A wave motion or flapping is usually caused by slippag between the belt and pulley, resulting from grease spots, etc. I may, however, be a warning of an excessive overload.

This fault may sometimes be corrected by increasing the tensio but a better remedy is to clean the belt. A back and forth mov ment on the pulley is caused by unequal stretching of the edge of the belt. If this does not cure itself shortly, examine the joint If they are evenly made and remain so, the belt is bad and shoul be discarded.

311. Gear Drive.—Gearing is the most positive form of pow transmission and is usually employed when the motor can b mounted directly on a machine. The points to be considered on gear drive are the following: (1) Speed reduction; (2) pitch of th gears; (3) number of teeth on the gears (pinion and gear); (4) fac of the gear; (5) pitch line speed; (6) distance between centers; (use of idler gears; and (8) mounting of the motor.

The speed reduction is the same as for the belt drive. Eac motor rating has a minimum pinion to limit stresses to safe value The pitch, number of teeth and face for motor pinions have bee standardized for back-gear motors and the best practice whe *gearing a motor directly to machines is to use these motor pinio if possible.* Table 326 gives the standard motor ratings and oth valuable gearing information. (The information on gear dri given herein is largely from an article in the *American Machi ct. 3, 1912*, by A. G. Popcke.)

312. The method of gearing depends largely upon the distanc between centers and the space available for the motors. In a cases the pinion must not be selected smaller than the minimu specified in **326**. The pitch-line speed must not exceed the limi given. There are two general cases covering the mounting of motor to drive a machine through gears; these are:

(1) Where the dimension of the motor or machine limits th distance between centers of the motor shaft and the driven shaf

(2) Where this limitation, (1), does not exist.

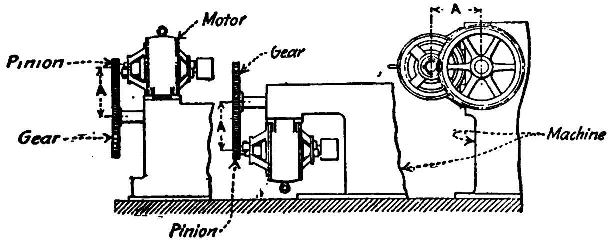


FIG. 135.—Motor mountings for gear drive (distances between gear cente limited).

The first case occurs when a motor is mounted on top, side c bottom of a machine, as shown in Fig. 135. The dimension causin limitations is indicated by *A* in these illustrations. The prop distance can be obtained by using large enough gears; the limit pitch-line speed. An intermediate idler gear frequently ove comes the difficulties here experienced.

In the second case the relation of the motor and machine shown in Fig. 136. In this case the motor can be mounted on a base and the motor pinion can mesh with the gear on the machine in any convenient position.

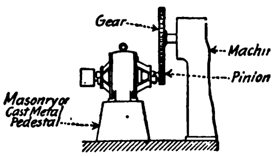


FIG. 136.—Motor mounting f gear drive (no limitation to cent distance).

If reductions greater than 7 to 1 are required, it is usually necessary to obtain the reduction by the use of two sets of gears. The back-geared motors discussed under "Belt Drive" can be used to furnish one set of gears in these cases. Thus if a reductio of 10 to 1 is desired, a back-geared motor with a standard 6 to reduction, with a further reduction from the countershaft c the motor to the machine of $\frac{10}{6}$ to 1 or 1.66 to 1 will fulfill th requirements.

Example.—The speed of the driven shaft of the machine is 210 r.p.m. *h.p. is 10; the motor is mounted* on the machine and the limiting distanc *tween centers is 12 in.* What are the sizes of gear and pinion to be *The machine is a* punch and shear.

Solution.—In this case a pitch-line speed of approximately 1,000 min. will be employed. Table 326 shows that a 10-h.p. at 850 r.p.m. is the highest speed motor that can be used for this pitch-line speed. The ratio of reduction is then

$$\frac{850}{210} = 4.05 \text{ (use 4 to 1)}$$

The distance between centers for any set of gears is determined by the formula:

$$a = \frac{b}{2P}$$

where a is the distance between centers in inches, b is the sum of the number of teeth in both gears and P is the diametral pitch. In this case

$$a \text{ or } 12 = \frac{b}{2 \times 5}; \; b = 120$$

The number of teeth in the pinion is,

$$\frac{b}{\text{Ratio of reduction plus 1}} = \frac{120}{5} = 24 = \text{number of teeth}$$

The number of teeth in the gear is $4 \times 24 = 96$.

Table 326 shows that the pitch-line speed for this motor with 20 teeth is 890 ft. per minute. The pitch-line speed with 24 teeth is

$$\frac{24}{20} \times 890 = 1{,}068 \text{ ft. per min.}$$

If quiet operation is desired a cloth or rawhide pinion should be used with a $3\frac{3}{4}$-in. face. Thus the gears are specified as follows:

Motor pinion—rawhide—$P = 5$, face $3\frac{3}{4}$ in., 24 teeth. Machine gear—steel $P = 5$, face 3 in., 96 teeth.

The bore for each is determined by the diameter of the shaft to which it is connected. The pinion is wider than the gears, so that the rawhide only engages with the gear. If it were the same width, the brass end-plates of the rawhide pinion would engage with the gear, causing noise.

313. In the selection or specification of pinions for motors (*C. W. Drake, Electric Journal*) for geared applications, three dimensions must be determined, namely, the face, diameter and pitch. These dimensions vary symmetrically according to the strength required, or, in other words, according to the torque exerted in transmitting power. As the horse-power and speed of the motor in any case determine the torque, it is evident these are the factors determining the proper dimensions of a pinion for the motor. A line of pinions with dimensions increasing symmetrically with the torque will therefore answer the purpose for all combinations of horse-power and speed. Every geared application requires special consideration, since the nature of the service, the shaft diameter, etc., may affect the dimensions of the pinion.

In gear drive the pinion is subject to most rapid wear owing to its smaller diameter. It is as important to have a pinion of good wearing qualities as it is to have one of sufficient strength and for a pinion of a given material, the ability to withstand wear depends mainly, if not wholly, on the width of the face. With a steel pinion and a cast-iron gear the former is usually the limiting factor of life and the latter the limiting factor of strength.

314. Cast-steel gears are about twice as strong as cast-iron, and should be used when the face of a corresponding cast-iron gear would be 4.5 in. or more, although the cost is approximately double that of cast-iron. With continuous contact all along the length of the teeth, the strength of the gear is approximately proportional to the face and the square of the circular pitch, but teeth seldom make such contact until worn down in service.

new gears the whole pressure is brought to bear on the high spots, and stripping may occur before they are worn down; hence the necessity of using the stronger material.

315. **Bronze and Rawhide Pinions.**—For equal strength the working face of rawhide pinions must be about 25 per cent. wider than corresponding steel pinions. For quiet operation, only the rawhide should be in contact with the gear, although for high torque motors and for other severe service the gears may be widened to cover the entire pinion, thus making use of the metal flanges. Where steel pinions would make objectionable noise, rawhide pinions should be used if the stresses permit, since the pitch-line speed with a rawhide pinion is limited more by the rapid wear of the pinion than by noise. A pitch-line speed of 2,000 ft. per min. is considered a fair average limit for rawhide, but 2,500 to 3,000 ft. per min. may be used under especially favorable conditions regarding attendance, lubrication, absence of moisture or high temperature, for intermittent service, or where the life of the pinion is not important.

The wear and noise of bronze pinions are intermediate between those of rawhide and steel. Bronze pinions are particularly adapted to conditions where heat and moisture prohibit the use of rawhide. Their cost is about the same as rawhide.

316. **Noise of Gears and Pitch-line Speed Limits.**—Spur gears ordinarily begin to make a noticeable noise at pitch-line speeds of about 600 ft. per min., but under average conditions may not become disagreeably noisy with pitch-line speeds under 1,200 ft. per min. The amount of noise allowable depends on the noise made by surrounding machinery, on the character of the workmen, and on the nature of the work in the vicinity. A noise that would be unnoticeable in a boiler shop might be exceedingly disagreeable in a shop that was otherwise comparatively quiet. Where noise is not a limiting feature there is no limit to allowable pitch-line speeds, except the increased wear and depreciation of the motor, gears and driven machine; but depreciation may become a very important factor with high pitch-line speeds, say 2,500 ft. per minute, or sometimes even less. Tests recently made to determine a design for gears that will give the least noise and yet have sufficient strength and wearing qualities, indicate the following facts, other conditions being the same:

1. Gears having large teeth give forth a relatively greater volume of noise at a low pitch that does not carry far, while gears having smaller teeth give forth a smaller volume of noise at a higher pitch that carries farther.

2. Most of the noise comes from the gear, and not from the pinion or the motor.

3. A gear designed so that it will give a dead sound when struck a blow with a hammer will be the least noisy in operation.

317. *Conditions for Noiseless* **Operation of Gears.**—Rigid and *massive supports and close* fitting bearings for both the motor *and the driven machine* are conducive to a noiseless gear drive *and the pinion should always* be placed close to the motor bearing *gear application* with motor mounted upon the ceiling might

twice as noisy as the same application with motor mounted on a concrete foundation.

318. **Pinions for High Torque Motors.**—For series motors and those heavily compounded, as bending roll motors, or for motors subject to very severe service of any kind, select a pinion suitable for a constant-speed motor of the same rated r.p.m., but of about 50 per cent. higher horse-power.

319. **Selection of Ratio for Back-geared Motors.**—A ratio of about 6 to 1 is usually standard for back-geared motors, and should be selected wherever possible, but smaller ratios down to 3 to 1 or maximum ratios up to 7 to 1 may be obtained in certain capacities of motors for service where the conditions of the application warrant the use of such ratios. (See preceding paragraphs on this subject.)

320. **Outboard Bearings for Geared Motors.**—Outboard bearings should be used for geared motors of about 40 h.p. and above in heavy geared service requiring continuous operation with frequent reversing and overloads; also for all motors of about 100 h.p. and above in any geared service. The proper use of outboard bearings cannot be emphasized too strongly, since on account of increased expense there is a tendency to omit them even where good engineering demands their use.

321. **How to Use the Chart for Determining Gear Dimensions** (*C. W. Drake, Electric Journal*).—The dimensions for pinions for average conditions of motor-drive service are given in Fig. 137. This chart is useful in making preliminary estimates or selections of pinions for geared motors. The chart applies without correction *to steel pinions only*. The diameters are considered about standard for the various ratings, although both smaller and larger pinions can generally be used, the limiting size for small pinions being the strength and number of teeth, and, for large pinions, the pitch-line speed.

For example, to determine the steel pinion for a 5-h.p. motor at 1,200 r.p.m., find the intersection of the oblique line marked 5 *h.p.* with the horizontal line through 1,200 *r.p.m.* On the vertical line through this intersection may be found 21.9 *lb. torque*, 2.3 *in. pinion face*, 3.2 *in. pitch diameter*, and a diametral pitch of 4.85. A 2.25-in. pinion face is good practice here, since pinion-face dimensions with fractions smaller than 0.25 in. are not commonly used. The diametral pitch is also usually a whole number, except for very large pinions, where half pitches are sometimes used, so that a pitch of 5 would probably be used in the above case. Since the number of teeth is the product of the pitch diameter and the diametral pitch, the assumed pitch diameter, 3.2 in., is satisfactory with the 5 pitch, because it gives a whole number of teeth; that is, 16.

322. **Gearing Definitions and Formulas.**—A circle whose circumference passes through the point of contact on each tooth of a gear or pinion when this point is on the line connecting the centers of the two wheels is called the *pitch circle*. The diameter of this circle is the *pitch diameter* and its circumference is the *pitch line*.

Diameter, when applied to gears, is always understood to mean the pitch diameter.

Diametral pitch is the number of teeth to each inch of the pitch diameter. To illustrate: If a pinion has 18 teeth and the pitch diameter is 3 in., there are 6 teeth to each inch of the pitch diameter, the diametral pitch is 6.

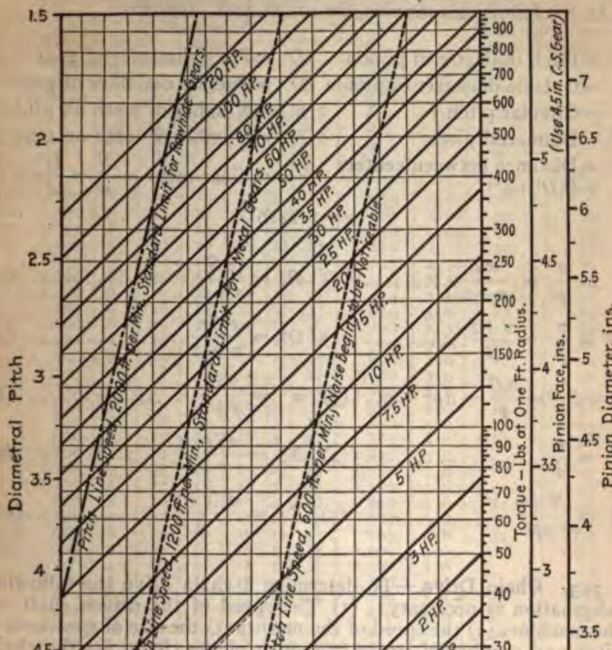


FIG. 137.—Chart for determining approximate commercial values of pinion diameter, pinion face, diametral pitch, pitch line speed, and torque, with revolutions per minute and horse-power of motor given. See accompanying paragraph for directions as to how to use.

Circular pitch is the distance from the center of one tooth to the center of the next, measured along the pitch line.

In the following formulas, for use in gear problems:

d^1 = Pitch diameter of pinion	D^1 = Pitch diameter of gear
d = Outside diameter of pinion	D = Outside diameter of gear
p = Circular pitch	n = Number of teeth on pinion
p^1 = Diametral pitch	N = Number of teeth on gear
S = Distance between centers $= \frac{1}{2}(D^1+d^1)$	r = Gear ratio $= \frac{N}{n} = \frac{D^1}{d^1} = \frac{D}{d}$

$$\pi = 3.1416$$

$$p = \frac{\pi}{p^1} = \frac{\pi d}{n+2} \quad \text{(1)} \qquad d^1 = \frac{2S}{r+1} \quad \text{(6)}$$

$$p^1 = \frac{\pi}{p} = \frac{n+2}{d} \quad \text{(2)} \qquad D^1 = \frac{2\,Sr}{r+1} \quad \text{(7)}$$

$$n = d^1p^1 = \frac{\pi d^1}{p} = dp^1 - 2 \quad \text{(3)} \qquad n = \frac{2Sp^1}{r+1} \quad \text{(8)}$$

$$p^1 = \frac{n}{d^1} \quad \text{(4)} \qquad N = \frac{2Sp^1\,r}{r+1} \quad \text{(9)}$$

$$S = \frac{N+n}{2p^1} \quad \text{(5)} \qquad S = \frac{d^1(r+1)}{2} \quad \text{(10)}$$

323. Chain Drive.—To determine a chain drive the following information is necessary: (1) The speed of the driven shaft on the machine; (2) the speed of the motor; (3) the size of sprockets—pitch and number of teeth; (4) width of the chain; (5) the chain speed, and (6) the horse-power transmitted.

The design of chains is more complicated than that of belts and gears and it is, therefore, best to let the various chain manufacturers specify the chain, giving them the above information. The minimum sprocket to be used on a motor is the same as the minimum pinion given in Table **326**. Chain speeds should not exceed 1,200 to 1,600. ft. per min. The best practice does not exceed 1,000 ft. per min.

324. Gear and Belt Drives for Adjustable-speed Motors.—The hereinbefore mentioned tables dealt with constant-speed motors. Adjustable-speed motor problems are solved similarly. The belt speeds and pitch-line speeds must be carefully considered at the maximum speeds of the motors. The minimum pulleys and pinions are determined by the minimum speeds of the motors. *Table 327 gives* the ratings commonly used and pulley and gear *information.*

325. *Vertical* motors can be applied to advantage in some cas... driven shafts are vertical. Their ratings and speed ch...ics are the same as those of horizontal motors.

326. Gear Data For Motor Applications.

(A. G. Popcke, *American Machinist*, Oct. 3 1912.)

R.p.m.	Diam. pitch	Number of teeth			Face		Standard pitch-line speed	Min. diam.	Max. no. of teeth for pitch-line speed of	
		Standard pinion	Min. raw-hide pinion	Min. pinion steel	Steel	Rawhide and cloth			1,000 ft. per min.	2,000 ft. per min.
1,700	8	17	15	13	1	1½	940	1.63	18	36
1,200	8	17	15	13	1½	2	665	1.63	25	50
1,700	8	17	15	13	1½	2	940	1.63	18	36
1,200	8	22	20	19	1¾	2¼	870	2.38	25	50
850	6	18	21	19	1¾	2¼	615	2.38	36	72
1,800	8	22	20	19	1¾	2¼	1,300	2.38	....	34
1,150	8	22	21	19	1¾	2¼	830	2.38	26	52
850	6	18	18	18	2¼	3⅜	670	3.0	27	54
1,800	8	22	21	19	1¾	2¼	1,300	2.38	....	34
1,200	6	18	18	18	2¼	3⅜	940	3.0	19	38
850	6	21	19	18	2¼	3⅜	990	3.0	27	54
1,700	6	18	18	18	2¼	3⅜	1,400	3.0	....	26
1,150	6	21	19	18	2¼	3⅜	1,050	3.0	20	40
975	5	19	18	18	3	3¾	970	3.6	19	38
850	5	19	18	18	3	3¾	850	3.6	22	44
650	5	20	18	18	3	3¾	685	3.6	29	58
1,700	6	21	19	18	2¼	3⅜	1,420	3.0	....	27
1,300	6	22	19	18	2¼	3⅜	1,250	3.0	....	35
1,150	5	19	18	18	3	3¾	1,150	3.6	....	33
850	5	20	18	18	3	3¾	890	3.6	22	44
730	5	21	18	18	3½	4¼	805	3.6	26	52
600	5	21	19	19	3½	4¼	665	3.8	31	62
1,700	5	19	18	18	3	3¾	1,700	3.6	....	22
1,250	5	20	18	18	3	3¾	1,300	3.6	....	30
1,150	5	21	18	18	3½	4¼	1,210	3.6	....	35
825	5	21	19	19	3½	4¼	910	3.8	23	46
675	4½	22	18	18	4	5	870	4.0	25	50
600	4½	22	19	19	4	5	770	4.22	29	58
1,700	5	20	18	18	3	3¾	1,780	3.6	....	22
1,100	5	21	19	19	3½	4¼	1,220	3.8	....	35
900	4½	22	18	18	4	5	1 150	4.0	19	38
750	4½	22	19	19	4	5	960	4.22	23	46
650	4	21	18	18	4¼	5¼	890	4.5	23	46
1,400	5	21	19	19	3½	4¼	1,550	3.8	....	27
1,100	4½	22	18	18	4	5	1,400	4.0	....	31
950	4½	22	19	19	4	5	1,220	4.22	....	36
825	4	21	18	18	4¼	5¼	1,130	4.5	18	36
600	4	22	19	18	4¼	5¼	860	4.5	25	50
1,700	5	21	19	19	3½	4¼	1,880	3.8	....	22
1,150	4½	22	19	19	4	5	1,470	4.22	....	30
975	4	21	18	18	4¼	5¼	1,330	4.5	....	31
725	4	22	19	18	4¼	5¼	1,050	4.5	21	42
600	3½	20	....	18	4½	..	970	5.53	20	40
1,700	4½	22	18	18	4	5	2,180	4.0	....	20
1,150	4	21	18	18	4¼	5¼	1,580	4.5	....	27
850	4	22	19	18	4¼	5¼	1,220	4.5	18	36
675	3½	20	....	18	4½	..	1,080	5.53	18	36
1 700	4½	22	19	19	4	5	2,180	4.22	....	20
950	4	22	19	18	4¼	5¼	1,370	4.5	....	32
775	3½	20	....	18	4½	..	1,250	5.53	....	32
600	3	18	....	15	4½	..	940	5.0	19	38
1,700	4	21	18	18	4¼	5¼	2 340	4.5	....	18
975	3½	20	....	18	4½	..	1,580	5.53	....	25
750	3	18	....	15	4½	..	1,170	5.0	15	30
565	3	20	....	18	4½	..	990	6.0	20	40

327. Adjustable-speed Motor Ratings and Pulley and Gear Data For Use When Connecting Adjustable-speed Motors to Drive Machinery

(A. G. Popcke, *American Machinist*, Oct. 3, 1912.)

Horse-power	R.p.m. Min.	R.p.m. Max.	Smallest pulley Dia.	Smallest pulley Face	Gear data Pitch	Gear data Face Steel	Gear data Face Rawhide	Gear data Min. teeth	Gear data Min. diam.	Pitch-line speed, at min. diam. Min. speed	Pitch-line speed, at min. diam. Max. speed	Max. teeth not to exceed 2,000 ft. per min. at max. speed
1	740	2,200	3	3	8	1¾	2¼	19	2.38	460	1,380	27
	600	1,800	3	3	8	1¾	2¼	19	2.38	375	825	46
	450	1,800	3	4	8	1¾	2¼	19	2.38	280	1,120	34
2	1,100	2,200	3	3	8	1¾	2¼	19	2.38	690	1,380	27
	740	2,200	3	4	8	1¾	2¼	19	2.38	460	1,380	27
	450	1,800	4	4½	6	2¼	3⅜	18	3.0	355	1,420	25
3	1,000	2,000	3	4	8	1¾	2¼	19	2.38	625	1,250	30
	660	2,000	4	4½	6	2¼	3⅜	18	3.0	520	1,560	23
	450	1,800	4½	5	6	2¼	3⅜	18	3.0	355	1,422	25
	375	1,500	5	6	6	2¼	3⅜	18	3.0	294	1,176	30
5	1,000	2,000	4	4½	6	2¼	3⅜	18	3.0	790	1,580	23
	750	1,500	4½	5	6	2¼	3⅜	18	3.0	590	1,180	30
	600	1,800	5	6	6	2¼	3⅜	18	3.0	470	1,410	25
	450	1,800	6	7	5	3	3¾	18	3.6	425	1,700	21
	375	1,500	6	7½	5	3½	4¼	18	3.6	355	1 420	25
7½	900	1,800	5	6	6	2¼	3⅜	18	3.0	705	1,410	25
	800	1,600	5	6	5	3	3¾	18	3.6	755	1,510	24
	600	1,800	6	7	5	3	3¾	18	3.6	570	1,710	21
	500	1,500	6	7½	5	3½	4¼	18	3.6	475	1,425	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	350	1,400	6½	9	5	3½	4¼	19	3.8	350	1,400	27
10	850	1,700	6	7	5	3	3¾	18	3.6	800	1,600	22
	750	1,500	6	7	5	3	3¾	18	3.6	710	1,420	25
	600	1,8c0	6	7½	5	3½	4¼	18	3.6	570	1,710	21
	500	1,500	6½	9	5	3½	4¼	19	3.8	500	1,500	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	375	1,500	7	8	4½	4	5	18	4.0	390	1 560	23
15	780	1,560	6½	9	5	3½	4¼	19	3.8	780	1 560	24
	600	1,200	7	8	4½	4	5	18	4.0	630	1,260	28
	500	1,500	7½	9½	4½	4	5	19	4.22	555	1,665	23
	400	1,200	8	9½	4	4¼	5¼	18	4.5	470	1,410	25
	375	1,500	9	10½	4	4¼	5¼	18	4.5	440	1,760	20
20	650	1,300	7½	9½	4½	4	5	19	4.22	720	1 440	26
	550	1,100	8	9½	4	4¼	5¼	18	4.5	645	1,290	28
	500	1,500	9	10½	4	4¼	5¼	18	4.5	590	1,770	20
	400	1,200	10	11	3¼	4½	....	18	5.53	580	1,740	21
	300	1,200	12	13	3	4½	....	15	5.0	390	1,560	19
25	550	1,100	9	10½	4	4¼	5¼	18	4.5	645	1,290	28
	400	1,200	12	13	3	4½	....	15	5.0	525	1,575	19
	300	1,200	12½	15	3	4½	....	18	6.0	470	1,880	19
30	550	1,100	10	11	3¼	4½	....	18	5.53	800	1,600	23
	350	1,050	12½	15	3	4½	....	18	6.0	550	1,650	22
	250	1,000	14	18	3	4½	....	18	6.0	390	1,560	23
40	550	1,100	12	13	3	4½	....	15	5.0	720	1,440	21
	350	1,050	12½	15	3	4½	....	18	6.0	550	1,650	22
	250	1,000	16	21	3	4½	....	19	6.33	415	1,660	2[illegible]
50	500	1,000	12½	15	3	4½	....	18	6.0	790	1,580	
	325	975	16	21	3	4½	....	19	6.33	540	1,620	

326. Gear Data For Motor Applications.

(A. G. Popcke, *American Machinist*, Oct. 3 1912.)

R.p.m.	Diam. pitch	Number of teeth: Standard pinion	Number of teeth: Min. raw-hide pinion	Number of teeth: Min. pinion steel	Face: Steel	Face: Rawhide and cloth	Standard pitch-line speed	Min. diam.	Max. no. of teeth for pitch-line speed of: 1,000 ft. per min.	Max. no. of teeth for pitch-line speed of: 2,000 ft. per min.
1,700	8	17	15	13	1	1½	940	1.63	18	36
1,200	8	17	15	13	1½	2	665	1.63	25	50
1,700	8	17	15	13	1½	2	940	1.63	18	36
1,200	8	22	20	19	1¾	2¼	870	2.38	25	50
850	6	18	21	19	1¾	2¼	615	2.38	36	72
1,800	8	22	20	19	1¾	2¼	1,300	2.38	....	34
1,150	8	22	21	19	1¾	2¼	830	2.38	26	52
850	6	18	18	18	2¼	3⅜	670	3.0	27	54
1,800	8	22	21	19	1¾	2¼	1,300	2.38	....	34
1,200	6	18	18	18	2¼	3⅜	940	3.0	19	38
850	6	21	19	18	2¼	3⅜	990	3.0	27	54
1,700	6	18	18	18	2¼	3⅜	1,400	3.0	....	26
1,150	6	21	19	18	2¼	3⅜	1,050	3.0	20	40
975	5	19	18	18	3	3¾	970	3.6	19	38
850	5	19	18	18	3	3¾	850	3.6	22	44
650	5	20	18	18	3	3¾	685	3.6	29	58
1,700	6	21	19	18	2¼	3⅜	1,420	3.0	....	27
1,300	6	22	19	18	2¼	3⅜	1,250	3.0	....	35
1,150	5	19	18	18	3	3¾	1,150	3.6	....	33
850	5	20	18	18	3	3¾	890	3.6	22	44
730	5	21	18	18	3½	4¼	805	3.6	26	52
600	5	21	19	19	3½	4¼	665	3.8	31	62
1,700	5	19	18	18	3	3¾	1,700	3.6	....	22
1,250	5	20	18	18	3	3¾	1,300	3.6	....	30
1,150	5	21	18	18	3½	4¼	1,210	3.6	....	35
825	5	21	19	19	3½	4¼	910	3.8	23	46
675	4½	22	18	18	4	5	870	4.0	25	50
600	4½	22	19	19	4	5	770	4.22	29	58
1,700	5	20	18	18	3	3¾	1,780	3.6	....	22
1,100	5	21	19	19	3½	4¼	1,220	3.8	....	35
900	4½	22	18	18	4	5	1 150	4.0	19	38
750	4½	22	19	19	4	5	960	4.22	23	46
650	4	21	18	18	4¼	5¼	890	4.5	23	46
1,400	5	21	19	19	3½	4¼	1,550	3.8	....	27
1,100	4½	22	18	18	4	5	1,400	4.0	....	31
950	4½	22	19	19	4	5	1,220	4.22	....	36
825	4	21	18	18	4¼	5¼	1,130	4.5	18	36
600	4	22	19	18	4¼	5¼	860	4.5	25	50
1,700	5	21	19	19	3½	4¼	1,880	3.8	....	22
1,150	4½	22	19	19	4	5	1,470	4.22	....	30
975	4	21	18	18	4¼	5¼	1,330	4.5	....	31
725	4	22	19	18	4¼	5¼	1,050	4.5	21	42
600	3¼	20	....	18	4½	..	970	5.53	20	40
1,700	4½	22	18	18	4	5	2,180	4.0	....	20
1,150	4	21	18	18	4¼	5¼	1,580	4.5	....	27
850	4	22	19	18	4¼	5¼	1,220	4.5	18	36
675	3¼	20	....	18	4½	..	1,080	5.53	18	36
1 700	4½	22	19	19	4	5	2,180	4.22	....	20
950	4	22	19	18	4¼	5¼	1,370	4.5	....	32
775	3¼	20	....	18	4½	..	1,250	5.53	....	32
600	3	18	....	15	4½	..	940	5.0	19	38
1,700	4	21	18	18	4¼	5¼	2 340	4.5	....	18
975	3¼	20	....	18	4½	..	1,580	5.53	....	25
750	3	18	....	15	4½	..	1,170	5.0	15	30
565	3	20	....	18	4½	..	990	6.0	20	40

SECTION III

OUTSIDE DISTRIBUTION

POLE LINES

1. **The reports of the committee on overhead line construc of the National Electric Light Association** contain what probably the best and most complete specifications for pole construction for lighting and power distribution that have been compiled. Much of the matter in this section regarding lines has been abstracted from those reports.

2. **Northwestern Cedarmen's Specifications for Poles.**—"S 5 in., 25 ft. and upward.

"Above poles must be cut from live growing timber, peeled reasonably well proportioned for their length. Tops must reasonably sound and when seasoned must measure as follows

"5-in. poles, 15 in. circumference at top end.
"6-in. poles, 18½ in. circumference at top end.
"7-in. poles, 22 in. circumference at top end.

"If poles are green, fresh cut or water soaked, then 5-in. p must be 5 in. plump in diameter at the top end, 6-in. poles mus 19½ in. in circumference, and 7-in. poles 22¾ in. in circumfer at top end.

"One way sweep allowable not exceeding 1 in. for every 5 ft.; example, in a 25-ft. pole, sweep not to exceed 5 in. and in a 4 pole 8 in.; in longer lengths 1 in. additional sweep permissible each additional 5 ft. in length. Measurement for sweep shal taken as follows: That part of the pole when in the ground (6 not being taken into account when arriving at sweep, tig stretch a tape line on the side of the pole where the sweep is greatest, from a point 6 ft. from butt to the upper surface at and having so done measure widest point from tape to surfac pole, and if, for illustration, upon a 25-ft. pole said widest p does not exceed 5 in. said pole comes within the meaning of t specifications.

"Butt rot in the center including small ring rot outside of center, total rot must not exceed 10 per cent. of the area of butt.

"Butt rot of a character which plainly seriously impairs strength of the pole above ground is a defect.

"Wind twist is not a defect unless very unsightly and exaggera

"Rough large knots, if sound and trimmed smooth, are n defect."

NOTE.—Large purchasers ordinarily adopt somewhat more r specifications than the above.

3. **The Best Wood for Poles.** (*The Standard Handbook* Cedar is believed on the whole to be the best wood for poles, on the Atlantic coast the supply of this timber is nearly exhaus Chestnut stands next, but this tree is more slender and he

likely to be weaker for the same diameter of top. In the South, yellow pine would appear to be the natural pole, but notwithstanding the pitchy quality of this wood it rots with alarming rapidity after being cut and set in the ground, so that juniper or cypress is chiefly used. In the middle West so-called Norway pine, usually cut in the forests of Oregon or in the Canadas, can be secured. On the Pacific Coast red wood is used to a large extent.

4. Weights of Wood Poles

Length of pole	Cedar—weight in lb.				Chestnut—weight in lb.		
	5-in. top	6-in. top	7-in. top	8-in. top	6-in. top	7-in. top	8-in. top
20	125	180	240	....	.....	....	....
25	200	260	340	430	500	600	720
30	290	360	450	580	660	800	940
35	400	480	600	760	.....	1,030	1,200
40	.....	640	780	980	.....	1,310	1,520
45	.....	830	1,020	1,270	.....	1,660	1,940
50	.....	1,050	1,300	1,600	.....	2,080	2,480
55	.....	1,310	1,640	2,000	.....	2,600	....
60	.....	....	2,080	.....	.....	....	....

The above figures are the average of shipping weights used by a large number of dealers in poles. Although poles are usually designated by the diameter of the top, as "5-in," "6-in," etc., this may be misleading, because an acceptable pole may not be exactly circular. The circumference of the top should be measured with a tape line and for seasoned poles should be approximately as follows: 5-in. poles, 15 in. circumference at top; 6-in. poles, 18½ in. circumference at top; 7-in. poles, 22 in. circumference at top.

5. Dimensions of Poles for Lighting and Power Lines.—The table gives average dimensions for poles for light transmission lines or for ordinary distribution lines. Heavier poles are used for heavy lines and lighter ones for lighter lines.

Length, feet	Cedar		Juniper		White chestnut	
	Cir. at top, inches	Cir. 6 ft. from butt, inches	Cir. at top, inches	Cir. 6 ft. from butt, inches	Cir. at top, inches	Cir. 6 ft. from butt, inches
25	25	36	25	36	....	....
30	25	40	25	38	22	36
35	25	43	25	43	22	40
40	25	47	25	47	22	43
45	25	50	25	50	22	47
50	25	54	25	54	22	50
55	25	56	25	56	22	53
60	25	63	25	59	22	56
65	25	66	25	63	22	59
70	....	....	....	....	22	62
75	....	....	....	....	22	65
80	....	....	....	....	22	69

6. Preserving Poles. Creosoting. (*Standard Handbook*).—Owing to the increasing scarcity of timber there is a growing interest in preservative methods that endeavor to impregnate the pole with some chemical solution which shall successfully resist or retard decay, but with the exception of what is called creosoting few have found much favor. By this method the pole is placed in a large tank hermetically sealed. After the tank is closed superheated steam is applied and the pole cooked sufficiently to raise its temperature to about 250 deg. fahr. Then by means of an air pump the tank is exhausted and the sap in the pole tends to flow outward and may be removed from the tank. This is intended to thoroughly season the pole, after which the tank is filled with dead oil of tar (creosote) and hydrostatic pressure applied, until such a quantity of oil is forced into the timber as may be specified.

It is usual to specify that creosoting shall be done with a steam pressure of not less than 45 lb. applied for not less than 4 hr. and then a vacuum of not less than 20 in. until all sap ceases to flow. The dead oil of tar (creosote) should be liquid at 100 deg. fahr., should contain at least 25 per cent. of constituents that do not volatilize at a temperature of 600 deg. fahr., should not contain over 5 per cent. of tar acid and no admixture of any substance not derived from the distillation of coal tar. After the oil is pumped into the tank it is usual to require that from 12 lb. to 25 lb. per cubic foot of timber shall be forced into the wood. The amount of oil is determined by noting the quantity pumped into the tank and the quantity pumped out after treatment, the difference being that absorbed by the wood. This difference divided by the volume of the timber treated gives the quantity of oil absorbed. The creosoting process is growing in favor.

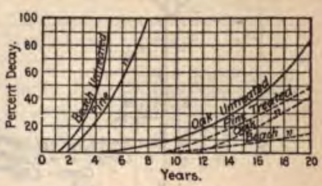


FIG. 1.—Life of treated and untreated poles.

Fig. 1 shows, as would be expected, that the softer and more porous woods that suffer most rapid decay are most benefited, and have the longest life after treatment. Such woods can absorb the most oil. The cost of treatment varies with the amount of oil injected and local conditions. Roughly, it usually about doubles the cost of the timber, while the life is increased from three to ten fold.

7. Steel poles are used because of their reliability and good appearance. Such poles are built up of structural steel, or made of special tubes. Poles made up of sections of wrought-iron pipe welded together are very common in railway work along city streets.

8. Reinforced-concrete poles (*Standard Handbook*) are the most permanent and usually the most expensive. The life of a properly designed concrete pole is practically unlimited. The facility with which special purposes may be served with reinforced concrete is also a great advantage. The exterior form may easily be modified to harmonize with any desired scheme of decoration

When it is desired to lead wires from the pole top to ground, the poles may be made hollow, and thus at a slight additional cost the wires are completely hidden from view and protected from the weather. Concrete poles may fail, but they will not fall to the ground. The principal drawback to this form of construction has been the cost and the difficulty of manufacture. They are heavy and cumbersome to transport, so that, where possible, it is well to make them in the neighborhood where they are to be used. Both concrete and steel poles may be transported in small packages over mountains and erected on the spot, but in this respect steel is much superior to concrete.

9. Cost of Concrete Poles.—The cost of installation depends to such a great extent upon the accessibility of the point of erection that it is impossible to give any general rule for its determination. Certain reinforced-concrete poles 35 ft. high 6 × 6 in. at the top and 14 × 14 in. at the butt weighed 2,500 lb. and cost to build $15 each. Another type of reinforced-concrete pole 35 ft. long, 7 in. diameter at the top and 11 in. diameter at the butt cost $11 to build, cement being $1.50 a barrel, sand $1 per cu. yd. and labor $2 per day. A 60-ft. pole for a 500-ft. span, 14 in. diameter at the butt, designed to carry a direct pull of 16,000 lb. at the top and a torsional effect of an arm 4 ft. long carrying 8,000 lb., cost $160 each.

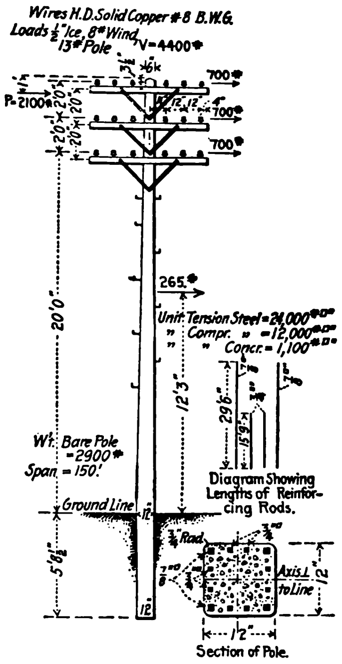


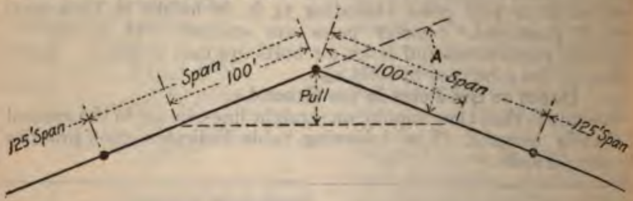
FIG. 1A.—A 30-ft. reinforced concrete pole (Universal Portland Cement Co.).

10. The design of reinforced concrete poles requires considerable skill. Where one who is unfamiliar with concrete pole design must build them, he had best accept the proportions of poles that have been built and that are giving good service. A very useful booklet—*Concrete Poles*—will be mailed free to any one interested by the Universal Portland Cement Co. of Pittsburg. This book gives the dimensions of many concrete poles. The design of Fig. 1A is from the booklet. The pole is proportioned, for a 150-ft. span, to successfully withstand a gale, with the wind at a velocity of 70 miles per hour, and ½-in. ice on the wires. The horizontal load thus imposed by the wind on all of the 18 wires, tending

Guy wires should be at least 18 ft. above a highway and 12 ft. above a sidewalk.

In cities it is good practice to use 35-ft. poles to carry either one or two cross-arms; 40-ft. poles to carry three or four cross-arms; and 45-ft. poles to carry over four cross-arms. For suburban lines 30-ft. poles are often used. For very light lines carrying only three or four wires, 6-in. poles 25 ft. long are sometimes used, though so light a pole is inexpedient if the number of wires is likely to increase. The height of a pole is always considered as the total length over all.

13. Poles should be spaced, in straight portions of a line, about 125 ft. apart. In curves and at corners the spans should be about as indicated in Fig. 2.



Note: If the "Pull" is less than 5,' the Spans Adjacent to the Angle Pole shall be Standard Length (125'). If the "Pull" exceeds 5,' the Spans Adjacent to the Angle Pole shall be Reduced to the Distance "Span" Given in Table.

Angle A.	Pull in feet.	Span	No. of 6000 lb. Side Guys. 1 Arm 6 Wires.	2 Arms 12 Wires.	3 Arms 18 Wires.
Less than 6	Less than 5'	125'	None	None	None
6°–11°	5'–10'	115'	None	1	1
11°–15°	10'–13'	105'	1	1	1
15°–22°	13'–19'	95'	1	1	2
22°–30°	19'–26'	85'	1	1	2
Over 30°	Over 26'	75'	1	2	2

FIG. 2.—Pole spacing and side guys on curves (National Electric Light Association).

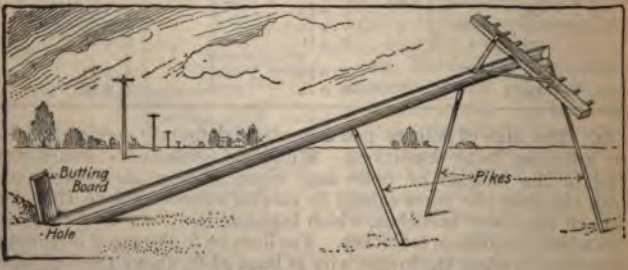


FIG. 2A.—Method of setting a pole with pikes.

14. *Holes for poles* should be large enough to admit the poles *without any slicing* or chopping and should be of the same diameter *from top to bottom.* The diameter of the hole should always be *at least large* enough so that a tamping bar can be worked on all sides between the pole and the sides of the hole.

15. Setting Poles.—On straight lines poles should be set perpendicularly. On curves poles should slant slightly so that the tension of the wires will tend to straighten them. In filling a hole after the pole is in it, only one shoveler should be employed and as many more men as can conveniently work around the pole should tamp in the earth as the shoveler throws it in. Some of the surplus earth should be piled around the butt of the pole so the water will drain away. Fig. 2A illustrates the method of setting a pole with pikes.

16. Setting Poles in Loose and Weak Soils.—Where the soil is fairly firm the sand-barrel, Fig. 3, is a valuable expedient. This consists of a strong barrel or barrels placed at the bottom of the hole into which the pole is set. The barrel is filled with a firm substantial soil. By this means the pole is given a larger bearing area. Sometimes a temporary sand-barrel is used consisting of a special iron cylinder that is placed around the pole filled with firm dirt and then hoisted away.

Fig. 3.—Sand barrel.

Where the soil is quite weak it is customary to use a base of concrete, Fig. 4A. A suitable mixture is one part cement, three parts of sand and three parts of broken stone or coarse gravel. Another expedient, Fig. 4B, consists in bolting transversely to the butt of the pole one or more logs some 6 or 7 ft. in length. This provides an additional bearing area that in many cases will be sufficient to support the pole. In marshy ground a more elaborate foundation (Fig. 4, C and D) is often necessary, and is made by building a wooden foundation to support the pole.

17. When setting poles in rock the hole may be blasted, or a hole 1½ in. in diameter may be drilled in the rock (Fig. 5) into which an iron pin is placed that extends about 6 in. above the surface. A similar hole is drilled in the butt of the pole, and the pole mounted on the pin. It must then be braced by three or four wood struts spiked to the pole 6 ft. from the ground, running diagonally to the rock and formed thereto, or by guy wires made fast to metal pins set in the rock.

18. Setting Poles with a Gin-pole.—A few men can set a large pole with a "gin-pole" as suggested in Fig. 6. The gin-pole can be a short wooden pole or, where the poles to be raised are not too heavy, a length of wrought-iron pipe. The "gin" need be only ½ as long as the pole to be raised. In setting a pole the "gin" is first raised to an almost vertical position with its top over the pole hole. It is held in that position by fastening the guy lines. Then the hook of the tackle blocks is engaged in a sling around the pole and the pole is raised, by men or by a team of horses, by pulling on the free end of the tackle block line. When high enough that its lower end can be slipped into it, the pole is dropped into the hole, adjusted to a vertical position with pikes and the eart s tamped in. Sometimes "gin-poles" are permanently mount on wagons for transportation and are then called **pole derricks**. They are great savers of time and money.

19. **Resetting Poles.**—When a pole becomes old and rotten at its butt it can be reset if the expense of a new pole is not justified. In resetting, the pole is temporarily sustained with 3 or 4 pole pikes

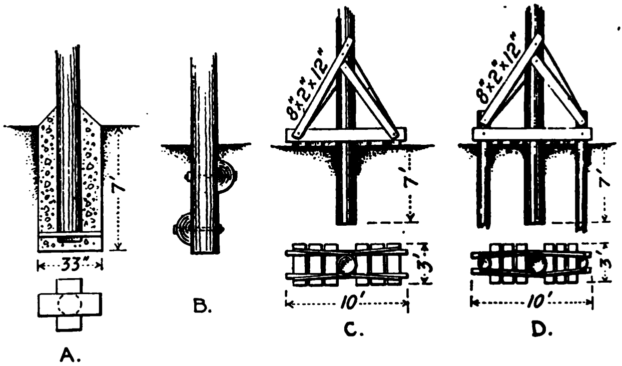


Fig. 4.—Methods of setting poles in poor soils.

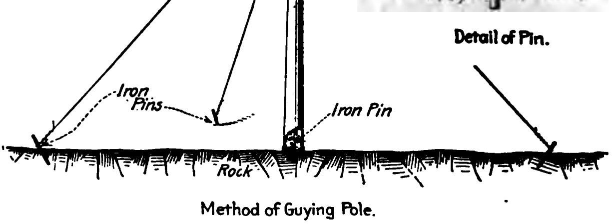


Fig. 5.—Method of setting pole on rock.

and chopped off just above the ground line. Then the lower end of the portion of the pole above ground line is set to one side and the butt in the ground dug out and thrown away. The lower end of the upper portion of the pole is then dropped into the hole. The reset pole is as many feet shorter than it formerly was as its set feet in the ground. Sometimes the hole is dug around the before the pole is chopped off. The method of reinforcing concrete and steel described in 20 is usually much superior setting.

. **Reinforcing Old Poles with Concrete and Steel.** (*Electric nal*, January, 1910).—Wooden poles usually become unsafe

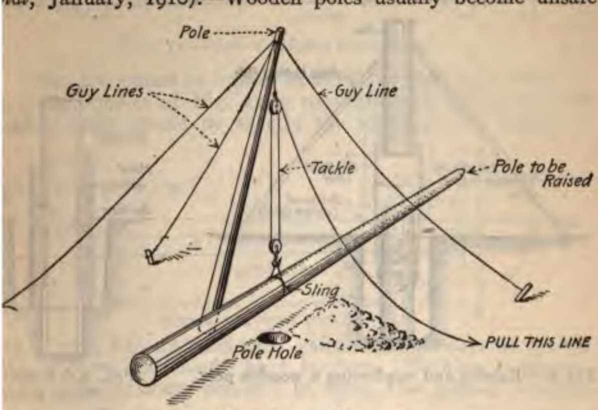


FIG. 6.—Gin-pole for raising poles.

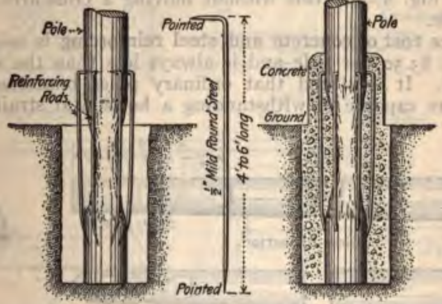


FIG. 7.—Reinforcing pole with concrete.

use of butt rot at the ground line. Such poles can be repaired out moving the wires they support by reinforcing them with and concrete as shown in Fig. 7. For ordinary poles and itions, 10 mild steel rods ½ in. in diameter and 4 ft. to 6 ft. are used for reinforcing. The lower end of each reinforcing s *pointed and is driven into the portion of the butt that re-s in the hole.* The other end is bent at right angles, and pointed. It is driven into the pole above the ground line. A 1–2½–5 mixture of concrete is used for the main body and a richer mixture is used for the portion above ground line and is molded in a cylindrical sheet-iron form. The concrete extends to about 1½ ft. above the ground line. Poles 15 to 20 years old have been satisfactorily repaired by this method without moving the wires

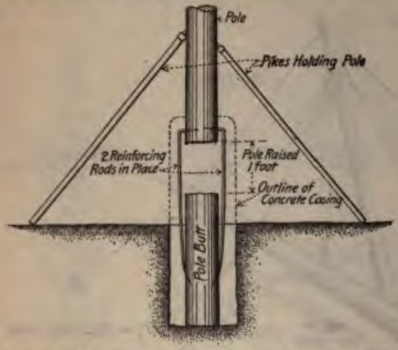


FIG. 8.—Raising and reinforcing a wooden pole.

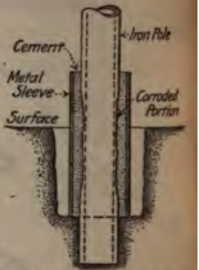


FIG. 9.—Repairing metal pole.

supported. Poles have been raised 12 in. and then reinforced as shown in Fig. 8, and this without moving a cross-arm or fixture on the pole.

21. The cost of concrete and steel reinforcing is said to average about $3.50 per pole and is always less than the cost of replacement. It is stated that ordinary poles reinforced by this method are capable of withstanding a horizontal strain of 1,000

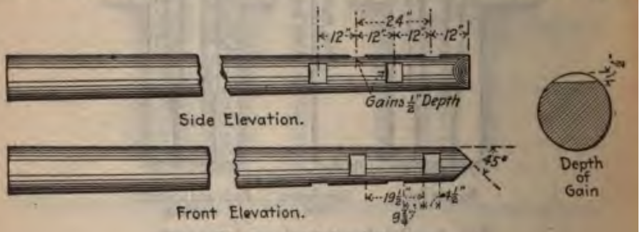


FIG. 10.—Gains in pole.

lbs. applied 27 ft. above the ground line. The reinforcement can be made almost as strong as one pleases by using more concrete and rods. The method is patented.

22. Repairing **Steel Poles.**—Metal poles sometimes corrode *very rapidly* at the ground and often when discovered the corrosion is too far advanced to make any preventive measures effective. A very satisfactory method (Fig. 9) of repairing steel poles is ce a loose-fitting metal sleeve around the butt of the pole and the space between the two with Portland cement.

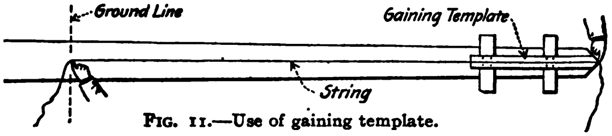


FIG. 11.—Use of gaining template.

3. **Poles are gained** or framed as shown in Figs. 10, 11 and 12. : gaining templet of Fig. 13 is convenient in laying out the ıs. The gain should be exactly the width of the cross-arm

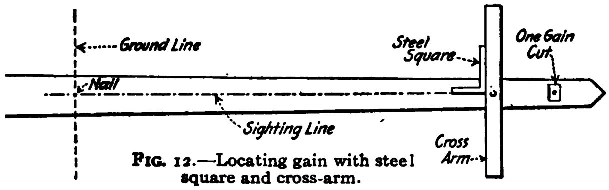
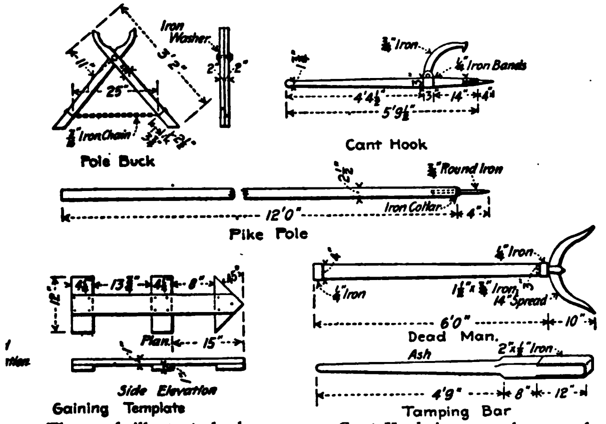


FIG. 12.—Locating gain with steel square and cross-arm.

ring a snug fit. In good work gains should always be spaced 24-in. centers and should be ½ in. deep. Nothing is accom-ıed by making them deeper. In using the gaining templet



te.—The tool illustrated above as a *Cant-Hook* is properly termed a ie. A peavie has a splice in the end of its handle, while a cant-hook ıo splice.

FIG. 13.—Some line-construction tools.

. 11) *the point of the* "roof" of the templet is placed exactly *the point of the roof* of the pole and the templet is shifted *its center line* (which should be marked thereon) lies exactly under a cord stretched from the roof point to the center of the pole, at the ground line. Then the positions of the cross-arm gains are indicated by knife scratches made along the sides of the cross pieces on the templet.

Where a gaining templet is not available a cross-arm (Fig. 12) can be laid on the pole with a steel square held against its lower face, the outer edge of the short limb of the square lying at the center of the pole and the center of the cross-arm. Rotate the cross-arm in a horizontal plane until, by sighting, it is evident that the edge of the square coincides with an imaginary center line to a nail in the center of the butt at the ground line. Indicate the gain location by knife scratches along the cross-arm sides.

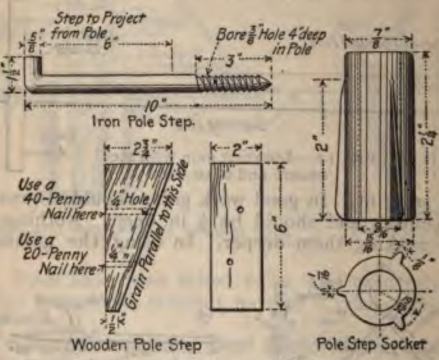


FIG. 14.—Pole steps and socket.

24. Pole steps (Fig. 14) can be located on the pole as shown in Fig. 15. A $\frac{3}{8}$-in. hole 4 in. deep is bored for the iron step. It is driven into the hole until it projects 6 in. from the pole and is then turned with a wrench until the hook end is vertical. The wooden step is held to the pole with one 40-penny and one 20-penny nail or with cut spikes. Often the wooden steps are omitted. The lowest iron step should be at least 7 ft. from the ground. Pole steps should extend from the pole in the same direction as that of the street on which the pole is set.

25. Pole step sockets, Fig. 14, are sometimes substituted for the wooden steps. The sockets drive into a $\frac{7}{8}$-in. hole. To climb the pole a lineman can temporarily insert bolts or similar pieces of metal into the sockets.

26. Pole braces are used where guying is not feasible and cost more than equivalent guys. Fig. 16 shows methods of bracing poles. The upper end of each brace fits in a notch cut in the pole and is bolted thereto.

27. Guying.—Probably there are not as many guys on pole lines as there should be to insure continuity of service and minimum maintenance expense. Lines should be guyed not for normal conditions but for the most severe conditions that are liable to obtain. The guys should be frequent and heavy enough to sustain the line after the heaviest snow storm or during the worst possible wind storm. A guy should be used on every pole where the tension of the wires tends to pull the pole from its normal position.

Terminal poles should always be head guyed and on lines carrying three or more cross-arms, the two poles next to the terminal pole should also be head guyed to distribute the stress.

Line guys are installed on straight pole lines to reinforce them against the excess stresses introduced by storms. It is good practice to install head line guys, as shown in Fig. 17, at about every twentieth pole. This applies only to lines carrying more than one cross-arm.

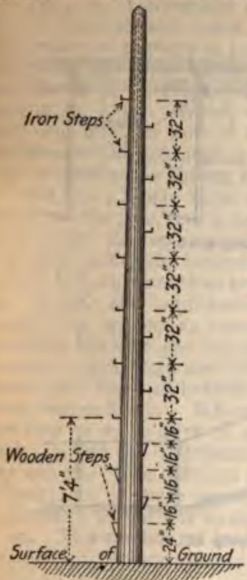


Fig. 15.—Location of pole steps on pole.

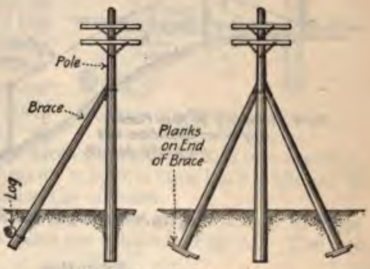


Fig. 16.—Bracing poles.

The installation of additional side guys, arranged at right angles to the line, to trees, stubs or anchors, is recommended. The side guys are attached to the same pole as the head guys.

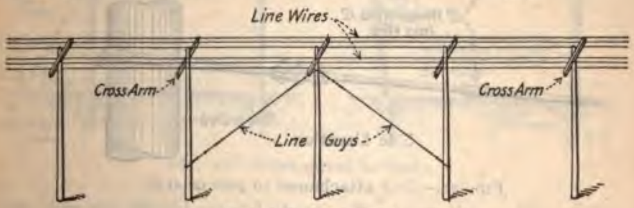


Fig. 17.—Line guys.

Side guys should be installed at curves, the guys taking the direction of radii of the curves. Fig. 2 shows a table that gives *the number of side guys* required for a given line with a given *"pull." The pull* is the distance from the pole to a line joining

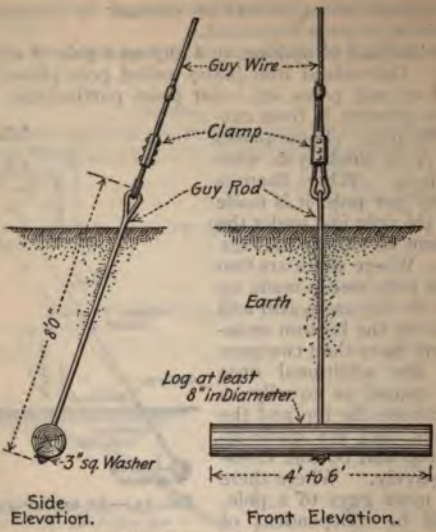


FIG. 23.—A guy rod and anchor.

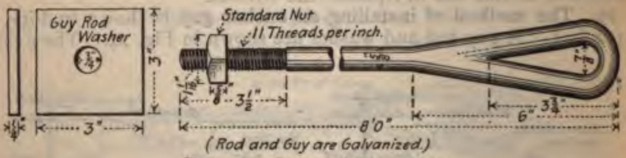


FIG. 24.—Guy rod and washer.

FIG. 25.—Methods of making up guys on guy rods.

pole as possible—at least a distance equal to $\frac{1}{4}$ the height of the pole.

30. The methods of installing stub guys are shown in Fig. 22. The stubs should be long enough that the guy wires will clear roadways by at least 18 ft., side walks by 12 ft. and electric wires by 3 ft. Stubs are used only when a line cannot be guyed properly

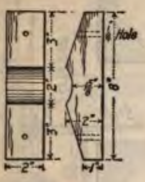


FIG. 26.—Details of tree-blocks.

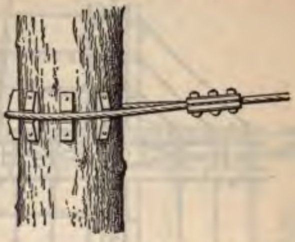


FIG. 27.—Guy wire fastened to tree.

to trees or poles. Stubs should satisfy the specifications of 2 for poles.

31. In guying to a tree, tree blocks (Figs. 26 and 27) should be used and the wire should pass but once around the tree. Tree guying is undesirable and should not be done unless absolutely necessary. Guys should preferably be attached to trunks or to limbs that are not less than 8 in. in diameter. Do not attach to a

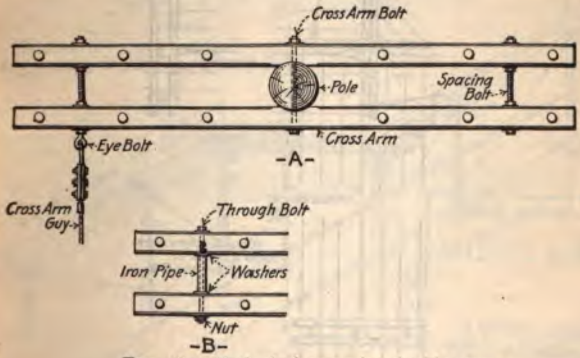


FIG. 28.—Method of arranging double arms.

limb that will swing with the wind and sway the pole. Enough tree blocks should be used so that the guy wire cannot touch the tree.

32. *Cross-arm guys* are used where the pull on a cross-arm is *balanced.* Figs. 28, 29 and 30 show examples. Cross-arm guy usually extend from the arm to a pole or stub but sometimes for light strains the Y or "bridle" guy (Fig. 31) is used.

33. A line must be thoroughly guyed where it crosses a road. Figs. 32 and 33 show two methods of holding a line at such a point.

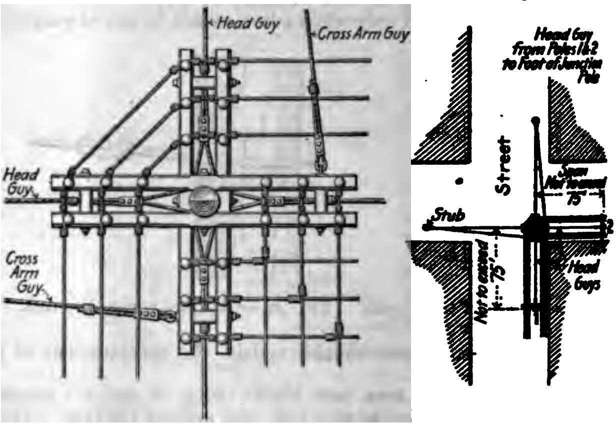


FIG. 29.—Method of turning corner with one pole.

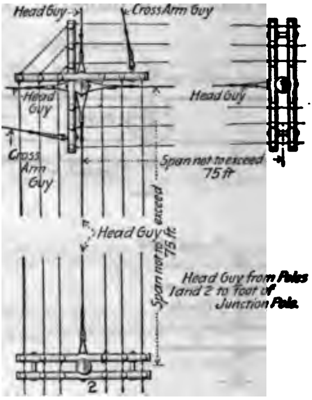


FIG. 30.—Corner pole without double arms.

The method involving the use of side guys is preferable, but the other one will give good service where side guys cannot be installed.

34. *Guy-Wire Insulation.*—Strain insulators should be inserted *in all guy wires* to poles carrying electric lighting or power wires

insulators should be inserted in each guy. One is located at t 6 ft. from the pole itself or 6 ft. below the lowest line wire. other is located at least 6 ft. from the lower end of the guy at least 8 ft. from the ground. The two strain insulators are

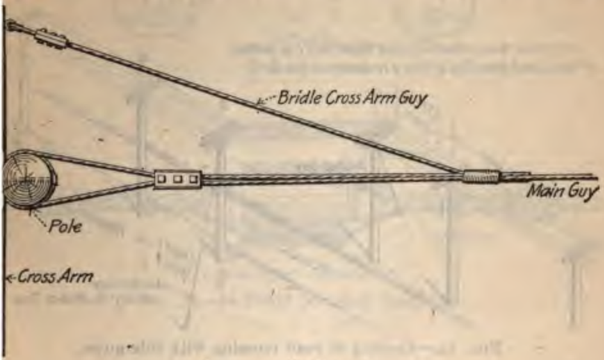


FIG. 31.—Bridle guy.

etimes coupled in series in short guys. Wooden tree blocks . 26) are used for insulation under guys attached to iron poles.
5. **Strain insulators** are used in guys as shown in illustrations his section and are also used in line wires at dead ending points.

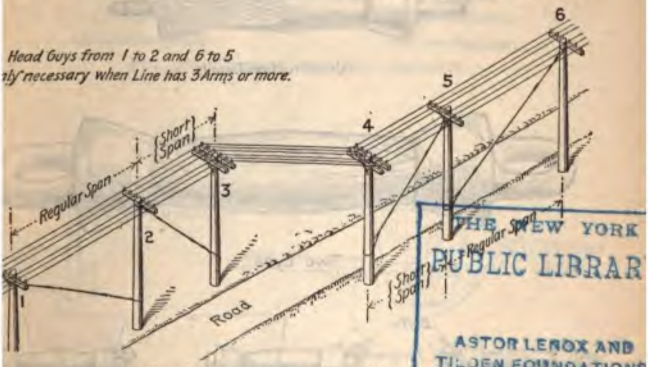


FIG. 32.—Guying at road crossing without side guys.

nposition, porcelain and *wooden strain insulators* are made. *den strain insulators* (Fig. 34) are popular with some companies afford excellent insulation but have the objection that if one the wires that it supports fall. Composition and porcelain insulators can be made so that even if the insulating materi fails, the supported wires will not fall. Figs. 35 and 36 show types meeting these requirements. The strain insulator of Fig. 35 is cheap and satisfactory and has lately become very popular in electric lighting line construction.

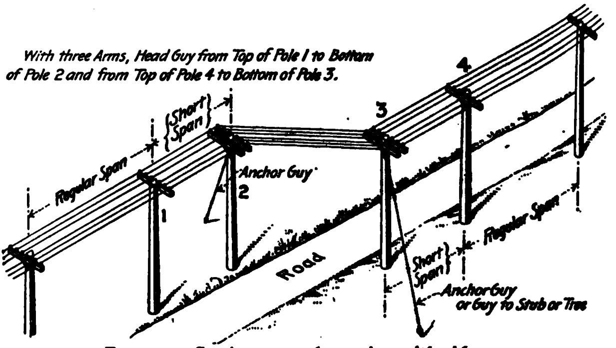


FIG. 33.—Guying at road crossing with side guys.

36. **Emergency strain insulators** can be made by knocking the ends out of common glass line wire insulators as illustrated in Fig. 37. To break out the end, hold the insulator in one hand

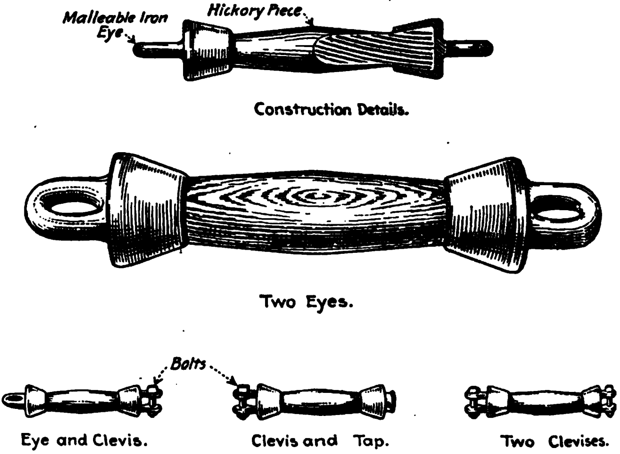


FIG. 34.—Wooden strain insulators.

and strike the inside of the top a sharp blow with the handle of a *pair of plyers* or of a pair of connectors or with a screw driver held in *the other* hand. Where one emergency insulator will not give

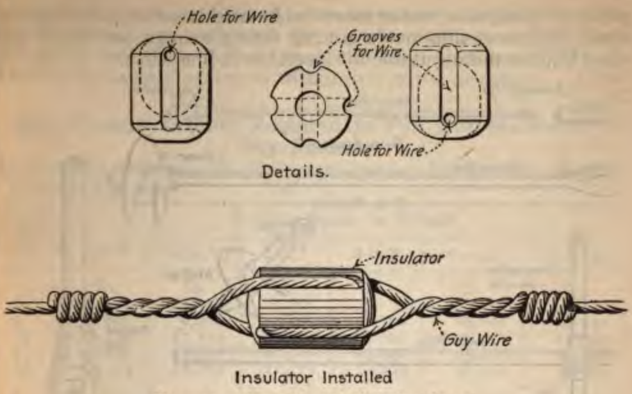


FIG. 35.—A strain porcelain insulator.

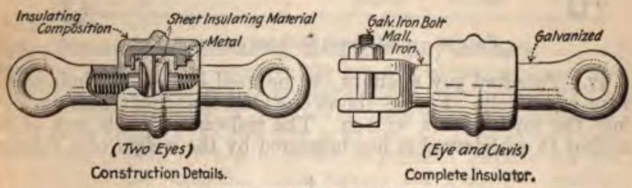


FIG. 36.—Composition strain insulators.

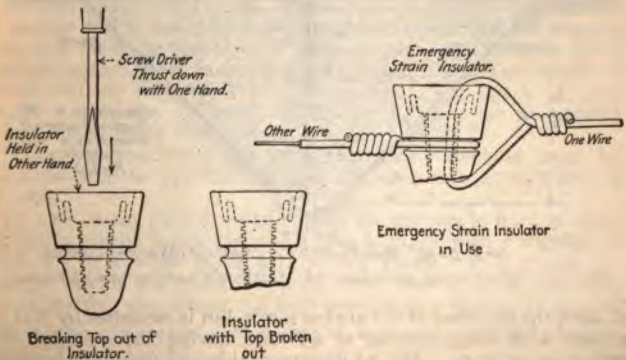


FIG. 37.—Emergency strain insulators.

sufficient insulation, two or more can be used in series. Emergency strain insulators thus made are not strong enough for heavy guy wires but are more suitable for insertion in line wires.

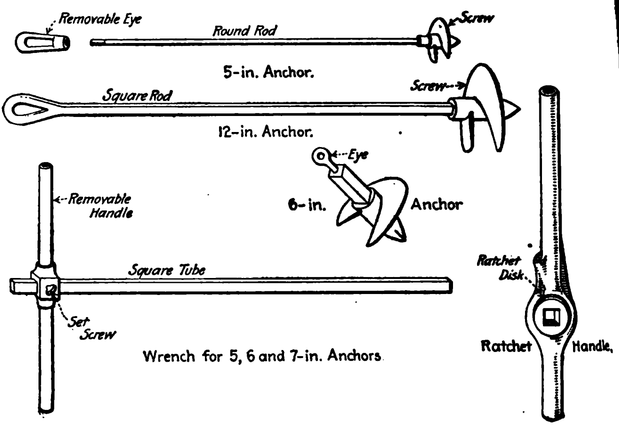


FIG. 38.—Matthew's anchors and wrenches.

37. **Patented guy anchors** can be used in certain kinds of soil very effectively. Fig. 38 shows one kind of anchor that is screwed into the earth with a wrench. The resistance of this sort of an anchor to withdrawal is not measured by the weight of a column

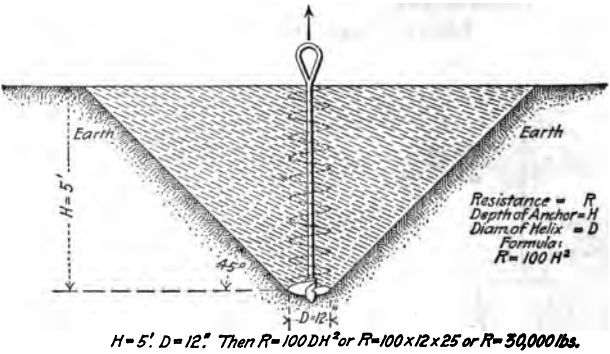


FIG. 39.—Illustrating resistance of Matthew's anchor to withdrawal.

of earth the diameter of the anchor screw, but is measured by that of a cone with sides slanting at 45° and having the point of the anchor as an apex. Fig. 39 illustrates this and shows the formula for computing the withdrawal resistance. Fig. 39 shows t chor inserted perpendicularly, but an anchor should always be erted at the same angle that the guy wire assumes, so the rod of anchor will be in a direct line with the guy wire. Table 38 es the actual resistances to withdrawal of the anchors.

38. Pounds Tension Required to Pull Out Matthews Guy Anchors

t Various Depths According to Prof. Carpenter's Formula (see Formula Diagram Fig. 39).

epth feet	Holding Strain in Pounds					
	5 in.*	6 in.*	7 in.*	8 in.†	10 in.†	12 inch†
	lb.	lb.	lb.	lb.	lb.	lb.
3½	6,125	7,350	8,575	....	....	....
4	8 000	9,600	11,200	12,800	16,000	19,200
4½	10,125	12,150	14,175	16,200	20,250	24,300
5	12,500	15,000	17,500	20,000	25,000	30,000
5½	15,125	18,150	21,175	24,200	30,250	36,000
6	....	....	....	28 800	36,000	43,200
7	....	....	....	39 200	49,000	58,800
8	....	....	....	51,200	64,000	76,800
9	....	....	....	64,800	81,000	97,200
0	....	....	....	80,000	100,000	120,000

9. **Directions for Installing Matthews Guy Anchors.** 5-, 6-, D 7-IN. WITH RODS.—Remove the eye of the anchor; pass the l through the wrench and replace the eye, which will serve to d the wrench rigidly to the anchor, then screw the anchor in, the same angle as the guy wire is to run, as far as ground conions will permit. When in as far as possible, remove the eye l pull out the wrench. Then replace the eye, thus making chor ready for guy wire. The handle bars of the wrench are justable and held in place with a set screw. They can be ved back as the anchor screws in.

3-, 10-, 12-IN. WITH RODS.—Place bar or other lever in eye anchor and screw it in as far as ground conditions will permit, ays at the angle that the guy wire is to run. Time will be saved l the anchor start easier if a few spades of earth are removed ore starting anchor. When the anchor is set, attach the guy and to the eye. Always pull anchor back as far as possible ore finally tying the guy wire.

NOTE.—If conditions are such that many anchors must be talled close to buildings, fences, etc., a rachet wrench should used.

IN DRY, HARD GROUND.—In setting all anchors in hard ground, work will be much easier if a hole is made with a digging or w bar or a wood auger with a long shank. This makes the h of the anchor easier. A little water poured down this hole ore starting the anchor will help considerably where the ground

It is impractical to install the 5- and 6-in. anchors at a greater depth than ft.

The 8-, 10- and 12-in. anchors will not bear a great strain at a lesser h than 4 ft.

is hard and dry. In installing 8-, 10-, and 12-in. anchors in very hard ground, clamp a lever to the rod by means of a chain, a foot or so above the ground. As the anchor is screwed down the lever can be moved up. The anchor will start easier if a few spades full of earth are removed at the angle desired to set the guy. If a man stands on the helix of the anchor when starting until the point bites the ground it will assist.

In localities where loose gravel or small flat rock occurs, drill a hole with a digging bar or crowbar, as suggested above. If a small rock is encountered it can be broken by the bar. If a large rock is "discovered," the bar can be removed and the hole drilled in another place. This will allow the use of anchors in many places where it would seem impossible to install them.

FIG. 40.—Cross-arm dimensions recommended by the N. E. L. A.

40. Guy Wire and Cable.—For unimportant work where strains are not heavy, a single strand of No. 4 or No. 6 galvanized steel wire is sometimes used (see index for table) but modern practice favors galvanized steel cable or "strand." (See index for table.) For cross-arms and other light guying, a 1/4-in. steel cable (tensile strength 2,300 lb.) can be applied. The standard guy for regular pole guying is a 5/16-in. special steel cable which should have a tensile strength of at least 6,000 lb. Many telephone lighting and power companies use this size and grade.

41. Cross-arms.—Table 43 shows the dimensions of the so-called standard arms. Fig. 40 shows the dimensions of cross-arms recommended by the National Electric Light Association. These arms have a spacing between center pins of 30 in., which is believ to provide a safe climbing space. Cross-arms are best made of long-leaf yellow pine, Norway pine, or Oregon fir. Cross-arm dimensions have not actually been standardized throughout the country. It is probable that arms of the N. E. L. A. dimensions (Fig. 40) will come into extensive use. It is modern practice not to paint cross-arms as soon as they are made. They are either treated with a wood preservative or are permitted to season naturally for at least three months and are then painted with two coats of green white-lead paint before erection. No cross-arm having a spacing of less than 20 in. between center pins or 10½ in. between side pins should be used. The six-pin arm (Fig. 40) is recommended for general use.

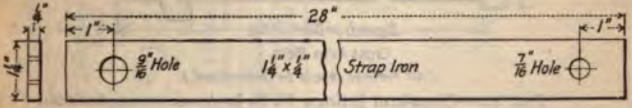


Fig. 41.—Cross-arm brace, N. E. L. A. recommendations.

42. **Cross-arm bolts** are standard ⅝-in. machine bolts preferably galvanized (Fig. 42). A square washer (Fig. 42) is used under both head and nut.

43. **Standard Cross-arms.** Finished size, 3¼ in. by 4¼ in. Bored for 1½-in. or 1¼-in. pins, two ⅜-in. carriage bolts and one ⅝-in. or two ½-in. bolts, as may be directed. Pin holes shall be a driving fit; carriage bolt holes $\frac{7}{16}$ in. diameter; ½-in. machine bolt holes $\frac{9}{16}$ in. diameter; ⅝-in. machine bolt holes $\frac{11}{16}$ in. diameter.

Length ft.	No. pins	Pin spacing			Approximate weight, lb.
		Ends, in.	Sides, in	Centers, in.	
3	2	4	....	28	10
4	4	4	12	16	14
5	4	4	15	22	17
6	4	4	21	22	21
6	6	4	12	16	21
8	....	4	16½	22	28
8	....	4	12	16	28
8½	10	3	10	16	29¾
10	8	4	15	22	35
10	10	4	12	16	35
10	12	4	9⅝	16	35

44. **Cross-arm braces** (Fig. 41) are of strap iron (mild steel) and are preferably galvanized. Braces are attached to the front of each cross-arm, each by a 4½-in. carriage bolt (Fig. 42), before the arm is fastened to the pole. The head of the bolt is at the back of the arm and has a round washer (Fig. 42) under it. The nut is on the brace side. There are braces of other sizes in use but the one of Fig. 41 appears to be best suited for general work. The braces are secured to the pole by a square-head coach or lag screw (Fig. 42) usually ½ in. by 3½ in. Table 46 shows proportions of lag screws of other dimensions. Dimensions of lag screws furnished by thirty-five different manufacturers vary.

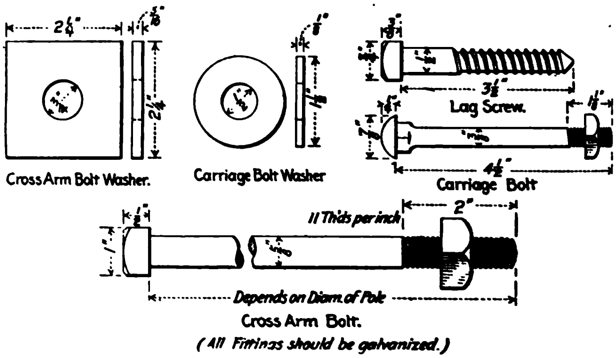


FIG. 42.—Cross-arm fittings, N. E. L. A. recommendations.

45. Dimensions of Machine Bolts and Nuts.

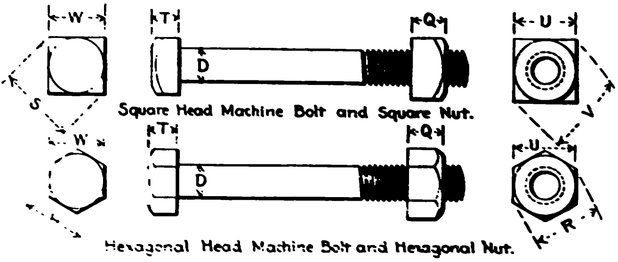


FIG. 42A.—Machine bolts and nuts.

D	T	W	S	H	Q	U	R	V
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible

46. Gimlet Point Square Head Coach or Lag Screw.—Lag screws 1½ in. long and under are threaded the entire length. Lag screws longer than 1½ in. are threaded but three-fourths of their lengths

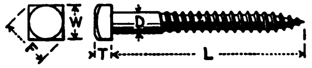


FIG. 43.—Square-head gimlet-point coach or lag screw.

D Diameter	T Thickness of head	W Width of side of head	F Distance across corners	Clearance bore for body of screw	L
1/4	3/16	3/8	17/32	5/16	Screws increase in length by ½-in. increments from 1½ in. to and including 8 in. Screws from 8 in. to 12 in. increase in length by 1-in. increments. Screws of diameters of ¼ in., 5/16 in., and ⅜ in. are made in lengths of 1½ in. to and including 6 in.; 7/16 in. dia. from 1½ in. to 9 in. long; ½ in. dia., 1½ in. to 12 in., 9/16 in. and ⅝ in. dia., 2 in. to 12 in.; ¾ in. dia., 2½ in. to 12 in.; ⅞ in. dia.; 3 in. to 12 in., 1 in. dia., 3½ in. to 12 in. long.
5/16	15/64	15/32	21/32	3/8	
3/8	9/32	9/16	51/64	7/16	
1/2	3/8	3/4	1 1/16	9/16	
5/8	15/32	15/16	1 21/64	11/16	
3/4	9/16	1 1/8	1 19/32	13/16	
7/8	21/32	1 5/16	1 55/64	15/16	
1	3/4	1 1/2	2 1/8	1 1/16	

47. Common or Button Head Carriage Bolts.

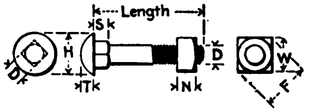


FIG. 44.—Common carriage bolt.

D Diameter, inches.	Threads per inch	T Thickness of head	S Length of square part	H Diameter of head	W Width of nut	N Thickness of nut	F Across corners of nut
1/4	20	3/32	1/4	17/32	1/2	1/4	[illegible]
5/16	18	1/8	5/16	[illegible]	[illegible]	5/16	[illegible]
3/8	16	5/32	3/8	[illegible]	[illegible]	3/8	[illegible]
1/2	13	7/32	1/2	1 1/32	7/8	1/2	1 1/4
5/8	11	9/32	5/8	1 9/32	1 1/16	5/8	[illegible]
3/4	10	[illegible]	3/4	[illegible]	1 1/4	3/4	[illegible]
7/8	9	7/16	7/8	[illegible]	1 7/16	7/8	[illegible]
1	8	1/2	1	2 1/16	[illegible]	1	[illegible]

48. Punched Wrought-iron Washers.

FIG. 45.—Punched wrought-iron washer.

Diam. bolt	D Outside diam.	T Approx. thick	H Diam. hole	Diam. bolt	D Outside diam.	T Approx. thick.	H Diam. hole
$\frac{3}{16}$	$\frac{9}{16}$	$\frac{3}{64}$	$\frac{1}{4}$	1	$2\frac{1}{2}$	$\frac{5}{32}$	$1\frac{1}{16}$
$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$2\frac{3}{4}$	$\frac{5}{32}$	$1\frac{1}{4}$
$\frac{5}{16}$	$\frac{7}{8}$	$\frac{1}{16}$	$\frac{3}{8}$	$1\frac{1}{4}$	3	$\frac{5}{32}$	$1\frac{3}{8}$
$\frac{3}{8}$	1	$\frac{5}{64}$	$\frac{7}{16}$	$1\frac{3}{8}$	$3\frac{1}{4}$	$\frac{11}{64}$	$1\frac{1}{2}$
$\frac{7}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$	$\frac{1}{2}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$\frac{11}{64}$	$1\frac{5}{8}$
$\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{32}$	$\frac{9}{16}$	$1\frac{5}{8}$	$3\frac{3}{4}$	$\frac{11}{64}$	$1\frac{3}{4}$
$\frac{9}{16}$	$1\frac{1}{2}$	$\frac{3}{32}$	$\frac{5}{8}$	$1\frac{3}{4}$	4	$\frac{11}{64}$	$1\frac{7}{8}$
$\frac{5}{8}$	$1\frac{3}{4}$	$\frac{1}{8}$	$\frac{11}{16}$	$1\frac{7}{8}$	$4\frac{1}{4}$	$\frac{11}{64}$	2
$\frac{3}{4}$	2	$\frac{1}{8}$	$\frac{13}{16}$	2	$4\frac{1}{2}$	$\frac{11}{64}$	$2\frac{1}{8}$
$\frac{7}{8}$	$2\frac{1}{4}$	$\frac{5}{32}$	$\frac{15}{16}$	....	....	....	....

49. Side arms are used (Fig. 46) in alleys and other locations where it is necessary to clear obstructions. These cross-arms are special, the dimensions are given in the illustration, and the fittings used on them are special. Side guys or crib braces (see illustration) are used where the line wires are heavy, to counteract the tendency of the pole to tip.

50. Double arms are used wherever the stress on the arms is unusually severe or where every precaution is necessary to insure safety. Double arms are often used on the poles at each side of a street, at each side of railroad crossings, at corners or other points where the direction of a line changes. Figs. 28, 29, 30, 32, 33, 47, 48, and 49 show examples of double-armed poles. The two cross-arms can be separated by wooden spacing blocks, Fig. 47, by spacing bolts, Fig. 28, *A*, or by spacing nipples, Fig. 28, *B*.

The spacing blocks can be *sawed from* a cross-arm. A $\frac{11}{16}$*-in. hole bored* through the

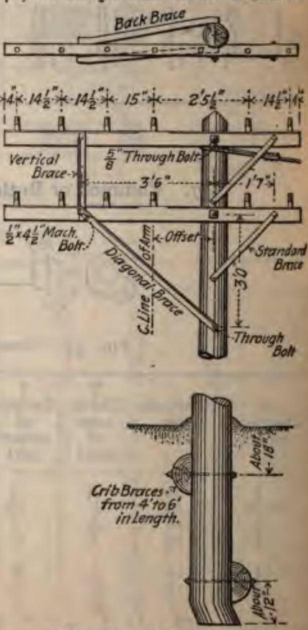


FIG. 46.—A side-arm pole.

ck and cross-arm accommodates a $\frac{5}{8}$-in. bolt. A washer is used ler bolt head and nut. Spreader bolts can be used instead of cing blocks (Fig. 28, *A*); the bolts are threaded their entire gths. A galvanized iron pipe nipple can also (Fig. 28, *B*) be d to separate the cross-arms. There is not a great deal of ice between the methods if the fittings for each are available. bably the wooden spacing-block method is most used because supplies required for it are always readily obtained "on the ." Where an arm guy is to be attached to the cross-arm, an -spreader bolt can be used as shown. Single-armed poles are v often used particularly on junction poles, as shown in the ompanying illustrations, in locations where double arms were

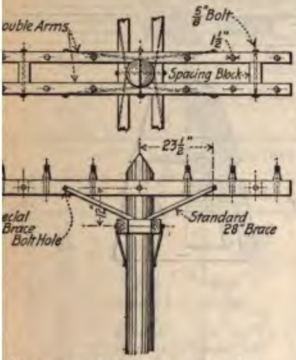


FIG. 47.—A buck-armed pole, doubled arms.

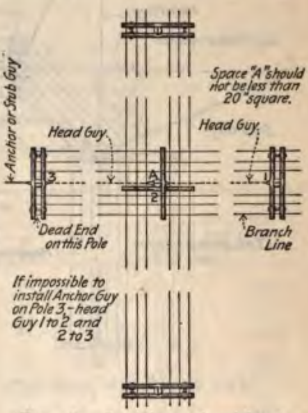


FIG. 48.—Junction pole without double arms.

merly thought necessary. The single arms are preferable in t they allow greater climbing space for linemen.

51. **Reverse or buck arms** are used at corners. See Figs. 29, 47 and 48. When placing buck arms, ample room must be proled through which a lineman can reach the top of the pole. A 20-square space is the minimum. Cross-arm braces on buck-arm les should be attached to the arms at a point $23\frac{1}{2}$ in. from the ter of arm instead of at 19 in., the standard distance for ordinary ming. The $\frac{3}{8}$-in. holes for the brace (carriage) bolts must be ecially bored, at the above spacing, in buck arms. The 23-in. acing is correct for 28-in. braces.

52. **Cross-arm pins** should be of locust. Oak pins are somenes used but they are treacherous and may break when they ould not and thereby cause accidents. Table **56A** and Fig. 53 ow dimensions of some standard pins. The pin dimensions commended by *the* National Electric Light Association for *linary distribution* use are shown in Fig. 51.

53. Pins are held in cross-arms with a six-penny nail as sho in Fig. 52. The nail should not be driven entirely in. Enou of its length should extend so that the cutting jaws of a pair plyers can be forced under the head and the nail thereby wit drawn. If this suggestion is followed and it is necessary to remo a pin, it can be readily accomplished.

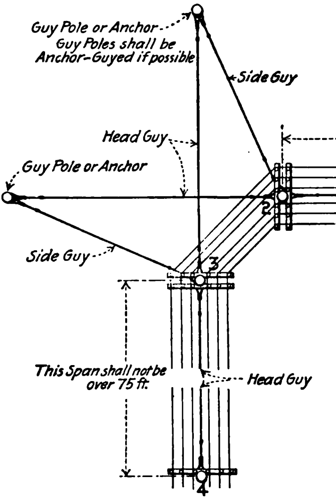


FIG. 49.—A right-angle turn.

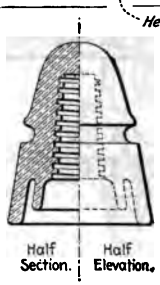


FIG. 50.—Double petticoat insulator.

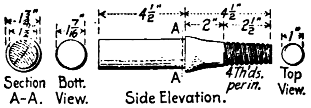


FIG. 51.—Pin recommended by the N. E. L. A.

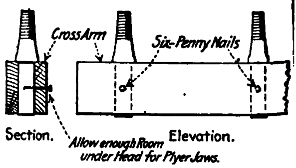


FIG. 52.—Fastening pin in cross-arm.

54. **Insulators.**—Glass insulators are ordinarily used fo conductors at pressures of 2,200 volts and under. However, porcelain insulators are much cheaper than they once were and porcelain is now a formidable competitor of glass as an insulato material for even the lower voltages. Insulators should be of th deep-groove double-petticoat type. The insulator illustrated Fig. 50 will give excellent service at pressures under 4,000 volt

55. **Glass insulators** are cheaper than porcelain, and owi its transparency, flaws can be detected by a simple insp

andard Handbook.) Glass has an exceedingly high dielectric ength and specific resistance. It condenses moisture on its face and the action of the distilled water destroys the smooth-ss of the surface and allows dirt to collect and form a leakage :h around the insulator.

56. **Porcelain insulators** give less trouble from leakage and are perior to glass in resisting constant and large changes in tem-rature. The surface resistance is increased by using a number petticoats.

56A. **Wooden Insulator Pins.**—All standard insulator pins of n. and 1⅜-in. top diameter have four threads to the inch and a pering diameter of $\frac{1}{16}$-in. increase for each inch in length.

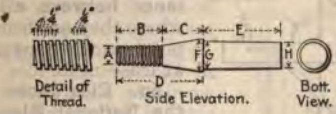


FIG. 53.—Wooden insulator pin.

Dimensions in inches								Shipping wt. per 1,000 lb.
A	B	C	D	E	F	G	H	
1	2½	2¼	4¾	4¼	1¾	1½	1 7/16	400
1	2½	4¾	7¼	4¼	2	1½	1 7/16	510
1	2½	4¾	7¼	4¼	2¼	1¾	1 11/16	700
1	2½	4	6½	5	2½	2	1 15/16	930
1⅜	2¼	2½	4¾	4¼	1⅞	1½	1 7/16	400
1⅜	2¼	5	7¼	4¼	2	1½	1 7/16	510
1⅜	2¼	5	7¼	4¼	2¼	1¾	1 11/16	700
1⅜	2¼	4¼	6½	5	2½	2	1 15/16	930
1⅜	2¼	7¼	9½	5	3	2	1 15/16	1,160
1⅜	2¼	8¾	11	5	3½	2	1 15/16	1,280
1⅜	2¼	9¾	12	5	3½	2	1 15/16	1,360

57. **In locating circuits on poles** the through wires or trunk lines ould be carried on the upper cross-arms and the local wires, those hich are tapped frequently should be carried on the lower cross-ms. The two or three wires of a circuit should always be carried adjacent pins. This is of particular importance with alternating-rrent circuits as the inductance, consequently the inductive ltage drop, is increased as the distance between the wires of a rcuit is increased. Wires of a circuit should always take e same pin positions on all poles to facilitate trouble hunting. ries circuits which do not operate during the day time may often carried on the pole pins of a cross-arm. High-tension multiple :uits that are "hot" continuously are well placed at the ends of arms out of the way of linemen. The neutral wire should ys be in the center of a three-wire circuit. Fig. 54 shows one arrangement on a two, four-pin-arm pole.

58. Wire and Wire Sizes for Electric Light and I No wire smaller than No. 6 is used in good constr wire. No. 8 is sometimes used for services, not mo long, that do not cross a street. Solid wires are ofte up to and including No. 00 and cable (stranded wi larger conductors. Triple-braid weatherproof is insulation of aeri Annealed or soft- preferable to hard- it is more readily h the sizes used, has strength.

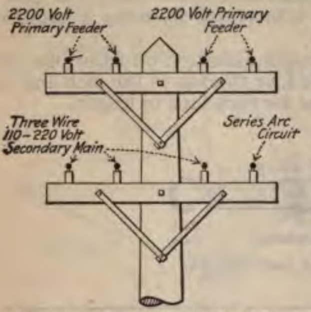


FIG. 54.—Location of circuits on a two-arm pole.

59. The perpe tance between al where they are firm poles or other supp at least 24 in.

60. Clearances the National Elec The following ind required for lines pressures exceedin It represents, how practice for 2,0 (The matter is taken from the Factory Mutual I pany's handbook.)

When it is necessary to carry 5,000-volt lines they must be at such height and distance from the to interfere with firemen in event of fire; therefore, of a building, they must be carried at a height not le the front cornice, and the height must be greater th cornice as the wires come nearer to the building, with the following table:

Distance of wire from building, feet	Elevation of wire a building,
25	0
20	2
15	4
10	6
5	8
2½	9

It is evident that where the roof of the building c in line with the walls, as in Mansard roofs, the heig of the line must be reckoned from some part of the from the cornice.

In order to make the intent of the above rule a as clear as possible, the following example is give in full lines a three-story building with flat roof overhanging about 2 ft. The poles carryin are set just inside the curbing, say 15 ft. from the building. cross-arm is 6 ft. long, bringing the outside wires say 3 ft. side of the pole. Therefore the wire nearest the building is from the cornice, in horizontal projection.

ference to the above table will show that under these condi- the wires must be at least 6 ft. above the cornice. If, now, the ing had had a very steep-pitched roof or especially one of the ard type, as shown in the dotted lines in this sketch, it will be y seen that the above arrangement would not be satisfactory, e wires would be very liable to interfere with fighting fire in the Assuming that the upper corner of the dotted roof is 5 ft. of the edge of the main cornice, this part of the roof is 15 ft. the nearest wire and conse- ly the wires must be raised bove their previous position ler that they may be 4 ft. the roof, as required in bove table when within 15 the building, as in this The cut shows very clearly at extent the dotted Man- roof affects the height of the

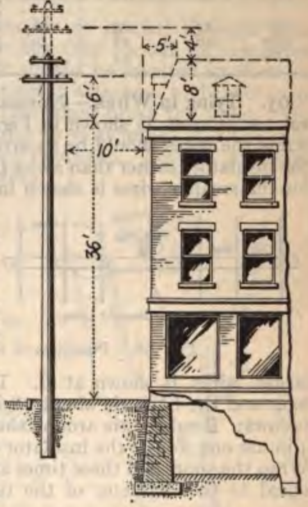


FIG. 55.—Wire location with reference to cornice.

Stringing Wire.—There wo methods, the choice de- ng on local conditions and ze and length of the circuit. ne method a reel of wire is one end of the line, and a carried 1,500 or 2,000 ft. the cross-arms and attached e wire that is then drawn the arms. The other way is ce the reel on a cart, and securing the end of the to the last pole the cart is d and the wire paid out till econd pole is reached, and the wire is hoisted up and n the arm. Wire should always be paid out from the coil, il revolving, so that the wire will not be twisted. Where is not received on reels it should be placed on them before g out.

Proper Sag in Annealed Copper Line Wires.—The wires d be pulled up until the sag equals that indicated in the fol- g table. The permissible sag is the same for wires of all sizes aries *only with the length* of span and the temperature of the *the time of stringing* the wire.

table is based on soft-drawn copper wire, ultimate tensile *1 34,000 lb.* per square inch. Triple-braided weatherproof *n.* Factor of safety, 4. Minimum temperature, −20 deg

Span in feet	Deflection in inches						
	Temperature in degrees Fahrenheit						
	30°	40°	50°	60°	70°	80°	90°
50	8	9	9	10	11	11	12
60	10	11	11	12	13	14	14
70	11	12	13	14	15	16	17
80	13	14	15	16	17	18	19
90	14	16	17	18	19	20	21
100	16	17	19	20	21	23	24
110	18	19	21	22	24	25	26
120	19	21	23	24	26	27	28
140	22	24	26	28	30	32	33
160	26	28	30	32	34	36	38
180	29	32	34	36	39	41	43

63. **Tying in Wires.**—Normally the wires should rest in the in-sulator grooves as shown in Fig. 56, *A*, but where there is a side stress the wires should be so arranged that the pull comes against the insulators rather than away from them, Fig. 56, *B*. A single tie for the smaller wires is shown in Fig. 57, *A*, and a back tie for the

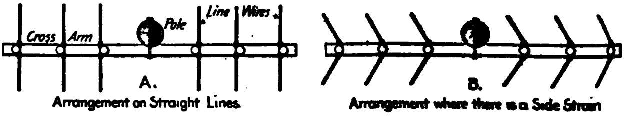


Fig. 56.—Positions of wires in insulator grooves.

larger wires is shown at *B*. The single tie wire is about 12 in. long and the back tie about 18 in. long. The back tie is made as follows: Bend the tie around the insulator under the line wire, with 4 in. on one side of the insulator and the balance on the other side. Wrap the short end three times around the line wire, leaving a space equal to the diameter of the tie wire between successive wraps.

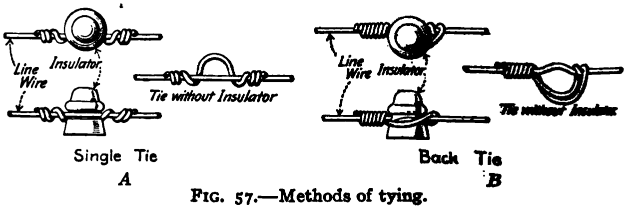


Fig. 57.—Methods of tying.

Now wrap the long end of the tie wire three times completely around the line wire, then back around the insulator and wrap it in the spaces left between the wraps of the other end of the tie wire. *The ends of* all tie wires should be cut off close to the line wire as *own in the* illustration.

64. Tie Wires.—Tie wires should be insulated with the same iaterial as the line wire. Do not use a tie wire twice as, after once eing bent and strained, it will be brittle. The following table of zes has been recommended for ordinary stresses. For very heavy resses heavier tie wires should be used.

Size, line wire	Size, tie wire	Kind of tie
6	6	Single.
4	6	Single.
2	4	Single.
1	4	Back.
00 and larger	2	Back.

65. Tree Wiring.—Where wires are so carried through trees iat they would rub against branches they should be supported y tree insulators of some sort or should be encased in abrasion olding. Wires should not be rigidly attached to branches or nbs because the swaying of the tree might break the wires. Fig. 3 shows some improvised tree insulators so arranged that the wires ive enough play to insure against breakage. Several good pat- ited tree insulators are on the market.

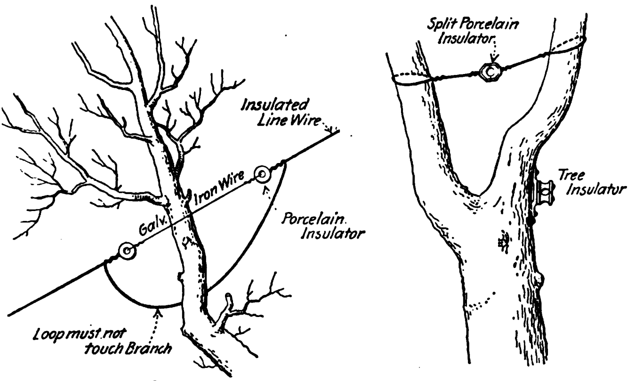


Fig. 58.—Improvised tree insulator.

66. Abrasion Molding.—Fig. 59 shows one type, made of wood, ound to the conductors with wire and taped at the ends to revent slipping. Improvised tree moldings can be made from rooden strips nailed into the form of a box. The molding takes he brunt of the wear and prevents injury to the insulation. A ength of abrasion molding should be sufficiently long that a branch annot catch on its end.

67. Cable clamps can often be used with economy at dead ling points and corners. Fig. 60 shows some examples. Throu use of a cable clamp the "making up" of "dead ends," whic expensive for heavy cables, is avoided; the line wire ca carried, without cutting, around a corner or in any new direction. The manufacturers claim, and it is probably true, that it is cheaper to purchase and install a cable clamp than to "make up a dead end" in any wire larger than No. 0000. The cable clamp grips the bare

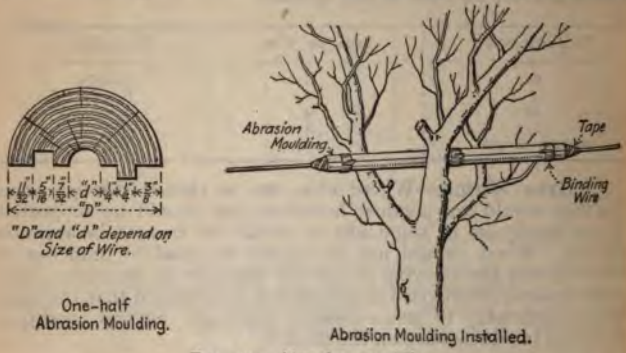


FIG 59.—Abrasion moulding.

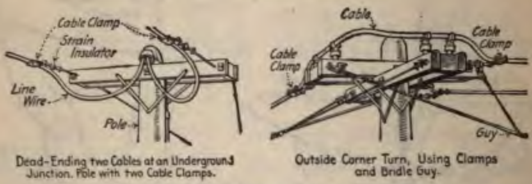


FIG. 60.—Application of cable clamp.

conductor, the pressure being furnished by four bolts. A strain insulator must be used to insulate the clamp from the bolt or turnbuckle that supports it. The dimensions of a Matthew's clamp for all wires of sizes from 000 to and including 2,000,000 cir. mils are given in Fig. 61.

FIG. 60A.—*Application of cable clamp.*

68. Specification and Test for Galvanized Iron and Steel for Line Construction.—The galvanizing shall consist of a coating of zinc, evenly and uniformly applied. The zinc shall be so applied that it will adhere to the surface of the iron or steel. The finished product shall be smooth.

Any specimen shall be capable of withstanding the following test: The sample shall be cleaned before testing, first with carbona, benzine or turpentine and cotton waste (not with a brush), and then thoroughly rinsed in clean water and wiped dry with clean cotton waste. The sample shall then be immersed in a standard solution of copper sulpha[te] for 1 min. and then removed, immediately washed in water [and] thoroughly wiped dry. This process shall be repeated. If, the fourth immersion there is a copper-colored deposit on the sample, or the zinc is removed, the lot from which the sample was taken shall be rejected. In the case of No. 14 galvanized-iron or steel wire, the time of the fourth immersion shall be reduced to ½ min.

69. Copper Sulphate Solution.—The standard solution of copper sulphate consists of commercial copper sulphate crystals in water. This solution has a specific gravity of 1.185 at 70 deg. fahr. While a sample is being tested the temperature of the standard solution should at no time be less than 60 deg. fahr., nor more than 70 deg. fahr.

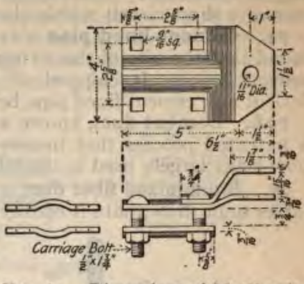


FIG. 61.—Dimensions of Matthew's cable clamp.

70. Cost per mile of pole-lines for 3-phase 2,300 to 6,600 volts. Data from six north-central and south-western states, 1909. From "Data," October, 1910. Figures are exclusive of painting, copper, engineering and general expense.

	Installation of minimum cost	Installation of maximum cost	Average
50 30-ft. poles	$171.00	$200.00	$218.90
50 sets pole hardware	8.30	16.00	10.25
50 2-pin cross-arms	17.00	11.50	14.00
150 insulators	6.75	11.20	9.00
Labor setting	55.00	200.00	109.00
Labor stringing wire	30.00	40.00	35.00
Incidentals	10.00	50.00	30.00
	$297.05	$528.70	$426.15

UNDERGROUND CONDUIT

71. Underground conduit construction is now an important and specialized branch of electrical engineering. In this book is given only enough information to enable one to lay out and install such minor underground structures as may be required in isolated plant or industrial plant work. Underground construction always costs more than overhead construction. In this country, "built-in" systems—those in which the cable is buried in the earth without protection—are seldom used because if trouble occurs on the conductors it is necessary to excavate to remove them.

72. *Commercial* duct materials are iron pipe, wood, cement-lined pipe, cement, vitrified clay and bituminized wood pul... Only iron pipe, cement and virtified clay are recommended in t... book as it is believed that, all things considered, these are the ... materials that can be thoroughly depended on for power se...

73. Creosoted wood ducts are low in cost but will probably decay in time. Their life is said to be about twenty years if thoroughly creosoted. Wood ducts are inflammable and may burn in case of a short-circuit within them.

74. Cement-lined pipe was once used extensively but it was found that the arcs of short-circuits within such a duct cracked the cement lining. It chipped off and blocked the duct. There is little if any cement-lined pipe being installed at present.

74A. Cement duct, known as "Stone Duct," manufactured by a patented process that insures homogeneousness and strength is now being largely used in the Chicago district.

75. Bituminized fiber duct is easily laid and when new permits cables to be drawn into it readily because of its smooth oily interior surface. It is a comparatively recent product and its life is as yet undetermined. Furthermore, cases have been reported where duct lengths, in piles left to action of the heat of the sun, have been distorted by the weight of the duct lengths piled above them. Cases have also been reported where cables have stuck in fiber conduit and their withdrawal was thereby prevented. Probably this condition is most likely to occur where the duct is heated continuously either by overloaded conductors or by adjacent steam pipes. The upper portion of the duct sags down until it rests on the cable or possibly obstructs the duct if there is no cable in it.

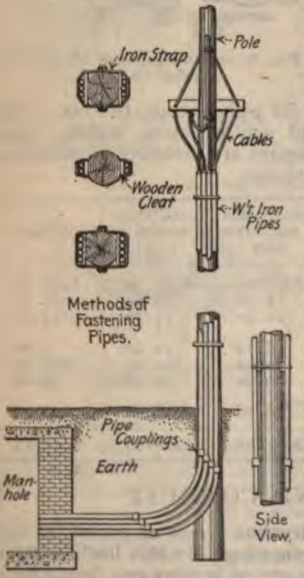


FIG. 61A.—Wrought-iron pipe laterals.

76. Iron pipe makes an admirable subway but its cost prevents its use except under certain conditions. Iron pipe appears to be the cheapest dependable duct material for laterals (Fig. 61, *A*) because it is not necessary to imbed it in concrete. It is also used where it is necessary to install many ducts in a limited space. It can be bent almost at will. Where it is necessary to thread a network of underground structures iron pipe is the only usable material. Where vitrified clay duct can be used it is to be preferred. *Wrought-iron electrical conduit can be used for underground conduit but it is the practice of the larger companies to buy ordinary commercial wrought-iron pipe, usually 3 in. Wrought-iron pipe is preferable to steel pipe,* which is often sold for wrought-iron, because the wrought-iron resists corrosion much more effect ively than does steel. See index for dimensions of wrought-iron conduit which are the same as those for wrought-iron pipe.

77. **Vitrified clay single duct** or hollow brick is the most popular for power cables. Fig. 62 shows a typical length. The dimensions of ducts furnished by the different manufacturers may vary from those of the illustration. The single duct is preferred because its walls are thick and in laying every joint is broken, eliminating the

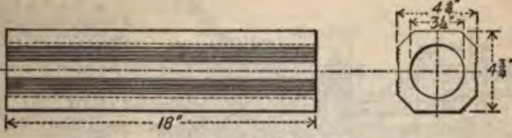


FIG. 62.—A piece of single duct.

possibility of the arc of a short-circuit on one cable affecting cables in other ducts in the same run. Single ducts can also be more readily laid around obstructions such as pipes and, furthermore, curves can be more readily formed with them than with multiple ducts.

78. **Vitrified clay multiple duct** is sometimes used for conduits for power cables but it is not as popular as single duct for the reasons given under "Single Duct." The four-way multiple duct is the

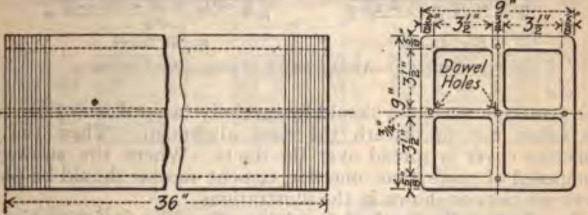


FIG. 63.—A piece of multiple duct.

most popular size (Fig. 63), although the six-way duct is frequently used. Nine,- twelve- and sixteen-way multiple ducts can be manufactured but they are seldom used because of their excessive weight and liability to breakage. The dimensions of the multiple ducts of a certain nominal size made by different manufacturers vary. Those shown in Fig. 63 for a four-way duct are typical.

79. **In laying any kind of a conduit,** after the trench is excavated its bottom should be rammed until solid and then leveled off *and graded so as to pitch,* from the center point between manholes *toward each manhole,* about 1 ft. in 100 ft. This is to insure *effective drainage.* The upper face of the conduit should be *least 2 ft. below* the surface of the ground. The trench should

be 6 in. wider than the conduit to provide space for the 3-in. casing of concrete which is usually necessary around vitrified conduits. No wooden form is required for the concrete if the earth is compact and self-supporting. In yielding soils a rough wooden form, which can be removed after the concrete has set, can be used. The 3-in. bed of concrete should be placed parallel with the bottom of the graded trench. After the pieces of duct material are laid,

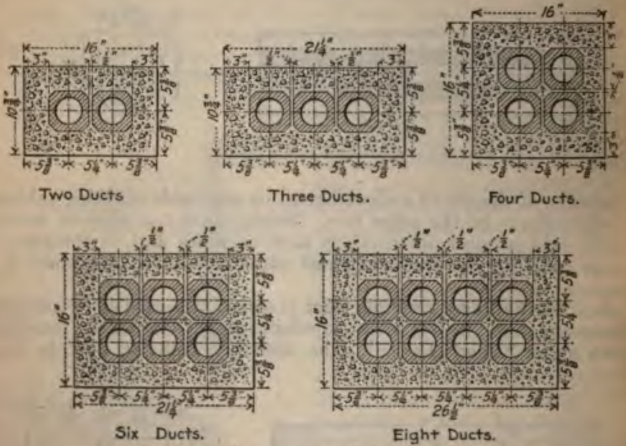


Fig. 64.—Arrangement of single-duct subway.

the 3-in. concrete sides should be carefully tamped in. Care must be taken not to disturb the duct alignment. Then the 3-in. concrete cover is spread over the ducts. Where the subway is composed of more than one tier, cement mortar should be placed between tiers as shown in the illustrations.

80. Laying Single-duct Conduit.—(See Fig. 64 for sections of single-duct runs.) A concrete bed, usually 3 in. thick, is placed on the bottom of the trench after the latter has been properly excavated, leveled and graded. After the bed is set the duct is laid in cement mortar. A mandrel (Figs. 65 and 66) is used to keep the successive pieces in line. It is customary to enclose the conduit in a continuous concrete encasement 3 in. to 4 in. thick.

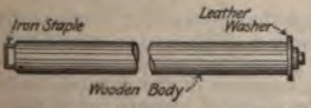


Fig. 65.—Mandrel for aligning conduit.

The mandrel is pulled through with a long hook as the conduit progresses, to align the ducts. The leather washer scrapes away any mortar that has oozed through between joints and leaves the duct quite clean. The end of a No. 12 galvanized-iron wire is frequently attached to the inner end of the mandrel and is pulled i duit as its construction progresses. The wire is used to the drawing-in rope which is used to pull in the cable. single ducts furnished by some manufacturers are provided ale and female ends which assist in aligning the ducts.

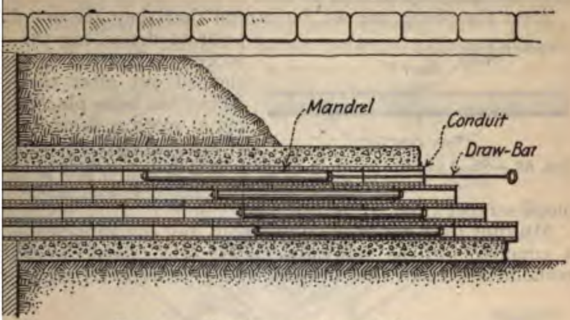


FIG. 66.—Showing use of mandrel.

Laying Multiple Duct.—Multiple duct is laid in about the way as single duct. Fig. 67 shows sections of multiple-duct The pieces are laid end-to-end and the joints, if there is han one tier in the subway, are broken. The pieces are ined in alignment by iron dowel pins or keys (Fig. 68)

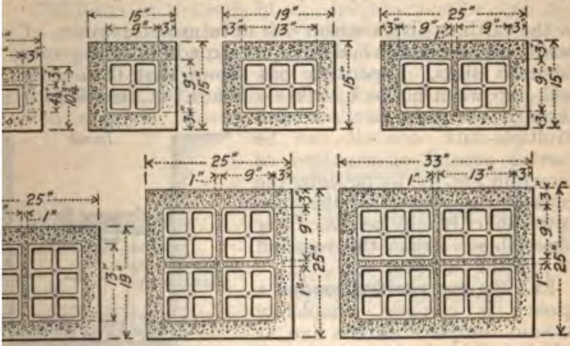


FIG. 67.—Sections of multiple duct.

fit in holes in the pieces. All joints are wrapped with pieces ap or coarse muslin, 4 in. wide and 3 ft. long for 4-duct tile, *re moistened to make them stick.* They are then coated *nent. The cloth prevents the entrance of cement or con- o the ducts.*
mes a mandrel (Fig. 65) $\frac{1}{4}$ in. to $\frac{1}{2}$ in. smaller than th

hole is drawn through as the construction progresses, as suggested in Fig. 66, to insure alignment of the pieces. The handle on the mandril should be long enough to reach back two joints so that one may be sure that the last three pieces set align, as they may have become displaced in setting.

After the pieces are set, be careful that they are not displaced prior to depositing the concrete jacket. The ducts should be cleaned out after the concrete jacket has been placed by drawing a wire brush or flue cleaner (Fig. 69) through them. The brush is somewhat bigger than the duct hole. Sometimes a metal scraper (Fig. 69) is also used.

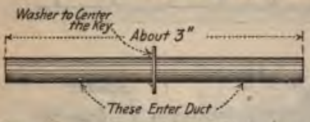


FIG. 68.—Steel key for multiple duct.

Multiple duct has been laid without any concrete casing, merely a concrete bed, as suggested in Fig. 70. This construction is economical in first cost but is apt to give trouble through settling

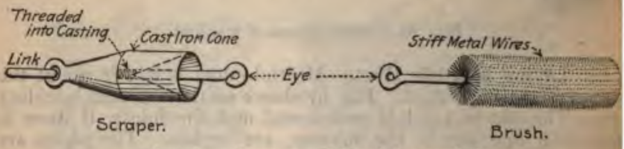


FIG. 69.—Scraper and brush for conduit.

of the earth or displacement due to future excavation. Creosoted boards are sometimes laid on top of a conduit run to protect against laborer's picks. Experience has shown that the average laborer will stop when his pick strikes a board but he will pick his way through concrete or duct material.

Multiple-duct conduit can be carried around obstructions, as shown in Fig. 71, by beveling the ends of the pieces. If the turn is too short it may be difficult or impossible to "rod" the duct and to pull the cable in.

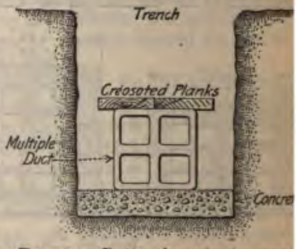
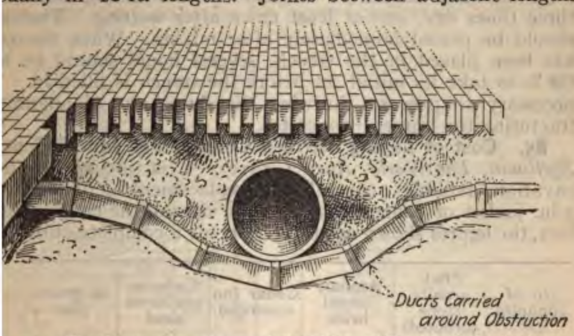


FIG. 70.—Protective planks over multiple duct.

82. To cut vitrified conduit a groove is chipped completely around the piece on the line at which it is desired to cut it. A hammer and cold-chisel are used for chipping the groove. Usually it will break off on the chipped line after continued chipping, but it may not. Some experience is required before one becomes skillful at this work. Short lengths can be furnished by the conduit manufacturers and their use is recommended.

83. In installing iron-pipe conduit no concrete casing is c necessary if only one duct is involved. Where there are ducts in the run, the ducts are sometimes laid on a 3-in. tion of concrete and concrete is tamped between and around cts as shown in Fig. 64 for single vitrified duct. Where cts will not be exposed to the dangers of future excavation st of the concrete is probably not justified. Iron pipe is sually in 20-ft. lengths. Joints between adjacent lengths



:. 71.—Breaking around an obstruction with vitrified duct.

de with ordinary pipe couplings. (Fig. 61, *A*.) See Index ensions of conduit and fittings which are the same as those :. The burrs at the ends of pipe lengths must be carefully d to prevent damage to the cable. Where it is incon- to use a coupling, a pipe union can be used instead or the can be omitted (Fig. 72) and the abutting ends encased ock of concrete. The ends should be wrapped with a piece :t iron wired in position before the concrete is applied.

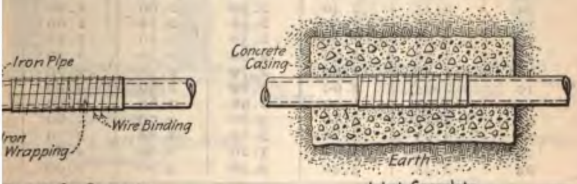


FIG. 72.—Cement joint on wrought-iron pipe.

pe for conduit is sometimes painted, inside and out, with um, but this is not considered necessary by all engineers. **Concrete for conduit work** should be clean, that is, foreign ces should not be permitted to enter into its composition. urface on which it is to be mixed is not smooth and clean, *boards or pans should* be used. Foreign material impairs *ngth of concrete* and it becomes porous and leaky. The concrete should be mixed from Portland cement, clean sand, and gravel or broken stone, in the proportions by volume, of one part of cement to three parts of sand and five parts of gravel or stone. Just sufficient water should be used to thoroughly wet the mixture and to permit a small amount of water to come to the surface when the concrete is tamped into final position. The cement, sand and stone should be "turned" on the mixing board at least three times dry, and at least twice after wetting. The concrete should be placed immediately after mixing. When the concrete has been placed in the trench, several hours should be allowed for it to take its initial set before the trench is filled in. This is necessary to prevent throwing the ducts out of alignment, or fracturing the "green" concrete.

85. Cost of Laying Vitrified Conduit Per Lineal Foot (*H. C. Spellman, The World*, April 7, 1910).—Cost includes conduit, excavation, refilling, removal and replacement of pavement and a 3-in. jacket of concrete on all four sides of the conduit line. In fact, the figures shown are total costs for a complete subway run.

No. of conduits	Brick, granite, stone (grouted)	Asphalt tarred brick	Cedar (on concrete)	Cedar or cobble on sand	In grass plat	Dirt
1	$1.15	$1.10	$1.00	$0.70	$0.60	$0.50
2	1.25	1.20	1.10	0.80	0.70	0.60
3	1.35	1.30	1.20	0.90	0.80	0.70
4	1.45	1.40	1.30	1.00	0.90	0.80
5	1.55	1.50	1.40	1.10	1.00	0.90
6	1.65	1.60	1.50	1.20	1.10	1.00
7	1.75	1.70	1.60	1.30	1.20	1.10
8	1.85	1.80	1.70	1.40	1.30	1.20
9	1.95	1.90	1.80	1.50	1.40	1.30
10	2.05	2.00	1.90	1.60	1.50	1.40
11	2.15	2.10	2.00	1.70	1.60	1.50
12	2.25	2.20	2.10	1.80	1.70	1.60
13	2.35	2.30	2.20	1.90	1.80	1.70
14	2.45	2.40	2.30	2.00	1.90	1.80
15	2.55	2.50	2.40	2.10	2.00	.190
16	2.65	2.60	2.50	2.20	2.10	2.00
17	2.75	2.70	2.60	2.30	2.20	2.10
18	2.85	2.80	2.70	2.40	2.30	2.20
19	2.95	2.90	2.80	2.50	2.40	2.30
20	3.05	3.00	2.90	2.60	2.50	2.40
21	3.15	3.10	3.00	2.70	2.60	2.50
22	3.25	3.20	3.10	2.80	2.70	2.60
23	3.35	3.30	3.20	2.90	2.80	2.70
24	3.45	3.40	3.30	3.00	2.90	2.80

86. Manholes are necessary in a subway system to permit of the installation, removal, splicing and rearrangement of the cables. A manhole is merely a subterranean vault or masonry chamber of sufficient size to permit of proper manipulation of the cables. The conduits enter the vault and on its sides devices are arranged whereby the cables within the manhole can be supported.

87. The location of manholes is determined largely by the lay-out of the district that is to be supplied with power. Where a branch or lateral extends from the main subway there must a manhole, and there must be manholes at intersections of subways. In general, cables are not made in lengths exceeding from 400 ft. to 600 ft. and, as it is necessary to locate splices in manholes, the distance between manholes cannot exceed these values. Furthermore it is not advisable to pull in very long lengths of cable because the mechanical strain on the conductors and sheath may then become too great during the pulling-in process. It is recommended that manholes be located not more than 500 ft. apart.

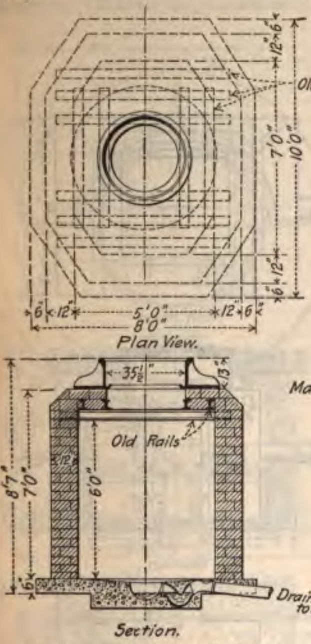


FIG. 73.—A 5 ft. × 7 ft. brick manhole.

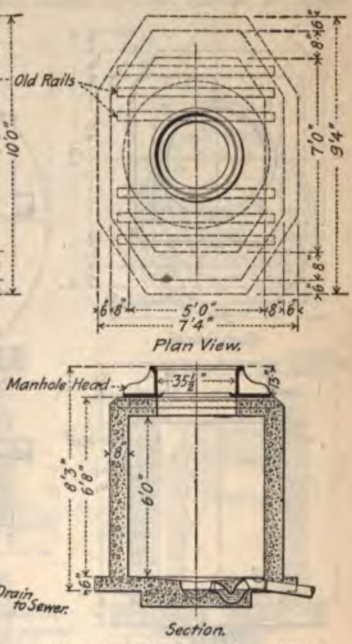


FIG. 74.—A 5 ft. × 7 ft. concrete manhole.

88. Manholes are made of many shapes and sizes to meet the ideas of the designer and to satisfy local conditions. It is established, however, that the form shown in Fig 73 is best for the average condition. Where there are obstacles about the point where a manhole is to be located, the form of the manhole must be *modified so as to avoid* them. The form approximating an *ellipse is used* so the cables will not be abruptly bent in training *them around the manhole.*

89. **Manholes are built of either brick or concrete,** or of bot[h] *these materials.* Where many manholes are to be built of o[ne] size and there are no subterranean obstructions, concrete is usually the cheapest and best material. But where only a few are to be constructed or where there are many obstructions a manhole with a concrete bottom, brick sides, and a concrete top is probably the best. Such a manhole can be constructed without having to wait for concrete to set before forms can be removed and, furthermore, no forms, except some planks to support the top, are necessary

90. **The size of manholes** will vary with the number of cables to be accommodated, but in any case there must be sufficient

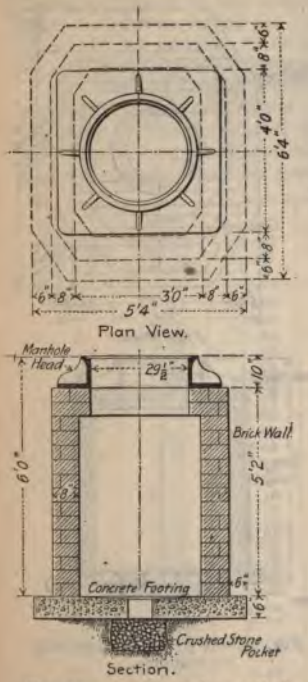


FIG. 75.—A 3 ft.×4 ft. manhole.

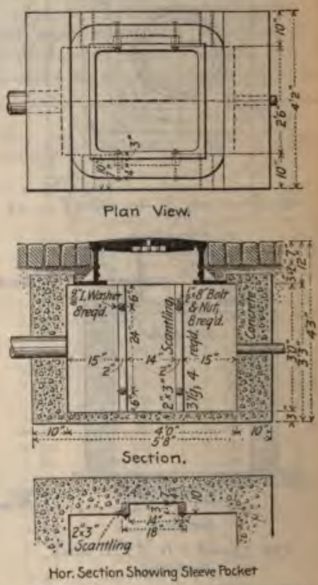


FIG. 76.—A concrete service box.

room to work in the manhole. A 5 ft. by 7 ft. manhole (Fig. 73) is probably as large as will be required in isolated plant work, while a 3 ft. by 4 ft. manhole (Fig. 75) is about as small as should be used.

91. **A concrete manhole is built** by first depositing the concrete *floor (Fig. 74)* and then erecting the form for the sides on this *floor. In a self-supporting soil the sides of the hole constitute the form for the outside of the manhole.* If the soil is not self-s

›rting, an outer form of rough planks must be made which is ›ually left in the ground. Steel reinforcing—old rails are good—ust be placed in the concrete top of a large manhole. In a small anhole the manhole head or cover will extend over the side walls ıd no reinforcing, or manhole roof for that matter, are required. ll reinforcing steel should be completely encased in concrete to ·event corrosion.

92. A manhole with brick walls is built (Fig. 73) by first de-›siting the concrete floor and then building up the brick walls ıereon. Where the manhole is large the roof can be of either

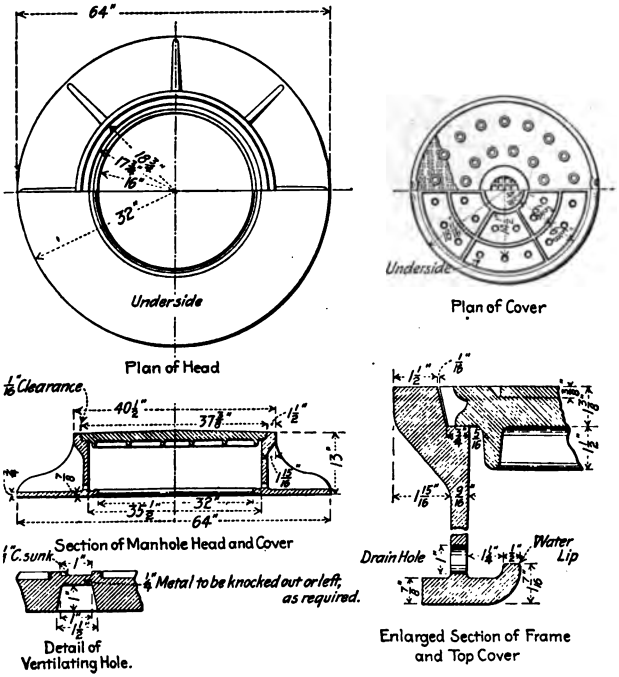


FIG. 77.—Head for large manholes.

eel-reinforced concrete or brick set between rails. Probably for .stallations where only a few manholes are to be built the brick-›tween-rails method is the best. For a small manhole no masonry ›f is necessary as the cast-iron manhole head forms the roof. 3. **Distribution or service boxes**, so called, which are reall ll manholes, often serve the purpose of, and can be used inste ›ger vaults in industrial and isolated plant installations.

design for a concrete service box is shown in Fig. 76. A brick one would be of approximately the same dimensions. The depressions in the side walls are sleeve pockets. The splicing sleeves on the cables lie partially in these, after installation, and therefore less of the valuable working space of the box is occupied by them. In spite of the fact that a square manhole cover can fall into the hole, heads with square covers are often used for distribution boxes so as to provide an orifice giving maximum working room.

94. Manhole heads are frequently made of cast-iron, but cast steel is better. Fig. 77 shows a design for cast-iron, for a large

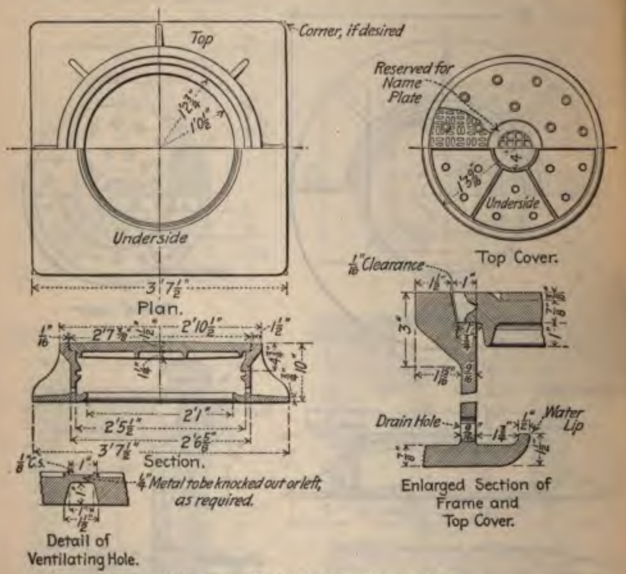


FIG. 78.—Head for small manholes.

manhole, and Fig. 78 one for a smaller manhole. Covers should be round so that they cannot drop into the hole. So-called water-tight covers are now seldom used as it is not feasible to make a satisfactory water-tight cover at reasonable expense and water gets into the manholes in any event. Covers should not be fastened down because if they are and accumulated gas in a manhole explodes, the vault will be shattered. If the manhole tends to fill with gas, holes should be made in the cover for ventilation. Dirt and water will get into the hole, but the dirt can be cleaned out and the water will drain out and no harm will result. If ventilation is not provided an explosion of gas may occur and do great damage.

Draining Manholes.—Where feasible, a sewer connection ad from the bottom of every manhole. (See Fig. 74.) The f the trap should be protected by a strainer, made of non-le wire, such as that used for leader pipes. Where a sewer on cannot be made there should be a hole in the manhole that water can drain out. A pocket, filled with broken der the hole will promote effective drainage. (See Fig. 75.)

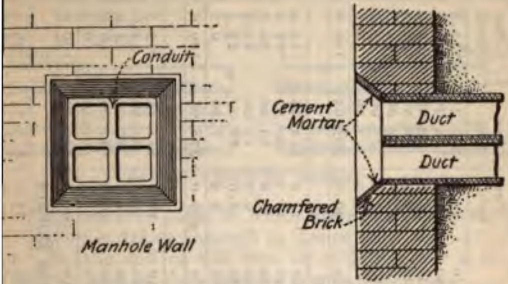


FIG. 79.—Chamfered wall at conduit entrance.

At the point where a conduit line enters a manhole the ould be chamfered off as shown in Fig. 79 to prevent the that might occur if a cable is bent over a sharp corner.

A manhole hook, a convenient tool for removing manhole shown in Fig. 80. A common pick can be used, but the wn is much more convenient.

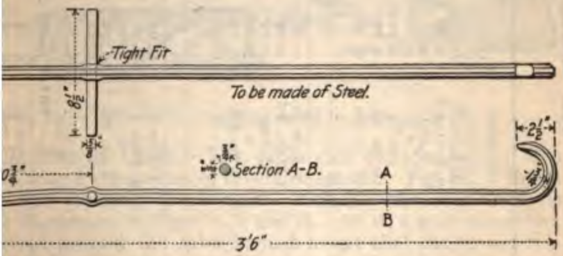


FIG. 80.—A manhole hook.

Cement mortar for building brick manholes or for conduit tion can be made by mixing together 1 part of cement and *f sand and about* ⅓ part of water, all by volume.

n installing cables **in conduit,** if a pull-in wire was not *at the time* the ducts were placed, the conduit is rodded, *wire or the* drawing-in-cable is drawn through, cleaners *through* and then the cable is drawn in.

100. Average Cost of Manholes in Dollars

(*Standard Handbook*)

Brick with brick roof

Item	Amount	Rate ($) Min.	Ave.	Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	12.6	$11.25	11.8	$ 15.00	11.2
Concrete	0.7 cu. yd.	5.00	7.00	9.00	3.50	5.9	4.90	5.1	6.00	4.4
Brick	2,200	12.00	15.00	18.00	26.40	44.5	33.00	34.6	39.60	29.4
Cover	1	5.00	10.00	15.00	5.00	8.4	10.00	10.4	15.00	11.2
Iron	500 lb.	0.015	0.03	0.05	7.50	12.6	14.00	14.6	25.00	18.6
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	7.6	15.00	15.7	24.00	17.8
Cleaning		0.50	0.75	1.00	5.00	8.4	7.50	7.8	10.00	7.4
Totals					$59.40	100.0	$95.65	100.0	$134.60	100.0
Brick with concrete roof										
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	14.8	$11.25	14.4	$15.00	13.8
Concrete	1.9 cu. yd.	5.00	7.00	9.00	9.50	18.7	13.30	17.0	17.10	15.7
Brick	1,600	12.00	15.00	18.00	19.20	37.8	24.00	30.7	28.80	25.7
Cover	1	5.00	10.00	15.00	5.00	9.9	10.00	12.8	15.00	13.8
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	8.9	12.00	15.4	24.00	21.9
Cleaning		0.50	0.75	1.00	5.00	9.9	7.50	9.5	10.00	9.1
Totals					$50.70	100.0	$78.05	100.0	$109.90	100.0
Concrete manhole										
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	16.8	$11.25	15.5	$ 15.00	14.3
Concrete	4.5 cu. yd.	5.00	7.00	9.00	22.50	50.5	31.50	43.6	40.50	38.8
Cover	1	5.00	10.00	15.00	5.00	11.2	10.00	13.9	15.00	14.4
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	10.2	12.00	16.6	24.00	23.0
Cleaning		0.50	0.75	1.00	5.00	11.3	7.50	10.4	10.00	9.5
Totals					$4.50	100.0	$72.25	100.0	$104.50	100.0

101. Cost of Sewer Connection in Dollars

...cavation	225 cu. ft.	0.02	0.03	0.04	$ 4.50	35.1	$ 6.75	26.0	$ 9.00	21.4
...te	5 cu. yd.	0.75	2.00	4.00	3.75	29.2	10.00	38.8	20.00	47.0
	1	1.00	2.50	4.00	1.00	7.6	2.50	9.6	4.00	9.3

2. **Rodding.**—Rods are pieces of round hickory about ¾ in. iameter and 3 ft. long. (See Fig. 81.) The ends of the rods equipped with brass knuckle-joint fittings so the rods can be ily joined together and disjoined. In rodding, a rod is pushed the duct and a second rod is coupled to it. The two are pushed the duct and a third rod joined on and the process is repeated the rods extend from manhole to manhole. A galvanized-wire is attached to the last rod and the wire is drawn into the

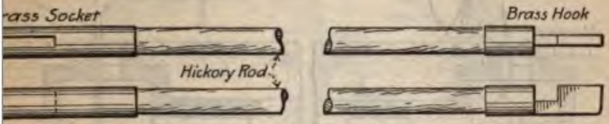


Fig. 81.—Rods for conduit.

rope or flexible steel cable to which are attached a scraper and ush (Fig. 69) is drawn through to insure that the duct is clear clean. To the end of this rope or cable another is attached h is used to pull in the electrical conductor cable.

here the conduit is short, a steel fish wire or ribbon, like that by electricians in wrought-iron conduit work, can be inserted ad of the rods. Sometimes a "fish" made of lengths of flex-bamboo is used instead for laterals and other short runs.

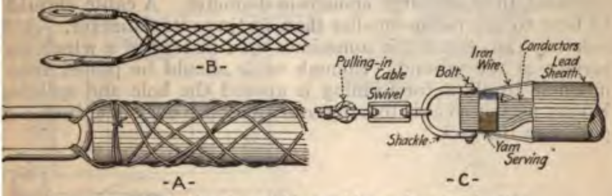


Fig. 82.—Methods of attaching cable to drawing-in line.

03. **Pulling in Cable.**—The cable can be attached to the ling-in wire by any one of several methods. Fig. 82, *C* shows that was formerly much used. Probably the best methods those illustrated in Fig. 82, *A* and *B*. At *A*, a galvanized iron e is laced around the cable in such a way that the harder it is led the tighter it grips. At *B* is shown a "grip" spirally laced m flexible steel strands. It slips over the cable sheath readily, when tension is applied it effectively grips the cable. A swivel uld always be inserted in any pulling-in line to prevent the un-isting of the drawing-in line under tension from twisting the le.

fter the cable is fastened to the pulling-in line a "protector" *ced in the mouth of the duct* to prevent abrasion of the cable. *protectors* can be purchased, but a good one can be forme *piece of sole leather.*

The cable is bent, as shown in Fig. 83, from the cable reel to the mouth of the duct and the pulling in commences. In the far manhole sheaves are arranged over which the pulling-in line passes. (See Fig. 83.) If eye bolts were built in the manhole sides the sheaves (snatch-blocks) can be fastened to them. Otherwise a guide-sheeve-rack (see Fig. 84 for detail and Fig. 83 for application) can be set up in the manhole.

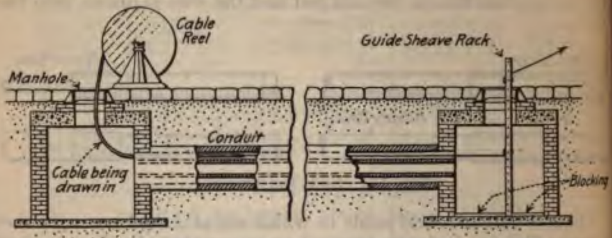


Fig. 83.—Drawing in cable with winch.

A winch or horses can be used for the pulling. Men can pull a cable in if the run is not too long. The cable sheath should be greased as it is drawn in to insure easy pulling. Where a length of cable longer than the distance between manholes is to be pulled through, it can pass over the sleeves on the guide sleeve rack, provided they are large enough in diameter. A cable should not be bent to any radius smaller than 10 times its diameter. A manhole capstan, Fig. 85, is sometimes used instead of a winch on the surface of the ground. Enough cable should be pulled into the manhole to allow for forming it around the hole and splicing it. Do not permit a cable to hang over the sharp edge of a duct. Support it in the rack.

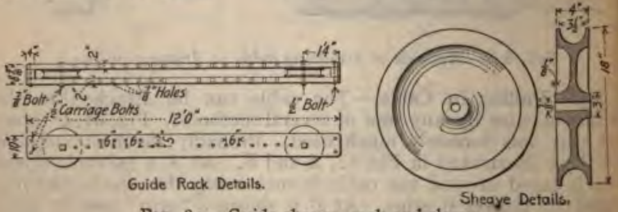


Fig. 84.—Guide sheave, rack and sleeve.

104. Supporting Cables in Manholes.—Some provision must be made. Creosoted planks, Fig. 86, are sometimes bolted to the manhole sides and the cables are held to the cleats with pipe straps. In other cases metal supports are used several forms of which are on the market. One that can be readily made is shown in Fig. 87. Shelves around the sides of the manholes can be formed of bricks as shown in Fig. 88. This is an excellent and probably the best method.

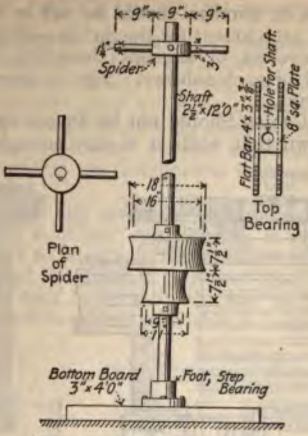


FIG. 85.—Manhole capstan.

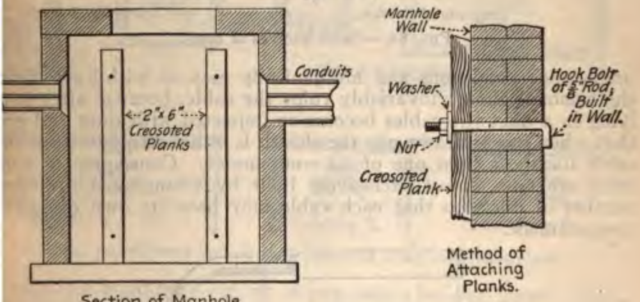


FIG. 86.—Creosoted plank cable supports.

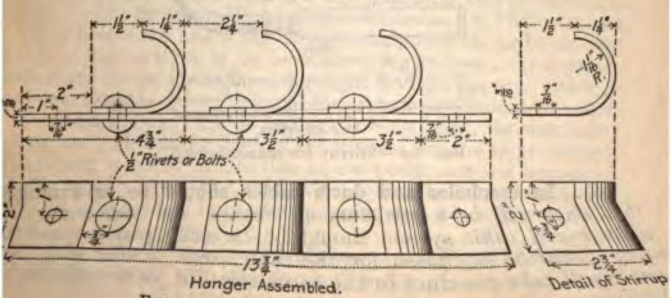


FIG. 87—Iron cable support.

105. Eyebolts or stirrups should be set in manhole walls to provide means of attachment for the tackle used in pulling in cables. (Fig. 88.) An eyebolt or stirrups should be set opposite the point of entrance of each subway. Fig. 89 shows the dimensions of a suitable stirrup.

106. Several Cables Should not be Placed in One Duct.—Experience has shown that while it is easy enough to install cables

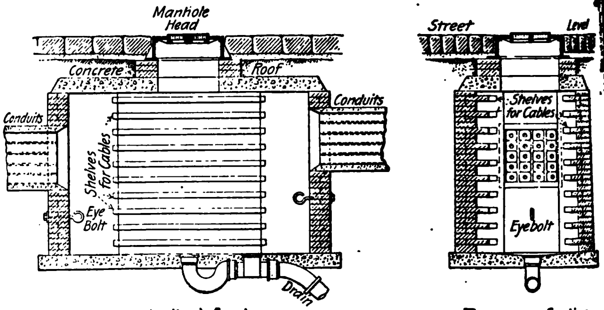


FIG. 88.—Cable shelves of brick.

under such conditions and mechanically easy to withdraw them, the removal almost invariably ruins the cable, because after long lying in a duct the cables become so impacted with dust and grit that when one is drawn out the sheath is either stripped from the cable itself, or from one of its companions. Consequently conduits are now almost exclusively built by arranging a sufficient number of ducts so that each cable may have its own exclusive compartment.

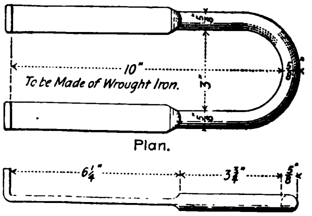


FIG. 89.—Stirrup for manhole wall.

107. In manholes and ducts cables should be so arranged *that there will be a minimum of crossing and recrossing. An underground cable system should be carefully planned and the ducts should be so chosen for the cables that, insofar as feasible, a cable will take the duct in the same relative position throughout he subway.*

IGN OF DISTRIBUTION INSTALLATIONS

In designing an installation of conductors for the dis-n of electricity there is no royal road. It is rather a "cut-" process and frequently, for a reasonably large installation, entative lay-outs must be made before the most suitable found. The design of such lay-outs is affected by so many ons that only the most general suggestions can be given. the information on distribution in the "Fundamentals" of this book.

In laying out any electrical distribution system the first the system is of any consequence, is to note on a scale the territory to be served, the locations at which electricity required and the amount of power that will be taken at In general, each building in the area to be served is con-as a unit as it is seldom advisable to install more than one

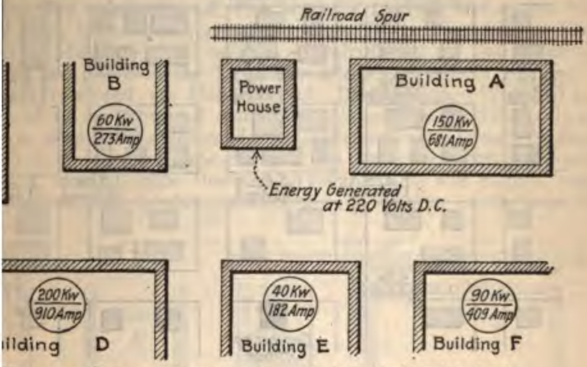


FIG. 90.—Power and current demands in an industrial plant.

to a building. Fig. 90 shows such a lay-out for an imagi-ndustrial plant and Fig. 91 for a portion of a town. The within the circles indicate the maximum power demands. bove the horizontal line is the power demand in kilowatts and ue below the line is the current, the power factor being con- if the system is to be alternating current. If separate s are to be maintained for light and for power, which is ractice, the power demand for each circuit should be noted. illustrations (Figs. 90 and 91) it is assumed, for simplicity, ower and lighting devices are served from the same circuits. urrent is noted in addition to the power demand because it ssary to know the current to determine the capacities of nd switches and to check conductor sizes for current-carrying y.

Lay-out of Feeders and Mains.—After the locations of the *here energy will be required* have been plotted and the f power that will be required at each has been noted the feeders and mains can be laid out and the conductor size them calculated. No hard and fast directions can be gi Each case must be treated individually in accordance with the ditions to be satisfied. The desideratum is to so plan the la that the cost of the conductors and their supports will be a mum and that, at the same time, the energy loss in the condu will be reasonably small, and the whole system will be as rel in operation and the voltage regulation will be as close as condi warrant. Sometimes considerable expense is justified to s reliability and close voltage regulation, but in other cases relia and close voltage regulation are unimportant and the che lay-out that will give service is the most desirable. Wheth distribution conductors are to be carried overhead—on po buildings—or underground will affect their routing.

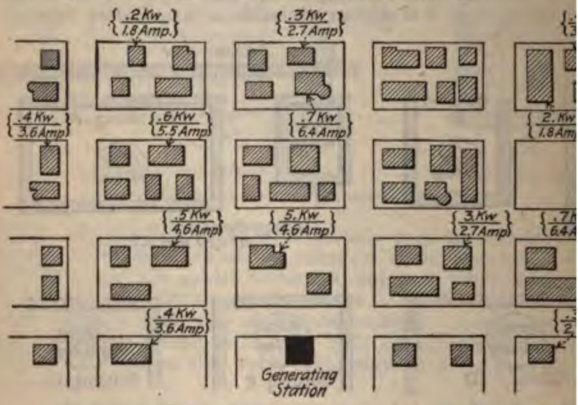


FIG. 91.—Power and current demands in a small town.

111. **The magnitude of load that should be served b feeder or main** is altogether a relative matter and depends extent upon the flexibility of control and of metering desir on the station capacity. In industrial plant installations desired to meter in the generating station the energy supp different departments or buildings, obviously an individual must be carried from the switchboard to every such bu It should be possible to disconnect portions of the load at the house, in case of trouble with the generators or in case a load increase is thrown suddenly on the station, to tide o emergency without shutting down the entire plant. In g in a small station, the load on any feeder should not be large can be readily carried by any one of the generating units is better to have the load further subdivided. Usually divides itself naturally into convenient units because of the ment of buildings, groups of buildings, departments or o graphical or commercial considerations.

112. **Mains are Sometimes Tapered.**—A tapered main is one which the conductor size diminishes from the point of source energy outward. (See Fig. 92.) It is usual, and ordinarily e best, practice to use a main of the same size conductor through-t its length. Splices and intermediate cut-outs are thereby oided. Theoretically, a tapering main, assuming a given maxi-um drop, does not effect a saving in copper as is often but errone-sly believed. See Croekers, *Electric Lighting*, Vol. I, page 32.

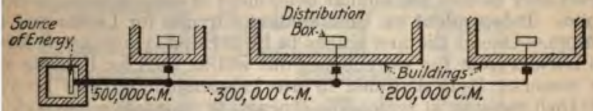


FIG. 92.—A tapered main.

113. **The calculation of wire sizes for feeders and mains for** tribution installations are made similarly to those for interior cuits. Methods and examples of calculation for the different stems are given in the **"Fundamentals"** section of this book.

114. **Overhead vs. Underground Distribution.**—Whether an erhead or underground distribution should be used depends in e case of small or medium-sized installations very largely on how ich can be spent for appearances. An overhead system, properly talled, can be made thoroughly reliable and will usually cost ich less than an equivalent underground system. Sometimes in

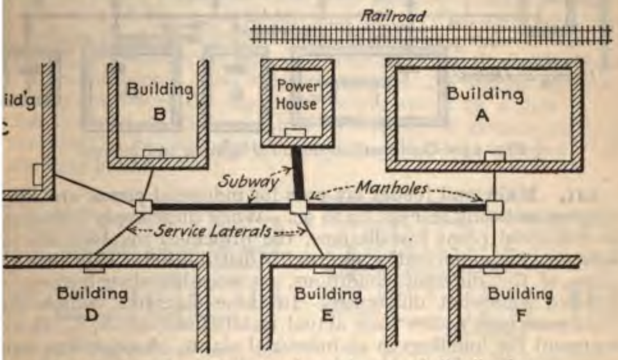


FIG. 92A.—Conduit system for underground distribution.

lustrial plant work it is necessary to build subways for pipes in y event and when such subways can also be utilized for electrical nductors a low installation cost may be possible.

15. *If the distribution conductors are to be carried under-und in conduit it is necessary to group the runs insofar as ble, as suggested in Fig. 92, A, to insure minimum cost for e ion and manholes.*

116. If the distribution conductors are to be carried overhead, more direct routes can be selected, as with overhead distribution conductors can, in industrial plant work, be carried over buildings in the most direct routes.

118. A combination main feeder or other circuit is one that serves all energy consuming devices, motors, lights and minor miscellaneous equipment.

119. An independent main, feeder or other circuit is one that serves only motors and similar equipment or only lighting devices.

120. Independent vs. Combination Circuits for Lights and for Motors.—One of the first things to be decided is whether individual circuits from the switchboard out will be used for lighting and for motors. It is desirable to use independent circuits because it is then possible, at reasonable expense, to maintain a much closer voltage regulation, hence steadier illumination on the lighting circuits. Furthermore, since troubles such as heavy short circuits and grounds occur more often on motor circuits than on lighting circuits, the possibility of such troubles throwing a building or an area in darkness is a minimum with independent motor and lighting circuits.

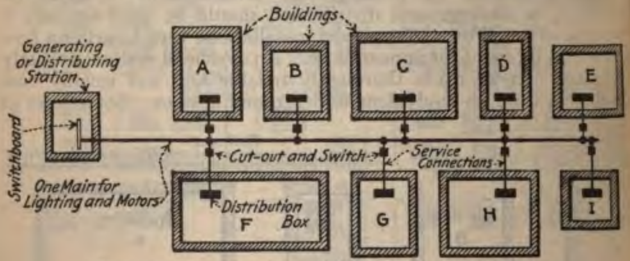


FIG. 93.—Combination main for lighting and motors.

121. Main and feeder lay-outs for industrial plants are shown diagrammatically in Figs. 93 to 99. While these apply principally to industrial plant installations, the principles involved are the same as for municipality electricity distribution. However, because of the different conditions, municipality distributions are handled somewhat differently. In these diagrams, which illustrate principles rather than actual installations, *A*, *B*, *C*, *D*, etc., represent the buildings in an industrial plant. A single line represents an entire circuit, two wires for a direct-current, two-wire circuit; three wires for a three-wire circuit, etc. The diagrams apply to any system of distribution. The service wires from the distribution circuits enter the buildings and terminate in distribution boxes—panel boxes or groups of cut-outs. From the distribution boxes the interior motor and lighting circuits, which are *not shown*, are supposed to radiate. For information regarding *the lay-out of interior wiring circuits*, refer to the section on *Interior Wiring*. See Index.

122. **A combination main for lighting and motors** (Fig. 93) can e used where the installation must be of minimum expense. n the illustration a single main, which may be either carried underround on poles or on fixtures attached to the buildings, extends rom the switchboard. Service connections are tapped from the nain for each building or group of buildings and are terminated n a distribution box—a panel box or a group of porcelain cut-out ittings—within the buildings. Since the service conductors will

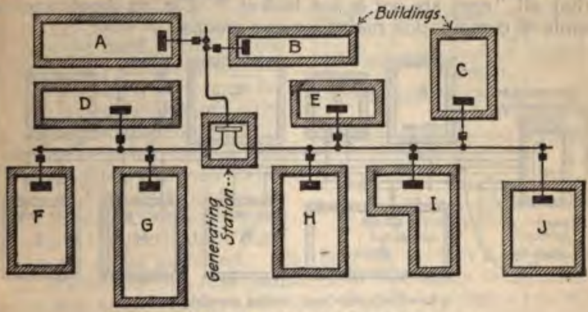


FIG. 94.—Combination mains serving groups.

e smaller than the main conductors a cut-out and, preferably, a witch are inserted in each. The only thing to commend a layut like that of Fig. 93 is its low first cost. With such a lay-out he voltage regulation on the lighting circuits is apt to be bad and ground or short-circuit on any circuit may put the entire plant ut of commission. With this arrangement the station operator as no control over the use of the power and if he wishes to derease the load on the generators by cutting off certain portions f the plant he has no means of doing so. It is an example of "all f the eggs in one basket."

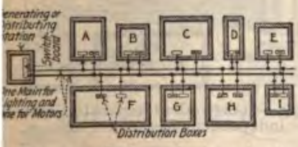


FIG. 95.—Independent main for lighting and one for motors.

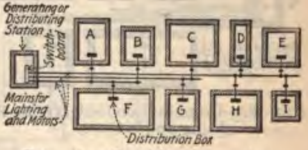


FIG. 96.—Combination mains serving groups.

123. **Independent mains for lighting and motors** (Fig. 95) are ometimes used. This is a better arrangement than that of Fig. 3 in that the lighting circuits are entirely separate from the notor circuits. But, if many lights or many motors are served y one main, trouble is apt to occur. Furthermore, it is not *ossible to control the power supply of each building from the nerating or distributing station.*

124. Combination Mains Serving Groups (Fig. 96). a modification of a single combination main lay-out an times used and is permissible in certain instances whe stallation cost must be low. It is better than a single co main arrangement, but is not very good as no arrangeme where lights and motors are fed from the same circuit, motor load is relatively unimportant. The station op some control over his load and the load is sufficiently sec so that all "eggs are not in one basket." Fig. 94 show example of combination mains serving groups.

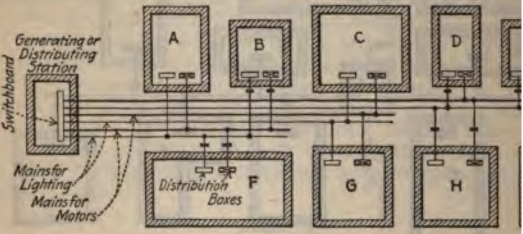


FIG. 97.—Independent mains serving groups.

125. Independent Mains Serving Groups (Fig. 97).– fairly good arrangement if the groups are not too l possible disadvantages are that with it it is not feasible the energy to each unit in the group at the generating s is it possible to disconnect each unit from the generatir These are not always disadvantages. Such an arrange ciously laid out will give excellent service.

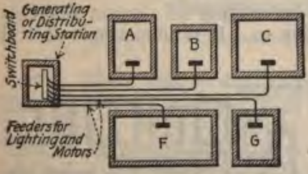


FIG. 98.—Combination feeders for lighting and motors.

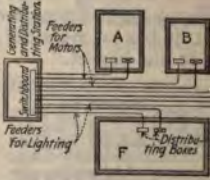


FIG. 99.—Independent feeders and independent feeders fo

126. Combination feeders (Fig. 98) possess the advan the load is well divided—"few eggs in a basket"—and feeder circuit can be readily controlled and metered at rating station. But they possess the disadvantages, alr merated, that always obtain where lighting appliances are served by the same circuit. As a general proposit lay-out is not to be recommended, though it may give service where the conditions are not exacting.

127. Individual feeders (Fig. 99) provide the r reasons that have been suggested in preceding paragraphs. is seldom that it is advisable to run a feeder to every building a group. A combination of the methods of Figs. 97 and 99 is ually used. Individual feeders are carried to the principal ildings and mains are arranged on the group plan to serve the ildings having small loads.

128. A direct-current, two-wire distribution is seldom used for y installation except a small industrial plant. The voltage ay be either 110 or 220. If ost of the load is lighting 110 olts may be used. But, if the ad is of any consequence, the nductors will be very large for 10 volts hence 220 is more often sed. The feeders and mains in n industrial plant can be laid ut in accordance with any of the ethods of Figs. 93 to 99 but, as utlined in connection with those lustrations, the methods of Figs. 7 or 99 are to be preferred. See the First Section for information in regard to the disadvantages of operating incandescent amps at any other voltage than 110. If a direct-current two-wire ystem is used for a municipality the feeders and mains can be aid out somewhat as suggested in Fig. 100.

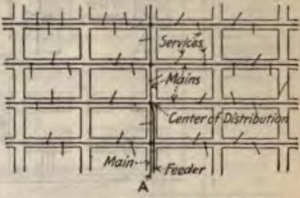


FIG. 100.—Primary distribution in a municipality.

129. Direct-current, three-wire distributions are frequently used in industrial plants where there are many adjustable-speed motors for machine tool drive and the like. Direct-current, three-wire distributions are also sometimes used in small municipalities.

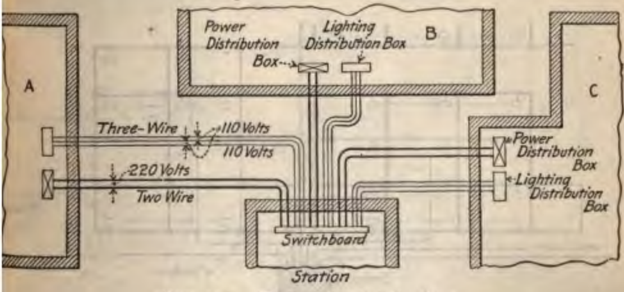


FIG. 101.—Three-wire distribution.

n either case the voltages are almost invariably 110 and 220. The est method for an industrial plant is suggested in Fig. 101 wherein *parate feeders are carried* from the switchboard to each building *group of buildings* for lighting and for power service. The *ting feeders are* three-wire so that the incandescent lamps can be *ated at 110 volts.* The motor feeders are usually 220 volts *vire unless* some scheme of motor speed control is used th requires all three wires. In municipalities, since the load is usu mainly lighting, all feeders and mains are three-wire and are la out as suggested in Fig. 100. This represents the arrangement i a small town or that in one of several similar districts of a large c

130. **Single-phase, alternating-current, high-voltage distrib tions** are seldom used in industrial plants, but are often used i municipalities. The voltage is usually 2,200; 1,100 was at o

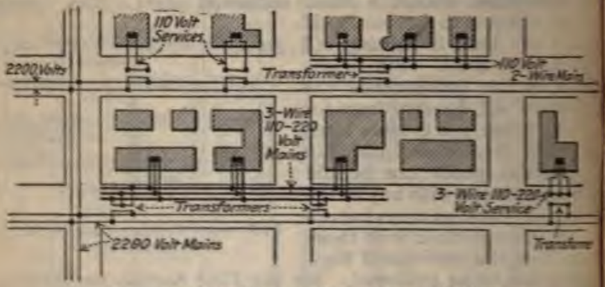


FIG. 102.—Single-phase, high-voltage distribution.

time popular, but was found to be too low for economy. In municipality, a feeder can be installed to serve each district (Fi 100) and an automatic potential regulator can, if necessary, be c into the feeder and so arranged to maintain the voltage consta at the center of distribution. If no regulator is used the feed might connect into the nearest point as *A* (Fig. 100) of the distrib tion system. Consumers are served through transformers whi

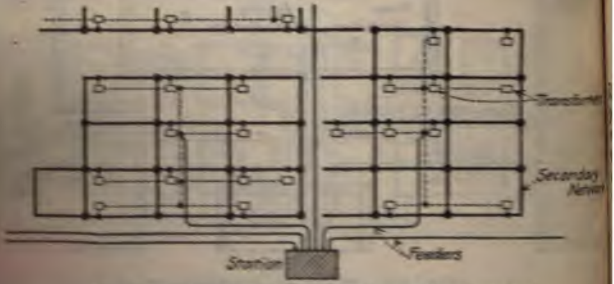


FIG. 103.—An alternating-current secondary network.

reduce the voltage (see Fig. 102) from 2,200 to 110 or 110-22 three-wire. (See section on Transformers.) Small single-pha motors, of capacities smaller than say 5 h.p. can be supplied fr the secondary conductors, but a separate service should be ru motors of capacities greater than 1 h.p. If motors larger are used it is well to serve them with a separate feeder.

Fig. 102 shows methods of serving subscribers. Single trans-rmers are used for detached subscribers. Where several sub-ribers are grouped it is good practice to run a secondary main pplied by one or more transformers. Through this arrangement e use of small transformers is avoided and the investment in ansformers is decreased. Large transformers are more efficient han small ones.

Secondary mains are usually made three-wire (Fig. 102) and the dvantages of the three-wire system (see *First Section*, Index) are hereby realized. Where the load is dense the secondary mains re tied together into a network (Fig. 103). Closer regulation is hereby assured. Such a network is usually 110–220 volts, three-ire. In modern practice, single-phase generators are seldom uilt. Alternating-current generators are usually three-phase, ut feeders may be single-phase and they are tapped from three-hase bus-bars as suggested in Fig. 104. The single-phase loads hould be, approximately, balanced on the three phases.

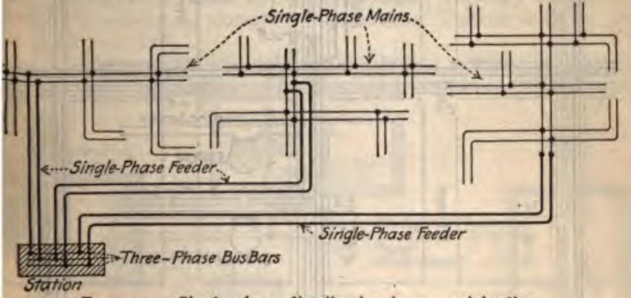


FIG. 104.—Single-phase distribution in a municipality.

131. Single-phase Distribution in Denver, Colo. (*Elec. World*, ec. 2, 1911).—See Fig. 105. The lighting service is fed by multi-e, single-phase, 2,200-volt primary feeders and mains, supplying ergy to secondary networks throughout the urban districts rough step-down transformers located at important centers of stribution and feeding individual consumers at 110 volts and 220 olts, according to the local load requirements.

The single-phase alternating-current system consists of twenty-x two-wire, 2,200-volt feeders extending from the station bus-bars the electrical center of a definite section of the city which is ectrically independent of any other section or feeder. The rimary mains extend from the center of distribution in each sec-on in the form of laterals or branches supplying energy to the ost remote transformers of the district with the usual inclusion intermediate transformers bunched, so far as practicable, to ure economy of operation and reasonable first cost. Any feeder be fed from a special auxiliary bus in the station in case repairs, stments or inspection are necessary in connection with th hes and regulators in routine service.

Within a given section, the secondaries of all transformers are connected by three-wire tie lines forming low-tension bus-bars from which the leads to the various consumers are tapped. The transformers used on the lighting system vary in size from ½ kw. to 50 kw., and all above 1-kw. rating are connected for 2,200 volts

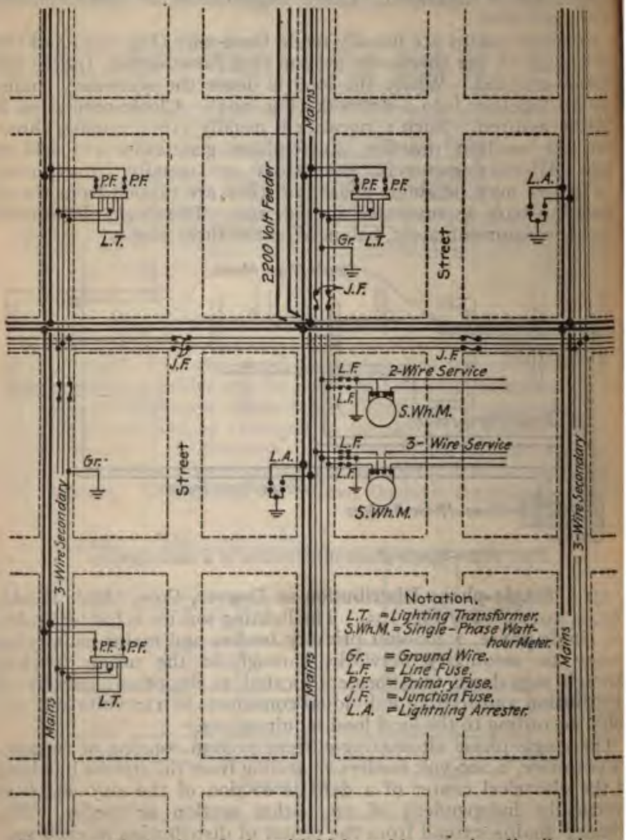


FIG. 105.—Single-phase feeder with high- and low-tension distributions.

on the primary. Each of the two secondary coils is connected so as to give 110 volts between the middle or neutral line and either of the outside lines and 220 volts between outers. The company has found that with the load well balanced considerable saving in secondary copper results from the three-wire method of operation ach transformer is connected to the primary main through ide-type primary fuses of double the transformer rating in eres. The secondary network is sectionalized between each of transformers by a set of fuses or junction cut-outs. These placed approximately at the point of zero current between the cent transformers on each secondary section. (See Fig. 105.) object of this fusing of secondary sections is to prevent the sformers on either side of a defective unit or secondary service assuming heavy overloads. As soon as any abnormal condi- s occur the junction fuses on either side of a defective section , as well as the primary fuses on the transformers, and the on is automatically cleared from the system. The junction s are of copper wire, being about 50 per cent. larger than the ng of the smaller of the two transformers between which they in each instance placed, and varying from about 60 amp. een 5-kw. transformers to 400 amp. between 50-kw. units. uses are installed in the neutral lines of the secondary networks, ough fuses are placed in all leads running from any wire of the ndary service to consumers' premises. The secondaries are nded; see **138**.

2. Three-phase low-voltage distribution systems are largely in industrial plants. The generated voltage is either 220 or

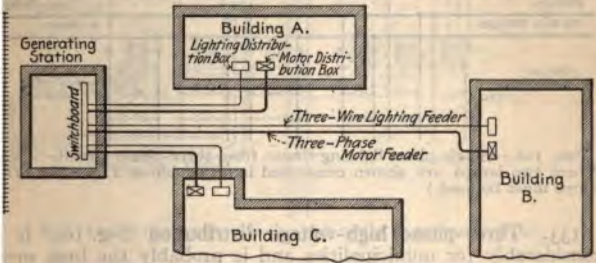


FIG. 106.—Three-phase individual feeder layout.

It is probable that 220 is to be preferred inasmuch as is too high a voltage for safety around cranes and other ored machines in a shop. Figs. 106 and 107 illustrate what robably the best lay-out for a three-phase industrial-plant em. Individual-motor feeders operate at either 220 or 440 and three-wire, single-phase lighting feeders at 110 and 220 are supplied through balance coils. (See section on *Transf- ers*.) The lighting load must be reasonably well-balanced ng the phases. Any of the schemes of distribution suggested gs. 93 to 99 could be used with the three-phase system, but that gs. 106 and 107 is probably the best. Where balance coils are used, single-phase incandescent-lamp circuits can be taken three-phase circuits as suggested in Fig. 108. The lamp load d be balanced among the phases. However, any series- ole scheme of connecting incandescent lamps should be avoided and incandescent lamps should always, where possible, be operated at 110 volts. (See *First Section*, Index.) Occasionally it is advisable to carry the lighting feeders three-phase to the building or group of buildings served and to the balance coils, providing three-wire circuits are installed within the buildings. See also section on *Transformers*.

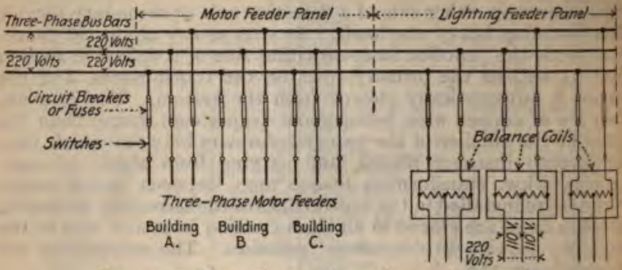


FIG. 107.—Connections at three-phase switchboard.

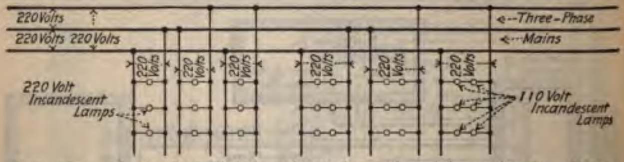


FIG. 108.—Single-phase lighting circuit from three-phase circuit. (*Note.*—Where two lamps are shown connected in series across 220 volts, 110-volt lamps must be used.)

133. Three-phase, high-voltage distribution (Fig. 109) is used considerably for municipalities and is probably the best method for average conditions. The voltage for three-wire three-phase systems is almost always 2,200 so that standard transformers can be used. Where a four-wire three-phase system is used the voltage between outer wires is, approximately, 3,800, but the voltage from any one of the outer wires to the neutral wire is 2,200 so standard transformers can be used. Single-phase transformers are used to serve the lighting loads. The transformers are so distributed on the three phases that the total load on the generator is approximately balanced. The secondaries of the lighting transformers are connected as are those of a system with single-phase primary conductors and may, as suggested in Fig. 102, be either two-wire or three-wire. All three wires of the three-phase circuit are not carried to all parts of the district served. Where the load is not dense only two wires—giving a single-phase circuit—are used. (See Fig. 109.)

Motors exceeding 5 h.p. in capacity should be at least 220-volt and should be three-phase rather than single-phase and separate

:es should be provided for motors exceeding 1 h.p. in capacity. methods of connecting transformers served by a three-phase m are given in the section on *Transformers*. It is best practice ·ovide individual feeders and mains for the motor and the ng loads, but this cannot always be done. The three-phase wire distribution system (Fig. 110) is used in several of the r cities. Its advantage is that it saves copper as the trans- on voltage is 3,800 rather than 2,200. For further information :ction on *Transformers*.

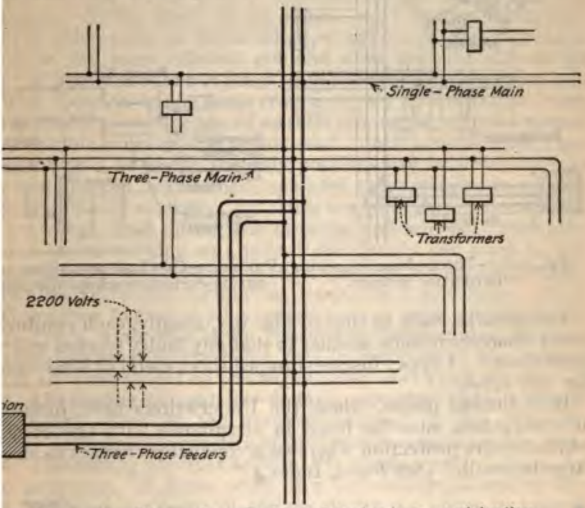


FIG. 109.—Three-phase feeder and mains in a municipality.

4. **Protection and Switches on Distribution Systems.**—In a description is given of the methods used for overload pro- on for the overhead three-wire secondary network used in ver, Colo. In general, it may be said that it is the practice of :ical operating men to use but very few fuses or other protective outs in overhead distribution systems. Where at all feasible, ch circuits are tapped to main circuits with soldered joints or a disconnective pot-head. Fuses are used as seldom as possible use it has been found that they make more trouble than they vorth. Porcelain high-tension fuse blocks are almost invariably posed in the primary leads to distributing transformers to :ct the transformer against overload.

g. 111 suggests the practice sometimes followed for pro- ng alternating-current distribution systems against overload. s are used *only on unimportant mains*. They are not used at *rtant points* because they are apt to rupture at the wrong time. A short-circuit on one of the principal conductors will usually burn itself clear and throw the station circuit-breaker simultaneously, so restoring the breaker restores service. If it does not burn itself clear it is necessary to send a man out to open the disconnectives in succession until the fault is located. This method has been found superior to one involving the use of many fuses.

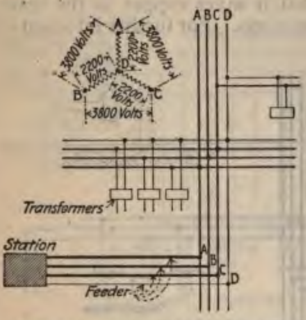


FIG. 110.—Three-phase four-wire distribution system.

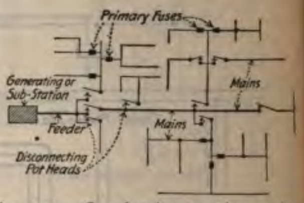


FIG. 111.—Overload protection on alternating-current overhead distribution.

In networks, such as that of Fig. 103, usually, each conductor is fused wherever it joins another so that any faulty section will "burn itself clear." Copper fuses—stamped sheet metal or wire—are best for this service.

In industrial plants, where the Underwriters have jurisdiction, all conductors must be fused in accordance with the code rules which require protection wherever a conductor changes in size from large to small. (See *Fuses*, Index.)

FIG. 112.—Open loop series circuit.

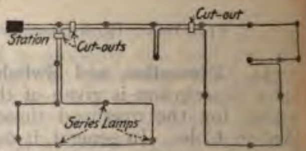


FIG. 113.—Mixed loop series circuit.

135. Series circuits (see "*Fundamentals*" section, Index, for further information) are used for series arc and incandescent lighting and for fire-alarm and watchman's circuits.

136. In laying out a series circuit the open-loop system of distribution (Fig. 112) can be used if the circuit covers a relatively *small area.* If a large area is covered the system suggested in *Fig. 113 should* be used because with it, if an open-circuit occurs in *some section,* the section can be quickly isolated by throwing the *cut-out switch* at the point where the section joins the main circ *Series cut-out* switches, especially designed, can be purchased electrical supply dealers. Obviously the open-loop plan requires a minimum of poles and wire, hence is the most economical to install. When laying out series circuits consideration should be given to future additions of lamps to the series circuit and the circuit should be so routed that they can be included with the least expense. These notes apply for either series incandescent or series arc-lighting circuits.

137. **Series Circuits on Pole Lines** (*From report of Committee on Overhead Line Construction, National Electric Light Association*, 1911).—Every series circuit should start from station, sub-station, or other point of distribution, on a given pin and cross-arm, and follow the same relative pin and cross-arm throughout its course. Circuits should not jump from one location on a cross-arm to another location on the same cross-arm, nor to a different cross-arm, but should always be placed on their proper pin. Such a system renders trouble hunting and repair work much simpler than they otherwise would be and is the only possible way in which circuits can be constructed, maintained, operated and extended in a satisfactory systematic manner. As series arc and series incandescent circuits are cut dead during the daytime and will not, therefore, hamper linemen working on a pole, these circuits can often be run to advantage on the pole-pins of the cross-arm. Such an arrangement is also convenient for making lamp loop connections. As it is usual practice to ground all constant-current series circuits in the station, these wires should be considered as grounded by linemen when working on the poles, this in addition to the general rule that all wires should be treated as being alive at all times.

138. **Alternating-current, low-voltage, secondary circuits should be grounded.** This is the recommendation of the National Electrical Code and the practice of progressive central station companies. Grounding prevents accidents to persons and damage, by fire, to property. If some point of a low-voltage secondary circuit is grounded, no point of the circuit can rise above its normal potential (except under unusual conditions) in case of a breakdown between primary and secondary windings of the transformer, or of other accidental connection between the primary and secondary circuits.

If the secondary is not grounded and the transformer breaks down, the primary voltage is impressed on the secondary circuit. A person touching any bare part of the secondary circuit would probably receive the primary voltage if he were grounded by contact with, say, a radiator or a gas fixture. Furthermore, the secondary not being grounded and there being a ground on the primary circuit, the primary voltage impressed on the low-voltage fittings of the secondary circuit might cause a fire. With the secondary grounded, a transformer breakdown will often reveal itself through the blowing of the primary fuses. *Where a normal voltage in excess of 250 is possible between any wire of a secondary circuit and ground, it is doubtful whether the secondary should be grounded, because shocks to ground from such a system might cause death. See The National Electrical Code for further information regarding grounding.*

139. Ground connections can be made in many ways. The may be made inside of buildings by connecting to pipes or may installed at the poles which support the transformers or the secon ary networks. Central-station practice favors grounds at pole Figs. 114 and 115 show the method of making a pole ground us by the Allegheny County Light Company. The lower end of t pipe is pointed, the upper end is "tinned" inside and the wood plug is inserted in the upper end of the pipe in the Company's sh In making a ground, the pipe is driven into the earth next to

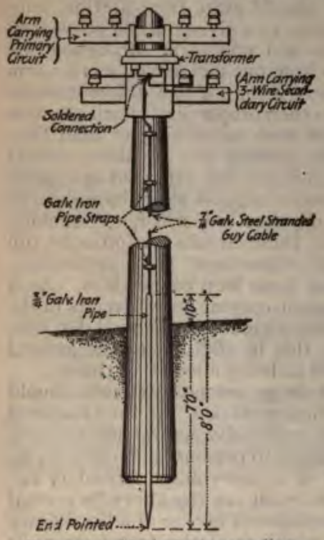


FIG. 114.—Method of grounding secondary circuit.

FIG. 11 Method of necting cabl pipe.

pole and the steel-cable ground conductor, its end having tinned, is soldered into the upper end of the pipe by p molten solder in around it. An excellent feature of this m is that the $\frac{7}{16}$-in. ground conductor is so strong that it will be disturbed. It is secured to the pole with pipe straps. (See

The ground-pipe cap illustrated in Fig. 116 is used by severa central-station companies for connecting the ground wire ground pipe. Soldering is not necessary. The cap with th in position is placed over the top of the pipe and the pipe d In driving, the wire is firmly wedged between the cap and th The cap protects the top of the pipe. The cap fits $\frac{1}{2}$-in. p $\frac{3}{4}$-in. rod, with a No. 6 ground wire. Where No. 4 wire is u is not necessary to double it. Ground pipes must be long to reach permanently moist soil, and in driving care must not to drive them into the pole and thereby insulate the es ground to fire hydrants. The ground wire is supported e pole by cleats or straps, and carried in a trench possibly ep, to the fire hydrant. It is connected thereto by clamp-der a footing bolt. In Denver this method costs $4.50 per the average length of ground wire required from pole top d being 60 ft.

Ground wires should be incased by wooden molding, for a of at least 7 ft. from the surface, to protect against shocks rsby. Under certain conditions of soil moisture, a shock eceived from a ground wire by a person standing on the ırface. The ground pipe extends about a foot above ground ot usually protected. Some companies incase the entire the ground wire in molding to protect the linemen.

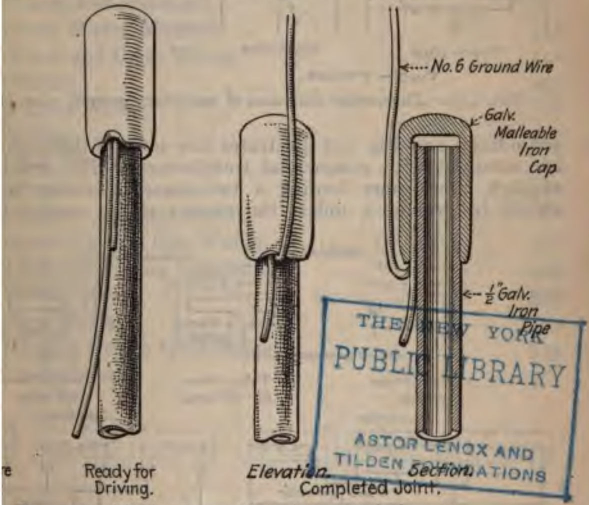


FIG. 116.—Making connection with ground-pipe cap.

pper wire smaller than No. 6 should be used for a ground some companies use nothing smaller than No. 4. Copper eferable. Bare wire is satisfactory and should be attached bles with cleats or straps. Staples, although used, should The National Electrical Code requires for three-phase that the ground wire be of the same carrying capacity ne of the three mains. There should be a ground for each ner or group of transformers, and when transformers twork with a neutral wire, there should, in addition, be a *t least every 500 ft.*

Ground-wire **connections to transformer secondaries** *made to the neutral point or wire if one is accessible. neutral point is accessible,* one side of the secondary circuit may be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts (*National Electrical Code*). Fig. 117 shows theoretical diagrams of ground connections to transformer

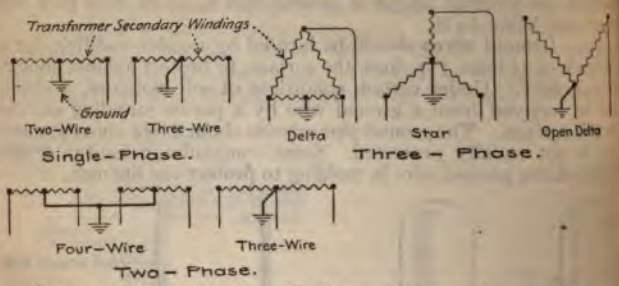


FIG. 117.—Theoretical diagrams of secondary ground connections.

secondaries and Fig. 118 illustrates how some of these connections are arranged with commercial transformers. The neutral point of each transformer feeding a two-phase, four-wire secondary, should be grounded, unless the motors taking energy from the

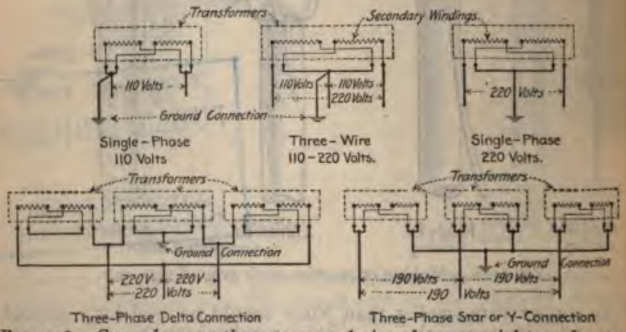


FIG. 118.—Ground connections to secondaries of commercial transformers.

secondary have interconnected windings. Where they are interconnected, the center or neutral point of only one transformer is grounded. No primary windings are shown in Figs. 117 and 118. In Fig. 118 the secondary winding of each transformer is shown divided *into two sections*, as it is in commercial transformers.

SECTION IV

INTERIOR WIRING

PAGE

GENERAL

ıtional Electrical Code Rules, the recommendations ıal Fire Protection Association, should be followed in interior wiring. These rules are revised every two mbered years) so it is inadvisable to include them in copy of these rules can be obtained by applying to inspection bureau or to The Underwriters' Labora- :o, Ill. The Factory Mutual Fire Insurance Com- Milk St., Boston, Mass., publishes an illustrated edi- ıles. The author's "*Wiring for Light and Power*," being a general treatise on the wiring of buildings, Iational Electrical Code and much data in explanation

are local regulations covering the installation of ce in many localities, which have been enacted by overnments. Sometimes these differ from the Na- gulations so it is always well to be familiar with all ons in force before starting any work. The city and in reality laws and therefore take precedence over *Electrical Code Rules* which have no legal status.

Suggestions (*Factory Mutual Fire Insurance Rules*).— work, conductors, however well insulated, should ated as bare to the end that under no conditions cely to exist, can a ground or short-circuit occur, ll leakage from conductor to conductor, or between ground, may be reduced to the minimum. Special t be paid to the mechanical execution of the work. at running, connecting, soldering, taping of conduc- ing and attaching of fittings, are specially conducive d efficiency.

t an installation, except for constant-current systems, ble effort should be made to locate distribution ily accessible places, at which points the cutouts and olling the several branch circuits can be grouped for nd safety of operation. The load should be divided possible among the branches, and all complicated ry wiring avoided. The use of wire-ways for render- wiring permanently accessible is most heartily en- commended; and this method of accessible concealed s advised for general use.

Wiring Rules in Brief (*Factory Mutual Rules*).— ed wire must be used in all damp places, in all conduit, ncealed work, and throughout all systems on which xceeds 550. For "open" work in dry places where *not over* 550, slow-burning wire is recommended, as it *quirement* for such work, is less expensive and will This wire has special merit for use in linty and dusty places, for lint does not readily adhere to the hard, smooth, outer surface, as is the case with wires having a weather-proof braid on the outside which in warm rooms becomes sticky. Moreover, what little lint may collect upon it can be easily brushed off, so that when "sweeping down" there is much less liability of breaking the insulators or badly deranging the wires.

Where of necessity a considerable number of "open" wires are brought close together as, for example, about the ordinary distributing switchboard, the wires should have either the slow-burning insulation as just described, or if a rubber insulation is necessary it should be protected by a heavy "slow-burning" outer braid. The weather-proof and rubber insulations in common use contain a large amount of inflammable material, which ignites easily and produces a fierce fire and dense smoke. It is therefore desirable to reduce, as far as possible, the amount of this inflammable material and to surround it with a tight, "slow-burning" cover to prevent rapid combustion. To still further reduce the amount of combustible material, the porcelain insulators by which the wires are held in place may be supported on an iron frame.

Before beginning work the circuits should be carefully mapped out and the work so planned as to secure the very simplest arrangement.

In mill work, "open" wiring securely supported on porcelain insulators is generally best. Mains of No. 8 B. & S. gage wire and larger are usually most conveniently carried through space from timber to timber and supported at each timber only. Smaller wires thus supported would be liable to be broken, and should therefore be wrapped around the beams or carried through them in holes bushed with porcelain, or they may be fastened to strong running-boards, well put up. The idea is to have the wires so rigidly supported on proper insulators that, even if they were bare, the insulation of the system would be perfect. All joints should be securely made and then carefully soldered and taped.

Wires should be carefully protected where liable to be deranged or injured, as in passing from story to story up side walls or columns, or near belts, or over shelves and similar places where anything is likely to be piled against them. Excellent protection can be secured by carrying them through iron pipe, first reinforcing the insulation of each wire by enclosing it in flexible insulating tubing (also referred to as "standard flexible tubing") unless the wire is double braided rubber covered in which case the insulating tubing is unnecessary. On alternating-current systems, the two or more wires of the same circuit should be run in the same pipe to avoid induction effects. (See Figs. 56 and 57.) Even on direct-current systems this arrangement is best, as then the expense and inconvenience of rewiring is avoided when it is desired to change such systems to alternating current which frequently happens. Protection may also be obtained by strong wooden boxing, with a slanting top to keep out dirt, the holes through which the wires enter the top being bushed with short porcelain tubes. (See Fig. 56.)

The use of incandescent lamps in series on constant-potential systems is not approved.

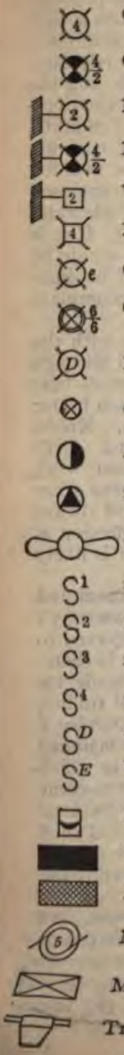
5. Brief of Underwriters' Rules for Wiring in Especially Hazardous Places (such as Picker and Carding Rooms, Napping Rooms, Dust Chambers, Etc.) (*Factory Mutual Wiring Rules*).—For incandescent lamps in these more hazardous places, an excellent pendant can be secured by using reinforced flexible cord and a keyless socket with an outlet threaded for ⅜-in. pipe and properly bushed, as advised for "Portable Lamps" in **6.** The cord should be securely supported from the ceiling by a porcelain cleat or split knob, and the two conductors should then be separated and soldered to the overhead circuit. (See Fig. 76.) The regular "Water-proof Pendant" described in **98** could also be used. As far as possible cut-outs should not be located in these rooms, but if this cannot be avoided they should be of the plug or cartridge type and should be enclosed in dust-tight cabinets of approved construction. (See Code rules governing the construction of dust-proof switch cabinet.) If it is desired to control the lights from points in these rooms, it should be done by snap switches, which should be either enclosed in dust-tight cabinets or located where lint and flyings cannot accumulate around them.

Drop cords can be effectively supported from a ceiling with the ceiling buttons shown in Fig. 76A. The cord is passed through the hole in the button and then soldered to the conductors that feed it. Some inspectors consider the ceiling button a much better support at a ceiling than either a rosette or a split knob. Knobs are not generally considered good supports for flexible cord. Ceiling buttons are particularly desirable in industrial plant work because there is no chance for the conductors to get loose from them. Where a drop cord is subject to vibration it should always be soldered to the conductors that feed it. If the connection is effected with the screw clamps of a rosette, the vibration is likely to loosen the screws and cause a loose connection.

6. Brief of Underwriters' Rules Covering the Arrangement and Use of Portable Lamps (*Factory Mutual Fire Insurance Company's Wiring Rules*).—In this class of work the fittings are subjected to much hard usage, and the very best possible construction is therefore necessary. Instead of the ordinary flexible cord made for pendant lamps, a special cord having an extra covering of rubber, reinforced by a tough outer braid, should be used. (See *Section 1* for dimensions of this cord.) The cord should be securely fastened to the wall or ceiling by a cleat or split knob near the point at which it connects to the rosette or supply wires, so that no strain can come on this connection. (See Fig. 76.) It should also be knotted inside the socket, as explained elsewhere. An approved metal shell socket with an outlet threaded for ⅜-in. pipe should be used, so that the whole cable may be drawn into the socket and still permit the use of a proper socket bushing.

The bulb of an incandescent lamp frequently becomes hot enough to ignite paper, cotton and similar readily ignitible materials, and in order to prevent it from coming in contact with such materials, as well as to protect it from breakage, every portable lamp should be surrounded with a substantial wire guard. Many of the lamp

STANDARD SYMBOLS ADOPTED BY THE NATIONAL CONT ORS' ASSOCIATION AND THE AMERICAN INSTITUTE OF ARCHITECTS



Ceiling outlet; electric only. Numeral in center indicate ber of standard 16 c-p. incandescent lamps.

Ceiling outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only,

Bracket outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

Bracket outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only,

Wall or baseboard receptacle outlet. Numeral in cent cates number of standard 16 c-p. incandescent lamps.

Floor outlet. Numeral in center indicates number of St 16 c-p. incandescent lamps.

Outlet for outdoor standard or pedestal, electric only. N indicates number of standard 16 c-p. incandescent lan

Outlet for outdoor standard or pedestal; combination. cates 6-16 c-p. standard incandescent lamps; 6 gas burn

Drop cord outlet.

One-lamp outlet, for lamp receptacle.

Arc lamp outlet.

Special outlet for lighting, heating and power-current, scribed in specifications.

Ceiling fan outlet.

S. P. switch outlet.

D. P. switch outlets.

3-way switch outlet.

4-way switch outlet.

Automatic door switch outlet.

Electrolier switch outlet.

Show as many syml there are switches. case of a very large g switches, indicate nu switches by a roma eral, thus; S′ XII; n 12 single pole switch

Describe type of sw specifications, that i or surface, push bu snap.

Meter outlet.

Distribution panel.

Junction or pull box.

Motor outlet. Numeral in center indicates horsepower

Motor control outlet.

Transformer.

FIG. 1.—Standard Wiring Symbols.

:D SYMBOLS ADOPTED BY THE NATIONAL CONTRACT-S' ASSOCIATION AND THE AMERICAN INSTITUTE OF ARCHITECTS.—*Continued*

——— Main or feeder run concealed under floor.

——— Main or feeder run concealed under floor above.

– – – – Main or feeder run exposed.

——— Branch circuit run concealed under floor.

——— Branch circuit run concealed under floor above.

——— Branch circuit run exposed.

– –●– – Pole line.

Riser.

Telephone outlet; private service.

Telephone outlet; public service.

Bell outlet.

Buzzer outlet.

Push button outlet. Numeral indicates number of pushes.

Annunciator. Numeral indicates number of points.

Speaking tube.

Watchman clock outlet.

Watchman station outlet.

Master time clock outlet.

Secondary time clock outlet.

Door opener.

Special outlet for signal systems, as described in specifications.

Battery outlet.

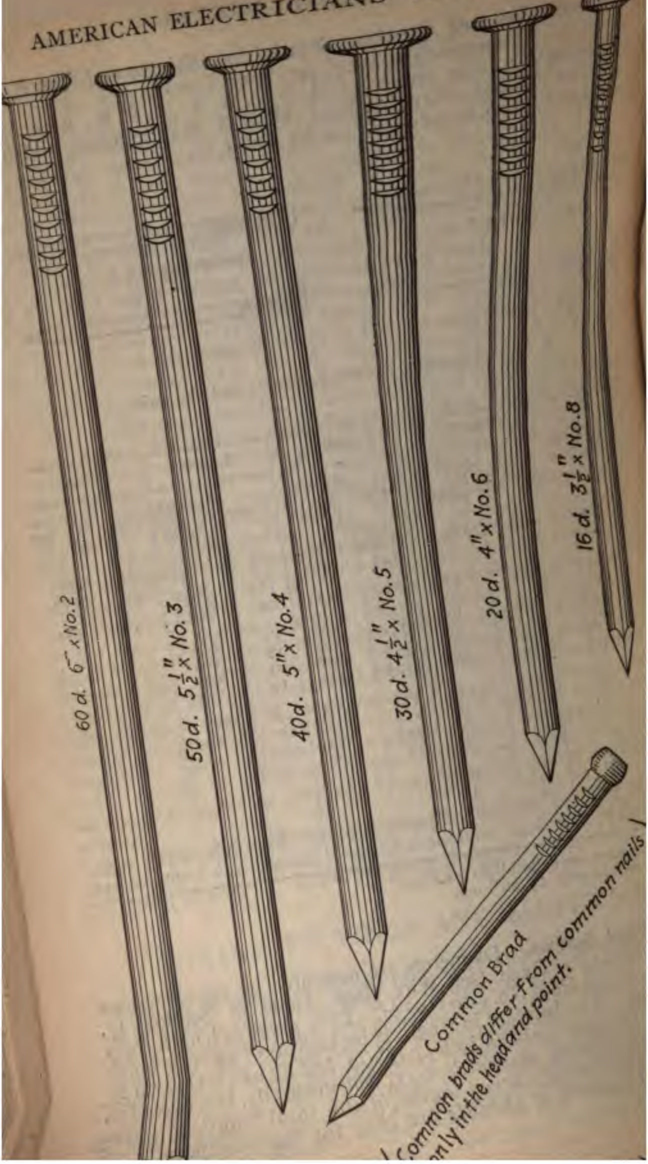
——— Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service wanted ascertained by symbol to which line connects.

——— Circuit for clock, telephone, bell or other service, run under floor above, concealed. Kind of service wanted ascertained by symbol to which line connects.

center of wall outlets (unless otherwise specified):

ving Rooms	5 ft. 6 in.
ambers	5 ft. 0 in.
ices	6 ft. 0 in.
ridors	6 ft. 3 in.
tches (unless otherwise specified)	4 ft. 0 in.

'IG. 1.—**Standard Wiring Symbols.—Continued.**


60 d. 6" x No. 2
50 d. 5½" x No. 3
40 d. 5" x No. 4
30 d. 4½" x No. 5
20 d. 4" x No. 6
16 d. 3½" x No. 8
Common Brad
Common brads differ from common nails only in the head and point.

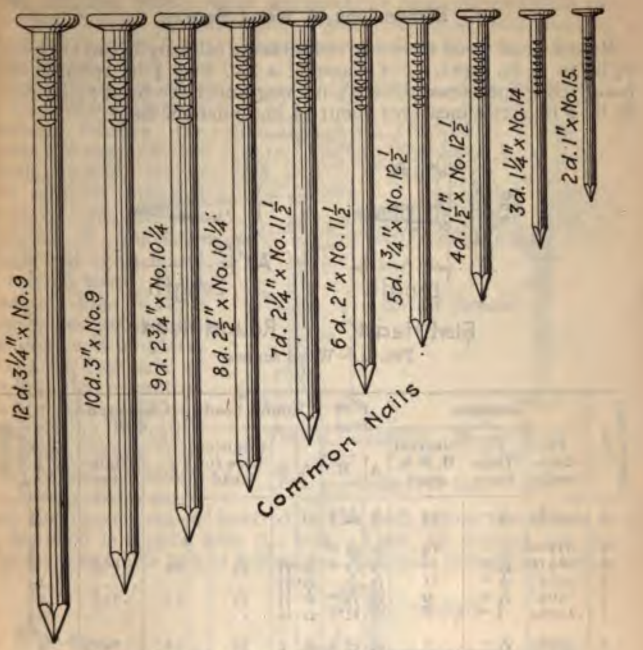


FIG. 3A.—Common nails (*Continued*).

14. Dimensions of Common Nails and Brads

(*American Steel & Wire Company*)

Size	Length, inches	A. S. & W. gage No.	Approx. No. to lb.	Diam. in decimals, inches	Approx. diam. in inches	Nearest B. & S. gage
2d	1	15	876	0.0720	5/64	13
3d	1¼	14	568	0.0800	5/64	12
4d	1½	12½	316	0.0985	7/64	10
5d	1¾	12½	271	0.0985	7/64	10
6d	2	11½	181	0.1130	7/64	9
7d	2¼	11½	161	0.1130	7/64	9
8d	2½	10¼	106	0.1314	1/8	8
9d	2¾	10¼	96	0.1314	1/8	8
10d	3	9	69	0.1483	9/64	7
12d	3¼	9	63	0.1483	9/64	7
16d	3½	8	49	0.1620	5/32	6
20d	4	6	31	0.1920	3/16	6
30d	4½	5	24	0.2070	13/64	4
40d	*5*	4	18	0.2253	7/32	3
50d	*5½*	3	14	0.2437	1/4	2
60d	*6*	2	11	0.2625	17/64	2

15. Dimensions of Wood Screws

Round-head wood screws do not measure full length, but are from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. short. For example: a No. 4 by $\frac{1}{2}$ in. round-head wood screw measures about $\frac{7}{16}$ in. long under the head and a No. 20 by 2 in. screw measures about $1\frac{7}{8}$ in. under the head.

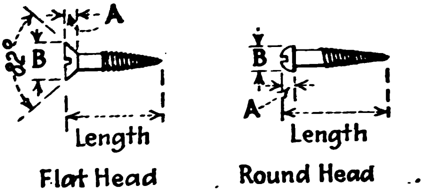


FIG. 4.—Wood screws.

Screw gage No.	Diameter: In decimals	Diameter: In fractions	Diameter: Nearest B. & S. gage	Flat head: A	Flat head: B	Round head: A	Round head: B	Round head: Counter-bore for head	Depth of hole = height of head A	Clearance drill: No.	Clearance drill: Diameter	Greatest length obtainable, inches
0	.05784	1/16 −	15	1/16	7/64 +	..	..	......		....	......	3/8
1	.07100	5/64 −	14	1/16	9/64 −	..	..	......		....	......	1/2
2	.08416	5/64 +	12	1/16	5/32 +	1/16	11/64	7/32		44	.086	3/4
3	.09732	3/32 +	11	1/16	3/16	5/64	13/64	......		....	......	1 1/4
4	.11048	7/64 +	9	1/16	7/32 −	5/64	13/64	7/32		33	.113	1 1/2
5	.12364	1/8 −	8	1/16	15/64 +	3/32	15/64	......		....	......	2 1/2
6	.13680	9/64 −	7	5/64	17/64 +	3/32	1/4	17/64		28	.1415	3
7	.14996	5/32 −	7	3/32	19/64 −	7/64	9/32	......		....	......	3
8	.16312	5/32 +	6	7/64	5/16 +	7/64	19/64	5/16		18	.1695	4
9	.17628	11/64 +	5	7/64	11/32 +	7/64	21/64	......		....	......	4
10	.18944	3/16 +	5	7/64	3/8 −	1/8	11/32	23/64		10	.1935	4
11	.20260	13/64 −	4	1/8	25/64 +	9/64	3/8	......		....	......	4
12	.21576	7/32 −	4	1/8	27/64	5/32	25/64	13/32		7/32	.2188	6
13	.22892	15/64 −	3	1/8	29/64	5/32	27/64	......		....	......	6
14	.24208	1/4 −	3	9/64	15/32 +	5/32	29/64	29/64		1/4	.250	6
15	.25524	1/4 +	2	9/64	1/2	11/64	29/64	......		....	......	6
16	.26840	17/64 +	2	5/32	17/32 −	11/64	31/64	......		....	......	6
17	.28156	9/32	1	5/32	35/64 +	11/64	1/2	......		....	......	6
18	.29472	19/64 −	1	11/64	37/64	3/16	17/32	35/64		....	.302	6
19	.30788	5/16 −	0	3/16	39/64 −	..	17/32	......		....	......	6
20	.32104	21/64 −	0	13/64	5/8 +	13/64	9/16	37/64		....	.323	6
21	.33420	21/64 +	0	13/64	21/32	13/64	19/32	......		....	......	6
22	.34736	11/32 +	0	13/64	11/16 −	7/32	5/8	......		....	......	6
23	.36052	23/64 +	000	7/32	45/64 +	7/32	41/64	......		....	......	6
24	.37368	3/8 −	000	7/32	47/64	15/64	21/32	43/64		....	.377	6
25	.38684	25/64 −	000	7/32	49/64 −	15/64	11/16	......		....	......	6
26	.40000	13/32 −	000	15/64	25/32 +	1/4	45/64	......		....	......	6
27	.41316	13/32 +	000	15/64	13/16	1/4	23/32	......		....	......	6
28	.42632	27/64 +	000	1/4	27/32	1/4	47/64	......		....	......	6
29	.43948	7/16 +	0000	1/4	55/64 +	17/64	3/4	......		....	......	6
30	.45264	29/64	0000	17/64	57/64	9/32	25/32	......		....	......	6

16. Toggle bolts, which are used for fastening molding and electrical devices to hollow tile or plaster-on-metal-lath surfaces, are of two general types. The screw type (Fig. 5) is the most frequently used but has the disadvantage that if it is ever necessary to entirely remove the screw, the toggle is lost within the wall. Where the object fastened must be removed and replaced a nut-type toggle bolt (Figs. 6 and 7) can be used. With that of Fig. 6 it is usually necessary, after the device is in place, to cut off the part of the bolt that extends so that the thing will look well. The so-called plumber's toggle bolt (Fig. 7) has a removable, hexagonal cap so that the device can be inserted in the wall before the object to be fastened is slipped over the bolt. Then, on putting the cap in place, the whole bolt is backed into the wall, hiding the surplus

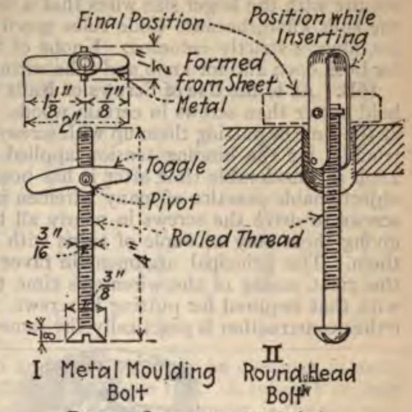


FIG. 5.—Screw-type toggle bolts.

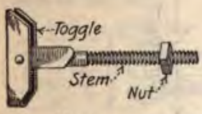


FIG. 6.—Nut-type toggle bolt.

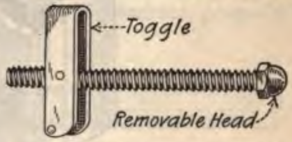


FIG. 7.—Plumbers' toggle bolt.

thread from view. Cone-head toggles, Fig. 8, are used principally for the erection of metal molding and have the advantage that the toggle head will readily pass through the hole in the molding backing. Toggle bolts are made in several diameters and lengths. That of Fig. 5, *I* and Fig. 8 are made by the National Metal Molding Co., Pittsburg. The others illustrated are made by the Chicago Nut Co., Chicago, Ill.

FIG. 8.—Toggle bolt for metal molding.

16A. Knobs, the small porcelain insulators used for supporting interior conductors, are of two general types, the solid (Fig. 8, B) and the split (Fig. 8, A). The solid knob is required by the Underwriters for certain work and is the cheaper of the two, but th dditional cost of the tie-wire required with it and the labor of ty makes the cost installed about equal to that of the split knob. The split or confining knob is unquestionably superior to the solid knob, as no tie-wires are required with it. In some places inspectors require with the larger size wires that a tie-wire be used even with the split knob, because Code rules specify tie-wires. The rule is not always strictly enforced. Knobs of the same kinds are used for both open and for knob and tube wiring.

16B. As to the Use of Screws or Nails with Split Knobs.—Nails hold better than screws in certain woods. The breaking of knobs at the time of putting them up with screws is not the only source of trouble, for the binding tension applied often acts to crack the knob a considerable time after it has been put in place. It is an objectionable practice of many wiremen in putting up knobs with screws to drive the screws in nearly all the way with a hammer, giving them only a couple of turns with a screwdriver to tighten them. The principal argument in favor of the use of the nail is the great saving of the wiremen's time that results as compared with that required for putting in screws. The insulating value of either construction is practically the same.

FIG. 8A.—Split knob.

16C. A split knob which clamps the conductor between its two halves is shown in Fig. 8, A. Split knobs must be used for conductors smaller than No. 8, B. & S. gage.

16D. Dimensions of Standard Porcelain Knobs
(*R. Thomas & Sons Company*)
All dimensions are in inches

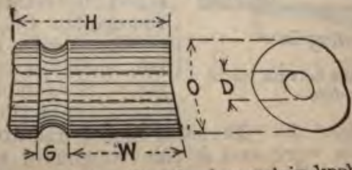


FIG. 8B.—Standard porcelain knob.

Trade number	H Height	O Outside diameter	D Hole diameter	G Width of groove	W Height of wire
0	2 1/4	3	1 1/4	1	9/16
1	3	2 1/8	7/16	3/4	1 1/4
2	2	2	1/2	1/2	1
3WG	1 3/4	2	7/16	3/4	9/16
3	1 3/4	2	7/16	7/16	3/4
3 1/2	2	2	7/16	7/16	1
4	1 11/16	1 1/2	3/8	3/8	7/8
Midway	1 7/8	1 3/8	3/8	3/8	1
4 1/2	1 7/8	1 1/2	3/8	7/16	1
5	1 1/4	1	1/4	5/16	11/16
5 1/2	1 9/16	1	1/4	5/16	1
6	7/8	13/16	7/32	1/4	1/2
7	3/4	7/8	1/4	7/16	5/8
8	15/16	1	1/4	5/16	7/16
9	1 1/8	5/8	3/16	3/16	3/4
10	1 3/4	1 5/8	3/8	3/8	1 5/16
10 1/2	1 7/8	1 1/2	3/8	3/8	1

16E. Tubes for knob and tube work can be obtained in many lengths and sizes, as indicated by Table **16F.** A tube 3 1/2 in. long, 5/8 in. external diameter and 5/16 in. internal diameter, is the size most frequently used in ordinary house wiring.

16F. Dimensions of Code Standard Unglazed Porcelain Tubes

(*R. Thomas & Sons Company*)

All dimensions are in inches. An allowance of one sixty-fourth of an inch for variation in manufacturing is permitted, except in the thickness of the wall.

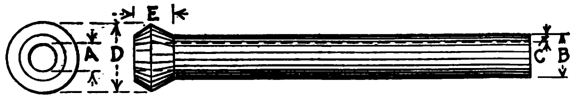


FIG. 8C.—Standard porcelain tube.

A	B	C	D	E	Greatest length made	Shortest length made
Diameter of hole	External diameter	Thickness of wall	External diameter of head	Length of head		
5/16	9/16	1/8	13/16	1/2	24	1/2
3/8	11/16	5/32	13/16	1/2	24	1/2
1/2	13/16	5/32	1 3/16	1/2	24	1
5/8	15/16	5/32	1 5/16	1/2	24	1
3/4	1 3/16	7/32	1 11/16	5/8	24	1
1	1 7/16	7/32	1 15/16	5/8	24	1 1/2
1 1/4	1 13/16	9/32	2 5/16	5/8	24	2 1/2
1 1/2	2 1/16	11/32	2 11/16	3/4	24	2 1/2
1 3/4	2 9/16	13/32	3 1/16	3/4	24	2 1/2
2	2 13/16	15/32	3 7/16	3/4	24	2 1/2
2 1/4	3 5/16	17/32	3 13/16	1	24	2 1/2
2 1/2	3 11/16	19/32	4 3/16	1	24	2

16G. Approximate Dimensions of Two- and Three-wire Porcelain Cleats

(The R. Thomas & Sons Company, East Liverpool, Ohio)
All dimensions are in inches

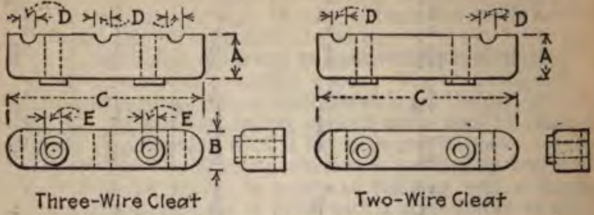


FIG. 8D.—Two- and three-wire porcelain cleats.

Standard No.	No. of wires	For size wires	A Height	B Width	C Length	D Groove	E Diameter screw hole
333	1	18–10	½	½	1 3/16	¼	3/16
[1] 333½	....	....	¼	½	1 3/16	....	3/16
334	2	18–10	1⅛	⅝	3⅜	3/16	7/32
335	2	18– 8	1⅛	¾	3⅜	5/16	7/32
336	2	18–10	1⅛	⅝	3⅜	3/16	7/32
[2] 337	3	....	....	....	....	....	....
350	2	4– 2	1½	¾	3½	½	3/16

[1] No. 333½ has no groove and of itself could not be used as a cleat. It is simply a flat piece of porcelain to be used in combination with No. 333, the screw holes of the two corresponding.

[2] No. 337 is a three-wire cleat and can be made of the dimensions of Nos. 334, 335 or 336.

16H. B. & D. Porcelain Cleats

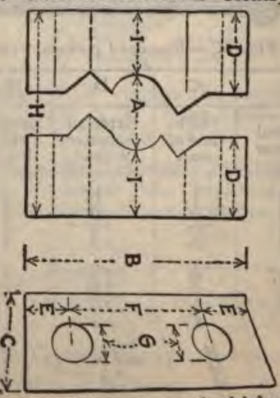


FIG. 8E.—Showing cleats the dimensions of which are given in Table 1

16I. Dimensions of Regular Style B. & D. Porcelain Cleats

(See Fig. 8E for key to reference letters.)

No.	Std. No.	Size wire R. C. B. & S.	Dimensions A Min in.	A Max. in.	B in.	C in.	D in.	E in.	F in.	G in.	H Min. in.	H Max. in.	Approx. price each
1	328	14 to 16	3/16	3/8	1 1/4	3/4	5/8	5/16	1 1/8	1/4	1 1/4	1 7/16	0.01
1½	329	10 to 2	3/16	7/16	2 1/4	15/16	3/4	15/32	1 5/16	5/16	1 3/8	1 1/2	0.016
2	....	2 to 0	3/8	1/2	2 1/4	1 1/16	13/16	15/32	1 5/16	5/16	1 5/8	1 3/4	0.019
2½	330	0 to 3/0	3/8	5/8	2 11/16	1 3/16	1	17/32	1 3/8	5/16	2	2 3/8	0.024
3	331	3/0 to 200,000 cm.	3/8	3/4	3 3/8	1 1/2	1 3/16	5/8	1 7/8	3/8	2 3/8	2 5/8	0.032
3½	331½	200,000 cm. to 500,000 cm.	3/4	1	3 3/16	1 5/16	1 3/8	3/8	1 15/16	3/8	2 3/4	3	0.049
4	332	500,000 cm. to 1,000,000 cm.	7/8	1 3/8	3 11/16	1 3/8	1 7/16	11/16	2 5/16	3/8	2 7/8	3 3/8	0.065
4½	332½	1,000,000 cm. to 2,000,000 cm.	1 3/8	1 15/16	5 3/8	2	1 15/16	7/8	3 5/8	3/16	3 3/4	4 3/16	0.164

NOTE.—Nos. 1 to 3 inclusive, regular cleats (as tabulated), approved for 300 volts and Nos. 3½ to 4½ regular cleats (as tabulated), approved up to 550 volts. If cleats Nos. 1 to 3 are desired for service above 300 volts "style A" should be specified, in which Dimension I is 1 in. in every case.

16J. Flexible tubing or circular loom (Fig. 8, *F*) finds application in mixed wiring, where short sections of rigid conduit are installed, being used as additional insulation and protection for the entire length of conductor within the rigid conduit. When metal outlet boxes are used, or switch boxes, flexible tubing is required from the last porcelain support and extending into the outlet box. Another application for flexible tubing is in buildings already completed where the wires are fished in between the walls and ceilings. The tubing is used as a covering on such wires separately encased. In concealed knob and tube work it is frequently impracticable to place wires 5 in. apart and 1 in. from the surface wired over as required by the code, and in such cases the wires may be separately encased in flexible tubing. In open wiring where the amount of separation required by the code from the surface wired over cannot be maintained, the wires may also be encased in flexible tubing.

The following is a list of places where flexible tubing is applicable. In open work where wires are exposed nearer each other than 2½ in.; on wires crossing other wires; on wires crossing gas pipes, water pipes, iron beams, wood work, brick or stone; on wires at chandelier and bracket outlets; on gas pipe back of insulating joints; on wires under the edges of canopies; and at distributing centers or where space is limited and the 5-in. separation required cannot be maintained, each wire must be separately encased in a continuous length of flexible tubing. In many other places flexible tubing is employed as an added protection to wires; as for instance on portable wires around machinery and in show windows, etc., where added protection although not required is often desirable.

Knox in his *Electric Light Wiring* says: The use of flexible tubing is becoming more limited every year and as a separate method of wiring is only approved by certain inspectors. It is used in non-fireproof buildings and is frequently used in conjunction with other methods of wiring, such as knob-and-tube wiring, exposed wiring on insulators, molding work, etc. It is also used at the backs of switchboards to cover conductors where they emerge from conduit, or where the conductors pass through walls, etc. It must be used on the loop system and be continuous from outlet to outlet. It must not be installed in damp places or in any way subjected to moisture (such as being placed in contact with damp mortar, plaster, etc.). Wires should not be drawn into flexible tubing until after the rough work in the building is finished as the tube is not strong mechanically and would not protect the wires from nails, etc. Duplex wires are not permitted in flexible tubing, although single-braided conductors are allowed.

Owing to the fact that flexible tubing is neither moisture-proof nor mechanically strong, it compares unfavorably with metallic conduits. Wiring with it is, however, cheaper than either rigid or flexible conduit wiring.

Flexible tubing should be used only in dry places.

16K. Properties of Flexible Tubing or Loom

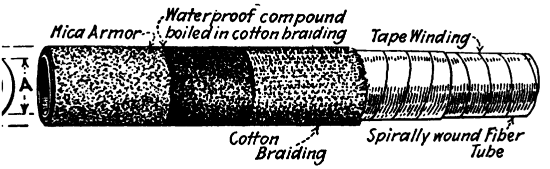


FIG. 8F.—Flexible tubing.

B Outside diam., inches	Ft. per coil	Largest wire, B. & S. and cir. mils	Weight per 1,000 ft.-lb.
17/32	250	No. 14	75 lb.
[illegible]	250	No. 12	110 lb.
[illegible]	200	No. 8	125 lb.
[illegible]	200	No. 4	155 lb.
1 1/16	150	No. 2	200 lb.
1 [illegible]	100	No. 00	275 lb.
1 11/16	100	200,000	360 lb.
2 1/16	100	400,000	400 lb.
2 1/2	100	600,000	440 lb
2 3/4	Odd lengths	800,000	600 lb.
3	Odd lengths	1,100,000	700 lb.
3 1/2	Odd lengths	1,300,000	700 lb.

ısulating tape for the United States Navy Department
sed under the following specifications:
ıe to be classified as follows:

ıbber tape.
ıtton tape.

h classes must meet the following requirements:

ıliveries shall contain full specified weight of tape, exclusive of and boxes. Net weight only of tape shall be paid for.
l tapes shall be of recent manufacture.
.e surface shall be smooth, the body entirely free from holes, the ight without selvage and widths even. When held before a strong must be no evidence of pin holes.
ıe wrappings shall be secure and protect the contents fully.

: cotton tape must be well saturated and frictioned, but .d shall not be put on in excess. Separation under a pull ɔer inch width applied to the material when wound from nal in a coil on a ½-in. mandrel under a tension of 10 lb. exceed 8 in. per minute at 75 deg. fahr.

en unwinding from the original coil there must be no to leave a thread sticking to the next layer in the case of ıpe, nor shall the separator show any tendency to stick ase of rubber tape. Rubber tape, when wrapped to a ; *of ½ in. and heated* to 150 deg. fahr. for 20 min., shall a *homogeneous* mass.

on *tape, when* exposed in strip to dry heat at 210 deg *hr. shall stand the* following separation test immediate after removal from the heat. Test similar to that in paragraph three will be made, except that the pull shall be two ounces per inch width and the separation shall not exceed 3 in. per minute.

6. The weight of the compound applied to the cloth shall be about 0.65 lb. per square yard.

7. To possess the following physical and chemical characteristics:

Width, inches: Rubber, ½, ¾, and 1; cotton, ½, ¾ and 1.

Thickness, inches: Rubber, 0.035, approximately; cotton, 0.015, approximately.

Package, pounds: Rubber, ½, ⅓, and 1; cotton, ⅛ to ¼ (all widths).

Length of tape per pound weight (minimum): Rubber, 27, 18, and 13.5 yards; cotton, 72, 48, and 36 yards.

Para rubber: Rubber, not less than 30 per cent.

Sulphur: Rubber, not more than 3½ per cent. total.

Ash by burning: Rubber, not to exceed 65 per cent.; cotton, not to exceed 45 per cent.

Tensile Strength: Rubber, 400 lb. per square inch at 75 deg. fahr.; cotton, 40 lb. per inch of width.

Dielectric Strength: Rubber, 250 volts per millimeter of thickness (5 minims); cotton, 1,000 volts (5 minims).

Color: Rubber, black; cotton, black.

Layer separation: Rubber, linen or glazed cloth.

Packing: Rubber, oil paper or tinfoil; and in pasteboard box; cotton, tissue paper or tinfoil and in tin box.

Markings of package: Rubber, maker's trade name, width, weight, directions; cotton, maker's trade name, width.

The test for tensile strength of the rubber tape shall be performed on a rubber testing machine, the rate of separation of the jaws which clamp the test piece being 3 in. per minute. The initial distance between the jaws shall be 3 in. The test for tensile strength of the cotton tape shall be conducted with a textile testing machine or by lifting the specified weight.

The dielectric strength tests to be conducted as follows: The test piece to be placed between two electrodes consisting of two brass balls, each 2 cm. in diameter, and the specified alternating potential having an effective value, at a frequency of 60 cycles, shall be continuously applied for 5 min. and no break-down shall result. The electrodes must be brought close together so that the tape will just move between them.

17A. Rosettes may be either fused or unfused. Fused rosettes are seldom used now. The usual practice is to connect 16 sockets to a branch circuit, through fuseless rosettes, so that the total wattage of the lamps will not exceed 660. Sockets are usually considered as requiring not less than 40 watts each. The branch circuit can then be properly fused at the point where it connects to the main circuit. Fused rosettes are used, with the underwriters' approval only for open work. Link-fused rosettes can be used for voltages not exceeding 125 and enclosed fused rosettes for voltages not exceeding 250. Where rosettes are fused 30 or 40 lamps may be connected to one branch circuit.

The rosette fuse must not exceed 3 amp. capacity and the fuse protecting the branch must not exceed 25 amp. capacity. It is not now considered good practice to load any incandescent lamp circuit to more than 660 watts. If there are too many lamps on one fuse, its blowing will render too great an area dark.

18. Insulating socket bushings must be used where a cord enters a socket to protect it against abrasion and grounding against the shell. The most popular bushings are of hard rubber or of a compound resembling it. Patented bushings which automatically grip the cord by a wedging action can be purchased.

19. **Sockets** made with a $\frac{1}{8}$-in. or a $\frac{3}{8}$-in. pipe thread. The so-alled $\frac{1}{8}$-in. sockets are used only on fixtures. The $\frac{3}{8}$-in. sockets can e used with reinforced lamp cord. In connecting a cord to a ocket, the cord should always have a knot (Fig. 9) tied in it that ill lie within the socket to insure against its pulling out and to ake the strain from the binding screw.

20. **Key sockets should not be used** in places where they are in n atmosphere filled with an inflammable dust. Weather-proof or eyless sockets should be installed in such places.

21. **Brass-shell or key sockets should never be used out of oors or in damp places.** Sometimes, even in bath-rooms, moisture ill get into the shell and ground socket. Occasionally the water omes from the hand of a person hat has just washed and turns he key before his hand is dry. The water enters through the slot n the shell. A keyless or a pull-hain socket should be installed n bath-rooms.

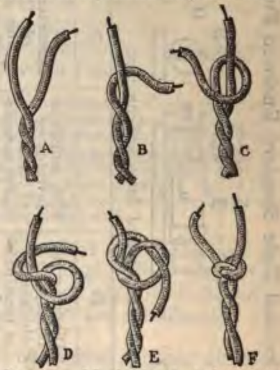


Fig. 9.—Method of tying supporting knot in flexible cord. (See Par. 9 for description.)

22. **Weather-proof sockets** are sed out of doors and in damp laces as suggested in **95**.

23. **Brief of Underwriters' Rules Covering Cut-outs** (*Factory Mutual Rules*).—Link fuses are ot suitable for general use about factory and will not be approved nless mounted on slate or marble bases made to conform to the pecifications given in the Code nd enclosed in dust-tight, fire proofed cabinets. (See Fig. 23.) The ordinary porcelain link-fuse cut-outs are not permissible. Approved plug and cartridge fuses may be used almost anywhere n the ordinary manufacturing plant without the enclosing cabinet, uch cabinets being necessary only in specially hazardous places, r where persons would be liable to come in contact with the bare ive parts. These fuses of the enclosed type are strongly recommended for general use.

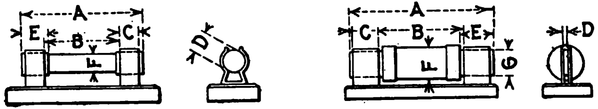
In 1903 the enclosed fuse was standardized by a special committee of the underwriters in consultation with the fuse manufacturers. (See specifications in **25**.) This was found necessary in order to secure an interchangeable fuse for any given capacity regardless of the make. This feature had previously been sadly lacking, and the result had been great inconvenience or the use of dangerous substitutes, such as fuse wire, wire nails, etc. The great advantages of an interchangeable fuse are evident.

24. **Relative cost of fuses** of capacities up to 25 amp. is given in Knox's *Electric Light Wiring* as follows: Open-link fuse with copper terminals, $\frac{3}{4}$ cent each; Edison fuse plug, 5 cents each; Edison fuse plug casing with cartridge fuse complete, 15 cents each; cartridge use, 8 cents each. These costs are approximate.

25. Dimensions of National Electrical Code Standard Enclosed Fuses

I Cartridge Fuse-Ferrule Contact (0 to 60 Amperes)

II Cartridge Fuse-Knife Blade Contact (61 to 600 Amperes)



. FIG. 10.—National electrical code standard fuses and holders.

Voltage	Rated capacity, amperes		A Length over terminals, inches	B Distance between contact clips, inches	C Width of contact clips, inches	D Diameter of ferrules or thickness of terminal blades, inches	E Min. length of ferrules or of terminal blades outside of tube, inches	F Diameter of tube, inches	G Width of terminal blades, inches		Rated capacity, amperes
0–250	0–30	Form 1	2	1	1/2	9/16	1/2	1/2		Form 1	0–30
	31–60		3	1 3/4	5/8	13/16	5/8	3/4			31–60
	61–100	Form 2	5 7/8	4	7/8	1/8	1	1	3/4	Form 2	61–100
	101–200		7 1/8	4 1/2	1 1/4	3/16	1 3/8	1 1/2	1 1/8		101–200
	201–400		8 5/8	5	1 3/4	1/4	1 7/8	2	1 5/8		201–400
	401–600		10 3/8	6	2 1/8	1/4	2 1/4	2 1/2	2		401–600
251–600	0–30	Form 1	5	4	1/2	13/16	1/2	3/4		Form 1	0–30
	31–60		5 1/2	4 1/4	5/8	1 1/16	5/8	1			31–60

26. **A cartridge fuse** consists of a tube of vulcanized fiber, aper or some similar material (Fig. 11) within which the fuse is nounted. The fuse terminals are connected with contact pieces t the ends of the tube. An insulating, porous powder resembling halk surrounds the fuse and fills or nearly fills the tube. When he fuse blows the powdered material disrupts the arc. Sometimes he fuse is surrounded by a small air chamber as shown in the lustration.

The formation of an arc is prevented in a cartridge fuse, thereore fuses of this type are more reliable than those of any other.

27. **National Code Standard Ferrule Contact Cut-out vs. dison Plug Cut-out.**—The following objections have been raised gainst the code standard fuse-and-holder combination, for currents f less than 60 amp., which is illustrated in Fig. 10.

1. The fuses are difficult to remove with the fingers. Tools are required some cases for their removal and the tools sometimes cause short-circuits.
2. The spring clips on the cut-outs are sometimes bent and broken off.
3. Frequently the contact between the fuse ferrules and the spring clips bad due to soft metal in the clips or bending by unskilled persons.
4. The ferrules of the 0–30 amp. fuse are so close together that a shock likely to be received when a fuse is being taken out or removed, when the orkman is standing on grounded conducting material.

The combination of a National Electrical Code standard fuse Fig. 12, *I*) enclosed in a porcelain Edison plug fuse casing (Fig. 2, *II*) and held in an Edison plug cut-out (*III*) is believed by any practical men to be much superior to the combination illusrated in Fig. 10.

The Edison plug arrangement, if it has any of the four disadvangeous features tabulated above, certainly has them to a lesser ex-

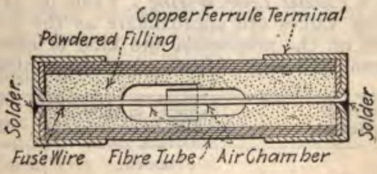


FIG. 11.—Cartridge-type enclosed fuse.

ent than does the spring-clip holder and ferrule fuse arrangement. dison plug cut-outs are not approved by the underwriters for ressures exceeding 125 volts or currents exceeding 30 amp.

An approved Edison plug cut-out and a fuse-plug casing of the –30 amp. size are made by the Bryant Electric Company for 250 olts. The threads of the cut-out socket and those of the casing e left-hand instead of the usual right-hand. Therefore fuse gs designed for 125-volt service (and which have a right-han ad) cannot be used in the 250-volt cut-outs.

28. Approximate Cost of Enclosed Fuses in Place (*Nelson S. Thompson, Electrical World*, Sept. 9, 1911).—5 to 65 amp., $0.10

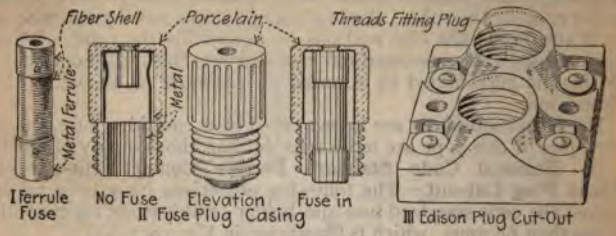


FIG. 12.—Edison plug cut-out and Edison fuse plug casing.

each; 65 to 100 amp., $0.25 each; 110 to 200 amp., $0.50 each; 225 to 400 amp., $0.90 each; 450 to 600 amp., $1.30 each.

29. Open-link fuses (Fig. 13) have the disadvantage of disrupting violently when short-circuited and may burn a person that is near. They blacken the panel that supports them. They are permitted by the Underwriters only when supported on slate bases and enclosed in iron cabinets. When so arranged they will give good satisfaction in industrial plant service where they are handled by journeyman electricians.

FIG. 13.—Link fuse.

30. Melting Points of Commercial Fuse Wire

From Knox's *Electric Light Wiring*. Table by Mr. Bathurst

The following values are approximate as the fusing point of metals depends on the proportion and kind of alloys used, kind and form of terminal, length of fuse and on other things.

Fusing current in amperes	Diameter in thousandths of an inch	Nearest B. & S. gage
1.7	0.010	30
4.9	0.020	24
9.0	0.030	20
11.3	0.035	19
13.3	0.040	18
19.8	0.050	16
25.4	0.060	14
32.0	0.070	13
39.1	0.080	12
54.1	0.100	10
63.1	0.110	9
81.1	0.130	8
90.6	0.140	7
100.5	0.150	7
110.7	0.160	6
132.1	0.180	5
154.7	0.200	4

31. Diameters of Wires of Various Materials That will be Fused by a Current of a Given Strength

Knox's *Electric Light Wiring*. Derived from tables of W. H. Preece

Current in amp.	Copper		Aluminum		German silver		Iron	
	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage
1	0.0021	43	0.0026	41	0.0033	39	0.0047	37
2	0.0034	39	0.0041	38	0.0053	35	0.0074	33
3	0.0044	37	0.0054	35	0.0069	33	0.0097	30
4	0.0053	35	0.0065	34	0.0084	31	0.0117	29
5	**0.0062**	**34**	**0.0076**	**32**	**0.0097**	**30**	**0.0136**	**27**
10	0.0098	30	0.0120	28	0.0154	26	0.0216	24
15	0.0129	28	0.0158	26	0.0202	24	0.0283	21
20	0.0156	26	0.0191	24	0.0245	22	0.0343	19
25	0.0181	25	0.0222	23	0.0284	21	0.0398	18
30	**0.0205**	**24**	**0.250**	**22**	**0.0320**	**20**	**0.0450**	**17**
35	0.0227	23	0.0277	21	0.0356	19	0.0498	16
40	0.0248	22	0.0303	20	0.0388	18	0.0545	15
45	0.0268	21	0.0328	20	0.0420	18	0.0589	15
50	0.0288	21	0.0352	19	0.0450	17	0.0632	14
60	**0.0325**	**20**	**0.0397**	**18**	**0.0509**	**16**	**0.0714**	**13**
70	0.0360	19	0.0440	17	0.0564	15	0.0791	12
80	0.0394	18	0.0481	16	0.0616	14	0.0864	12
90	0.0426	18	0.0520	16	0.0667	14	0.0935	11
100	0.0457	17	0.0558	15	0.0715	13	0.1003	10
120	**0.0516**	**16**	**0.0630**	**14**	**0.0808**	**12**	**0.1133**	**9**
140	0.0572	15	0.0698	14	0.0895	11	0.1255	8
160	0.0625	14	0.0763	13	0.0978	10	0.1372	7
180	0.0676	14	0.0826	12	0.1058	10	0.1484	7
200	0.0725	13	0.0886	11	0.1135	9	0.1592	6
225	**0.0784**	**12**	**0.0958**	**10**	**0.1228**	**8**	**0.1722**	**5**
250	0.0841	12	0.1028	10	0.1317	8	0.1848	5
275	0.0897	11	0.1095	9	0.1404	7	0.1969	4
300	0.0950	11	0.1161	9	0.1487	7	0.2086	4

32. Switches may be classified thus: (1) Surface switches, arranged for mounting on the surface of a wall, which may be of either the open knife-blade or of the enclosed snap-switch types. (2) Flush switches arranged for mounting in a wall or partition with their face plates and operating buttons practically flush with the surface of the wall. (3) Canopy switches which are mounted in wall bracket, electrolier or portable lamp canopies. (4) Pendent switches arranged to hang from a two-conductor cord and open and close the circuit of the cord.

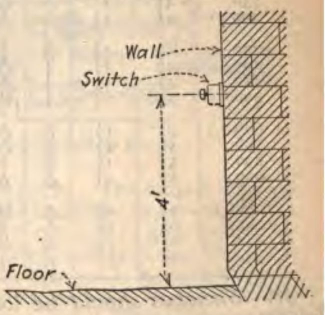


FIG. 14.—Location of wall switch

33. Copper fuses (Fig. 15) *stamped from sheet copper are used for the protection of underground and aerial circuits.* They have the disadvantage of becoming very hot before they rupture; at *75 per cent. of their fusing capacities they often becom* hot as to heat terminals or switches to which they are connected to undesirably high temperatures. Copper fuses should always be enclosed in iron boxes. The General Electric Company marks its copper fuses with the current that they will carry without undue heating and recommends them for the protection of underground circuits against dead short-circuits only. Many thousand are in use in this service and for it give excellent satisfaction.

34. Data on Dimensions of Copper Fuses
(From *Electric Light Wiring*—Knox)

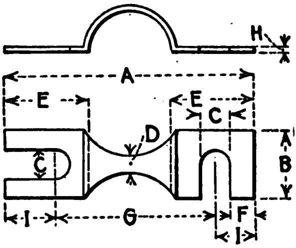


FIG. 15.—Stamped copper fuse.

Amperes	A	B	C	D	E	F	G	I	H
25	1 15/16	7/16	3/16	1/16	17/32	1/8	1 1/2	7/32	0.0071
50	2 1/4	5/8	1/4	1/8	11/16	3/16	1 5/8	5/16	0.0071
75	2 5/8	3/4	5/16	3/32	7/8	7/32	1 7/8	3/8	0.0126
100	3 1/8	7/8	5/16	1/8	1	9/32	2 1/4	7/16	0.0126
150	4 1/8	1	3/8	3/16	1 1/8	5/16	3 1/8	1/2	0.0126
200	4 1/4	1	7/16	1/8	1 3/16	9/32	3 1/4	1/2	0.025
250	4 1/4	1	7/16	5/32	1 3/16	9/32	3 1/4	1/2	0.025
300	4 5/8	1 1/8	7/16	7/32	1 3/8	11/32	3 1/2	9/16	0.025
350	4 5/8	1 1/8	7/16	1/4	1 3/8	11/32	3 1/2	9/16	0.025
400	4 3/4	1 1/4	1/2	9/32	1 7/16	3/8	3 1/2	5/8	0.025
450	4 3/4	1 1/4	1/2	5/16	1 7/16	3/8	3 1/2	5/8	0.025
500	5 1/8	1 3/8	1/2	11/32	1 5/8	7/16	3 3/4	11/16	0.025
600	5 1/4	1 1/2	9/16	3/16	1 11/16	15/32	3 3/4	3/4	0.051
700	5 1/4	1 1/2	9/16	7/32	1 11/16	15/32	3 3/4	3/4	0.051
800	5 1/2	1 3/4	9/16	1/4	1 13/16	19/32	3 3/4	7/8	0.051
900	5 1/2	1 3/4	9/16	5/16	1 13/16	19/32	3 3/4	7/8	0.051
1,000	5 1/2	1 3/4	9/16	11/32	1 13/16	19/32	3 3/4	7/8	0.051
1,100	6 1/2	2 1/4	9/16	3/8	2 5/16	21/32	4 1/4	1 1/8	0.051
1,200	6 1/2	2 1/4	9/16	13/32	2 5/16	21/32	4 1/4	1 1/8	0.051
1,500	7 1/2	2 3/4	9/16	1/2	2 13/16	1 3/32	4 3/4	1 3/8	0.051

5. **Switches should be located** 4 ft. from the floor (Fig. 14) ... are to control lighting circuits. This is the practice recom- ... *by The* American Institute of Architects. Sometimes the ... *the* **wood** work or decorations makes it necessary to ... **this standard.** Switches controlling the lights in a

room should be located at the entrance to it and not behind the door. Consult the plans and find which way the doors open. Cellar lamp switches should be at the head of the stairs. Hall lamp switches should be near the door into the hall. In first class work three- and four-way switches should be used so the hall lights can be controlled from any floor.

37. Cost of Knife Switches in Place

(*Nelson S. Thompson, Electrical World*, Sept. 9, 1911)

The values are for 250-volt, single-break switches with extension for fuses, polished and without bases, but mounted on panels.

Rating, amperes	Double-pole	Triple-pole
30	$ 1.80	$ 2.30
50	3.05	4.35
100	4.65	6.75
200	7.45	10.95
300	10.45	15.20
400	13.00	19.55
500	18.10	27.00
600	23.10	34.45
800	27.95	41.80
1,000	53.35	63.65
1,200	67.25	87.40

The cost of mounting an unmounted switch not including the drilling of the tablet board is $1.00 per switch.

38. **Knife switches** (*Power*, April 23, 1912) made by reputable manufacturers are constructed in accordance with National Electrical Code requirements. This pretty effectively protects the buyer, but any switch should be carefully inspected before it is purchased.

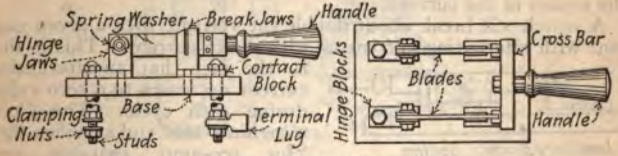


FIG. 16.—Names of knife blade switch parts.

Fig. 16 gives the names of knife switch parts. The contact between the break-jaws and the blade should be carefully inspected, as it is at this point that knife switches are most apt to give trouble by overheating. The contact between the hinge-jaws and the blade seldom limits the capacity of a switch, because it is under pressure from the hinge bolt and the spring washers. The capacity of a switch is determined by its temperature rise. The Code specifies a maximum rise in any part of 50 deg. fahr. at full-load.

39. *To make a contact between switch blade and jaws considerable skill is required.* After a switch is assembled, the jaws

are first bent into correct position either by hand or by driving a block of wood against the distorted portion with a hammer. Then they are "ground in" with vaseline and fine (FF) pumice stone. Often the "fit" of a switch is reasonably good at the start, and merely working the blade in and out of the jaws by hand will grind them in. Before the grinding process is started, the portion of the blade that wipes the jaws should be daubed with the vaseline and pumice stone compound. The abrasive not only "grinds in the fit" but wears off the lacquer, which, if it remained, might be the cause of a bad contact. The surplus compound should be removed with a rag.

40. **A test for good blade contact** can be made by trying to insert a "feeler," which is a leaf of very thin steel, mica or paper, between the jaws and blade at the corners and sides. About 0.001 in. to 0.004 in. is about the right thickness for a "feeler." An excellent feeler can be made by hammering down to a knife edge, the edges of a strip of very thin metal possibly 4 in. long and $\frac{3}{4}$ in. wide. If the feeler slips in at any point, it is evident that the "fit" is poor at that point and the contact bad. Proper forming of the jaw will correct the difficulty. There have been cases where switches have been made to carry, without excessive temperature rise, currents 50 per cent. greater than their normal ratings, by merely carefully fitting their jaws to their blades.

41. **Knife Switch Ratings.**—About 1,000 amp. per square inch of copper section and 50 to 75 amp. per square inch of sliding contact surface is usually allowed in designing switches.

A switch that will carry, possibly, 1,000 amp. with a 20 deg. temperature rise, will carry possibly 2,000 amp. with about a 60 deg. rise. The radiation of heat from the switch increases more rapidly than does the rise in temperature, and as the heat generated varies as the square of the current, it is evident that the temperature rise will be somewhat less than proportional to the square of the current.

A switch will break about double the voltage, with a given current with alternating current as with direct current. This is due to the fact that an alternating current decreases to a zero value during each cycle. The Code recognizes this and specifies that "for 100-amp. switches and larger, the spacings for 250 volts, direct current, are also approved for 250 volts alternating current."

FIG. 17.—A quick-break switch.

The voltage drop from contact-block to hinge-block of a good switch should not exceed about 12 milli-volts with full-load current.

42. **Quick-break switches** (Fig. 17) have an auxiliary breaking arrangement, actuated by a spring, making it difficult to draw an arc even if the switch is opened slowly. Usually the quick-break attachment is relatively delicate and is apt to get out of order. Where feasible, it is always better to use a switch without a quick-break attachment.

43. **Single-throw knife switches should be so mounted th**

gravity will tend to open rather than to close them. Double-throw switches can be mounted horizontally, but often when so mounted, it is inconvenient to connect to them, and they do not work in well with many switchboard arrangements; hence they are often mounted vertically and an insulating guard, possibly of wood, is arranged that may be slipped over the jaws on the lower terminals of the switch, to prevent accidental contact. Usually it is best to so connect a switch that the break-jaws will be "alive" and the blades dead when the switch is open. The blades expose more surface and extend further than do the jaws, hence are more liable to accidental contact and short-circuits than are the jaws.

44. **Enclosed snap switches are usually preferable to knife switches,** where it is feasible to use them. Snap switches can be obtained for breaking currents as great as 30 amp. at 250 volts. The unskilled person in opening and closing a knife switch is apt to draw an arc between the contacts, or only partially close the switch, which will pit the metal and ultimately ruin the switch. This condition cannot occur with a good snap switch. Only indicating switches should be installed.

45. **The remote control switch** can often be advantageously used. One manufacturer gives the following as a list of its desirable properties as applied to theater, large building and general wiring:

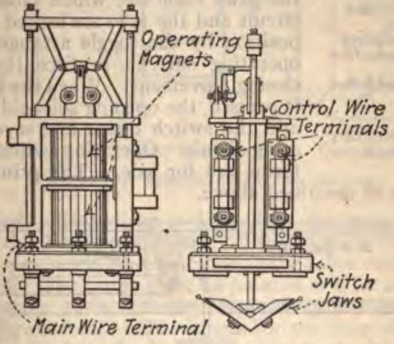


FIG. 18.—A three-pole remote control switch.

1. Simplifies wiring. Main wires can be run in most direct routes, without considering the locations of switch outlets.
2. Often saves money. It takes much less conduit and wire to properly wire some buildings and control the lights with remote control switches than with any other method.
3. Saves annoyance after the building is wired. All lights, or any groups of lights, in a building can be absolutely controlled at all times from any part of the building. Considerable advantages result and great savings ar thereby effected in public building and in apartment house light wiring.
4. Enables the owner or custodian of a building to positively cut off entire current supply of the building by merely pressing a flush push bu when leaving the building. This prevents waste of current by lights have been accidentally left burning, and it eliminates danger of ele fires.

5. Permits a watchman to control show-window or other store lights without entering the premises.
6. Makes possible the control of current distribution from distant points.

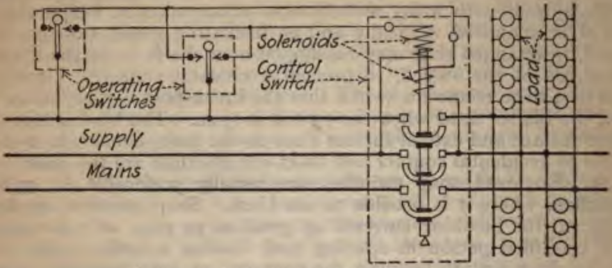


FIG. 19.—Remote control switch circuits.

46. A remote control switch is shown in Fig. 18, its circuits in Fig. 19, and the operating switch in Fig. 20. When the white button of the operating switch is pressed, it permits current to flow through the solenoid that closes the switch. It pulls the jaws together, which closes the main circuit and the jaws are locked in the closed position by the toggle arrangement. The operating current is discontinued by the closing movement. When the black button is pressed, the opening solenoid is energized and the switch opens and severs the operating circuit. Operating switches of several forms are for sale. The principles of all are essentially as described above.

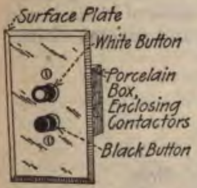


FIG. 20.—Momentary contact switch.

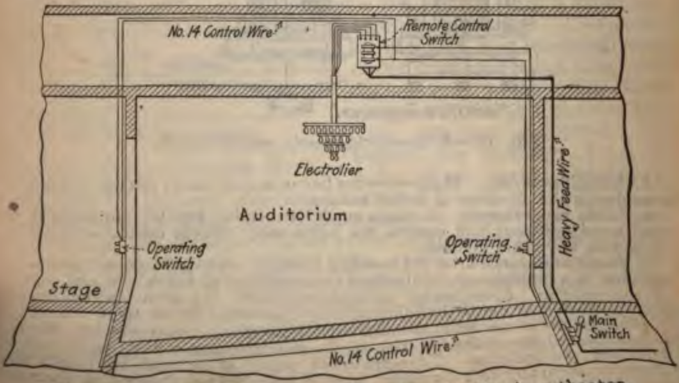


FIG. 21.—Remote control switch installation in a theater.

47. A typical remote control-switch installation is showı Fig. 21. The main conductors serving the electrolier are car to the remote control switch near it. Branch lighting circ from the remote control switch pass to the electrolier. The ϵ trolier is controlled by two conveniently located operating swit —there could be as many more operating switches as desired— the heavy conductors are not carried to the operating switc A saving in the cost of conductors thereby results. The opera circuits are of No. 14 wire. Many other applications will sug themselves wherein circuits may be controlled from various po without its being necessary to carry the main conductors to tl points.

48. An iron switch box can be readily made as illustrate Fig. 22 of sheet metal. It is probably always cheaper to bu switch box than to make one. When the homemade article n be used, the box is bent from the sheet metal which is indic

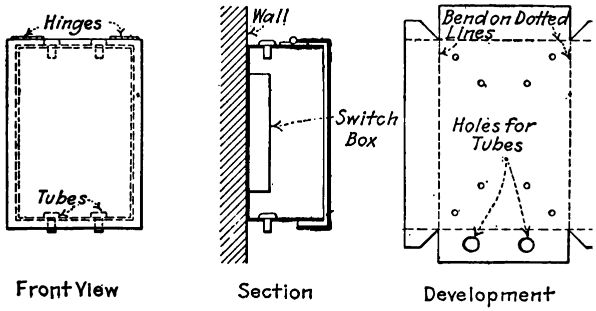


FIG. 22.—A homemade iron switch box

at *Development*. The cover is formed in the same way. A being bent, the sides are held in position with rivets. Holes punched for conductor outlets and ordinary tubes are used in tl for insulation. The boxes must be painted and be made of m not less than No. 12 B. & S. gage (approx. $\frac{1}{12}$ in.) thick to con with Code requirements. The hinges for the door are riveted Holes are provided in the back for securing the box to the and for supporting the switch within it with stove bolts. (*E trical World*, March 9, 1912.)

49. Wooden Switch Boxes can be Readily Made (*Elect World*, May 4, 1912).—Iron ones are preferable and can now secured from jobbers at costs that compare favorably with or less than those for homemade wooden boxes. Wooden b (Fig. 23) should be of $\frac{7}{8}$-in. well-seasoned wood and lined $\frac{1}{8}$-in. asbestos, secured in place with tacks and shellac. *iron $\frac{1}{16}$ in. thick or two $\frac{1}{32}$*-in. sheets may be used instead *bestos. The door should* close against a rabbet so as to *tight. Where a door is* wider than, say, 12 in., it should be *with either wood or* glass, to insure against distortion due ing. A space of 2 in. should be allowed between fuses and the door. A reliable catch should be provided on the door. Porcelain tubes or bushings should be used for insulating where wires enter the box, and should fit the holes snugly. Where necessary, wires should be taped so as to completely fill the holes in the bushings. Bushings reaching just to the inside of the box should be used, as longer ones will be broken. It is recommended that, for factory use, the top of the box be slanted as at III, so that it will not be used as a shelf. A box should be thoroughly filled and painted before it is lined.

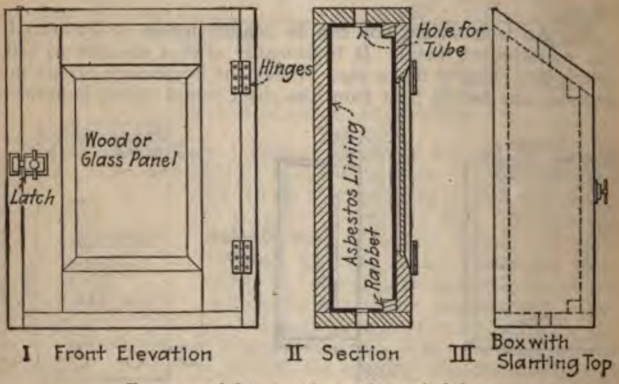


FIG. 23.—A homemade wooden switch box.

Several switches either snap or knife can be mounted in a box like that shown; in fact it might be used as a panel box. A box or cabinet similar to that of Fig. 24 is often convenient, in that it is not necessary to open the door to manipulate the switch. The heavy iron wire handle can be attached to the switch by bending it around the wooden handle, or the wooden handle can be removed and the wire fastened with a nut or a screw eye. If iron conduits, armoured cable or metal moulding terminate in a box, it should be of sheet iron.

50. Tablet or panel boards are made in many standard forms and capacities to fit the panel boxes made by their respective manufacturers. Practically all are constructed in accordance with the requirements of the National Electrical Code. One can be reasonably sure that the construction of the tablet boards that have been approved in accordance with the code will be of good construction. Plain black finished slate is probably the best and most serviceable material for a board and a plain lacquered finish on the copper is probably as good as any. In general, plug cut-outs are to be preferred and also snap switches are better than knife switches, particularly where they are to be manipulated by persons unskilled electrically. Tablet boards can be assembl from standard porcelain fittings, as suggested in Fig. 25, held with wood screws.

51. Panel boxes are cabinets arranged to contain cut-outs or cut-outs and switches for protecting and controlling branch circuits where they branch from a main. The miniature switchboard within the box supporting the cut-outs and fuses is called the panel board or the tablet board. It has been found desirable, in so far as possible to group cut-outs in a wiring system and

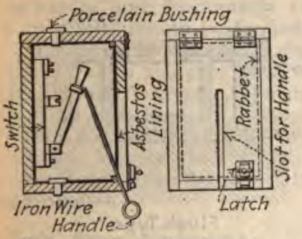


FIG. 24.—An enclosed wooden switch box.

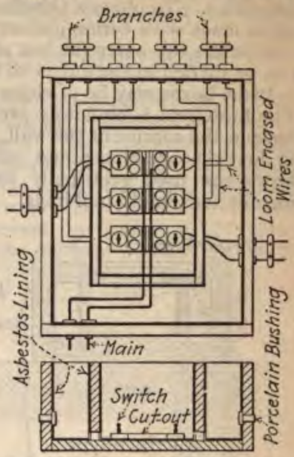


FIG. 25.—A homemade panel box.

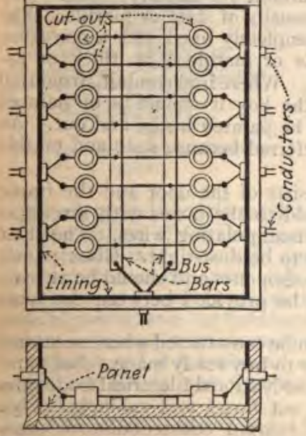


FIG. 26.—A panel box without gutter.

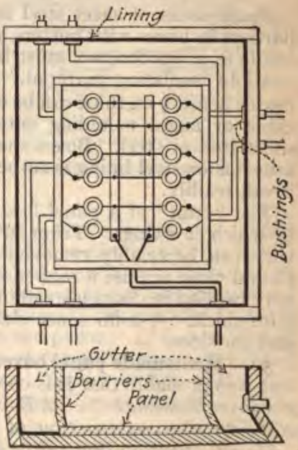


FIG. 27.—Panel box with gutt

this accounts partially for the popularity of panel boxes. The panel boxes were made without gutters (Fig. 26) and boxes type are still used to some extent. Their disadvantage is that it is necessary to carry the wires for each branch circuit to a point of the box opposite the proper cut-out. This is often inconvenient and expensive. To obviate this disadvantage panel boxes are now most often made with wiring gutters (Fig. 27). With this arrangement conductors can enter the box at any point on the sides or top and can be carried in the gutter to a point opposite the cut-out.

Panel boxes may be of either the flush or surface type (Fig. 28). The flush type is obviously preferable because it extends but little beyond the surface of the wall. Flush type boxes are always used in first-class residence and office building wiring. Surface type boxes are used principally for factory wiring and for conduit installations in old buildings.

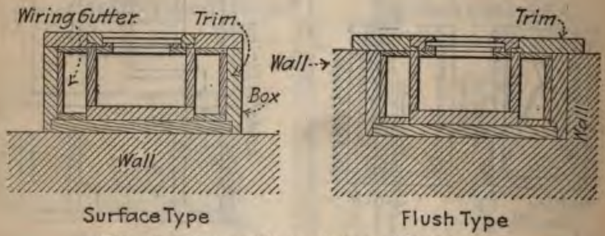


FIG. 28.—Boxes of the surface and flush types.

Panel boxes of sheet steel are suitable for factory work. The barriers in boxes with gutters are usually of slate or marble. The inside of a wooden box must be completely lined with a non-combustible insulating material. Slate or marble ¼ in. thick or asbestos board ⅛ in. thick can be used. Where iron conduit, armoured cable or metal moulding enters the box it should be of painted sheet iron or steel. Boxes should be painted inside and out. An asbestos or steel lining is to be preferred because slate and marble break readily.

The "trim" of a panel box consists of the door and the frame in which it swings. Trims are held to the boxes with screws so they can be readily removed for manipulating wires. The door should close against a rabbet so as to be dust-tight. Glass panels may be used in doors instead of wooden ones and should be at least ⅛ in. thick. A 2-in. space should be provided between the fuses and the door.

52. **Homemade panel boxes** can be constructed where necessary but it is probable that it is cheaper to buy ready made. See paragraph on *Homemade Switch Boxes* and National Electrical Code rules regarding the construction of cut-out boxes and cabinets. Figs. 23, 25, 26 and 27 illustrate the general construction of boxes. The barrier in a homemade box can be of wood in which case it must be covered on both sides with ⅛-in. sheet asbestos. For a homemade box standard porcelain cut-out fittings and standard snap switches can be used. They are held with screws to the

bestos covered back of the box. Heavy wire can be used for bus-bars. Fig. 25 illustrates the appearance of such a box and the trim can be made as shown in Fig. 28, which illustrates a box with a barrier. One without a barrier would appear like that of Fig. 26.

MISCELLANEOUS WIRING METHODS

53. **Service entrances** may be made as suggested in Fig. 29 where the wires enter the attic and as in Fig. 30 where the entrance switch and meter are in the basement. The cut-out (fuse-block) should protect the switch. The conductors should be bushed with porcelain tubes where they pass through a wall. Tubes or conduit should be cemented in the wall. The tubes should slant outwardly and downwardly to prevent the entrance of water. A drip loop should be formed in the service wires. The main switch should be arranged to disconnect all of the equipment in the building, except the main cut-out, from the outside wires. Where conduit is used for an entrance two or three rubber-covered wires can be carried in one conduit.

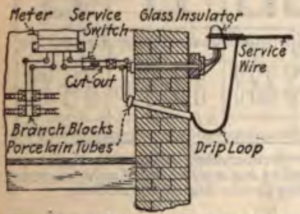


Fig. 29.—Entrance and service switch.

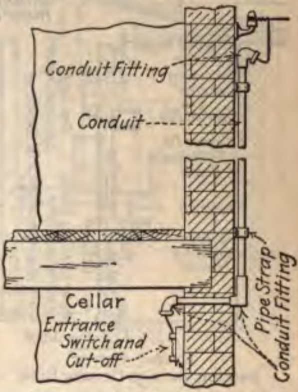


Fig. 30.—Conduit entrance.

54. **A typical electric service board** is shown in Fig. 31. (*Rules and Regulations of the Commonwealth Edison Co.*).—Service boards are used for installations of considerable capacity. The features of the board shown are: (1) The provision for the removal of links for meter testing and (2) the division of the elevator from the general power, and the lighting from the power. If energy is to be purchased a maximum demand form of contract, space and drilling must be provided for demand meters. Service boards of the general form shown are required by the Commonwealth Edison Company.

55. ***Brief of Underwriters'* Rules Covering the Installation of Switchboards** (*Factory Mutual Fire Insurance* Co's Wiring Rules).—*Switchboards should be made of slate or marble, supported metal frames, and should be located well away from combust materials. They* should always be open at the sides, and a

of at least 12 in. should be left between the floor and the board, and 3 ft., if possible, between the ceiling and the board, in order to lessen the danger of communicating fire to the floor or ceiling, and to prevent the formation of a partially concealed space, very liable to be used for the storage of rubbish, oily waste, etc. The instruments should be neatly arranged and the wiring on the back should be laid out in a careful and workmanlike manner.

It is recommended that all live parts, such as bus-bars and other conductors, be protected against accidental contact as far as practicable by suitable insulation, which shall be "flame-proof" or "slow-burning" and designed to withstand a reasonable amount of abrasion. The chances of accidental short-circuit and arcing

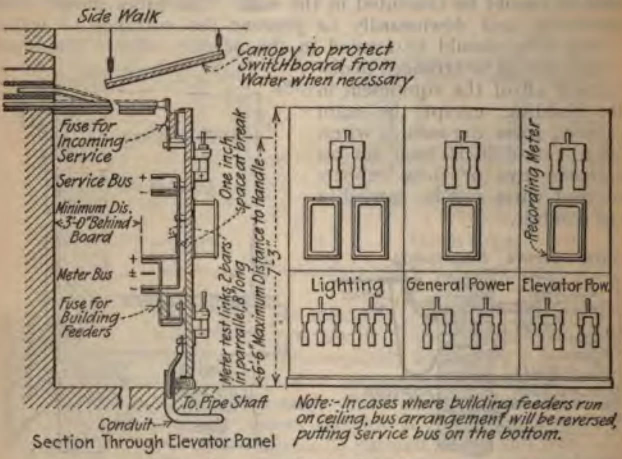


FIG. 31.—Service board.

at these points may thereby be greatly reduced. Insulated cable for bus-bars and connections is excellent for this purpose. However, the conductors could be wrapped or taped if this should be found more convenient, but this method should never be used unless it can be done *well*. Special precautions might also be necessary with either method if applied to high-voltage switchboards.

In addition to the usual measuring instruments and other apparatus, the switchboard should contain reliable devices for testing for grounds.

56. The following suggestions should be followed in wiring for watt-hour meters (*Rules and Regulations of the Commonwealth Edison Co., Chicago*): Meter loops should be provided in the mains at an accessible point, and so arranged that the meter may be mounted with ordinary wood screws on the wall. A meter board must be provided of sufficient size to allow the installation of a recording wattmeter and maximum demand meters. T demand meters are installed on three-wire mains. Maximum meters will not be installed on installations under 1 kw. Sufficient space must be provided about the meters to allow the removal of the case.

Meter boards should not be erected on a wall which is subject to any considerable vibration, or in places subject to excessive moisture or heat. A pressure wire tap must be provided in all cases where all wires of the circuit are not looped out. On three-wire mains the pressure wire tap must be made on the neutral wire. The general arrangements of meter loops should be such that a meter can be installed without crossing any wires, if possible. If this is impracticable, sufficient flexible tubing should be left on the wires to make possible an installation which will be in accordance with the wiring rules.

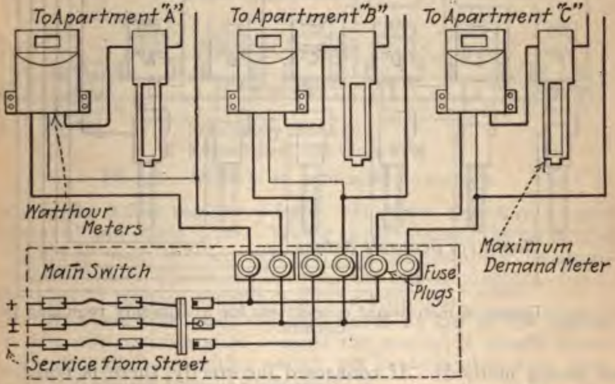


FIG. 32.—Diagram of meter connections and general wiring of meterboard for apartments requiring but one circuit.

Meter loops should not be placed above 7 ft. from the floor, and should be as near the point of entrance of the service as possible. In office buildings meter loops should be located at a central point in meter closets or public corridors, and in apartment buildings in the basement of the building, so that meters may be installed and maintained without annoyance to tenants.

Meter loops must be located relative to fuses so that meters are protected by the fuses. See Figs. 32 and 33. They must never be placed between the service and the service switch. Generally speaking, not more than one meter installation will be provided *for the same class of service* in any one building.

Meter loops for service to supply temporary lighting or power *to new buildings during construction must be located on adjoinin* *premises.* No three-wire meters larger than 200 amp. are use *stallations* requiring meters of larger capacity will be provi with two meters, one on each side of the three-wire main; space should be allowed accordingly in arranging meter boards.

57. **In connecting Edison plug cut-outs,** they should always be so arranged that the screw shells, which extend beyond the porcelain, will not normally be alive. Fig. 34, *I* and *II*, show the right

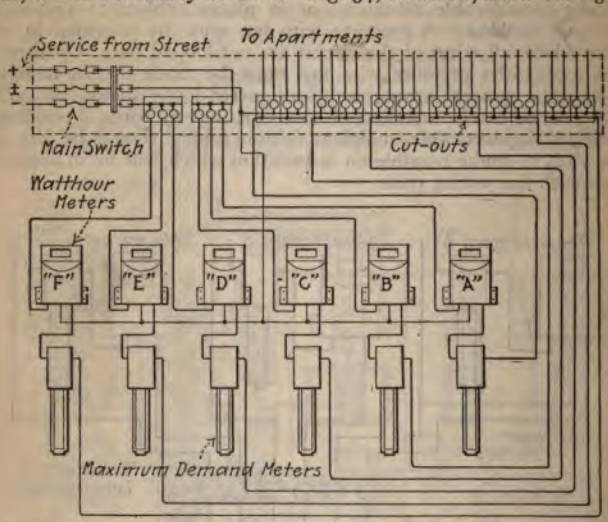


FIG. 33.—Design of meterboard connections for apartments requiring two circuits.

and wrong methods. If connected incorrectly, there is constant danger of short-circuit or shock when men are working about the cut-outs with bare wire ends or tools. Some makes of plug cut-outs are so constructed that the porcelain is higher than the screw shell which is thereby protected. Such cut-outs would be properly

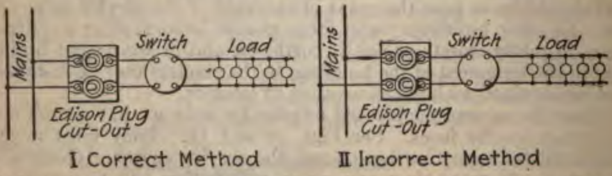


FIG. 34.—Correct and incorrect methods of connecting Edison plug cut-outs.

connected as shown in either *I* or *II* and should therefore be selected where possible. (*Electrical World*, May 4, 1912.)

58. **In protecting reinforcing conductors,** that is, in protecting conductors that are to operate in parallel with conductors alrea

installed, the methods illustrated in Fig. 35 may be used. Where small wires are involved and are so located as to be apt to be broken, each reinforcing wire should be protected with its own cut-out, as shown in *I*. Where the wires are heavy and not liable to breakage, both the reinforcing and the reinforced wire can be connected in parallel and can be protected by one fuse, *II*. If the method of *II* were used for the conditions recommended for *I*, one of the wires might break and the remaining one would be

FIG. 35.—Methods of reinforcing conductors.

protected by a fuse too heavy for it. It might, therefore, become overheated and cause a fire. Where at all feasible, the method of *II* should be used, because with that of *I* there is apt to be unproportional division of current between the two conductors, due to differences in contact resistance at the terminals.

59. A single-pole switch should never be cut in the neutral wire of a three-wire system because the neutral is usually intentionally grounded and with a switch, cut in the neutral wire, open, the path to ground may be destroyed.

60. A three-wire to two-wire change-over switch, or as it is sometimes called, a break-down switch, is connected as in Fig. 36. Such a switch is used when it is necessary to feed a three-wire system from a two-wire or from a three-wire source of energy. Where such a switch is installed the neutral of the three-wire system must have an area equal to the sum of the areas of the two outside wires because when operating from a two-wire source the current in the middle wire will be twice that (assuming the system to be balanced) in either of the outer wires. If arc lamps are used on such a three-wire system hey must all be connected between the neutral and a certain one f the outside wires or some special scheme of connection must be lopted. If they are not so connected, polarities will be reverse en the change-over switch is thrown.

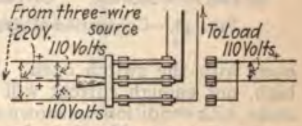


FIG. 36.—Three-wire to two-wire switch.

61. Connections are sometimes reversed in double-pole, snap switches, even by experienced wiremen. Many makes of snap switches "cross-connect" (Fig. 37), that is, the contact bar, when the switch is closed, connects each terminal with the one diagonally opposite. If, through error, the leads are connected as at *II*, a short-circuit may be established through the switch.

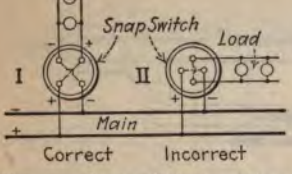


FIG. 37.—Snap switch connections.

62. Single-pole switches are permitted, by the Underwriters, on circuits carrying loads not exceeding 600 watts at pressures not exceeding 300 volts. This gives a maximum permissible current of 3 amp. at 220 volts, or 6 amp. at 110 volts. With these loads, single-pole switches will give good service in residences where the circuits are not apt to be disturbed, but in industrial plants, single-pole switches may give trouble, as described below, and it is good practice to use double-pole switches in such installations where reliability of service is important.

63. Single-pole switches may cause trouble because they open but one side of the circuit. For example (Fig. 38 *I*), if one side of a two-wire main happens to be grounded, a ground on the side of opposite polarity, on a branch circuit controlled by a single-pole switch, will form a closed circuit. If the grounds are of sufficiently low resistance, enough current will flow to light the lamps,

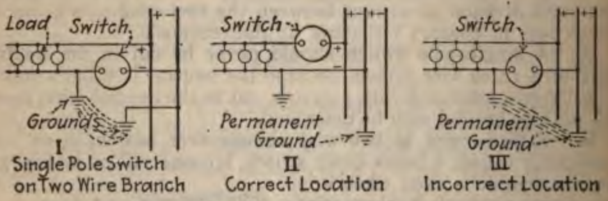


FIG. 38.—Connection of single-pole switch on branch circuits.

even with the switch open. If the resistance of the grounds is high, not enough current will flow to light the lamps. Furthermore, with conditions as shown at *I*, if a wireman accidentally touches a wire of the + side of the branch circuit to any grounded object, such as a gas pipe, a short-circuit would result.

64. Single-pole switches in two-wire branches from three-wire mains should not be inserted in the branch wire connected to the neutral wire of the three-wire system. (See Fig. 38, *II* and *III*.) The neutral of a three-wire system is usually permanently grounded at the central station as well as elsewhere, and with the switches in a neutral branch wire (*III*), trouble is more apt to occur than when the switch is in the other branch wire, as at II.

65. Where the switch must be at the opposite end of a room om the entrance the wiring should be arranged as shown at Fig. 9, *II* rather than as at . The method of *I* re-uires four wires the ength of the room while hat of *II* requires but hree.

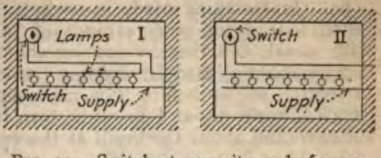


FIG. 39.—Switch at opposite end of room from entrance.

66. Wiring for a witch-controlled light-g circuit, which feeds om another circuit hich is also controlled y a switch. Three methods are shown in Fig. 40. With that f *I*, when the main circuit is switched off the branch circuit is

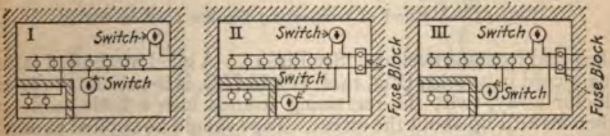


FIG. 40.—Control of lights on sub circuit.

extinguished also. With the methods of *II* and *III*, either the main or the branch circuit can be controlled independently but the arrangement of *II* requires four wires the length of the room, while that of *III* re-quires but three wires.

67. Where each half of the lamps in a room must be controlled in-dependently the method of Fig. 41, which permits of such control with minimum wiring, can be used.

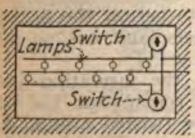


FIG. 41.—Each switch controls half of the lamps.

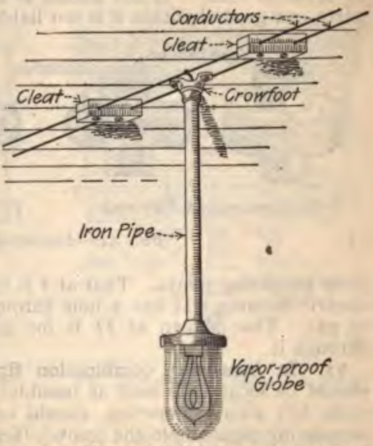


FIG. 42.—Vapor-proof globe on pipe hanger.

68. Sockets in rooms **where inflammable gases may exist** *hould be enclosed in* a vapor-tight globe (Fig. 42) and supported on a pipe-hanger, wired with approved rubber-insulated wire soldered directly to the circuit. The upper end of the pipe should be sealed with compound if the room is damp.

69. **In fastening cords in sockets,** some precaution should be taken to prevent stray strands of wire from coming in contact with metal, and thereby causing short-circuits or grounds. This can be accomplished by dipping the bared conductor of the cord in molten solder before it is made up under the binding screw. Strips of tape, about $\frac{1}{4}$ in. wide, torn from wider pieces, are sometimes wound about the braid at the end of bared cord, to prevent

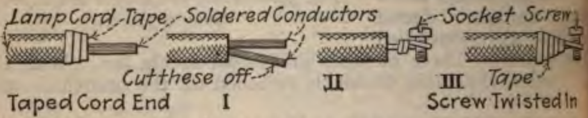


Fig. 43.—Method of connecting flexible cord in socket.

the braid from unraveling. See Fig. 43. A good method of fastening a cord in a socket (Fig. 43, *I*, *II* and *III*), is to cut half of the conductor away, twist the remaining strands into a little cable and then make it up about the screw. Tape should be applied as shown (*Electrical World*, May 4, 1912.)

70. **Insulating joints** (*Electrical World*, June, 29, 1912) are used to insulate fixtures from grounded parts of a building. The wiring spaces within fixtures are so confined that grounds are very liable to occur in them. If the fixture is insulated from the grounded parts, one ground within it is not liable to do harm. Fig. 44 shows

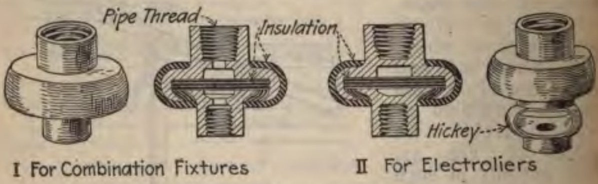
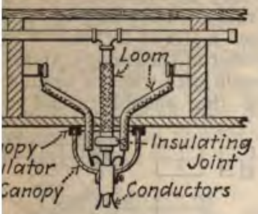


Fig. 44.—Insulating joints.

some insulating joints. That at *I* is used for combination gas and electric fixtures. It has a hole through it to permit the passage of gas. That shown at *II* is for electroliers, and has no hole through it.

71. **In insulating combination fixtures,** the insulating joint should be located as near as feasible to the ceiling, and the wire ends, left after connecting, should never be twisted around the supporting pipe above the joint. (See Fig. 45.) Flexible tubing is required on the wires in knob and tube work and it should extend to below the joint. The Code requires that the pipe above the joint be protected with insulating tubing, which may be either a heavy wrapping of tape or circular loom.

. **Fixtures can be supported in frame buildings** by the method g. 46. A wooden strip or cleat should be fastened just above ath during the construction of the building to take the screws ld a canopy block. The wooden canopy block supports, with len screws, the fixture crow-foot and insulates the canopy



5.—Insulating joint for a combination fixture.

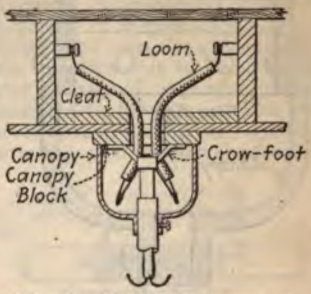
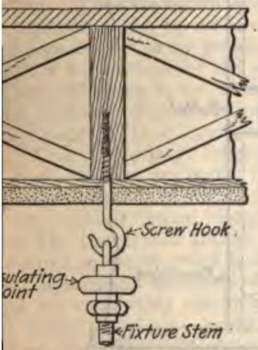


FIG. 46.—Electric fixture support.

the ceiling. A screw hook turning into a joist (Fig. 47) can sed for sustaining heavy fixtures in frame buildings. A special ating joint having an eye is screwed on the fixture stem to ate the fixture from the ceiling or a chandelier loop can be on a regular insulating joint. In fire-proof buildings, where



G. 47.—Supports for heavy fixtures.

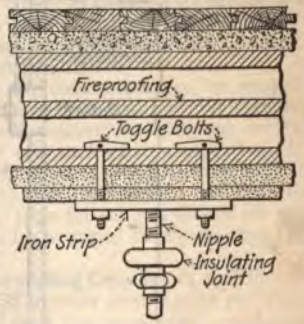


FIG. 48.—Support from a fireproof ceiling.

es must be erected after the building is completed, an iron (Fig. 48) held to the surface of the ceiling with a couple of e bolts can be utilized for supporting a fixture. A pipe or *it nipple, turning into* a threaded hole in the strap, takes the *t of the fixture.*

73. **Fixture canopies can be insulated** from ceilings and w
with commercial canopy insulators, of which there are many f
on the market. Canopies are usually supplied already fitted
insulating rings by the fixture manufacturers. Where canopy i
lators must be "home-made," the method of Fig. 49 or that of
50 may be followed. In Fi
a ring of fiber formed from
sheet material is bent to fi
interior of the canopy, and is
therein with wires or small ri
The ring should extend a

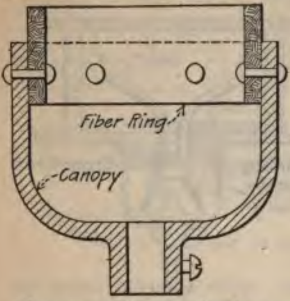


FIG. 49.—Fiber-ring insulator.

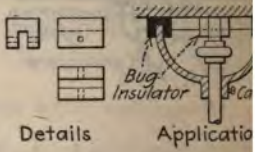


FIG. 50.—Bug insulator.

⅜ in. above the top edge of the canopy. Another canopy insul
sometimes termed a "bug" insulator, can be sawed from b
fiber, as shown in Fig. 50. The upper edge of the canopy
in a slot sawed in the "bug." At least three such insulators sh
be used for every canopy. A small nail or wire driven throu

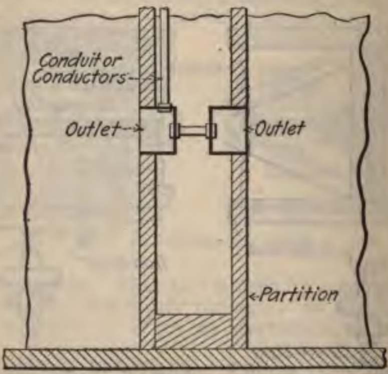


FIG. 51.—Outlets opposite one another in a partition.

hole in the insulator, and one in the canopy, holds each "bug
position. This method of Fig. 50 is not approved by the Un
writers, whose rules require that the entire edge of the canop
insulated.

74. **Wall or partition outlets in adjoining rooms should a** ***be located opposite one another*** (Fig. 51).—In general, this

both switch and fixture outlets. The reason is that in nearly ry case a considerable amount of wiring can be saved by follow- this construction. This applies to conduit as well as to knob l tube wiring.

5. **A method of making up a ground wire** where it is to be con- ted to a pipe and no ground clamp is available. A length, sibly 3 ft., of the ground conductor is "skinned" and carefully iped or cleaned with fine sandpaper. The pipe on which the nection is to be made is filed bright and clean for a distance of eral inches and "tinned" if the connection is to be soldered. en the bared end of the conductor is arranged, on the brightened tion of the ground pipe, as indicated in Fig. 52, *I*. The free of the wire (*c*, *c*, *c*) is then served around the pipe as suggested *II*, and the free end, *c*, of the wire is passed through the loop *B*

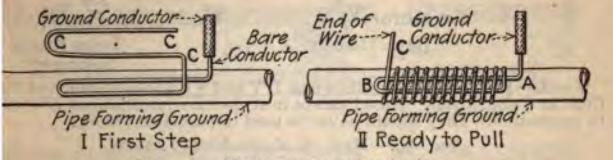


FIG. 52.—Making-up a ground wire.

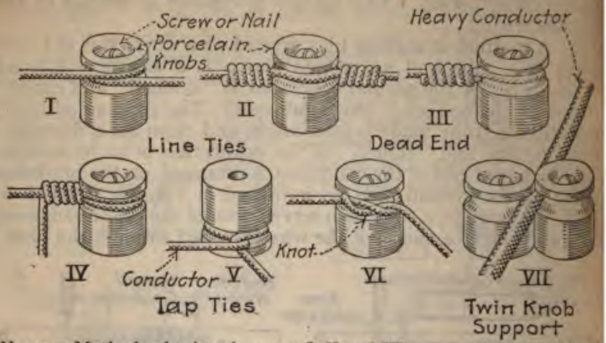
end *A* is then pulled. This draws the loop *B* and the end *c* tightly against the other turns and effectively prevents the pping from unwinding.

n an actual connection the turns on the pipe are wound closely ether. They are shown separated better to illustrate the method. connection can be soldered with a blow torch and wire solder g a paste flux or by pouring molten solder over the connection il it is hot enough for the solder to adhere.

Where soldering is not feasible the connection can be wrapped a couple of layers of tin-foil and then with several layers of tion tape. These layers exclude moisture and prevent oxidiza- . One of the large telephone companies has used the tin-foil tape method on many hundreds of ground connections for phone subscribers' stations with excellent results. The tin-foil tape should extend along the pipe for several inches on each of the connection and should be wrapped firmly so that they form a moisture-proof jacket.

5. **Knobs and Methods of Supporting Conductors on Them.**— obs for supporting conductors in interior work are of porcelain. t knobs or cleats should be used for supporting conductors ller than No. 8 B. & S. gage. Some methods of securing es to knobs are shown in Fig. 53. The line tie of *I* is made by ding the conductor once around the knob so both ends of the e must be under tension to hold the wire in position. A tie- e is used at *II*. In making up the tie-wire the slack can be wn out of the conductor. A dead end or termination is shown *II*. *Where it is necessary to change the direction of a run to the conductor to an outlet or for any other reason*, tap-ties

IV, V and *VI* are used. It is not practicable to tie large conductors so they may be supported as at *VII*. See following note.



NOTE.—Methods of tying shown at I, V and VI, are not approved by the *Code* and should not be used except in temporary installations not subject to inspection. They should never be used in permanent work.

FIG. 53.—Methods of attaching to knobs.

77. **Tie-wires** must have an insulation equal to that of the conductors they confine and may be used in connection with solid knobs for the support of wires of size No. 8 or larger.

EXPOSED KNOB AND CLEAT WIRING

78. **Exposed knob and cleat wiring** is one of the cheapest and best methods when properly installed (*Standard Handbook*). It finds wide application in factories and mills and in places where appearance is of little consequence. It is also used for running feeders in tunnels and in specially built feeder shafts in fireproof buildings. The wires may be rubber-covered or provided with slow-burning weather-proof installation. Slow-burning wire can not be used in cellars, basements, under roofs or in other places exposed to moisture. The wires must be supported at least every $4\frac{1}{2}$ ft., except in mill buildings where a support on each beam may be approved for wires No. 8 and larger if they are separated at least 6 in. The wires must, in dry places, be separated $\frac{1}{2}$ in. from the surface wired over and spaced $2\frac{1}{2}$ in. apart for voltages below 300. Above 300 volts and up to 550 volts, the wires must be separated from the surface wired over by at least 1 in. and must be spaced 4 in. apart. In wet places wires must be at least 1 in. from surface wired over for voltages below 300.

79. **Mechanical Protection of Exposed Surface Wiring.**—The wires must be protected on side walls from mechanical injury and when crossing floor timbers in cellars or in rooms where they may be disturbed (Fig. 54), the wires must be attached by their insulating supports to the under side of a wooden strip or "run

oard" not less than ½ in. thick and 3 in. wide. Instead of running oards, guard strips on each side of and close to the wires may be ubstituted. The strips should be at least ⅞ in. thick and should e as high as the insulators. The wires should also be protected y porcelain tubes when passing over pipes (Fig. 55) or any other nembers.

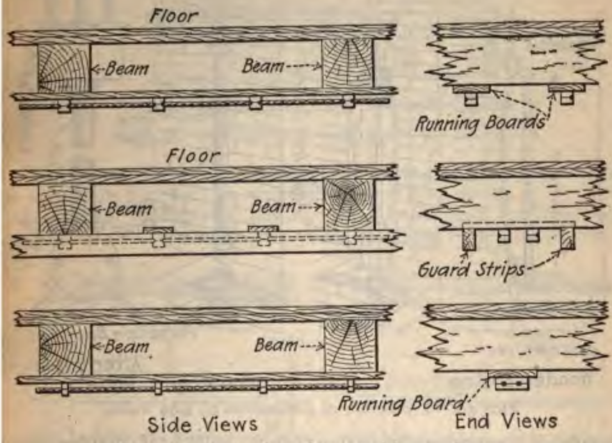


FIG. 54.—Protection of open-wiring on beams.

80. Suitable protection on side walls should extend not less han 7 ft. from the floor (Fig. 56). This may consist of substantial oxing, providing an air space of 1 in. around the conductors, losed at the top (the wires passing through porcelain bushed oles) or of approved wrought iron conduit or commercial wrought

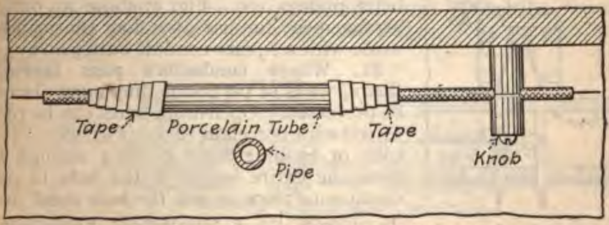


FIG. 55.—Protection of conductor passing over pipe.

on pipe. When common pipe is used, the insulation of each *re must be reinforced by approved flexible tubing extending n the insulator next below the pipe to the one next above it. ere single-braid rubber-insulated wire is used in conduit th* same protection must be provided. Where double-braid-insulated wire is used in conduit the flexible tubing can be omitted, but each end of the pipe must be provided with an approved outlet box.

The two or more wires of a circuit, each with its approved flex-

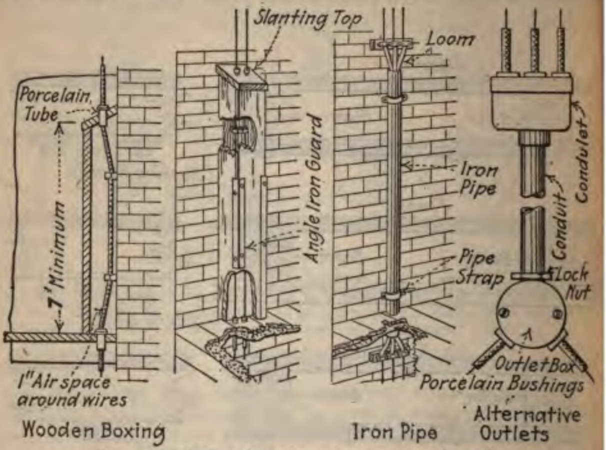


FIG. 56.—Protection of conductors on side walls.

ible tubing, if carrying alternating current, *must*, or if carrying direc current, may, be placed within the same pipe. In damp places th wooden boxing may be preferable because of the precautions whic would be necessary to secure proper insulation if pipe were usec With this exception, however, iron pipe considered preferable to wooden boxing, an its use is strongly urged. It is especiall suitable for the protection of wires ne belts, pulleys, etc. Fig. 57 shows an outl arrangement for use at a floor that can b made with a square conduit outlet box.

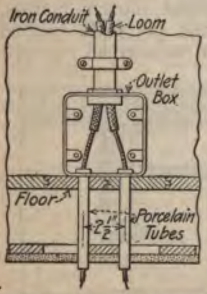


FIG. 57.—Another outlet arrangement.

81. **Where conductors pass throug floors, walls or partitions they must alwa be protected.** Open-work wires can be pr tected with porcelain tubes (Fig. 58). Th tube or bushing must be long enough bush the entire length of the hole in or continuous piece or else the hole must fir be bushed by a continuous water-pro tube. This tube may be a conductor, suc as iron pipe, but in that case an insulati *bushing must* be pushed into each end of it, extending far eno to keep the wire absolutely out of contact with the pipe.

82. **A tube for protecting a wire where it crosses anothe should always be so placed that the tube will not force t**

protected wire against the surface supporting the conductors. The tube should always be on the inner wire (Fig. 59). If placed on the outer wire, the tube may force the unprotected wire against the surface as shown in Fig. 59, *I*. (*Electrical World*, April 6, 1912.)

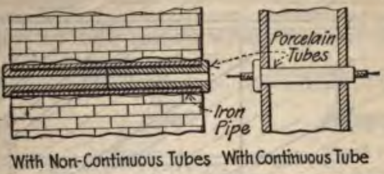


FIG. 58.—Protection through walls and partitions.

83. A method of supporting open wiring in concrete buildings is shown in Fig. 60. A round groove of $\frac{3}{8}$-in. radius is cast in the faces of the beams, by having $\frac{3}{4}$-in. half-round molding nailed in the forms. Wrought-iron yokes are bent to fit the grooves as

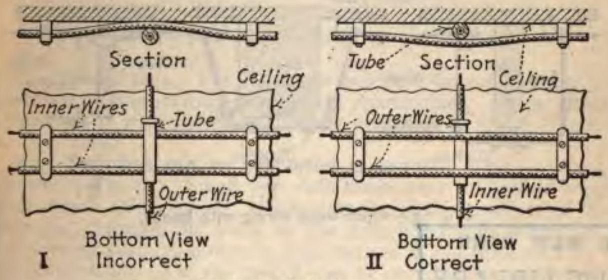


FIG. 59.—Methods of placing protecting tubes.

shown, and $\frac{1}{2}$-in. bolts clamp them in position. Although molding and conduit is shown supported in the illustration, wooden blocks can be bolted to the yokes and thereby open wiring can be supported.

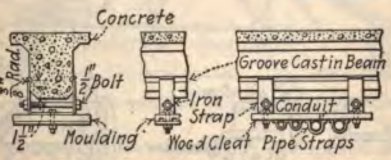


FIG. 60.—Supporting conductors on a concrete beam.

84. Methods of carrying exposed wiring around and through beams are illustrated in Fig. 61 which shows the tube and cleat arrangements. In Fig. 62 are shown some methods that can be used when wires are supported on knobs.

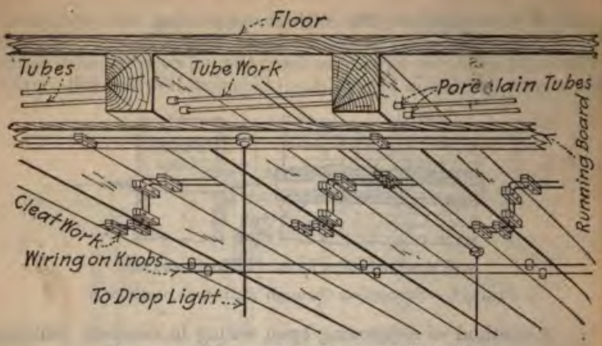


FIG. 61.—Open-work wiring in a mill building.

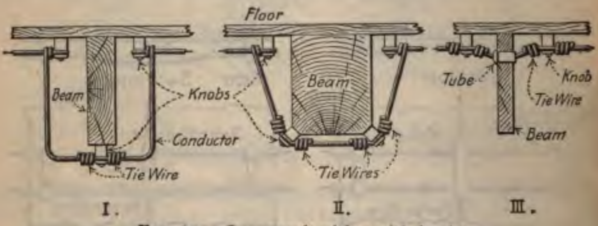


FIG. 62.—Open work wiring with knobs.

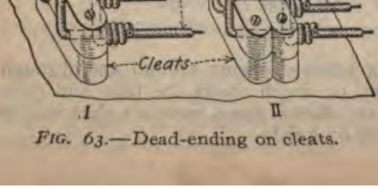


FIG. 63.—Dead-ending on cleats.

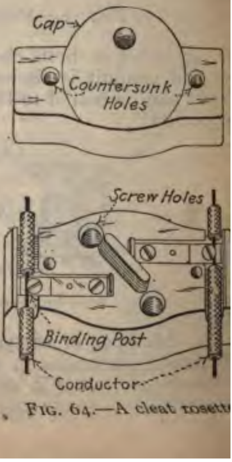


FIG. 64.—A cleat rosett

85. The method of dead ending on a cleat at the end of a run is illustrated in Fig. 63, *I*. After the wire is passed through the groove the free end is given several short turns around the line. Where a long run is dead ended it is often advisable to so fasten two sets of cleats that one bears against the other so that both will assume the strain as shown at *II*.

86. Rosettes for open surface wiring are used to connect the drop cords for the incandescent lamps to the branch circuits. A rosette with protected (concealed) contact lugs is preferable to one

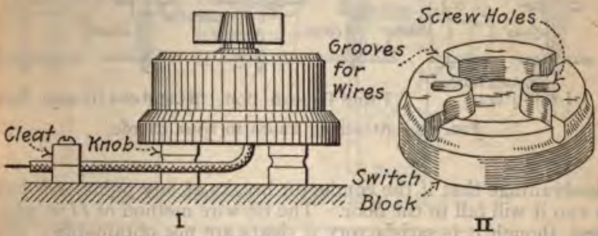


FIG. 65.—Supporting switches in exposed surface wiring.

with exposed lugs. Fig. 64 shows one good type. Another good method of supporting drop cords, particularly where there is vibration, is with the ceiling button described in **5** and illustrated in Fig. 76A.

87. Switches can be supported in exposed surface wiring as shown in Fig. 65. Small porcelain knobs may be used to support the switch (Fig. 65, *I*), which permits of the conductors being brought through the back of the switch without touching the supporting surface, however, this method is not approved by the National Code. Or the switch can be mounted on a commercial porcelain switch block (Fig. 65, *II*), which is an approved method.

FIG. 66.—Conductors carried on roof truss.

88. The different approved methods of exposed surface wiring as arranged in a building of mill construction are illustrated in Fig. 61. Which method should be used in any particular case is a matter that is largely determined by the size of wire involved and other local conditions.

89. ***In steel mill buildings* heavy conductors may be carried** *on the lower chords of the roof trusses* (Fig. 66). This is a good location as the conductors are out of the way and not liable to be disturbed. At each truss the conductors can be supported by one of the methods illustrated in Fig. 67. With the method of Fig. 67, *I*, the conductor merely rests in the insulator and the entire longitudinal strain is taken by strain insulators, attached to tightening bolts or turnbuckles, at the ends of the run. This method has the

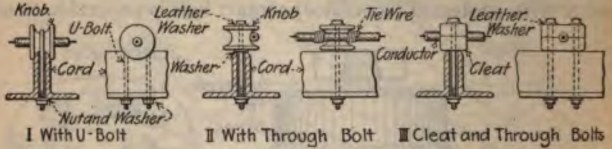


FIG. 67.—Attaching knobs to truss chords.

disadvantage that if the conductor breaks at any point or is burnt in two it will fall to the floor. The tie-wire method of *II* is seldom used, though it is satisfactory if cleats are not obtainable. (Split knobs or cleats must be used for conductors smaller than No. 8.) The cleat and through-bolt method of *III* is probably the best, all things considered. After the conductor has been drawn taut with the tightening bolts at the ends of the run the cleat bolts are tightened and each cleat then assumes its share of the strain. Tie-wires which are unreliable and which may cut into the insulation of the conductor are unnecessary. Leather washers should be used between the insulator and bolt to prevent breakage. Material that follows on Steel Mill Building Wiring is largely from an article in the *Southern Electrician*, December, 1912, by the compiler of this book.

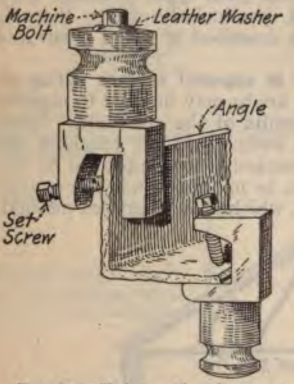


FIG. 68.—Universal insulator supports on an angle. (Note that split knobs must be used where conductors smaller than No. 8 are to be supported.)

90. For supporting conductors on steel angles the Universal Insulator Support (Figs. 68 and 69 and Table **91**) is a convenient fitting. It is of malleable iron and can be clamped on the flanges of steel beams, angles, channels, Z-bars, and on round, square and flat bars. It can be also attached to gas and water pipes, and to the edges of plates and tanks. Two insulators can be fastened to each support when necessary. Cup-pointed, case-hardened set screws are used. Leather washers should be used under the bolts that hold the insulators.

91. Dimensions of Universal Insulator Supports
(*Steel City Electric Co., Pittsburgh, Pa.*)

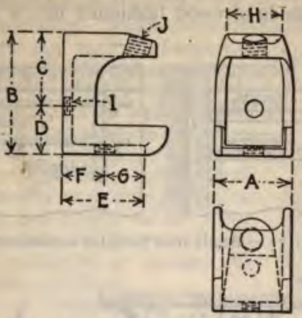


FIG. 69.—The universal insulator support.

For insulators, numbers	B in.	C in.	D in.	E in.	F in.	G in.	H in.	I Dia. of tapped hole	J Dia. of set screw furnished
5, 5½	1½	$\frac{7}{8}$	$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{9}{16}$	½	¾	¼	$\frac{5}{16}$
10, 4, 4½	1¾	1¾	$\frac{5}{8}$	1½	$\frac{9}{16}$	¾	¾	$\frac{5}{16}$	$\frac{7}{16}$
1, 3, 3 W.G., 3½, 24	2	1	1	2	1	1	¾	$\frac{3}{8}$	½
25, 29, 34	2½	1¼	1¼	2½	1¼	1¼	¾	½	$\frac{5}{8}$

. **For supporting conductors on steel columns** a wooden -board for the cleats clamped to the column with hook-bolts,

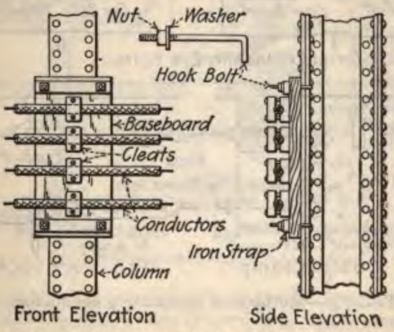


FIG. 70.—Attachment of wiring board to column.

, *is a good arrangement.* The board must be cut out in or the rivet heads in the column. Strap iron cleats through he hook-bolts pass prevent warping and splitting.

93. Wire-racks are used to support conductors, principal heavy ones, where there are many conductors in the run. Th conductors should have flame-proof or slow-burning insulation. wire-rack can be made of wood fashioned into a framework som

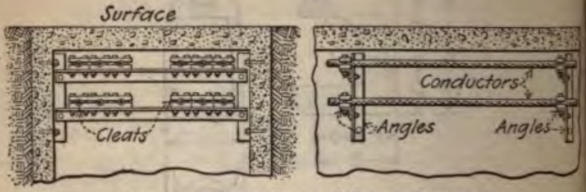


FIG. 71.—Angle iron rack for conductors.

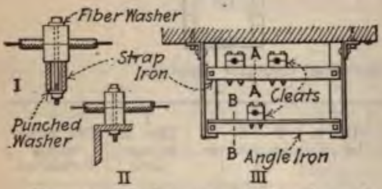


FIG. 72.—Rack composed of angles and strap iron.

FIG. 73.—A commer insulator rack.

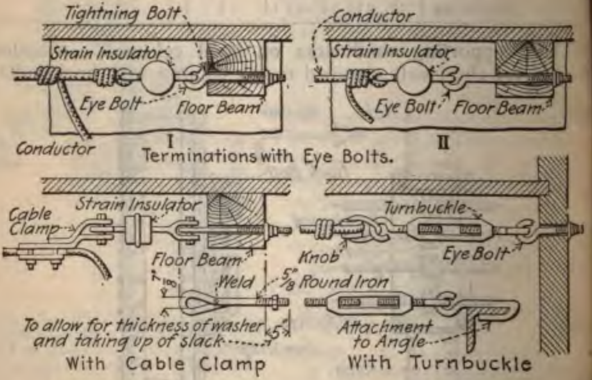


FIG. 74.—Methods of terminating conductors.

what along the lines of the steel ones of Figs. 71 and 72. Th cleats insulating the conductors are held to the frame with w screws or, preferably, with machine or stove bolts. A comm wire rack with a cast-iron base that can be bolted to any is shown in Fig. 73. Generally a steel-frame rack is prefer oden one. The rack of steel angles of Fig. 71 was designed for tallation in the top of a pipe tunnel. The insulators are held to cross angles with bolts with a leather washer under the head each. The structural steel rack of Fig. 72, *III*, is arranged for porting from a ceiling. Angle cross-arms can be used as at *II*, the cross-arms can each be formed of o iron straps as at *I*. With the two-strap thod, drilling for the cleat bolts is unnecary and the cleats can be shifted along arm into any desired position and there mped fast. Strain insulators engaging turnbuckles or tightening-bolts should used at the ends of each straight run to ume the strain and to provide for tighting or else the arms and cleats at the run ls should be reinforced to assume the ess that will come on them.

FIG. 75.—Weatherproof socket.

4. Methods of Terminating Heavy nductors.—At the ends of all important en-wire runs of wires larger than, say,. . 8, strain insulators engaging in some e-tightening device should be used. Fig. 74 illustrates some thods. Either tightening-bolts or turnbuckles can be used. e insulator may be of the type extensively used in trolley line struction as in *I*, *II* and *III*, or it may be a heavy knob (*IV*), d to the tightening device with stout wire. Where a run anges direction a cable clamp (see index for a further descrip-

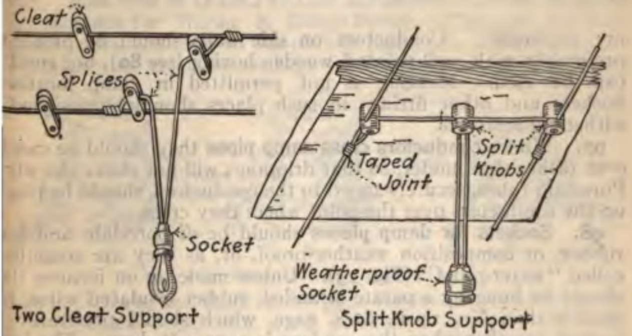


FIG. 76.—Short weatherproof pendant.

n) can often be used with economy, particularly with large conctors. Where a cable clamp is used it is unnecessary to cut the nductor to change its direction and the necessity of making-up ns about the line wire as in *I* and *II* is eliminated.

. Water-proof Pendants (*Factory Mutual Wiring Rules*).—incandescent lamps in wet places, approved water-proof ts should be used. These sockets should be suspended by separate, *stranded*, rubber-covered wires, soldered to the socket leads and also to the overhead wires. Where the pendant is over 3 ft. long, the wires should be twisted together. The entire weight of the pendant should be borne by cleats or some other independent means, in order to prevent any strain on the connection to the overhead wires. (See Figs. 75, 76 and 77.)

96. In wiring in damp places such as in dye-houses, stables and breweries, wires should be rubber insulated, and separated at least 1 in. from the surface wired over, preferably by knobs. Solid knobs are preferable to split ones, because there is more liability of current leakage to the screw of a split knob. They should be separated by at least $2\frac{1}{2}$ in. for voltages up to 300 and 4 in. for voltages up to 600. Greater separations

FIG. 76A.—Ceiling buttons.

FIG. 77.—Long weather-proof pendant.

are preferable. Conductors on side walls should be protected preferably with well-painted wooden boxing (see **80**), but conduit can be used. Molding is not permitted in damp locations. Sockets and other fittings in such places should be designed to withstand moisture.

97. Where conductors cross damp pipes they should be carried over rather than under, so that drippings will not strike the wires. Porcelain tubes, securely taped to the conductors, should be placed on the conductors over the point where they cross.

98. Sockets for damp places should be of porcelain and hard rubber, or composition weather-proof, or, as they are sometimes called "water-proof" (Fig. 75). Unless made up on fixtures they should be hung by separate stranded, rubber insulated wires, not smaller than No. 14 B. & S. gage, which should preferably be twisted together when the pendant is over 3 ft. long. The leads furnished in weather-proof sockets are 6 in. or 8 in. long, but longer ones can be supplied on special order. The socket leads should be soldered direct to the circuit wires but supported independently of them. Fig. 76 shows a short drop and Fig. 77 a long one; both figures illustrate the method of using cleats to remove the stress from the line conductors. Water-proof sockets are always keyless. Porcelain sockets are easily broken; hence, although their use not formally approved by the Underwriters', brass-shell sock thoroughly taped and coated with water-proof paint, are sometimes used. Where not liable to be broken, porcelain sockets are the best.

99. Receptacles for damp places are shown in Fig. 80. They are especially designed to withstand moisture, but should always be supported on porcelain knobs. The rubber insulated leads extend 6 or 8 in. from the body. The leads should be soldered directly to the line wires and the joint well taped.

100. Wiring troughs are sometimes used in damp places. (Fig. 78.) The troughs protect the conductors from drippings, but not from water that condenses on them out of the atmosphere. In assembling wiring troughs, abutting edges should be coated with

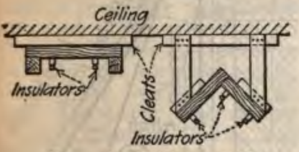


FIG. 78.—Wiring troughs.

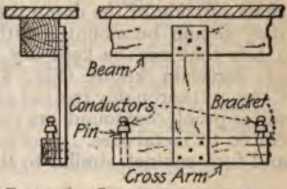


FIG. 79.—Cross-arm support.

tar or with a thick water-proof paint. Screws smeared with paint should be used to hold the pieces together and the screw heads should be painted. A wiring trough in addition to keeping drippings from the conductors, constitutes a mechanical protection for the conductors. The wiring trough serves the same purpose as a running board in this respect.

101. Porcelain or Glass Petticoat Insulators Probably Form the Best Support for Wiring in Damp Places.—These are the same insulators that are used on out-of-door pole lines. There is apt to be considerable electrical leakage in damp places with ordinary

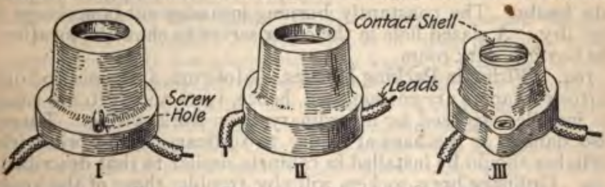


FIG. 80.—Receptacles for damp places.

knobs and cleats, and the long creepage distance provided by petticoat insulators constitutes good protection against this. The insulators are supported on thoroughly painted wooden pins or brackets, which are held by small cross-arms (Fig. 79). In no case should the insulator be mounted upside down. Glass or porcelain knobs, mounted on a small cross-arm, are sometimes used instead of insulators, *but are not as good from an insulation standpoint. The advantage of mounting* them on the arm is that an ample *separation from the surface* wired over is thus provided. The *cross-arm and support* should be thoroughly painted with a water-*proof paint or tar.*

102. Joints and splices in damp places must be solde great care and should be thoroughly taped. A thorough of the tape wrapping, with a water-proof compound, as or tar, will protect against the entrance of moisture. Splic be avoided in damp places, but where necessary, they sl located at some distance from a point of support, because th tion resistance of the insulation around a splice is less tha equal length of perfect wire.

103. Switches and fuses for wiring in damp locations if possible, be located outside of the damp room and in a d Where it is impossible to locate them outside of the damp room they should be mounted within a box that can be kept dry, or on porcelain knobs (Fig. 81). Cabinets thoroughly treated with water-proof compound are preferable to metal ones. A switch-and-fuse cabinet similar to that

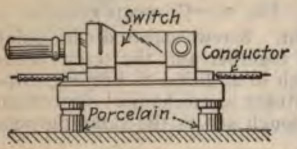


FIG. 81.—Knife switch mounted on porcelain knobs.

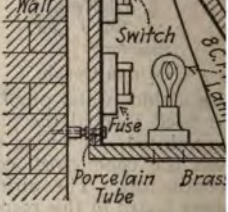


FIG. 82.—Switch and fus damp places.

of Fig. 82 can be made of ⅞-in. stock. It is lined with well asbestos board and mounted away from the damp wall o lain knobs. The constantly burning incandescent lamp k box dry. A glazed hole in the cover serves to show the lo the box in a dark room.

104. Wiring in Packing Houses.—Moisture, ammonia a corrosive vapors are encountered, hence, fuses and switche be installed exposed as in ordinary open-work wiring. also danger of mechanical injury to ordinary open-work Switches should be installed in cabinets similar to that des 103. Ordinary brass sockets will give trouble; those of the type of porcelain, hard rubber or composition may be used wiring on knobs is usually preferable because of the tro countered with conduit due to corrosion, even if it is th painted. The rusting gives the most trouble at the threa couplings.

To support the knobs, blocks of wood impregnated with tum, tar or shellac are nailed to the wall or ceiling. Th provide ample clearance between the surface and the con A method of carrying conductors that largely prevents r from reaching them and the knobs is shown in Fig. 79. T are considered preferable to split knobs for this work becau better insulating properties of the tie knobs.

105. Brewery wiring is subject to conditions similar to, though less severe than, those affecting packing-house installations and in general should be treated accordingly. Conduit can be installed to advantage in many locations. In the others, open wiring on knobs can be effectively used, especially in the compressor rooms, the wash rooms and in the tank cellars. Weather-proof switch boxes of the type herein before described should be used unless switch cabinets are installed.

106. Wiring in Flour, Cereal and Planing Mills.—Switches and fuses should be installed in dust-tight cabinets, as should starting rheostats for the motors. There are on the market dust-proof switch cabinets, starting boxes and other appliances which should be used in preference to homemade ones. Lamps installed in sockets attached to side walls involve a fire risk as the dust may deposit on them and ignite. Suspend the lamps from the ceiling. Since the dust may get into them and be the cause of an explosion or a short-circuit, key sockets should not be used. Wrought-iron conduit work is probably the preferable type of wiring.

107. Chemical Works Wiring.—Lead cable sheaths, iron conduit and slate are usually attacked by the vapors, while porcelain, as a rule, is not. The following method of installing conductors has been used with success in one prominent works. Conductors having weather-proof insulation are installed in hard-wood molding and are buried in tar in the grooves. Both the molding base and the capping are served with a thick coating of tar before they are installed and also afterward. For lamp outlets, molding receptacles are used. Before each lamp is screwed into its socket, a ring of heavily tarred wire is slipped over the base. This ring seals the opening and prevents the entrance of corrosive vapors into the receptacle. The entire installation—molding and fittings—should be thoroughly coated with tar.

108. Wiring in Dry Kilns (H. G. Wilson, *Electrical Review*, Feb. 17, 1912).—Rubber-covered wire is of little practical value in these excessively hot places either on knobs or cleats or in conduit, as after a comparatively short time the rubber is thoroughly dried out and becomes brittle and crumbles. Dry kilns are usually constructed of brick with a structural steel framework. Experience has shown that wooden blocks fastened to the walls and framework shrink to quite an extent and in some places char with the heat. Consequently, they become loose and fail to sustain the wires. Profiting by experience, rubber-covered wire, wooden blocks and conduit were eliminated altogether from a certain dry-kiln job. Asbestos-covered wires with a 6-in. separation and not less than 1 in. from the surface wired over were installed. Supports were placed every $4\frac{1}{2}$ ft. Split knobs fastened securely to the iron framework with bolts were used, the holes being drilled through so that nuts held them in place and, where this was impossible, the holes were drilled and tapped with threads corresponding with those on the bolts. For supporting the wire on brick side walls, iron brackets were made which carried knobs.

Porcelain wall sockets were used where practicable. For drop lights another Code rule was "stretched," as No. 14 solid asbestos-covered wire had to be used. The drop wires were pe separated, from their joints on the circuit wire to the sockets, by cleats held together by stove bolts, thus givi separation, and the taps were anchored by split knobs, or wire. Fuses, switches and cut-out cabinets were plac of the kilns.

109. Wiring in Metal Refineries (H. G. Wilson, *Review*, Mar. 2, 1912).—While, as a rule, the motors en plants of this kind can be placed beyond the reach of mental effects of heat and acid fumes, the use of sq induction motors is to be preferred, since these have contacts. When these are used it is best to paint the of wires exposed to acid fumes with hot tar. If dire motors must be employed, these should be completely i protect them from the effects of dust, which is always pr

Overhead wiring in furnace buildings, in which it is al hot, should preferably be with asbestos-covered cond cleats or split knobs which hold them 1 in. from the sur over and 6 in. apart. Screws should be used rather than leather washers in securing the knobs or the cleats, for where the temperature is from 125° to 150°, as it is in thes heads soon become practically worthless.

When installing wiring in metal refineries already con much of the work as possible should be done outside t since on the inside the acid fumes and heat may be very workmen. This outside work may include such jobs screwing the insulators to the supporting blocks, cutting c to the proper length, and making splices and taps for d With this done, the installation can be rapidly completed

Only the best workmanship and material should be for, since the making of repairs is apt to be very trying, t possible degree of permanency is desirable. Contracto mitting bids on jobs of this kind, should make a generous for labor, as only about half the work can be accompli would be under better conditions. This precaution ap where the wiring must be done after the plant is running

Wiring in furnace buildings for switch legs and on should be placed in rigid conduit as a protection from n injury. Porcelain sockets seem to withstand the conditi than others. Single-wire cleats or split knobs shoul rather than rosettes, with each wire anchored separat cut-out cabinets are preferable, as wooden asbestos-li soon dry out and become defective unless they are t seasoned. All openings around wires should be filled t the entrance of dust, which will, in time, cause poor con for this same reason snap switches are preferred to knife No. 14 rubber-covered stranded wire for drop cords can good advantage.

A permanent method for wiring the copper sulphate still being sought, as the sulphuric acid fumes rot the b the wire and also have a dehydrating effect on the rub soon dries it out and renders it useless as an insulator.

phere is moist due to the escaping steam from the vats. This may render other insulations than rubber unreliable. Conduit work and lead-covered twin wiring on insulators have been used with only fair results. However, the conduit does not protect the insulation from the acid fumes. The difficulty of readily making a good joint in the lead-covered cable has made its use undesirable.

A certain metal refinery which had been annoyed with breakdowns in the electric wiring due to the causes indicated, tried the following construction. The first cost was high, but several years' use of the system has shown the investment to be a wise one. Sound hardwood molding was thoroughly warmed and generously painted on all surfaces with hot tar, so that the pores were well filled. The rubber-covered wire was coated with tar. Care was taken that no uncovered spots were left. The wires then were placed in the grooves in the molding and the space that then remained unfilled was also tarred with as much tar as could be made to adhere. The capping was then put in place after receiving a coat of tar on all surfaces. The molding was placed on its supporting surface at a time when it was comparatively dry and a strip a little wider than the molding was painted with tar. Porcelain molding receptacles were used wherever practicable and for drop lights No. 14 rubber-covered stranded wire was employed.

MOLDING WIRING

110. Wooden molding wiring is frequently used for additions to existing installations and where a low-priced job of neat appearance is required. Its use is prohibited by the Underwriters in damp places, in rooms where there are fumes or in elevator shafts. (Iron conduit should always be used in elevator shafts.) Approved fittings are made whereby molding wiring can be used in combination with the other methods. Single-braid, rubber-insulated wire must be used in molding. Where a circuit in molding runs into conduit, double-braid wire, spliced to the single-braid molding wire, must be used in the conduit. Where wire from molding runs into flexible tubing or loom, single-braid wire may be used in both molding and flexible tubing. (The material that follows on Molding Wiring is taken largely from articles on the subject written by the complier of this book and printed in *The Practical Engineer* and in *Electrical Engineering*.)

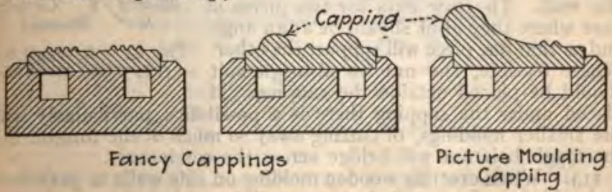


FIG. 83.—Special cappings.

111. *Wooden molding* is made in many forms. The standard *designs are shown in Fig.* 86 for two-wire, and Fig. 87 for three-wire. For first-class work hard-wood molding and capping matching in finish the trim of the room in which it is installed can be used. Capping of various designs can be purchased (Fig. 83). When buying molding one should see that it conforms to code requirements. Second-rate material which may be cross-grained or knotty should be avoided because it will be more expensive in the long run than first-class stock. Patented moldings (Fig. 84) are

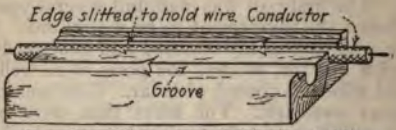


FIG. 84.—Kirkpatric's hold-wire molding.

obtainable which will retain the wire when it is pressed into the grooves, making the use of brads for temporary support unnecessary. Although it is recommended by the Code, hard-wood molding is little used. Georgia pine, oak or similar hard-wood moldings cost about twice as much as the ordinary white wood (soft wood) stock. Table 114 gives the dimensions of standard molding.

112. **Molding is supported** on lath and plaster with long, small-diameter, flat-head screws. Nails are permissible when running over a wooden surface. On brick walls, the wall is drilled and plugged and a wood screw turning into the plug supports the molding. In fire-proof buildings using hollow tile partitions and arches toggle bolts (Fig. 85) are used. Wood screws have been used for this work by drilling holes, of a slightly smaller diameter than the screw, in the tile. Then turning the screw into the hole causes it to cut its own thread. Base should be supported every 1½ ft. to every 3 ft. and the capping somewhat more frequently. With very large molding support points should be even closer together.

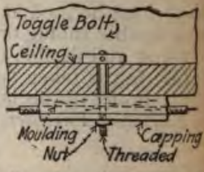


FIG. 85.—A toggle bolt supporting molding.

Either screws or nails can be used to support capping and they should, if feasible, pass entirely through the capping and into the wall. The saw cuts for two pieces of base where they abut should be at an angle and so that one piece will support the other. Where feasible, the nut on a toggle-bolt should be placed outside the capping. If placed under the capping there is a possibility, particularly with the smaller moldings, of cutting away so much of the tongue that the toggle-bolt nut will bridge across the conductors.

113. **When erecting wooden molding on side walls or partitions,** it should never be installed where it will be subjected to mechanical *injury and* as a general proposition should not be used within 6 ft. *from the floor.* Conduit or pipe protection (see 80) is preferable *in such locations.*

114. Standard Two- and Three-wire Wooden Molding

(*Kirkpatric Manufacturing Company*)

The products of various manufacturers vary somewhat in dimenons. All dimensions are given in inches.

A Size of groove	Will accommodate wires: Solid	Will accommodate wires: Stranded	B	C	D	E	F
Two-wire molding							
1/4	14 to 12	......	1 1/2	5/8	1 1/8	3/16	13/16
3/8	10 to 8	8	1 3/4	3/4	1 3/8	3/16	15/16
1/2	9 to 4	5 to 6	2 1/8	1	1 5/8	7/32	1
5/8	3 to 0	4 to 1	2 1/2	1 3/16	1 7/8	7/32	1 1/8
3/4	......	0 to 4/0	2 7/8	1 1/4	2 3/16	1/4	1 3/8
7/8	......	4/0 to 250,000	3 1/8	1 3/8	2 7/16	1/4	1 1/2
1	......	250,000 to 500,000	3 5/8	1 5/8	2 11/16	1/4	1 3/4

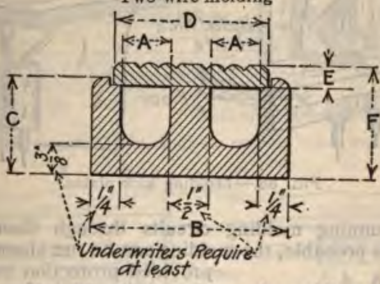


FIG. 86.—Section of two-wire molding.

A Size of groove	Will accommodate wires: Solid	Will accommodate wires: Stranded	B	C	D	E	F
Three-wire molding							
1/4	16 to 12	......	2 3/8	11/16	1 7/8	3/16	13/16
3/8	10 to 8	8	2 3/4	13/16	2 1/4	3/16	15/16
1/2	8 to 4	5 to 6	3 1/8	1	2 11/16	1/4	1 1/8
5/8	3 to 0	4 to 1	3 5/8	1 3/16	3	[illegible]	[illegible]
3/4	......	0 to 4/0	4 1/8	1 1/4	3 3/8	5/16	1 3/16
7/8	......	4/0 to 250,000	4 1/2	1 3/8	3 7/8	[illegible]	[illegible]
1	......	250,000 to 500,000	5 1/4	1 5/8	4 1/2	[illegible]	[illegible]

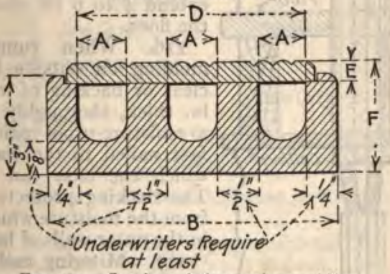


FIG. 87.—Section of three-wire molding.

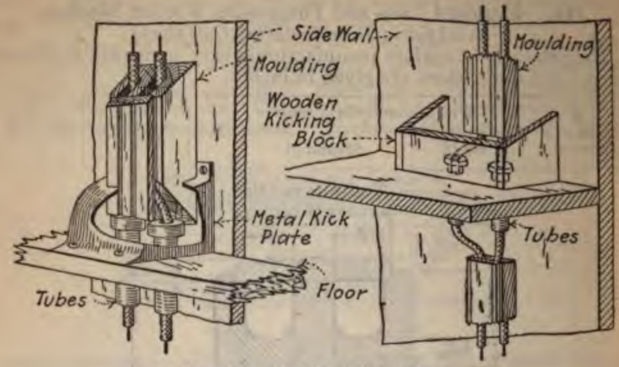


FIG. 88.—Molding kick plates.

115. In running molding circuits through floors where no interference is probable, the molding can be run almost to the floor provided protection such as a kick plate (Fig. 88) is installed at the floor. This construction is permissible in residences, offices and similar places. An iron pipe may be used instead of a kick plate to protect wires from molding where they pass through a floor (Fig. 89), provided the wire within the pipe is encased in loom. The pipe should extend 4 to 6 in. above and below the floor.

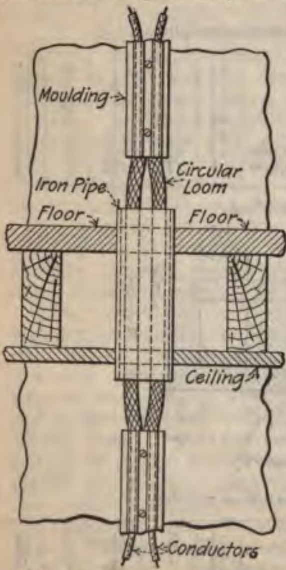


FIG. 89.—Iron pipe protection through floor.

116. When running wooden molding on outside brick walls a cleat or backing of wood $\frac{1}{2}$ in. or $\frac{7}{8}$ in. thick, thoroughly painted with a moisture-proof paint, should be first nailed to the wall (Fig. 90) to which the base can be fastened. The backing protects the molding from the moisture which often exists in the outer walls of brick buildings.

117. Mitering molding at turns should be done as suggested in Fig. 91, *I*. A fine-tooth miter saw and a miter-box, preferably a metal one, can be used to advantage. A rough and ready method that cannot be considered safe wiring is shown at Fig. 91, *II*. The capping hides the botch job.

***118.* Molding can be bent** around the curved surfaces often found in modern office buildings as shown in Fig. 92. Saw cuts are made in the base with the miter-saw. Moistening the base and capping renders it more easily bent. For first-class work, glue painted into the saw cuts before the base is formed to position will tend to better hold the base in shape.

119. The molding lay-out should conform to symmetrical designs in first-class work even if it is necessary to place "dead" molding to complete the design. It may be necessary to run

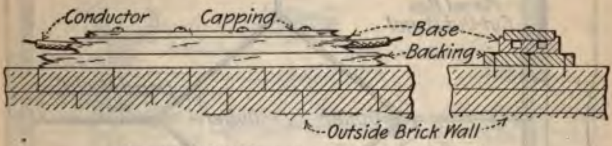


FIG. 90.—Molding on an outside brick wall.

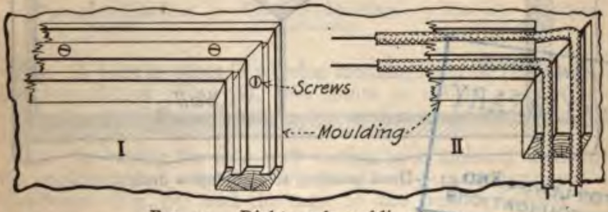


FIG. 91.—Right-angle molding turns.

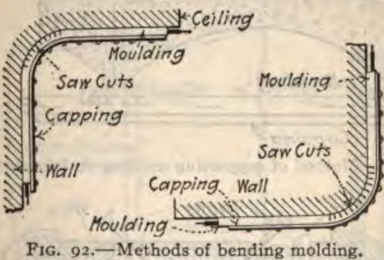


FIG. 92.—Methods of bending molding.

molding with picture-molding capping around the walls of an entire room even if that on three walls is dead. Fig. 93 shows an arrangement of dead molding on a ceiling.

120. To support wooden molding to the lower flanges of I-beams in fire-proof and structural steel buildings I-beam hooks, Fig. 94, which are punched from sheet metal and which can be purchased from supply dealers, are used. Wood screws passing through the hook enter the base and thus secure it in position. Where the span between beams is long it may be necessary to support a running board with the beam-hooks and then fasten the molding to the running board.

121. When placing wires in molding that does not have one of the

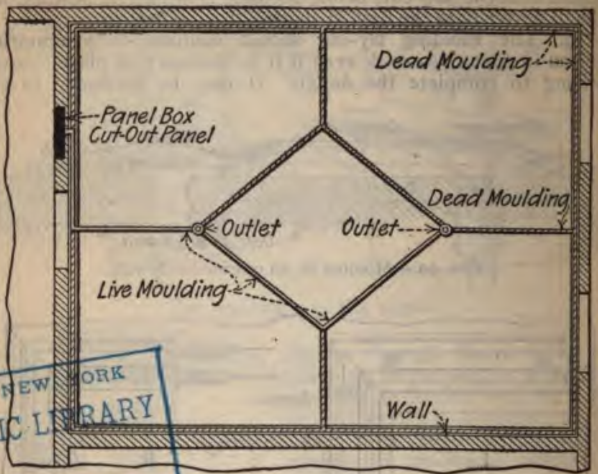


FIG. 93.—Dead molding to complete a design.

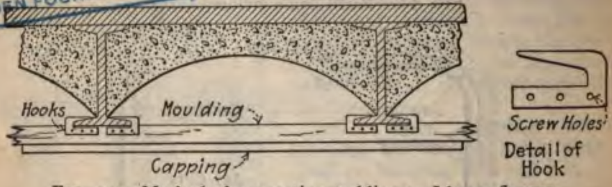


FIG. 94.—Method of supporting molding on I-beam flanges.

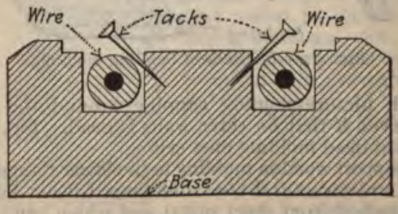


FIG. 95.—Brads holding wires.

patented "wire grip" features they can be temporarily held in the grooves with tacks or brads (Fig. 95) until the capping is placed.

122. In tapping off a branch in wooden molding wiring an pproved "taplet" fitting (Fig. 96) must be used. It was formerly ermissible to solder on the tap wires and bring one of them over he capping, but this is no longer permitted by the Underwriters. No joints or splices are permitted in molding wiring except at utlets or fittings.

123. A cross-over in wooden molding wiring is made with a itting as in Fig. 97.

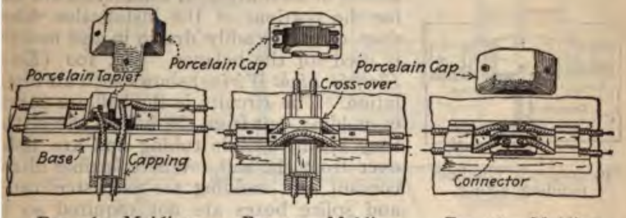


FIG. 96.—Molding taplet. FIG. 97.—Molding cross-over. FIG. 98.—Molding connector.

124. A joint in wires in wooden molding must be made with an pproved fitting (Fig. 98). No joints or splices are permitted ithin the molding itself, that is, the wires must be continuous from utlet to outlet.

125. In wiring for side-wall outlets in a molding installation he molding can often be advantageously carried around the ase-board (Fig. 99) and the taps to the outlets carried down ithin the partition in loom. The taps are fished down within the artition.

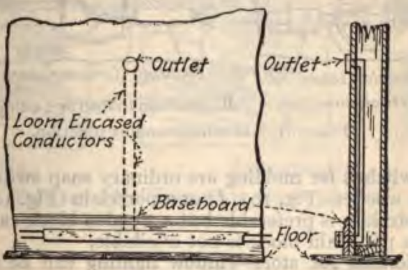


FIG. 99.—Molding on baseboard.

126. Special Fittings are Made for Connecting Conduit Circuits o Molding Circuits.—Fig. 100 illustrates one of the many forms. These compact fittings can be substituted for the bulky and unightly pressed steel outlet boxes.

127. ***In carrying wires from conduit to molding,*** the single-braid olding wire must be spliced to the double-braid conduit wire within an outlet box (Fig. 101). Flexible conduit or porcelain bushings must protect the molding wires where they enter the box. Where the junction between molding and conduit systems is on a wall or ceiling wherein the conduit is embedded, the connection may be made as at *II*. An additional outlet box is attached over the old one with long screws.

128. **When using molding in combination with flexible conduit or flexible steel armored cable for old building wiring,** flexible tubing or steel armored conductors are used for the portions of the installation where they can be readily drawn in and molding is used for the balance. Fig. 102 (Knox, *Electric Light Wiring*) shows such an installation. The circuits in the hall are carried in molding, but from the hall to the outlets they are in flexible tubing and are fished over from the hall. Where flexible fibrous conduit and molding are used steel outlet and splice boxes are not required so the work can be economically done and it looks well when finished. Auerbacher says (*Electrical Contracting*): "If ceilings are furred, an apartment of this kind should be wired in two days by a journeyman and helper without breaking walls or ceilings.

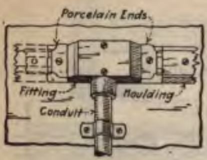


FIG. 100.—A "condulet" molding fitting.

129. **Molding receptacles and rosettes** (Fig. 103) should be of the types for which the backing does not have to be cut for their installation. Fittings are on the market which require the cutting of the backing and these should be avoided.

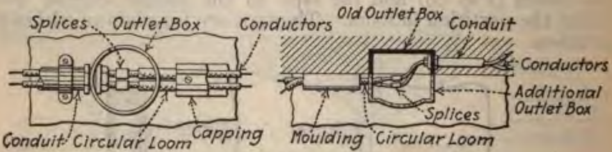


FIG. 101.—Molding-conduit junction.

130. **Switches for molding** are ordinary snap switches mounted on either a wooden (Fig. 104, *I*) or a porcelain (Fig. 104, *II*) switch block. Porcelain is preferable but a wooden block can be made on the job if a porcelain block is not available.

131. **Molding for store-window lighting** can be erected as in Fig. 105. This is a good method where expense must be a minimum. (Auerbacher, *Electrical Contracting*.) An aluminum reflector requiring no shade-holder can be used. The reflectors are spaced 6 in. to 12 in. The molding can be made up complete with wires and receptacles in the shop and can be erected in a short time. For further information see the section on *Illumination*.

132. ***In wiring in molding for drop lights on a fire-proof ceiling*** (*Electrical Contracting*, Auerbacher) (Fig. 106), if the panel has no

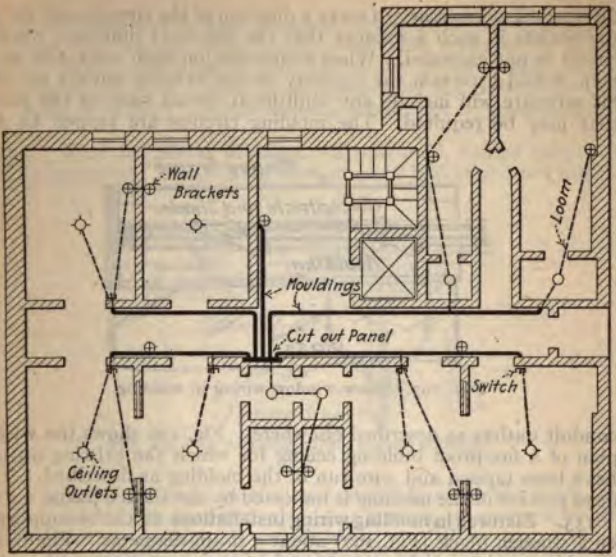


FIG. 102.—Combined molding and circular loom job.

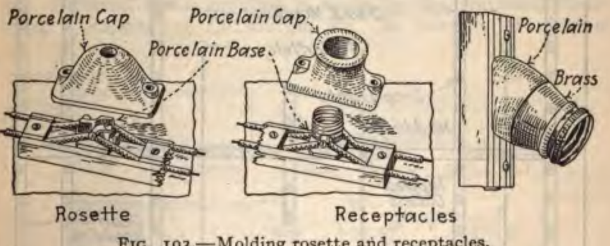


FIG. 103.—Molding rosette and receptacles.

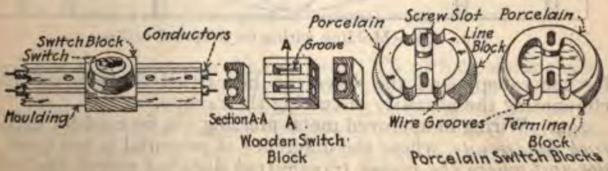


FIG. 104.—Switches on molding.

directory it is necessary to make a diagram of the circuits and to tap the outlets in such a manner that the 660-watt limit per branch circuit is not exceeded. When estimating on such work the wireman should ascertain the capacity of the existing outlets so that his estimate will include any additional circuit runs to the panel that may be required. The molding circuits are tapped to the

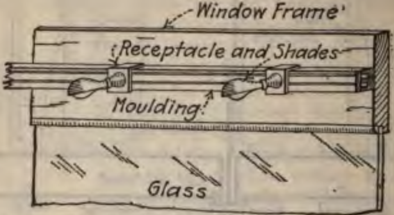


FIG. 105.—Show-window wiring in molding.

conduit outlets as described elsewhere. Fig. 106 shows the wiring plan of a fire-proof building ceiling for which the existing outlets have been tapped and wire run in the molding as described. The dead portion of the molding is indicated by the shaded parts.

133. **Fixtures in molding wiring installations** should be supported on a wooden block (Fig. 107) about 5 in. in diameter. The block provides a substantial support for the fixture, constitutes a backing

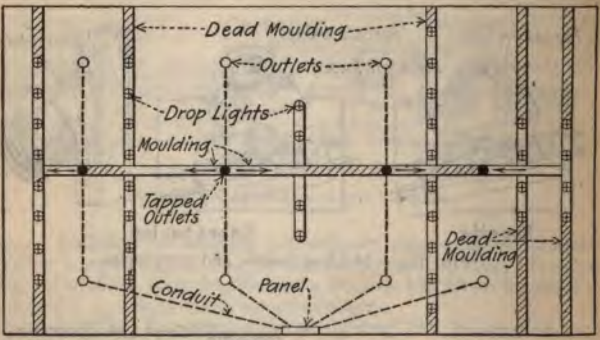


FIG. 106.—Molding wiring on fireproof ceiling.

for the canopy and the wires can be carried through the block eliminating the necessity of cutting the canopy.

134. **Wiring in approved metal molding** can be used for exposed work for circuits, where the difference of potential is not over 300 volts and where the power transmitted does not exceed 660 watts. *Metal molding* must be continuous from outlet to outlet, to junction

ox or to approved fittings designed especially for use with metal nolding. All outlets must be provided with approved terminal ttings which will protect the insulation of conductors from brasion unless such protection is afforded by the construction of he boxes or fittings. Metal molding should not be used in damp laces.

135. Wire for Metal Molding.—Single-braid, rubber-insulated vire is approved. In all cases wires must be laid in and not fished.

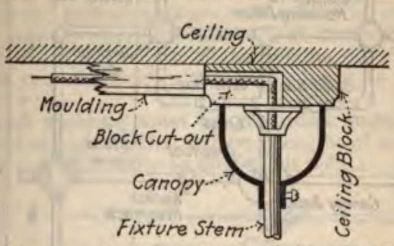


FIG. 107.—A molding-wiring fixture support

There is sufficient space in National Metal Molding for 4 No. 14 ingle-braid, rubber insulated wires. It is often necessary to insert his number at double-pole switch loops, etc. The two or more vires of an alternating-current circuit must be in the same molding nd those of a direct-current circuit should be so that if a change s made to alternating-current reconstruction will not be necessary.

136. National metal molding is made by the National Metal Molding Company of Pittsburgh, Pa. It consists of channel

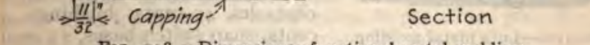


FIG. 108.—Dimensions of national metal molding.

apping that snaps over a channel base. The principal dimensions re given in Fig. 108. It is furnished in lengths of 8 ft. 6 in. It is herardized, a process whereby finely divided zinc is driven into he pores of the metal forming an iron-zinc alloy which is thoroughly ust-proof and which cannot be knocked off. Either water or oil aints adhere well to it. Because of the small space that it occupies can be used to advantage on steel ceilings, in show-windows, in show-cases and in other locations where appearance is a factor and where safety is essential.

137. The application of national metal molding and fittings is illustrated in Fig. 109, an imaginary lay-out shown to indicate how the material may be used.

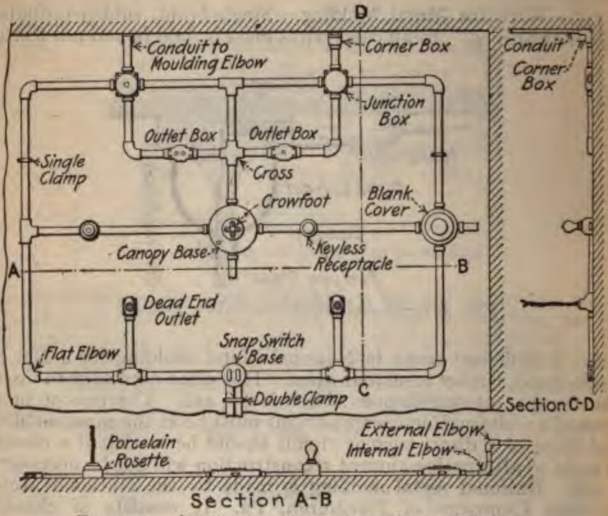


FIG. 109.—Application of metal molding and fittings.

138. The cost of national metal molding is $8.00 per 100 ft. list with a discount varying from 20 per cent. to 50 per cent. and with the point of delivery and the quantity purchased.

139. The Cost of Metal Molding Fittings.—The same discounts apply as those applying to molding. List prices for some are as follows: Cross, 17 cents each; base coupling, 2.5 cents; tee, 14 cents; elbows, internal, external and flat, 11 cents; outlet box, 20 cents; metal covers 5.5 cents; receptacles, 45 cents; bushings, 3.5 cents; snap switch bases, 25 cents; one-piece porcelain rosettes, 8 cents; two-piece porcelain rosettes, 25 cents.

FIG. 110.—Lutz metal molding.

140. Lutz metal molding consists of a channel-shaped base and a strip of sheet metal that slips in, as illustrated in Fig. 110 which constitutes the capping. It is electro-galvanized and is furnished in 10 ft. lengths. Capping can be removed at either end or at *any other point* desired by making two hack-saw cuts with a fine-*tooth (tubing)* saw through the flanges of the base and slightly *opening the cut* portion to release the ends of the capping. It is recommended that in making installations these hack-saw cuts be made at intervals to permit the future removal of the capping

141. **Fittings for Lutz molding** are made which are somewhat similar to those for the National. All fittings are arranged to insure electrical conductivity throughout the molding installation.

142. **Where metal molding passes through floors** it should be carried through an iron pipe extending from the ceiling below to a point 5 ft. above the floor, which will serve as an additional mechanical protection and exclude moisture. In residences, office buildings and similar locations where appearance is an essential feature, and where the mechanical strength of the molding itself is adequate, the iron pipe can extend from the ceiling below to a point 3 in. above the floor

143. **Metal molding must be grounded permanently** and effectively and so installed that adjacent lengths of molding will be mechanically and electrically secured at all points. It is essential

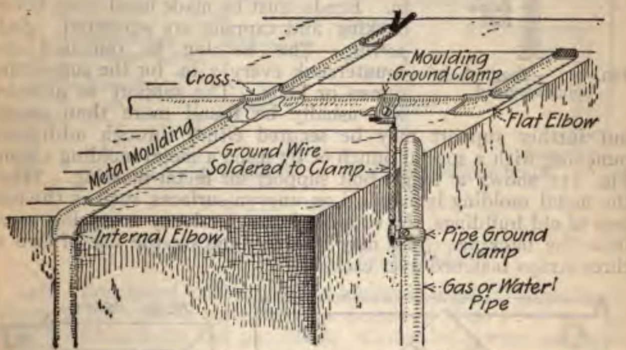


FIG. 110A.—Grounding metal molding.

that the metal of such systems be joined so as to afford electric conductivity sufficient to allow the largest fuse in the circuit to operate before a dangerous rise of temperature in the system can occur. Moldings and gas pipes must be securely fastened in metal outlet boxes, so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection the metal molding must be joined around them by suitable bond wires. Where sections are installed without being fastened to the metal structure of the building or grounded metal piping, they must be bonded together or joined to a permanent and effective ground connection.

The metal molding manufacturers provide fittings suitable for joining adjacent lengths of backing together and ground clamps (Fig. 110, *A*) for grounding. Lapping the capping from one length to the adjacent one constitutes an electrical connection. Ground wires must be at least No. 10 B & S gage.

144. Installing National Metal Molding. *Separating.*—Reasonable care should be exercised in separating the backing and capping preparatory to installation. As the quickest, most satisfactory method, hooking one of the punched holes in the backing over a convenient nail or screw and drawing the capping off is recommended. *Cutting.*—Except in cases where the backing of the molding passes through under the fittings and is not cut, backing and capping should be cut before being separated in all cases. Because of the light stock, hack-saw blades having fine teeth and commonly known as "tube saws" should be used for cutting. Some construction men recommend marking deeply with a file and breaking. *Bending.*—The molding is readily bent and, with reasonable care, may be worked to any radius down to one of 4½ in. Bends must be made in all cases before backing and capping are separated. *Supporting.*—The backing is punched and countersunk every 2 in. for the supporting screws or bolts. The support so afforded will usually be found more than ample, but further support may be secured either through additional punching with a special punch or by using a metal molding clamp. Fig. 111 shows a toggle bolt support for metal molding. When the metal molding is installed on uneven surfaces, such as the ceilings of old buildings, the capping has a tendency to spring away from the backing. This may be overcome by the use of two or three straps fastened over each length.

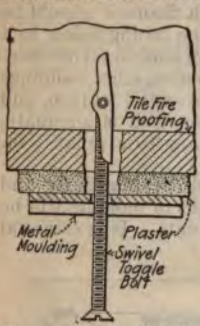


FIG. 111.—Toggle bolt being inserted.

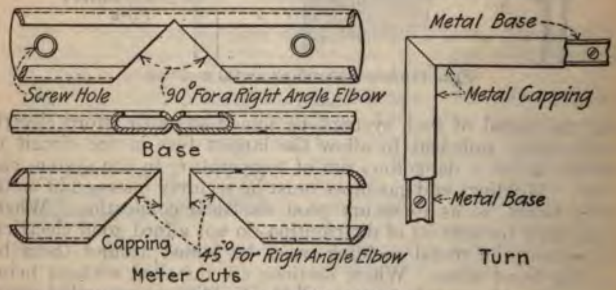


FIG. 112.—Mitered turn.

Loose Capping.—If the capping of the molding is loose, it should be removed from the backing and tightened by tapping it with a mallet or hammer at points about 8 in. apart but on one edge *only.*

145. Metal molding can be mitered for elbows and bends by *cutting it with a hack-saw.* Elbows and bends thus made have the advantage that they fit into corners more closely than do the purchased fittings. Electrical conductivity is preserved by always leaving a portion of the backing intact. Fig. 112 shows how a turn can be made and Fig. 113 the method for an elbow.

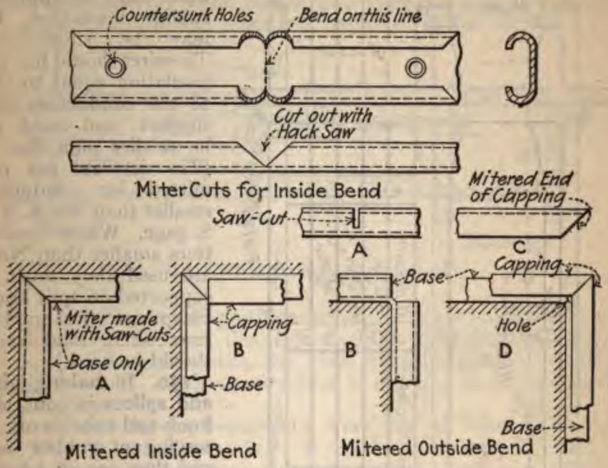


FIG. 113.—Mitered elbows.

KNOB-AND-TUBE WIRING

146. Concealed knob-and-tube wiring is used in frame houses where a low cost of installation is essential. The wires are concealed within floors and partitions. Concealed wiring can be installed cheaper by the knob-and-tube method than by any other (unless wooden moulding wiring be considered as concealed wiring), but the cost is greater than for open work on knobs and cleats. (Much of the matter on knob and tube wiring is from articles on this subject published in the *Pract. Eng.* commencing Sept. 1, 1912.)

147. The use of knob-and-tube work should be discouraged in so far as possible (Knox, *Electric Light Wiring*), as it is subject to mechanical injury and is liable to interference from rats and mice. The wires may sag against beams, laths, etc., or may be covered by shavings or other inflammable building material. Knob-and-tube work is prohibited by municipal ordinances in many cities and is being superseded by flexible steel and rigid iron conduit installations.

148. The wires are run just after the floors and studding are in place and before the lathing is done. This principal part of the work is called the "roughing in," and comprises the installation of the mains and the branches and the taps to the outlets. Frequently the basement wiring is not done until the building is practically completed. The "finishing," which comprises the installation of the switches, fixtures, meter board, distributing panels, etc., is not usually done until the building is otherwise completed.

149. Wire and tie-wires for concealed knob-and-tube wiring must have an approved rubber insulation, but may be single-braid. Tie-wires should have an insulation equal to that of the conductors they support, and must not be smaller than No. 14. (Tie wires are not permitted for conductors smaller than No. 8. B. & S. gage. Where conductiors smaller than No. 8 are used they must be supported on split knobs except at the ends of runs where solid knobs should be used.)

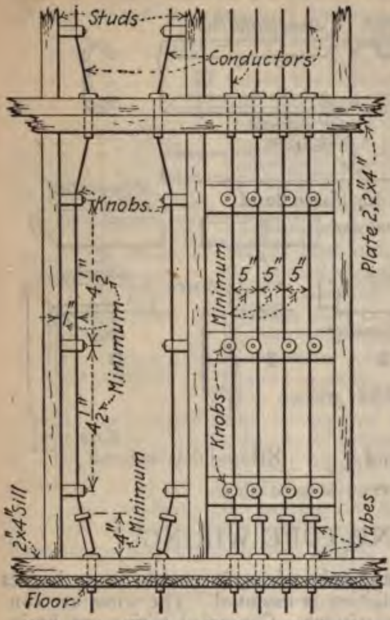


FIG. 114.—Knob-and-tube vertical run.

150. In making joints and splices in concealed knob-and-tube work, a serving of rubber tape and then one of friction tape are made around the splice. Inasmuch as most of the joints are inaccessible after the completion of the building, they should be very carefully made.

151. Wires must be supported in knob-and-tube wiring by approved porcelain knobs, which separate the wires at least 1 in. from the surface wired over. The wires must be maintained at least 5 in. apart, and when possible should be run (Fig. 114) on separate timbers and studding. Knobs are located at least every $4\frac{1}{2}$ ft. where the wire run is parallel to the supporting timber. Where it is impossible to maintain the 5 in. separation, the wires can be run closer together, provided each is encased in a continuous length of flexible tubing, or as it is often termed, "loom." When passing through floors, walls, etc., the wires must be protected by glass or porcelain tubes, as outlined in Fig. 114. Flexible tubing may in dry *places be used to* insulate the wires where projecting members of *the building interfere* with them. Porcelain tubes should be used *where the wires* cross each other or cross pipes (Fig. 115).

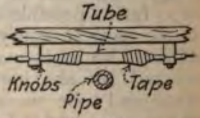


FIG. 115.—Wire crossing pipe.

52. **Where circuits cannot be supported on porcelain or glass, knob-and-tube work,** approved metal conduit or approved ıored cable must be used, except that for voltages of less than ', where the wires are not exposed to moisture, they may be ed from outlet to outlet on the loop system if each is encased oughout in continuous lengths of approved flexible tubing.

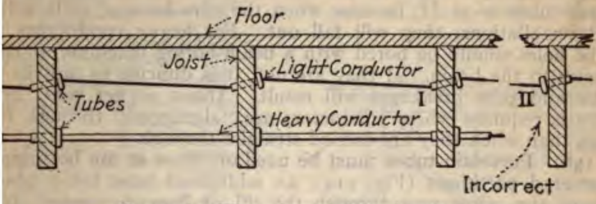


FIG. 116.—Wires through joists in tubes.

53. **In wiring in thin partitions** where there will not be at least ı. clear space between the surface of the wires and the plaster t oozes between the laths, the wires must be encased in loom xible conduit). This construction is required in the so-called ı. pártitions.

54. **Knobs for knob-and-tube work** are of either the solid e (Fig. 8B and Table 16D), or of the split type (Fig. 8A). it knobs are required for conductors smaller than No. 8, except the ends of runs. Solid knobs are permitted only when used :ake the strain from the circuit wires—at the ends of runs and to

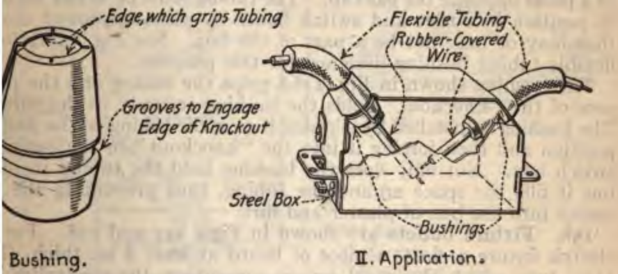


FIG. 116A.—Bushing for flexible tubing.

port outlets. The knob must provide at least a 1-in. sepa- on from the surface wired over. See **16A** for further information ut knobs.

55. **Porcelain tubes provide insulation where the wires are** ied **through joists.** (See **16F** for further information on tubes.) *holes for the tubes* should (Fig. 116) preferably be slightly *ler than the tubes,* so that the tubes when driven home with

a block of wood will stay in place. The holes for tubes for small wires should be pitched as this tends to retain the tubes in position in the timber. A long bit, the shank of which when in use rests on the joist next to the one being bored, is the best tool for boring pitched, tube holes. Tubes should always be so placed in pitched holes that their enlarged ends will be at the top, as a (Fig. 116, *I*), which will prevent their falling through. Never place tubes as at *II*, because when the wire loosens, as it will in old installations, they will fall out. For heavy conductors the tube holes should be bored with a beam-boring machine, at right angles to the beam. If they are not, it is difficult to pull in the wire and tube breakages will result. About 10 per cent. more wire is required where conductors are "zigzagged" through timbers than when they are carried straight through.

156. **Porcelain tubes must be used on wires at the bottoms of plastered partitions** (Fig. 114), an additional tube being placed where the wires pass through the sill or floor to protect from plaster droppings. The tubes must extend to at least 4 in. above the timber. Knobs must be so arranged that no strain that might tend to break them can come on tubes. Fig. 115 shows how a wire crossing a pipe should be protected by a procelain tube.

157. **Flexible tubing must be used at all knob-and-tube work outlets to encase each wire.** (See **16K** for properties of flexible tubing.) It should be used at distributing center, switch, fixture and similar outlets, and at all points where the wires cannot be separated from one another or from the surface wired over the distances specified for unprotected wire. The flexible tubing or loom must encase each wire from the last porcelain support (knob or tube), to 1 in. below the outlet, or with combination fixtures, to a point opposite the gas cap. The tubing must be firmly secured in position in outlet and switch boxes by some approved device that may or may not be a part of the box. See Fig. 116A for a flexible tubing bushing designed for this purpose.

The bushing shown in Fig. 116A grips the tubing and the pressure of the "knockout" holds the bushing securely to the tubing. The bushing is installed by slipping it over the tubing to the desired position and then forcing it into the "knockout" in the outlet or switch box. Not only does the bushing hold the tubing in place but it fills the space around the tubing, thus preventing the entrance into the box of plaster and dirt.

158. **Fixture outlets** are shown in Figs. 117 and 118. For an electric fixture a cleat, a piece of board at least $\frac{7}{8}$ in. thick (Fig. 117), into which the wood screws supporting the electrolier can turn, should be nailed between the joists or studs. Holes are bored through the cleat, through which the loom can pass. With a combination fixture (gas and electric) (Fig. 118) no cleat is necessary, because the gas pipe supports the fixture. The loom should be wired—iron wire will do—to the gas pipe, to prevent displacement by artisans that have occasion to work around the outlet.

159. **In wiring for switches,** loom must be used on the conductor ends from the last porcelain support, (Figs. 119, 120 and

ı1), the same as on conductor ends for other outlets. A pressed eel switch box (Fig. 122), should be used to encase each flush vitch mechanism, even though it already be encased in porcelain. $\frac{7}{8}$ in. wood cleat or cleats are arranged to support the switch

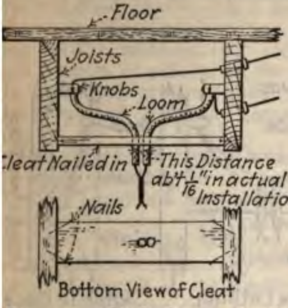


FIG. 117.—Outfit for an electric fixture.

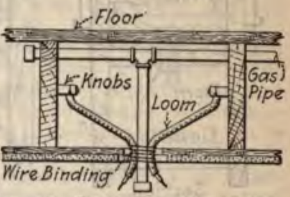


FIG. 118.—Loom protection at combination fixture outlet.

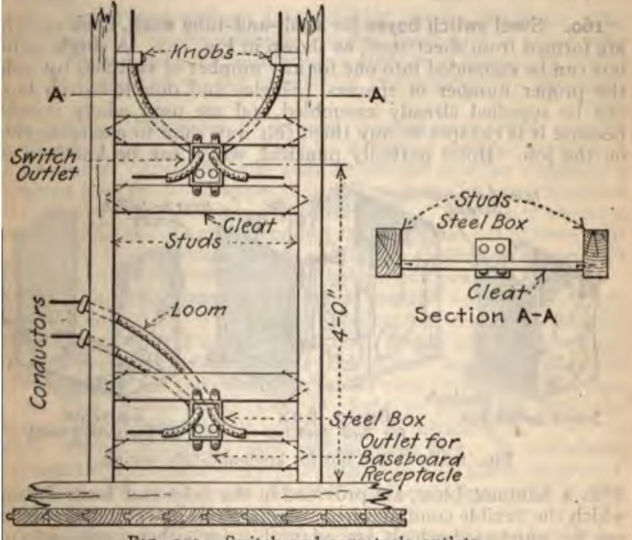


FIG. 119.—Switch and receptacle outlets.

x. These wooden cleats should not be set out flush with the ter edges of the studs, but should be set about $\frac{3}{8}$ in. back, as ıstrated, to allow a space in which the plaster can take a "grip." e Fig. 121.) For a surface snap switch outlet (Fig. 121), an iron box is not necessary, but a $\frac{7}{8}$-in. cleat must be installed to hold the loom in place and to provide a proper support for the screws that hold the switch. In wiring old buildings, where supporting cleats were not originally provided back of the plaster, a $\frac{3}{4}$-in. wooden block or plate should be installed on the surface, to which the switch can be attached.

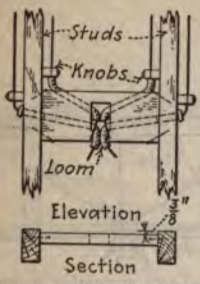


FIG. 120.—Arrangement of switch outlet wiring.

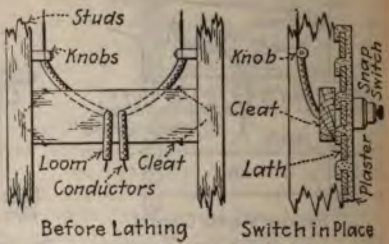


FIG. 121.—Surface switch wiring.

160. Steel switch boxes for knob-and-tube work, flush switches are formed from sheet steel, as shown in Fig. 122. A single-switch box can be expanded into one for any number of switches by using the proper number of spacers. Single- and double-switch boxes can be supplied already assembled and are used where feasible, because it is cheaper to buy them this way than to assemble them on the job. Holes partially punched, which can be knocked out

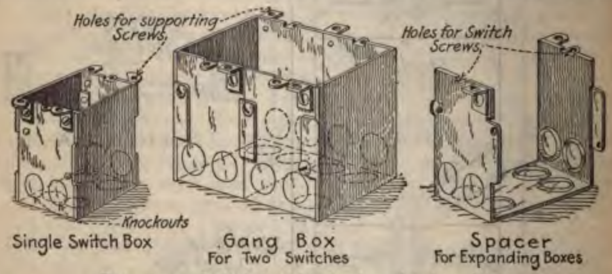


FIG. 122.—Switch box for knob-and-tube wiring.

with a hammer blow, are provided in the sides and back through which the flexible conduit wire protection can be extended. Boxes can be purchased which are adaptable for either knob-and-tube (flexible conduit or loom) or wrought-iron conduit work. Boxes which have adjustable supporting lugs, so the box can be moved in and out in relation to them to provide for adjustment to the surface of the plaster, are preferable. (See also 190 under "Conduit Wiring" for further information on steel switch boxes.)

CONDUIT WIRING

1. **There are two classes of conduit wiring,** rigid or iron con- wiring, and flexible metal conduit wiring. Although steel- red conductor wiring is not truly conduit wiring it is usually ed in the conduit wiring group and is so described in this . (The material that follows on Conduit Wiring is largely a series of articles on the subject written by the compiler of book and printed, under the pen name of O. N. Casey, in *Practical Engineer* commencing with the March 1, 1913 .)

2. **Rigid iron conduit wiring** is approved for both exposed and ealed work and for use in nearly all classes of buildings. For iary conditions wiring in iron conduit is probably the best ugh it is the most expensive. The advantages of iron con- are: (1) It is fire-proof; (2) it is moisture-proof; (3) it is g enough mechanically so that nails cannot be driven through d so that it is not readily deformed by blows or by wheel- ws being run over it; (4) it successfully resists the normal n of cement when imbedded in partitions or walls of fire-proof lings.

3. **Lined and unlined iron conduit** can be obtained. The conduit is merely ordinary conduit lined with a paper tube is treated with an insulating water-proof compound. The g is cemented to the interior of the conduit by the com- id.

4. **The advantages of unlined conduit** over lined conduit (*Electric Light Wiring, Knox.*): (1) It is cheaper because it no lining. A smaller size conduit can be used for conductors given size; (2) it is cheaper to install, as it can be bent, threaded cut more readily than can lined conduit; (3) it is easier to draw s into and out of unlined conduit than into and out of lined con- (4) in lined conduit in hot places the conductors sometimes to the lining which prevents their withdrawal.

5. **The disadvantages of unlined conduit** are (*Electric Light ng, Knox.*): (1) The unlined iron conduit may rust through to the combined action of water or steam and the chemical ents in ash or other cements; (2) double-braided conductors be used in unlined conduit to satisfy code rules. The increase st due to this requirement is slight as compared with the er cost of lined conduit and the cost of installing it.

6. **Lined conduit is very seldom used now.** It sometimes application where every precaution must be taken to protect nst trouble that might occur if the outer iron tube rusted ugh.

7. **Galvanized iron conduit** should be used if conduit is in- ed out of doors or in damp places or where it is imbedded in ent.

8. **When to use Iron Conduit Wiring.**—As a general prop- on, *conduit wiring should be used whenever the job will the cost.* Ordinances of some cities now require that all

concealed wiring shall be in iron conduit. It is probable th
the method will, because of its inherent advantages, grow
popularity and will ultimately be almost universally used. Ir
conduit protects the conductors it contains and provides a smo
race-way permitting ready insertion or removal.

169. Use of Iron Pipe in Place of Conduit.—Electrical cond
is merely commercial standard-weight wrought-iron pipe that h
been carefully reamed inside to remove burrs and then treated w
zinc, or an enamel, baked on, to prevent rust. The threads on t
ends of conduit lengths are standard pipe threads. Hence, wh
underwriters' inspectors do not have jurisdiction iron pipe can
used instead of conduit. The pipe is cheaper, and in dry locati
it appears to serve as well as conduit. A coat of black stove-p
enamel on the outside of the pipe will give it a finished appeara
and more than a superficial inspection is required to distinguis
pipe so treated from conduit. It is the practice in some pla
where the buildings are fire-proof and where no insurance is car
to use galvanized iron pipe instead of conduit.

170. Wire for use in unlined wrought-iron conduit must
rubber-covered except in permanently dry, hot locations wh
slow-burning insulation may be permitted. Single-braid wir
permitted for conductors smaller than No. 6. Conductors N
and larger should be double-braid. Duplex or multiple condu
cables must be double braid. Each conductor must be continu
from outlet to outlet without splices or taps. The same cond
can contain as many as four 2-wire or three 3-wire circuits of
same system. The same conduit must never contain circuits
different systems. Duplex wire (see Sect. I) particularly No.
is largely used for branch circuits in conduit wiring. Solid
is used for conductors up to and including No. 8 or No. 6. La
conductors should be stranded so that they can be readily pu
into the ducts.

171. Where alternating-current circuits are in conduit, al
the wires (two wires for a single-phase, three wires for a three-
or three-phase and three or four wires for a two-phase circuit)
the circuit must be carried in the same conduit to prevent induct
voltage droo and dangerous overheating of the conduit.

172. Table 173 of Conduit, Elbows and Couplings.—Electr
conduit is merely standard-weight wrought-iron pipe, enamel
Sherardized or galvanized. The diameters are given in decim
common fractions and sixty-fourths for convenience, because th
are times when the values are needed expressed in each of th
ways. When figuring wire and wire insulation diameters,
values are usually expressed in sixty-fourths which makes the six
fourths columns very valuable for ready reference. The weig
columns are convenient for estimating transportation charges, a
from the values in the list price columns, the cost of the materi
can be obtained by applying the discount that one receives.
an estimating discount 50 per cent. can be safely used. Dimensio
of elbows and couplings are often used in laying out work on th
drawing-board or in cases where clearances must be estimated
advance. Table 185 gives the dimensions of standard co
threads.

FIG. 123.—Section of conduit.

FIG. 124.—Conduit elbow.

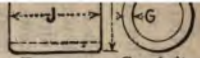


FIG. 125.—Conduit coupling.

Nominal size	A Outside diameter. Actual	A Fractional in. to 64ths.	A In 64ths to nearest 64th.	B Inside diameter. Nominal	B Fractional in. to 64ths.	B In 64ths to nearest 64th.	C Thickness of walls. Nominal	C Fractional in. to 64ths.	C 64 ths to nearest 64ths.	Nominal weight lb. per ft.	List price per 100 ft.	D Radius of ϕ in.	E Offset ins.	Weight, lb. of 100	List price, per 100	F Length, straight portion	I Outside diam.	J Length	G Thickness	Weight of 100 in lb.	List price, per 100
1/2	0.84	27/32	54/64	0.623	5/8	40/64	0.109	3/32	7/64	0.85	$ 8.50	4 1/2	7 1/2	73	$19.00	2 9/16	1 3/32	1 5/16	1/8	15 1/2	$ 7.00
3/4	1.05	1 1/16	67/64	0.824	53/64	53/64	0.113	7/64	7/64	1.12	11.50	5 3/8	9 1/4	132	25.00	3 1/4	1 11/32	1 9/16	13/64	25 1/2	10.00
1	1.315	1 21/64	84/64	1.048	1 3/64	67/64	0.134	1/8	9/64	1.67	17.00	5 3/4	10 1/8	200	37.00	4 3/8	1 21/32	1 3/4	11/32	40 1/2	13.00
1 1/4	1.66	1 43/64	106/64	1.380	1 24/64	88/64	0.140	9/64	9/64	2.24	23.00	7 1/4	11 1/2	300	45.00	3 7/16	2	1 15/16	11/32	57 1/2	17.00
1 1/2	1.90	1 29/32	122/64	1.611	1 39/64	103/64	0.145	9/64	9/64	2.68	27.50	8 1/2	12 3/8	415	60.00	3 3/16	2 9/32	2 3/16	3/8	71 1/4	21.00
2	2.375	2 3/8	152/64	2.067	2 1/16	132/64	0.154	5/32	10/64	3.61	37.00	9 1/2	15 1/4	700	110.00	4 9/16	2 27/32	2 5/16	15/32	132	28.00
2 1/2	2.875	2 7/8	184/64	2.468	2 15/32	158/64	0.204	13/64	13/64	5.94	58.50	10 1/2	17 3/4	1,138	180.00	5 13/16	3 9/32	2 11/16	17/32	185	40.00
3	3.50	3 1/2	224/64	3.067	3 1/16	196/64	0.217	7/32	14/64	7.54	76.50	13	19 3/8	1,885	480.00	4 3/8	4 1/64	3	33/64	300	60.00
3 1/2	4.00	4	256/64	3.548	3 35/64	227/64	0.266	7/32	17/64	9.00	92.00	15	21	2,100	1060.00	4	4 1/2	2 1/8	1/2	400	80.00
4	4.50	4 1/2	288/64	4.026	4 1/32	258/64	0.237	15/64	15/64	10.66	109.00	16	22 1/2	2,160	1225.00	4 1/4	5 3/32	3 1/8	1/2	412	100.00

All tubes 10 ft. long, threaded, both ends with coupling.

Price list in effect Aug. 1, 1913.

174. Table 178 of conduit bushing dimensions, gives v which are helpful when laying out conduit holes in outlets or p boxes. Clearances can be provided and holes can be so disp that the bushings will have ample turning room. The dimens in the table were taken from samples.

175. Table 179 of conduit nipple dimensions is, since the f tion of the nipple is about the same as that of the bushing, for the same purposes as the bushing table. The nipple scr into a coupling (see Table 181), while the bushing screws onto threaded end of a length of conduit. The nipple is more comp than the bushing, hence is preferable for some work.

176. Punched steel lock-nuts are shown in Table 180. Lo nuts are used on conduit on the outside of the box wherever conduit enters an outlet-box, and their dimensions must often known in laying out panel or outlet boxes, so that proper tur clearances can be provided for the nuts.

177. Galvanized iron pipe straps (Table 183), are used for s porting conduit to surfaces. The dimensions in the table valuable, when laying out multiple conduit runs, to deter the spacings necessary between the conduits to allow for pro placing of the straps. The screw hole dimensions enable one order in advance screws of the proper diameters to support straps. Unfortunately, there are no standard dimensions in by all the manufacturers of pipe straps, and those furnished different makers will vary somewhat in size. The dimensio given are from one manufacturer's line, and are typical.

178. Malleable-iron Conduit Bushings

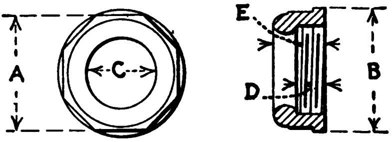


FIG. 126.—Conduit bushing.

Nominal size of conduit	A	B	C	D	E
3/8	15/32	27/32	25/32	3/16	11/32
1/2	19/32	1 1/32	15/16	1/4	13/32
3/4	3/4	1 1/4	1 5/32	1/4	[illegible]
1	31/32	1 17/32	1 13/32	5/16	[illegible]
1 1/4	1 5/16	1 29/32	1 11/16	3/8	[illegible]
1 1/2	1 17/32	2 5/32	1 31/32	13/32	[illegible]
2	1 15/16	2 11/16	2 15/32	13/32	11/32
2 1/2	2 11/32	3 5/32	2 7/8	15/32	[illegible]
3	2 27/32	3 11/16	3 11/32	[illegible]	[illegible]

179. Conduit Nipples

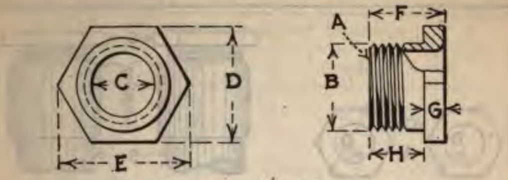


FIG. 127.—Conduit nipple.

Size of conduit	A Threads per inch	B Diameter of threads	C	D	E	F	G	H
½	14.0	0.82	0.62	1.00	1.15	0.62	0.12	0.50
¾	14.0	1.02	0.82	1.25	1.44	0.81	0.19	0.62
1	11.5	1.28	1.04	1.37	1.59	0.94	0.25	0.69
1¼	11.5	1.63	1.38	1.75	2.02	1.06	0.25	0.81
1½	11.5	1.87	1.61	2.00	2.31	1.12	0.31	0.81
2	11.5	2.34	2.06	2.50	2.89	1.31	0.31	1.00
2½	8.0	2.82	2.46	3.00	3.46	1.44	0.37	1.06
3	8.0	3.44	3.06	3.75	4.33	1.50	0.37	1.12
3½	8.0	3.94	3.54	4.25	4.91	1.62	0.44	1.19

180. Punched Steel Conduit Lock-nuts

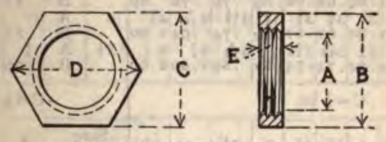


FIG. 128.—Conduit lock-nut.

Nominal size of conduit	Threads per in.	A	B	C	D	E
⅜	18	0.568	0.658	1	1⅜	$\frac{3}{16}$
				oct. hex.	oct. hex.	oct. hex.
½	14	0.701	0.815	1–1$\frac{1}{16}$	1$\frac{1}{16}$–1$\frac{7}{32}$	$\frac{5}{32}$–⅛
¾	14	0.911	1.025	1¼	1$\frac{7}{16}$	$\frac{5}{32}$
1	11½	1.144	1.283	1½	1$\frac{23}{32}$	$\frac{3}{16}$
1¼	11½	1.488	1.627	2$\frac{1}{32}$	2$\frac{5}{16}$	$\frac{3}{16}$
1½	11½	1.727	1.866	2¼	2$\frac{9}{16}$	$\frac{3}{16}$
2	11½	2.223	2.339	2$\frac{23}{32}$	3⅛	$\frac{7}{32}$
2½	8	2.620	2.820	3¼	3¾	¼
3*	8	3.241	3.441	4$\frac{11}{32}$–3$\frac{11}{16}$	4$\frac{11}{16}$–4	$\frac{11}{32}$–$\frac{11}{32}$

*The 3 in. lock-nut is octagonal instead of hexagonal.

181. Spacings for Conduit with Given Clearances

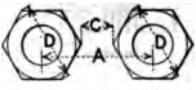


Fig. 129.—End View.

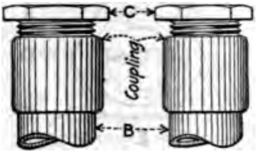


Fig. 130.—Elevation.

C = 1/8 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 1/4	1 3/8	1 1/2	1 11/16	1 13/16	2 1/8	2 7/16	2 3/4	3 1/2
	B	.41	.43	.42	.43	.44	.52	.58	.58	.70
3/4	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 9/16	3	3 1/4
	B	.43	.45	.44	.45	.46	.54	.60	.60	.72
1	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3	3 3/8
	B	.43	.45	.44	.46	.46	.54	.60	.60	.72
1 1/4	A	1 11/16	1 13/16	1 15/16	2 1/8	2 1/4	2 9/16	2 7/8	3 1/4	3 9/16
	B	.43	.46	.46	.46	.47	.55	.62	.67	.74
1 1/2	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 11/16	3	3 3/8	3 11/16
	B	.44	.46	.46	.47	.47	.56	.62	.67	.74
2	A	2 1/8	2 1/4	2 3/8	2 7/16	2 11/16	3	3 5/16	3 5/8	4
	B	.52	.54	.53	.55	.56	.63	.63	.69	.82
2 1/2	A	2 7/16	2 9/16	2 11/16	2 7/8	3	3 5/16	3 5/8	3 13/16	4 5/16
	B	.58	.60	.60	.61	.62	.69	.76	.76	.89
3	A	2 3/4	3	3	3 1/4	3 3/8	3 5/8	3 13/16	4 7/16	4 3/4
	B	.58	.60	.60	.67	.67	.69	.74	.94	1.00
3 1/2	A	3 1/8	3 1/4	3 3/8	3 9/16	3 11/16	4	4 5/16	4 3/4	5
	B	.70	.72	.73	.74	.74	.82	.89	1.00	1.00

C = 3/8 in.

Size conduit		1/2	3/4	1
1/2	A	1 1/2	1 5/8	1 3/4
	B	.66	.68	.67
3/4	A	1 5/8	1 3/4	1 7/8
	B	.68	.70	.69
1	A	1 3/4	1 7/8	2
	B	.68	.69	.69
1 1/4	A	1 15/16	2 1/16	2 3/16
	B	.68	.71	.71
1 1/2	A	2 1/16	2 3/16	2 5/16
	B	.69	.71	.71
2	A	2 3/8	2 1/2	2 5/8
	B	.77	.79	.78
2 1/2	A	2 11/16	2 13/16	2 15/16
	B	.83	.85	.85
3	A	3	3 1/8	3 1/4
	B	.83	.85	.85
3 1/2	A	3 3/8	3 1/2	3 5/8
	B	.96	.98	.98

C = 1/4 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 9/16	2 7/8	3 1/4
	B	.53	.55	.54	.55	.56	.64	.70	.70	.83
3/4	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3	3 3/8
	B	.55	.57	.56	.58	.58	.66	.72	.72	.86
1	A	1 5/8	1 3/4	1 7/8	2 1/16	2 3/16	2 1/2	2 13/16	3 1/8	3 1/2
	B	.55	.57	.56	.58	.58	.66	.72	.72	.85
1 1/4	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 11/16	3	3 3/8	3 11/16
	B	.55	.58	.58	.58	.59	.67	.73	.79	.86
1 1/2	A	1 15/16	2 1/16	2 3/16	2 3/8	2 1/2	2 13/16	3 1/8	3 1/2	3 13/16
	B	.56	.58	.58	.59	.59	.68	.74	.79	.87
2	A	2 1/4	2 3/8	2 1/2	2 11/16	2 13/16	3 1/8	3 7/16	3 3/4	4 1/8
	B	.64	.66	.65	.67	.68	.75	.81	.81	.94
2 1/2	A	2 9/16	2 11/16	2 13/16	3	3 1/8	3 7/16	3 3/4	4 1/16	4 7/16
	B	.70	.72	.72	.73	.74	.81	.87	.88	1.00
3	A	2 7/8	3	3 1/8	3 3/8	3 1/2	3 3/4	4 1/16	4 9/16	4 7/8
	B	.70	.72	.72	.79	.79	.81	.88	1.06	1.12
3 1/2	A	3 1/4	3 3/8	3 1/2	3 11/16	3 13/16	4 1/8	4 7/16	4 3/4	5 1/8
	B	.83	.86	.85	.86	.87	.94	1.00	1.12	1.12

C = 1/2 in.

Size conduit		1/2	3/4	1
1/2	A	1 5/8	1 3/4	1 7/8
	B	.78	.80	.79
3/4	A	1 3/4	1 7/8	2
	B	.80	.82	.81
1	A	1 7/8	2	2 1/8
	B	.80	.81	.81
1 1/4	A	2 1/16	2 3/16	2 5/16
	B	.80	.83	.83
1 1/2	A	2 3/16	2 5/16	2 7/16
	B	.81	.83	.83
2	A	2 1/2	2 5/8	2 3/4
	B	.89	.91	.90
2 1/2	A	2 13/16	2 15/16	3 1/16
	B	.95	.97	.97
3	A	3 1/8	3 1/4	3 3/8
	B	.95	.97	.97
3 1/2	A	3 1/2	3 5/8	3 3/4
	B	1.01	1.04	[illegible]

Spacings for Conduit with Given Clearances (*Continued*)

D in nearest practical dimension			
Conduit	D	Conduit	D
1/2	1 3/8	2	2 7/8
3/4	1 5/8	2 1/2	3 1/2
1	1 7/8	3	4 5/16
1 1/4	2	3 1/2	4 7/8
1 1/2	2 1/4	....	....

C = 3/8 in.				C = 5/8 in.										
2	2 1/2	3	3 1/2	Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
2 3/8	2 11/16	3	3 3/8	1/2	A	1 3/4	1 7/8	2	2 3/16	2 5/16	2 5/8	2 15/16	3 1/4	3 5/8
.77	.83	.83	.96		B	.91	.93	.92	.93	.94	1.02	1.08	1.08	1.14
2 1/2	2 13/16	3 1/8	3 1/2	3/4	A	1 7/8	2	2 1/8	2 5/16	2 7/16	2 3/4	3 1/16	3 3/8	3 3/4
.79	.85	.85	.98		B	.93	.95	.94	.96	.96	1.04	1.10	1.10	1.17
2 5/8	2 15/16	3 1/4	3 5/8	1	A	2	2 1/8	2 1/4	2 7/16	2 9/16	2 7/8	3 3/16	3 1/2	3 7/8
.78	.85	.85	.98		B	.92	.94	.94	.96	.96	1.03	1.10	1.10	1.16
2 9/16	3 1/8	3 1/2	3 13/16	1 1/4	A	2 3/16	2 5/16	2 7/16	2 5/8	2 3/4	3 1/16	3 3/8	3 3/4	4 1/16
.80	.87	.92	.99		B	.93	.96	.96	.96	.97	1.05	1.12	1.17	1.24
2 13/16	3 1/4	3 5/8	3 13/16	1 1/2	A	2 5/16	2 7/16	2 9/16	2 3/4	2 7/8	3 3/16	3 1/2	4	4 3/16
.81	.87	.92	.99		B	.94	.96	.96	.97	.97	1.06	1.11	1.17	1.24
3 1/4	3 7/16	3 7/8	4 1/4	2	A	2 5/8	2 3/4	2 7/8	3 1/16	3 3/16	3 1/2	3 13/16	4 1/4	4 1/2
.88	.88	.94	1.07		B	1.02	1.04	1.03	1.05	1.05	1.13	1.13	1.19	1.32
3 9/16	3 5/8	4 3/16	4 7/16	2 1/2	A	2 15/16	3 1/16	3 3/16	3 3/8	3 1/2	3 13/16	4 1/8	4 1/2	4 13/16
.94	1.01	1.01	1.13		B	1.08	1.10	1.10	1.11	1.12	1.19	1.26	1.26	1.39
3 7/8	4 3/16	4 11/16	5	3	A	3 1/4	3 3/8	3 1/2	3 3/4	4	4 1/4	4 1/2	4 13/16	5 1/4
.94	.99	.99	1.25		B	1.08	1.10	1.10	1.17	1.17	1.19	1.24	1.24	1.44
4 1/4	4 9/16	5	5 1/4	3 1/2	A	3 5/8	3 3/4	3 7/8	4 1/16	4 3/16	4 1/4	4 13/16	5 1/4	5 1/2
1.07	1.13	1.25	1.25		B	1.14	1.17	1.16	1.24	1.24	1.32	1.39	1.44	1.56

C = 1/2 in.				C = 3/4 in.										
2	2 1/2	3	3 1/2	Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
2 1/2	2 13/16	3 1/8	3 1/2	1/2	A	1 7/8	2	2 1/8	2 5/16	2 7/16	2 3/4	3 1/16	3 3/8	3 3/4
.89	.95	.95	1.08		B	1.03	1.05	1.04	1.05	1.06	1.14	1.20	1.20	1.26
2 5/8	2 15/16	3 1/4	3 5/8	3/4	A	2	2 1/8	2 1/4	2 7/16	2 9/16	2 7/8	3 3/16	3 1/2	3 7/8
.91	.97	.97	1.10		B	1.05	1.07	1.06	1.08	1.08	1.16	1.22	1.22	1.29
2 3/4	3 1/16	3 3/8	3 3/4	1	A	2 1/8	2 1/4	2 3/8	2 9/16	2 11/16	3	3 5/16	3 5/8	4
.90	.97	.97	1.10		B	1.04	1.06	1.06	1.08	1.08	1.15	1.22	1.22	1.35
2 15/16	3 1/4	3 5/8	3 15/16	1 1/4	A	2 5/16	2 7/16	2 9/16	2 3/4	2 7/8	3 3/16	3 1/2	3 7/8	4 3/16
.92	.99	1.04	1.11		B	1.05	1.08	1.08	1.08	1.09	1.17	1.24	1.29	1.36
3 1/16	3 3/8	3 3/4	4 1/16	1 1/2	A	2 7/16	2 9/16	2 11/16	2 7/8	3	3 5/16	3 5/8	4 1/8	4 5/16
.93	.98	1.04	1.11		B	1.06	1.08	1.08	1.09	1.09	1.18	1.25	1.29	1.37
3 3/8	3 11/16	4	4 3/8	2	A	2 3/4	2 7/8	3	3 3/16	3 5/16	3 5/8	3 15/16	4 3/8	4 5/8
.00	1.00	1.06	1.20		B	1.14	1.16	1.15	1.17	1.18	1.25	1.25	1.31	1.45
3 11/16	4	4 5/16	4 11/16	2 1/2	A	3 1/16	3 3/16	3 5/16	3 1/2	3 5/8	3 15/16	4 1/4	4 5/8	4 15/16
.06	1.13	1.13	1.26		B	1.20	1.22	1.22	1.23	1.24	1.31	1.36	1.38	1.51
	4 5/16	4 13/16	5 1/8	3	A	3 3/8	3 1/2	3 5/8	3 7/8	4 1/8	4 3/8	4 5/8	5 1/16	5 3/8
.06	1.14	1.14	1.31		B	1.20	1.22	1.22	1.29	1.29	1.31	1.45	1.36	1.56
[illegible]	4 11/16	5 5/16	5 3/8	3 1/2	A	3 3/4	3 7/8	4	4 3/16	4 5/16	4 5/8	4 15/16	5 3/8	5 3/4
.13	1.31	1.31	1.37		B	1.26	1.29	1.28	1.36	1.37	1.45	1.51	1.56	1.68

182. Table 181 of conduit spacings for different clearances between conduits and their lock-nuts, is exceedingly valuable to a man who is designing or erecting conduit work. From it he can determine directly just what the distance between centers of conduits should be for given clearances between nipples or conduit. This data is indispensable when laying out the centers of a row of holes through which conduit is to enter a panel box, or in laying out the supports for a multiple conduit run.

183. Galvanized Iron Pipe Straps

All dimensions are in inches

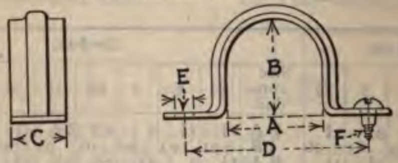


FIG. 131.—Pipe strap.

Nominal size of conduit	A Width of opening	B Height of opening	C Width of strap	D Distance between centers of screw holes	E Diameter of screw hole	F Size of wood screw to use	Approximate cost per 100	Approximate number per pound
						No. in.		
1/4	9/16	17/32	5/8	1 9/16	0.20	8 × 5/8	$0.40	75
3/8	11/16	21/32	5/8	1 3/4	0.20	8 × 3/4	0.45	72
1/2	7/8	25/32	5/8	1 7/8	0.20	8 × 3/4	0.50	40
3/4	1 1/8	1	3/4	2 1/8	0.22	10 × 3/4	0.75	29
1	1 3/8	1 11/32	3/4	2 3/8	0.22	10 × 7/8	1.00	21
1 1/4	1 3/4	1 5/8	13/16	2 3/4	0.22	10 × 1	1.25	18
1 1/2	2	1 7/8	13/16	3	0.22	10 × 1	1.50	14
2	2 1/2	2 5/16	1	3 3/4	0.22	10 × 1 1/4	2.00	12
2 1/2	2 3/4	2 15/16	7/8	4 3/8	0.25	11 × 1 1/4	2.75	6

184. That the conductors can be removed and replaced in conduit is one of the advantages of conduit wiring. If a size of conduit is selected that is too small for the wires, they will become wedged in, particularly in a warm location and withdrawal will be impossible.

184A. In selecting a conduit size for the conductors of a three-wire system with a neutral twice the size of the outer conductors, use a conduit of a size to take four wires the size of the outers. For example, the conduit for a three-wire main composed of 2–200,000 cir. mil outers and 1–400,000 cir. mil neutral should be large enough to accommodate 4–200,000 cir. mil conductors. The Underwriters (except by special permission) permit but four *2-wire circuits* or three 3-wire circuits in one conduit. Circuits of *different systems* must never be carried in the same conduit.

185. Standard Conduit and Pipe Threads

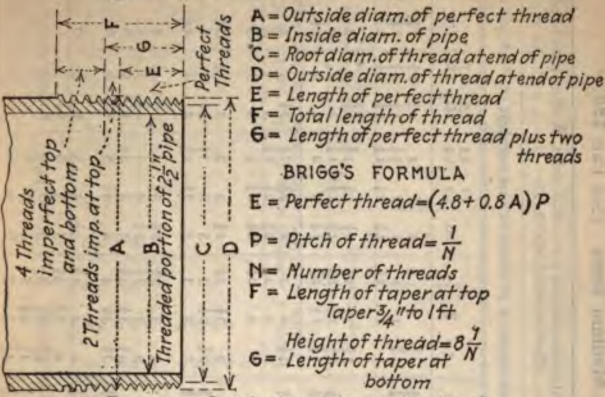


FIG. 132.—Standard conduit and pipe threads.

Size, pipe	No. of threads per in.	A	B	C	D	E	F	G	Diameter drill
1/8	27	0.405	0.270	0.334	0.393	0.19	0.41	0.264	21/64
1/4	18	0.540	0.364	0.433	0.522	0.29	0.62	0.402	7/16
3/8	18	0.675	0.494	0.567	0.656	0.30	0.63	0.408	9/16
1/2	14	0.840	0.623	0.702	0.816	0.39	0.82	0.534	11/16
3/4	14	1.050	0.824	0.911	1.025	0.40	0.83	0.546	29/32
1	11 1/2	1.315	1.048	1.144	1.283	0.51	1.03	0.683	1 5/32
1 1/4	11 1/2	1.660	1.380	1.488	1.627	0.53	1.06	0.707	1 15/32
1 1/2	11 1/2	1.900	1.611	1.727	1.866	0.55	1.07	0.724	1 23/32
2	11 1/2	2.375	2.067	2.200	2.339	0.58	1.10	0.757	2 7/32
2 1/2	8	2.875	2.468	2.618	2.818	0.89	1.64	1.138	2 5/8
3	8	3.500	3.067	3.243	3.443	0.95	1.70	1.200	3 1/4
3 1/2	8	4.000	3.548	3.738	3.938	1.00	1.75	1.250	3 49/64
4	8	4.500	4.026	4.233	4.443	1.05	1.80	1.300	4 1/4

186. Conduit Wire Capacity.—**187, 188** and **188A**, which gives *Nat. Elec. Code* recommendations, show how many rubber-covered conductors can be pulled into standard, iron conduit (iron pipe sizes). Table **187** gives values for medium runs,—average runs as defined under Table **187**. Where runs are short or have few turns smaller conduit can be used than for long runs with several sharp turns. Table **188** indicates about the minimum and maximum limits. Conduit smaller than ½ in. is not permitted for light or power wiring, but ⅜-in. conduit is used for signal work. No wire smaller than No. 14 is permitted for light or power, but smaller ones are used for signal work.

Conduit should always be large enough that great force will not be necessary to pull wires into it. Where too much force is used the insulation will be injured and the wires wedged so that they cannot be withdrawn. Conduit is too small if block-and-tackle must be used to pull in small- and medium-sized wire. Wire larger than No. 8 should be stranded.

187. Wire Capacity of Unlined, Wrought Iron Conduit—Medium Runs (See Par. **186**)

	Size wire		Safe carrying capacity, amp. Rubber insulation 1915 Code Rules	Diam. rubber insul. double braid. in 32ds in.	Size of unlined, wrought-iron conduit for 0–600 volts, rubber-insulated double-braid wires															
					Permissible number of wires in one conduit															
	American or B. & S. gage	Circular mils			1	2	3	4	5	6	7	8	9	10	11 12	13 14	15 16	17 18	19	20 21
Solid	18	1,624	3	6	3/8	3/8	3/8	1/2	3/4	3/4	3/4	3/4	3/4	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4
Solid	16	2,583	6	7	3/8	3/8	1/2	1/2	3/4	3/4	3/4	1	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4
Solid	14	4,107	15	8	3/8	1/2	3/4	3/4	1	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2
Solid	12	6,530	20	9	3/8	3/4	3/4	3/4	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2
Solid	10	10,380	25	10	3/8	3/4	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2
Solid	8	16,510	35	11	3/8	3/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2	2 1/2	2 1/2
Stranded	6	26,250	50	14	1/2	1	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	3	3	3
Stranded	5	33,100	55	15	3/4	1 1/4	1 1/4	1 1/4	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	2 1/2	3	3	3	3
Stranded	4	41,740	70	16	3/4	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	3	3	3	3	3 1/2
Stranded	3	52,630	80	17	3/4	1 1/4	1 1/4	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	3 1/2
Stranded	2	66,370	90	19	3/4	1 1/2	1 1/2	2	2	2 1/2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	4	4	4
Stranded	1	83,690	100	21	1	1 1/2	2	2	2 1/2	2 1/2	3	3	3	3	3 1/2	3 1/2	4	4	4 1/2	4 1/2
Stranded	0	105,500	125	23	1	2	2	2	2 1/2	3	3	3	3 1/2	3 1/2	3 1/2	4	4 1/2	4 1/2	5	5
Stranded	00	133,100	150	24	1	2	2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	4	4	4 1/2	5	5	5
Stranded	000	167,800	175	26	1 1/4	2	2 1/2	2 1/2	3	3	3 1/2	3 1/2	3 1/2	4	4	4 1/2	5	5	6	6
Stranded	0000	211,600	225	28	1 1/4	2	2 1/2	3	3	3 1/2	3 1/2	3 1/2	4	4	4 1/2	5	5	6	6	6
Stranded	....	250,000	200	30	1 1/4	2 1/2	2 1/2	3	3 1/2	3 1/2	4	4	4 1/2	4 1/2	5	5	6	6	6......	......
Stranded	....	300,000	275	32	1 1/2	2 1/2	3	3	3 1/2	4	4	4 1/2	4 1/2	5	5	6	6......	......	......	......
Stranded	....	350,000	300	1″ 2	1 1/2	3	3	3 1/2	3 1/2	4	4 1/2	4 1/2	5	5	6	6	6......	......	......	......
Stranded	....	400,000	325	1″ 3	1 1/2	3	3	3 1/2	4	4 1/2	4 1/2	4 1/2	5	5	6	6	......	......	......	......
Stranded	....	450,000	360	1″ 5	1 1/2	3	3	3 1/2	4	4 1/2	4 1/2	5	5	6	6	6	......	......	......	......

187. Wire Capacity of Unlined, Wrought Iron Conduit—Medium Runs (See Par. **186**) (*Continued*)

Stranded	500,000	400	1″	6	2	3	3½	3½	4	4½	5	5	6	6	6	....	....
....	550,000	450	1″	8	2	3	3½	4	4½	5	5	6	6	6		....	....
....	600,000	450	1″	9	2	3½	3½	4	4½	5	5	6	6	6		....	....
....	650,000	475	1″	11	2	3½	3½	4	4½	5	6	6	6	6		....	....
....	700,000	500	1″	12	2½	3½	4	4½	5	6	6	6	6	....		....	....
....	750,000	525	1″	13	2½	3½	4	4½	5	6	6	6		....		....	....
....	800,000	550	1″	14	2½	3½	4	4½	5	6	6	6		....		....	....
....	850,000	575	1″	15	2½	3½	4	4½	5	6	6	6		....		....	....
....	900,000	600	1″	16	2½	4	4	4½	5	6	6	6		....		....	....
....	950,000	625	1″	17	2½	4	4½	5	6	6	6			....		....	....
....	1,000,000	650	1″	18	2½	4	4½	5	6	6							
....	1,100,000	690	1″	20	2½	4	4½	5	6	6							
....	1,200,000	730	1″	22	2½	4½	5	5	6......								
....	1,300,000	770	1″	24	3	4½	5	6	6......								
....	1,400,000	810	1″	25	3	4½	5	6	6......								
....	1,500,000	850	1″	27	3	4½	5	6..........									
....	1,600,000	890	1″	28	3	5	5	6..........									
....	1,700,000	930	1″	30	3	5	6	6..........									
....	1,800,000	970	1″	31	3	5	6	6..........									
....	1,900,000	1,010	2″	1	3	5	6	6..........									
....	2,000,000	1,050	2″	2	3	6	6	....									

Table of conduit sizes for No. 14 B. & S. duplex, double-braided cables for 0 to 600 volts

Size conduit	No. of duplex cables, ordinary runs
½	1
¾	2
1	3
1¼	6
1½	8
2	15

A **short run** is one that is not over 150 ft. in length and that **is** almost straight but it may have one or two bends of a radius not less than 3 ft. Good conditions for pulling and feeding wire are assumed.

A **medium run** is one that does not exceed 150 ft. in length and has not more than three or four easy bends. Or it may be **250 ft.** long and nearly straight. Or it may be a short run with one close bend and one or two easy ones.

A **long run** is one of a length exceeding 150 ft. with close or medium bends: a run with more than one close bend, or any run with an extra close bend.

188. Wire Capacity of Unlined Wrought-iron Conduit for Short, Medium and Long Runs. (See Pars. 186 and 187.)

Size of wire			Size of conduit, inches								
			1 wire in conduit			2 wires in conduit			3 wires in conduit		
	B. & S. Gage	Circular mils	Short Run	Medium Run	Long Run	Short Run	Medium Run	Long Run	Short Run	Medium Run	Long Run
Solid	14	4,107	½	½	½	½	½	¾	½	¾	1
	12	6,530	½	½	½	½	½	¾	¾	¾	1
	10	10,380	½	½	½	½	¾	¾	¾	1	1
	8	16,510	½	½	½	¾	¾	1	1	1¼	1¼
Stranded	6	26,250	½	½	¾	1	1	1¼	1	1¼	1¼
	4	41,740	½	¾	¾	1	1¼	1¼	1¼	1¼	1½
	3	52,630	½	¾	¾	1¼	1¼	1½	1¼	1¼	1½
	2	66,370	½	¾	1	1¼	1½	1½	1¼	1½	2
	1	83,690	¾	1	1	1¼	1½	2	1½	2	2
	0	105,500	¾	1	1	1½	2	2	2	2	2
	00	133,100	1	1	1	1½	2	2	2	2	2
	000	167,800	1	1¼	1¼	2	2	2	2	2½	2½
	0000	211,600	1	1¼	1¼	2	2	2½	2	2½	3
	.....	300,000	1¼	1½	1½	2	2½	2½	2½	3	3
	.....	400,000	1½	1½	2	2½	3	3	3	3	3½
	.....	500,000	2	2	2½	3	3	3½	3½	3½	4
	.....	700,000	2	2½	2½	3	3½	4	4	4	4½
	.....	1,000,000	2	2½	3	4	4	4½	4½	4½	5
	.....	1,500,000	3	3	4	4½	4½	5	5	5	6
	.....	2,000,000	3	3	4	6	6	7	6	6	7

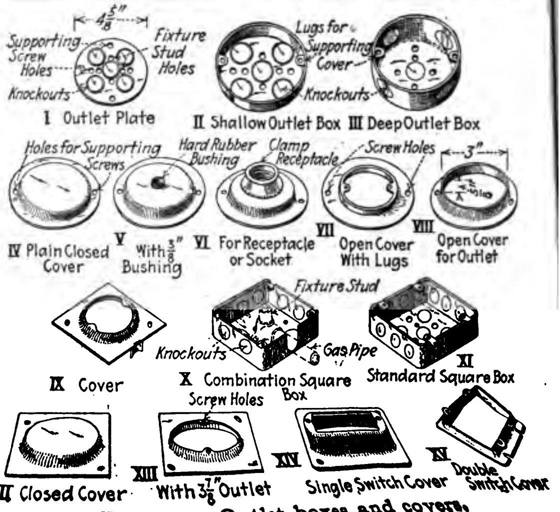


FIG. 133.—Outlet boxes and covers.

188A. Standard Code Sizes of Unlined Wrought-iron Conduit for Installation of Wire and Cables.—Conduit sizes based on the use of not more than three 90-degree elbows in runs taking up to and including No. 10 wire, and two elbows for wires larger than No. 10. Wires No. 8 and larger are stranded. Special permission is required of the inspection department having jurisdiction for the installation of more than nine wires in the same conduit. The wires used by the telephone companies of various cities differ as to thickness of insulation. The table "A" gives values satisfactory for both light and heavy insulation. For explanation of column heading reference letters for this table A, see footnotes. All data in following table from 1915 Nat. Elec. Code, except those in *italics* which are Nat. Elec. Contr's Ass'n recommendations.

Size of wire		Single wires				Twin or duplex wires			Three-wire convertible system		
B. & S. or A.W.G.	Circular mils	1 wire	2 wires	3 wires	4 wires	Size, A.W.G. or B. & S.	Number of wires	Size of conduit	Size of conductors, A.W.G. or B. & S.: 2 conductors	Size of conductors, A.W.G. or B. & S.: 1 conductor	Conduit size, in.
14	4,107	1/2	1/2	1/2	3/4	14	1	1/2	14	10	3/4
12	6,530	1/2	3/4	3/4	3/4	14	2	3/4	12	8	3/4
10	10,380	1/2	3/4	3/4	1	14	3	1	10	6	1
8	16,510	1/2	1	1	1	14	4	1	8	4	1
6	26,250	1/2	1	1 1/4	1 1/4	12	1	1/2	6	2	1 1/4
5	33,100	3/4	1 1/4	1 1/4	1 1/4	12	2	3/4	5	1	1 1/4
4	41,740	3/4	1 1/4	1 1/4	1 1/2	12	3	1	4	0	1 1/2
3	52,630	3/4	1 1/4	1 1/4	1 1/2	12	4	1 1/4	3	00	1 1/2
2	66,370	3/4	1 1/4	1 1/2	1 1/2	10	1	3/4	2	000	1 1/2
1	83,690	3/4	1 1/2	1 1/2	2	10	2	1	1	0000	2
0	105,500	1	1 1/2	2	2	10	3	1 1/4	0	250,000	2
00	133,100	1	2	2	2 1/2	10	4	1 1/4	00	350,000	2 1/2
000	167,800	1	2	2	2 1/2				000	400,000	2 1/2
0000	211,600	1 1/4	2	2 1/2	2 1/2				0000	550,000	3
	200,000	1 1/4	2	2 1/2	2 1/2				250,000	600,000	3
	250,000	1 1/4	2 1/2	2 1/2	3				300,000	800,000	3
	300,000	1 1/4	2 1/2	2 1/2	3				400,000	1,000,000	3 1/2
	400,000	1 1/4	3	3	3 1/2				500,000	1,250,000	4
	500,000	1 1/2	3	3	3 1/2				600,000	1,500,000	4
	600,000	1 1/2	3	3 1/2	..				700,000	1,750,000	4 1/2
	700,000	2	3 1/2	3 1/2	..				800,000	2,000,000	4 1/2
	800,000	2	3 1/2	4	..				....	....	....
	900,000	2	3 1/2	4	..				....	....	....
	1,000,000	2	4	4	..				....	....	....
	1,250,000	2 1/2	4 1/2	4 1/2	..						
	1,500,000	2 1/2	4 1/2	5	..						
	1,750,000	3	5	5	..						
	2,000,000	3	5	6	..						

A Conduit capacities for various wires

Conduit	1 a	1 b	1 c	d	e
1/2	3	*10*	*18*	*5*	*3*
3/4	5	*20*	*30*	*10*	*6*
1	10	*30*	*40*	*15*	*10*
1 1/4	18	*70*	*100*	*25*	*16*
1 1/2	24	*90*	*130*	*35*	*25*
2	40	*150*	*200*	*50*	*35*
2 1/2	74	...	...	..	..
3	90	...	...	..	..

1—Based on straight run without elbow.

a—No. 14 R. C. d. b. solid wires. **b**—No. 16 light insulation fixture wires. **c**—No. 18 light insulation fixture wires. **d**—No. 20 braided and twisted pair. Switchboard or desk instrument wire. Based on not more than two 90-degree elbows. **e**—No. 19 braided and twisted pair. Standard 3/32 insulation telephone wire. Based on not more than two 90-degree elbows.

189. Conduit should run as straight and direct as possible. There should never be more than the equivalent of four right-angle bends between drawing-in outlets.

190. Outlet boxes that are used for conduit wiring are of sheet *steel, preferably* coated with zinc. They not only hold the conduit ends firmly in position and form a pocket for enclosing wire joints but they constitute electrical connectors between the elements of the conduit system all of which must be in good electrical contact. Each conduit run in an installation must terminate in an accessible outlet box. Outlet plates are thinner than boxes and are used where the installation of outlet boxes is not feasible.

191. Conduit outlet boxes are made in many different forms (Figs. 133 and 134) and covers for them are also made in many different forms adaptable for special purposes. For ordinary work it is necessary to stock boxes of but two of these forms, the shallow box *II* and the combination box *X*. The shallow box which is designed primarily for outlets on terra cotta (Fig. 159) in fire-proof buildings can be used for ceiling outlets where it is convenient to enter the conduits into it from the back. Where the conduits should enter the sides or for combination fixture outlet work the combination box of Fig. 133, *X* can be used, when equipped with a suitable cover. Two of the knock-outs in the combination box are so formed that, when they are removed, either a round opening for conduit or an oblong opening for pipe is afforded. The shallow box which can be purchased with or without screw lugs for covers is cheaper than the combination box. The outlet plate *I* may be used where it is not feasible to use an outlet box.

FIG. 134.—Bracket, outlet and junction box.

Outlet boxes are made of No. 10 to 12 gage sheet steel and Sherardized or galvanized ones are preferable to the japanned as with them the electrical conductivity of the conduit system is better preserved. Round boxes are made 3 in. and 4 in. in diameter. The 3-in. size is large enough for ordinary building wiring. Shallow boxes are about $\frac{1}{2}$ in. or $\frac{3}{4}$ in. deep. Standard round boxes for installation in brick are about $1\frac{1}{2}$ or $1\frac{5}{8}$ in. deep while those for lath and plaster are about $2\frac{1}{4}$ in. deep. This depth is necessary to insure that conduits entering the side knock-outs will clear the plaster. Square boxes are about 4 in. square and about $1\frac{5}{8}$ in. deep for brick and $2\frac{1}{4}$ in. deep for lath and plaster.

192. All boxes should be installed so that the outer edge of the box or the cover mounted on the box will come flush with the surface of the plaster. An outlet or junction box should never be concealed as concealment would defeat its purpose.

192A. Switch outlet boxes for one or two switches can be formed by equipping a square box with switch cover as at *XIV* and *XV*, Fig. 133. Where more than two switches are required in one group special outlet boxes for the group can be purchased.

193. A special bracket, outlet and junction box (Fig. 134) $3\frac{15}{16}$ in. in diameter and 2 in. deep is of great convenience where there are many bracket outlets to install in that two parallel conduits can be run into it as with a square box but at the same time its diameter is such that a bracket canopy will cover it. A square box with a round-opening cover will accomplish the same end but the combination will cost more than the special box illustrated.

194. Every conduit outlet should be equipped with an outlet box or plate to satisfy code requirements. Although inspectors

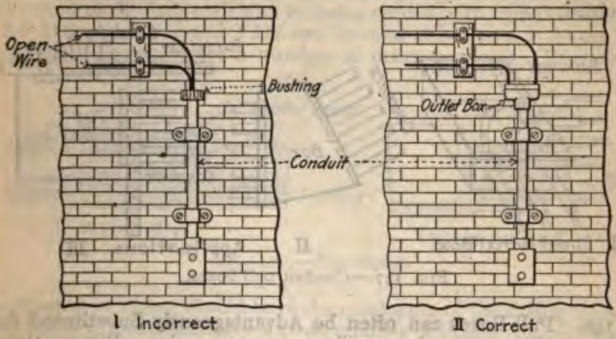


FIG. 135.—Outlet box on conduit.

sometimes accept the arrangement of Fig. 135 *I*, that shown in *II* is much better and should be used inasmuch as it provides the $2\frac{1}{2}$-in. separation required for open wiring when the conductors are not enclosed in flexible tubing.

195. Conduit junction boxes which are in reality nothing more than pull boxes on a large scale are often very convenient at points

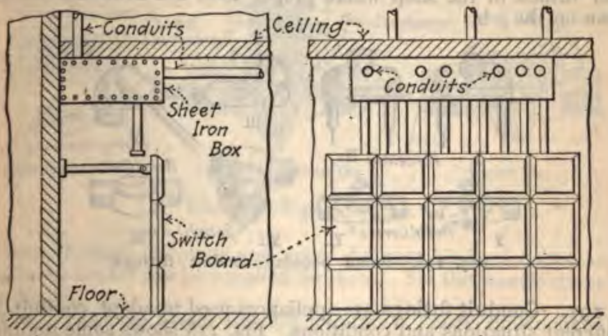


FIG. 136.—A sheet-iron conduit junction box.

where several conduit lines intersect, as for instance over a switchboard (Fig. 136) from which conduit lines radiate. The junction box is usually supported from the ceiling and is best made of sheet iron on an angle iron frame. The sides should be held on with machine screws turning into tapped holes in the frame so that they can be readily removed. Round holes can be cut in the sheet-iron sides for the conduits or instead, and often preferably, slots can be provided. The conductors within the box can be carried from conduit outlet to conduit outlet in any direction desired, and the use of elbows and troublesome conduit crossings can, thereby, be avoided.

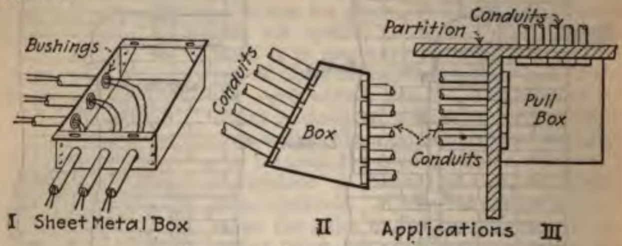


FIG. 137.—Conduit pull boxes.

196. Pull Boxes can often be Advantageously Substituted for Elbows (Fig. 137).—Large elbows are expensive. Where there are three or more right-angle turns in a run, a pull box should be inserted in any event. One pull box may be substituted for several elbows. Wire can be pulled in more readily where there are pull boxes hence, with them smaller conduit can often be used. Pull boxes can be made of sheet steel (Fig. 137, *I*) or of wood lined with sheet steel. Iron boxes should be made in accordance with the directions of a preceding paragraph (191). Boxes should be made and drilled in the shop where proper tools are available rather than on the job.

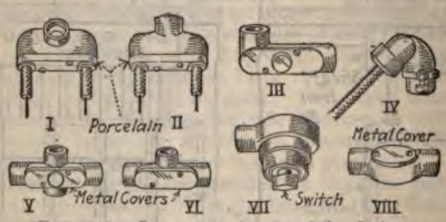


FIG. 138.—Some popular conduit fittings.

197. Conduit fittings are appliances used to adapt conduit to different situations and conditions. Fig. 138 shows some popular fittings, the applications of which are obvious. The code specifies that every conduit outlet must be equipped with an outlet box or plate. *A fitting like that of I or II placed on a conduit end fulfils this requirement.* Crosses, tees, and elbows *V*, *VI* and *III can be obtained* fitted with either metal covers or with outlet or *other devices.* The fitting of *IV* is used on the end of an out-ofloor piece of conduit into which wires enter. Its shape is such that vires must enter upwardly preventing the entrance of moisture. As it is almost impossible to pull wires through a fitting of this kind after it is in place it is therefore held to coupling on the end of the conduit with screws turning into a flange. The wires can be pulled into the conduit and the fitting slipped over them and attached to the flange without its being necessary to turn the fitting. The fittings of *VII* and *VIII* can be used either as pull boxes to support switches or for a number of other purposes. Everyone

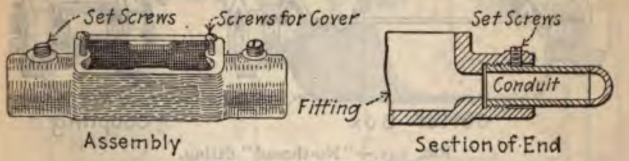


FIG. 139.—Pipe taplet.

interested in wiring should have the catalogues of the fitting manufacturers. These illustrate a great number of fitting combinations and applications.

198. "Pipe Taplet" fittings for conduit, Fig. 139 (H. T. Paiste, Philadelphia) have a set screw which assists the usual pipe threads holding the conduit. With Pipe Taplets it is necessary to cut only 4 or 5 full threads on the conduit. The steel set screws in the hubs of the fittings insure secure attachment and enable the wireman to accurately line up his conduit. Many different forms

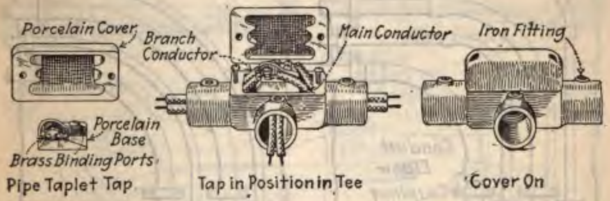


FIG. 140.—Pipe taplet tap.

of these fittings are made and many different kinds of outlet and appliance covers can be supplied for them. See the manufacturer's catalogue.

199. The Pipe Taplet Tap, Fig. 140 (H. T. Paiste, Philadelphia), is an exceedingly convenient appliance of porcelain with brass binding screws and strip. It fits in the Pipe Taplets described in the preceding paragraph. It is used for joining branch circuits to main circuits in conduit wiring. No soldering is necessary as the conductors are connected by clamping them under the binding posts. The porcelain cover encloses the completed splice. A similar appliance is made for molding wiring applications. See the manufacturer's catalogue.

200. "No-thread" fittings, Fig. 141 (*Appleton Electric Co., Chicago*), can be used with unthreaded conduit. Tightening a bushing or a lock-nut, clamps the conduit within the fitting. Their application is objectionable in some instances because they do not look as well as fittings that expose no threads.

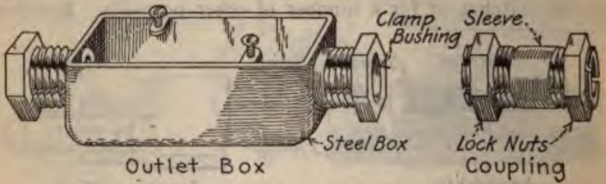


FIG. 141.—"No-thread" fitting.

201. Properly bent conduit turns look better than elbows and are therefore preferable for exposed work. See Fig. 142. If bends are formed to a chalk line, drawn as suggested in **202,** the conduits can be made to lie parallel at a turn in a multiple run as shown at Fig. 142, *II*. If standard elbows are used it is impossible to make them lie parallel at the turns. They will have an appearance similar to that shown at *I*.

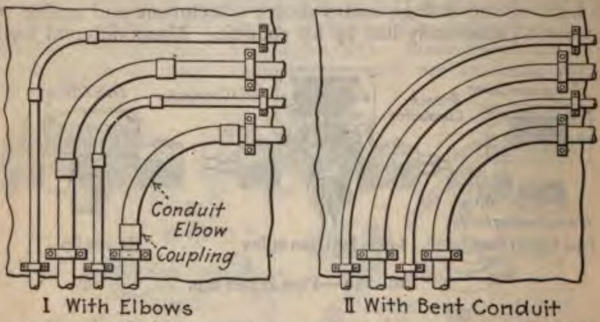


FIG. 142.—Right angle turns with elbows and with bent conduit.

202. To Lay out a Right-angle Conduit Bend.—Draw a chalk-line diagram of the contour of the bend on the floor as follows: See Fig. 143. Draw a base line *CO* of any length. Lay off *AO* 4 units long. (The units may be any dimensions whatever.) With a cord and a piece of chalk with *O* as a center and a radius of 3 units describe the arc *IJ*. With *A* as a center and a radius of 5 units describe the arc *EH*. The line OD drawn from O through *B*, the intersection of the two arcs, will be at right angles with CO.

CO and *OD* may now be prolonged for any desired distance. The arc *CD* is drawn with the cord and chalk with any required radius *R*. The conduit bend should lie parallel to this arc when the bend is laid on the floor for inspection as shown in Fig. 144. Table

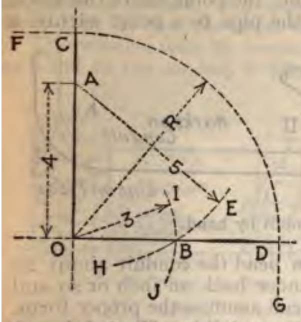


FIG. 143.—Laying out a right angle.

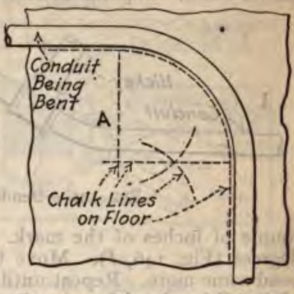


FIG. 144.—Forming a conduit to chalk lines.

173 shows the minimum radii that should be used for conduit bends.

203. Hand conduit benders are shown in Fig. 145. Many satisfactory commercial benders are obtainable but they usually

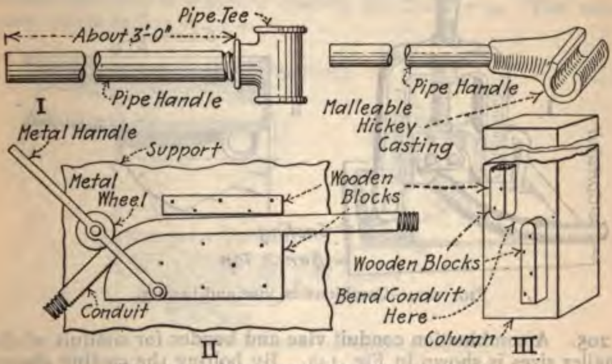


FIG. 145.—Some conduit-bending appliances.

have the disadvantage that the work must be carried to them to be bent. The "hickeys" shown at *I* can be used anywhere, hence are very popular. For $\frac{1}{2}$- or $\frac{3}{4}$-in. conduit the "hickey" should be a *1-in. tee and pipe.* A bender with a grooved metal wheel that *any one can make* is shown at *II*. The arrangement of III can be used for large conduit. It consists of two heavy wooden blocks bolted to a column or other substantial vertical support.

204. To bend conduit by hand, butt the end in which the bend is not to be made against a wall or other vertical substantial object and mark off on the floor, with a line, the point where the bend should come. Slip the bender onto the pipe to a point within a

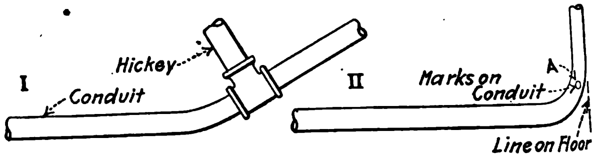


FIG. 146.—Bending conduit by hand.

couple of inches of the mark. Then bend the conduit about 20 degrees (Fig. 146, *I*). Move the bender back an inch or so and bend some more. Repeat until the bend assumes the proper form. Make all bends with as large a radius as possible. The minimum radius of inside of bend for any bend is 3½ in. Where a line is drawn on the floor, conduit can be bent accurately to it (Fig. 146, *II*) but if a mark is placed on the conduit as at *A* it very difficult to make a proper bend.

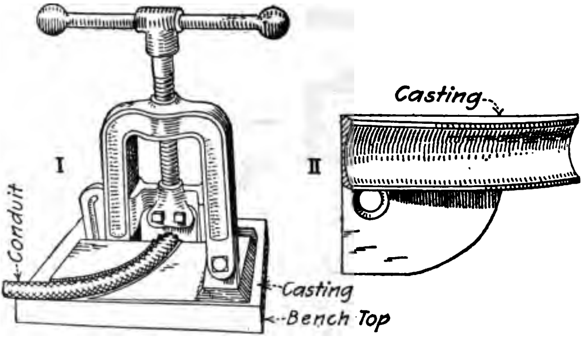


FIG. 147.—Combination vise and bender.

205. A combination conduit vise and bender for conduit of the smaller sizes is shown in Fig. 147. By bolting the casting shown at *II* to a commercial vise the arrangement shown at *I* results.

206. The best vise for large conduit is the so-called combination vise which is a combination of a pipe vise and a machinist's vise.

207. Cold Bending Large Conduit.—A rig for doing this shown in Fig. 148. The bending rig can be set up in a door-way or between any strong vertical supports. It is usually cheaper to bend large elbows than to buy them. Always carefully lay out chalk line (see **202**) on the floor to bend to before starting. In forming a bend, start at one end of the curve that is to be, bend a little with the jack screw and then take the conduit out and to the chalk line and compare it therewith. Proceed thus until the bend required is formed. A hydraulic rather than a screw jack may be necessary for conduits larger than 2 in. diameter.

The wooden form by means of which the jack screw's pressure is applied to the conduit is detailed in Fig. 149. It should be of a

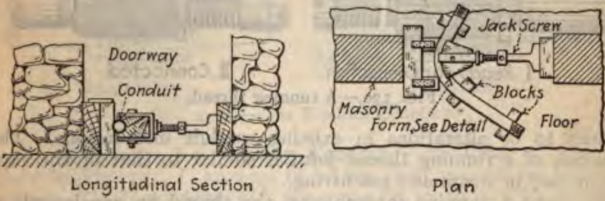


FIG. 148.—Cold bending conduit with a jack-screw.

hard close-grained wood such as maple. The diameter of the groove should be a trifle larger than that of the conduit. There should be a block for each size conduit, but sometimes a conduit can be successfully bent with a block for a larger size. If the groove does not fit, the pipe may crush. The iron strap reinforces the groove. The bolt should fit the hole for it in the block tightly or the block may crush. The radius *R* (Fig. 143) should be not less than that of standard elbows; see Table **173**. The minimum, inside radius, is $3\frac{1}{2}$ in.

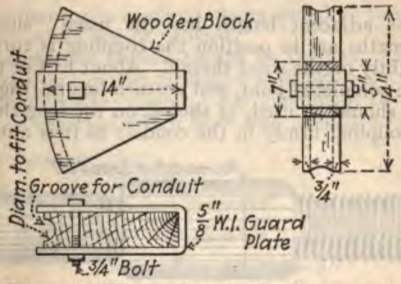


FIG. 149.—Wooden form for bending conduit.

208. Threading Conduit.—The same dies that are used by steam and gas fitters for threading pipe are used for threading conduit. It is usual practice when a lot of conduit is received to rethread all of the ends which may have become filled with paint or dirt or distorted by blows. Rethreading will save more than its cost in *that it insures rapid erection.* Always *ream conduit after cutting a thread on it.*

209. Pipe-threading machines for threading conduit, preferably those operated by motors, should be used on big jobs and will soon pay for themselves in the time that they save.

210. Running thread joints (Fig. 150) are sometimes used when it is necessary to connect the ends of two lengths of conduit neither of which can be turned. Running threads are often used in making

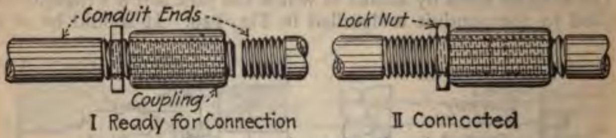


FIG. 150.—A running thread.

repairs to or alterations in existing conduit installations. The function of a running thread joint is similar to that of the pipe union used in steam and gas fitting.

To make a running thread joint, the thread on one length of conduit (Fig. 150) is cut sufficiently long that the coupling can be run entirely on it while the adjacent length is being fitted into

FIG. 151.—Showing lock-nut sawed from coupling.

position. The adjacent length has the usual "short thread." After both lengths are in position the coupling is turned until it wedges up tightly on the short thread. About half of the coupling should, in the completed joint, rest on each length (Fig. 150, *II*).

A lock-nut should be used, as shown, on the long thread length to hold the coupling firmly in the conduit as it is apt, otherwise,

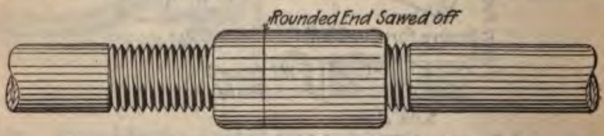


FIG. 152.—Coupling end sawed off to make flush joint.

to fit loosely because of the long thread. An excellent lock-nut can be made by sawing off, with a hack-saw, about one-third of a coupling and using this third, as shown in Fig. 151. The standard, hexagonal, conduit lock-nut often gives trouble because it has only a few threads and they may be "loose." Where a very neat job is required, saw off the rounded end of the standard coupling so that the sawed end of the improvised coupling lock-nut will have a square surface on which to abut. See Fig. 152 for an illustration.

210A. The Erickson coupling (Fig. 152, *A*), was devised for the same applications as those for which the running thread is used. The illustration shows the construction of the device.

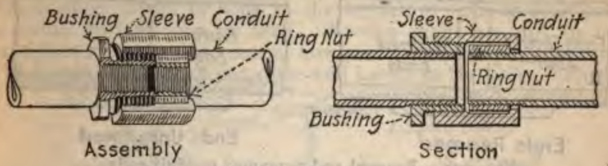


FIG. 152A.—The Erickson coupling.

211. Wrenches for Turning Conduit.—The form of wrench shown in Fig. 153, *I*, appears to be the most popular for turning conduit. Chain wrenches (*II*) are not as yet much used for conduit work but in instances where they have been tried they have proven very satisfactory. Their advantages lie in the facts that they can be used with one hand after the chain is around the conduit and

FIG. 153.—Wrenches for conduit.

that they can be used in confined places and close to walls where a Stilson wrench could not be utilized.

212. Conduit ends should always be reamed. A reamer like that of Fig. 154 that can be turned by a bit brace is a good tool for small and medium size conduit. For conduit of the larger sizes, reamers can be obtained which have long handles attached, giving

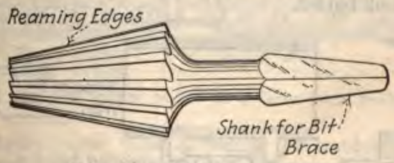


FIG. 154.—A bit-brace reamer.

the needed leverage. When conduit is received, and after it is cut, the ends are frequently turned in (Fig. 155, *I*) and when screwed together in a coupling form a knife-like edge which will abraid insulation. When the ends are properly reamed they appear as shown in Fig. 155, *II*, but if they are screwed together too tightly they may turn up as at *I*, defeating the thing that reaming should accomplish. Where no other tool is available, conduit can be reamed by hand with a half-round file.

213. **The best tool for cutting conduit** is a hack saw. Pipe

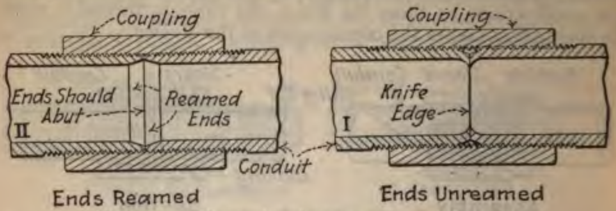


FIG. 155.—Reamed and unreamed conduit ends.

cutters are frequently used but leave a large burr on the inside of the conduit which takes time to ream out. While cutting, the conduit should be held in a vice. On jobs where there is a great deal of conduit to cut, the installation of a motor-driven cold-cut-off saw, such as is used for cutting structural steel and rails, will prove economical. A rapidly rotating steel disc without teeth cuts the pipe. Water must be sprayed on the disc to keep it cool.

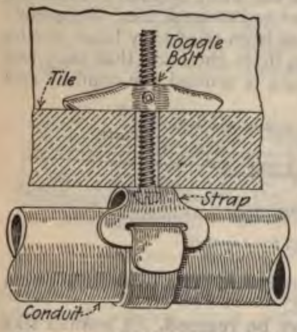


FIG. 156.—Conduit toggle bolt.

214. **In installing exposed conduit runs** where there are several conduits in the run it is usually better to carry the erection of all of them along together rather than to complete one line before starting the others. If all are carried along together it is easier to maintain all of the ducts parallel, particularly at turns, and the chances are that the job will thereby look better.

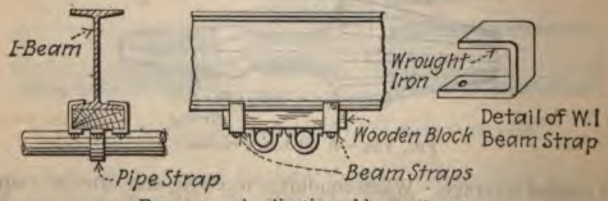


FIG. 157.—Application of beam straps.

215. **A hanger for supporting conduit on hollow tile** (Fig. 156) is made by the Yonkers Specialty Co., Yonkers, New York. With it only one hole is necessary through the tile which is considerabl

weakened by the two holes and plugs close together that are necessary for a pipe strap. The flexible metal strap is bent around the pipe and through the slot after the conduit is in position.

216. Conduit can be supported on surfaces with pipe straps (Table 183). On wooden surfaces wood screws secure the straps in position. On masonry surfaces wood screws turning into wooden plugs driven in holes in the surface or turning into lead expansion anchors can be used. Wooden plugs are apt to be unsatisfactory because no matter how well seasoned a plug appears to be it will usually dry out some and loosen in the hole. Where

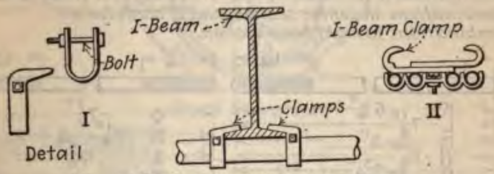


FIG. 158.—Commercial conduit clamps.

conduit is carried on the flanges of I-beams one of the many commercial clamps can be used or the one referred to in **219** can be applied. Conduit can also be supported on an I-beam by first clamping a wooden block to the beam and then securing the conduit to the block with pipe straps. (See Fig. 157.)

217. Some commercial I-beam conduit hangers are shown in Fig. 158. The one at *I* is an I-beam clamp formed from wrought-iron strap. The hanger or clamp—the part that grips the beam—of that at *II* can be purchased of either stamped steel or malleable

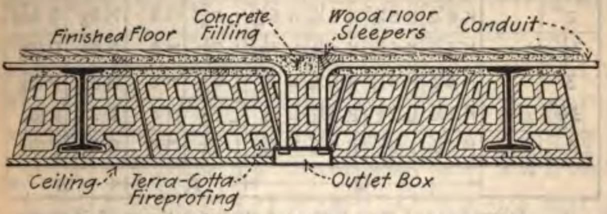


FIG. 159.—A fixture outlet in a terra-cotta ceiling.

iron. The support—the yoke in which the conduits rest—is of malleable iron and can be purchased to accommodate one or several conduits of different sizes.

218. Conduit in fire-proof buildings is usually carried over and is supported by the floor beams (Fig. 159) when carried within the floors. Where necessary the terra-cotta fire-proofing is channeled to receive it. In vertical runs in walls or partitions the fire proofing is either channeled for or built around the conduit which is held in place prior to plastering with cut nails or pipe hooks.

219. The I-beam conduit clamps of Table 220 will be found of great convenience in steel mill and fire-proof building work. Their principal advantage is that they draw the conduit up closely against the I-beam and grip it very firmly. In a multiple-conduit run each conduit can be secured to a given beam with its own pair of clamps. Where the clamps are used on conduits in a group that lie close together the stove bolts should be used in

In case studs are used instead of stove bolts:– Use "Q" studs for all combinations in left hand section of table, use "R" studs for all combinations in center section, and "S" studs for all combinations in right hand section.

Conduit	4"	6"	7"	8"	9"	10"	12"	15"	18"
½"	T 5½"	K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
¾"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1¼"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1½"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2½"		K 6¼"	K 6¼"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3"		K 6¼"	K 6¼"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3½"		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
4		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
		←—— Q			——→	← R	→	← S	→

(Column header above the I-beam sizes: SIZE OF I BEAMS)

FIG. 160.—Dimensions of store bolts and studs for the conduit clamps of Fig. 161.

preference to the studs so that they can be drawn up with a screw driver. For a single isolated conduit either studs or stove bolts can be used.

Fig. 160 shows the size of the stove bolts or of the studs, that should be used with a given I-beam and a conduit of a given size. Stove bolts of the sizes indicated are regularly manufactured, but are not always readily obtained. The studs can be easily made by threading the ends of ¼-in. wrought iron rod. In cramped locations the nuts on the studs can be tightened with pliers.

220. Dimensions of I-beam Conduit Clamps.—Clamps to be made of cast or malleable iron. See Fig. 160 showing dimensions of stove bolts and studs for clamps.

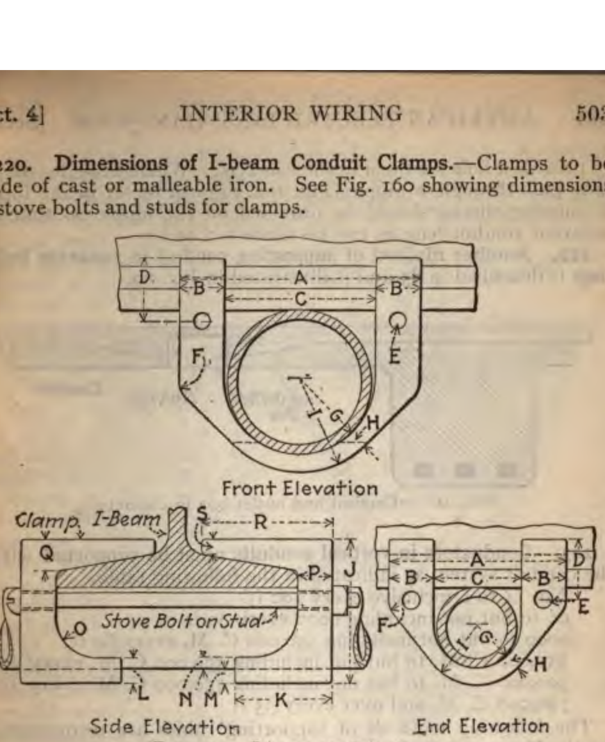


FIG. 161.—I-beam conduit clamp.

Size conduit, inches	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1 ½[1] 4" beam	2 5/16	11/16	15/16	3/4	5/16	11/32	15/32	1/4	23/32	1 11/16	1 1/2	3/8	1/4	1/8	1/2	1/2	11/32	1 1/2	3/16
1/2	2 5/16	11/16	15/16	1 1/8	5/16	11/32	15/32	1/4	23/32	2	1 1/2	3/8	1/4	1/8	1/2	1/2	15/32	2 1/8	3/16
3/4	2 1/2	11/16	1 1/8	1 1/8	5/16	11/32	9/16	1/4	13/16	2 1/4	1 1/2	3/8	1/4	1/8	1/2	9/16	15/32	2 1/8	3/16
1	3	3/4	1 1/2	1 7/32	5/16	3/8	3/4	1/4	1	2 5/8	1 5/8	7/16	1/4	3/16	11/16	9/16	33/64	2 3/16	1/4
1 1/4	3 1/4	3/4	1 3/4	1 3/16	5/16	3/8	7/8	1/4	1 1/8	2 29/32	1 5/8	7/16	1/4	3/16	11/16	9/16	33/64	2 3/16	1/4
1 1/2	3 1/2	3/4	2	1 3/16	5/16	3/8	1	5/16	1 5/16	3 3/16	1 7/8	1/2	5/16	3/16	11/16	9/16	33/64	2 3/16	1/4
2	4	3/4	2 1/2	1 1/4	5/16	3/8	1 1/4	5/16	1 9/16	3 3/4	1 7/8	1/2	5/16	3/16	1 1/8	5/8	37/64	2 1/4	5/16
2 1/2	4 3/4	7/8	3	1 15/32	5/16	7/16	1 1/2	5/16	1 13/16	4 1/2	2	9/16	15/16	1/4	1 1/4	11/16	41/64	2 5/16	3/8
3	5 3/4	1	3 3/4	1 5/16	5/16	1	1 5/8	3/8	2 1/4	5 1/8	2 1/8	9/16	3/8	3/16	1 1/4	11/16	41/64	2 3/8	3/8
3 1/2	6 1/4	1 1/8	4 1/4	1 3/8	5/16	1 1/4	2 1/8	1/2	2 5/8	5 11/16	2 1/4	11/16	1/2	3/16	1 1/4	13/16	11/16	2 15/32	7/16
4	7 1/2	1 3/8	4 3/4	1 7/16	5/16	1 3/8	2 3/8	1/2	2 7/8	6 1/4	2 1/4	3/4	1/2	1/4	1 1/4	13/16	29/32	2 7/16	1/2

[1] This clamp is designed for 4-in. I-beams only.

221. Conduit in concrete buildings—much of it at any rate—should *be installed while* the building is being erected. *The outlets and the conduit between* outlets should be attached to the *forms and the concrete* can be poured around them (Fig. 162). *Where several conduits* are to pass through a wall, partition or floor *plugged sheet-iron tube* (Fig. 163, *I*) should be set in the form to provide a hole for them in the concrete. Where a single conduit is to pass through, a nipple (Fig. 163, *II*) can be set in the forms. A running thread should be provided on the nipple so that the adjacent conduit lengths can be connected to it.

222. Another method of supporting conduit in concrete buildings is described in **83** and is illustrated in Fig. 60.

FIG. 162.—Conduit and outlet box in concrete.

223. Conductors in vertical conduits must be supported within the conduit system as indicated in the following table.

No. 14 to 0 inclusive every 100 ft.
00 to but not including 0000 every 80 ft.
0000 to but not including 350,000 C. M. every 60 ft.
350,000 C. M. to but not including 500,000 C. M. every 50 ft.
500,000 C. M. to but not including 750,000 C. M. every 40 ft.
750,000 C. M. and over every 35 ft.

The following methods of supporting cables are recommended by the Underwriters:

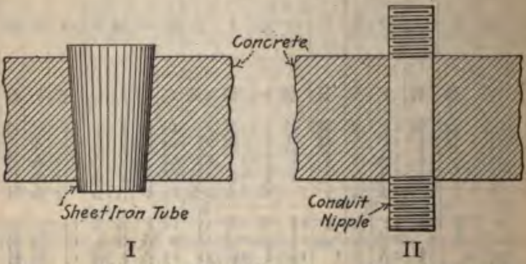


FIG. 163.—Methods of providing passages through concrete.

1. Approved clamping devices constructed of or employing insulated wedges inserted in the ends of the conduits.

2. Junction boxes may be inserted in the conduit system at the required intervals, in which insulating supports of *approved* type must be installed and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto, the boxes to be provided with proper covers.

3. Cables may be supported (Fig. 164) in *approved* junction boxes on two or more insulating supports so placed that the conductors will be deflected at an angle of not less than 90 degrees, and carried a distance of not less than twice the diameter of the cable from its vertical position. Cables so suspended may be additionally secured to these insulators by tie wires.

Other methods, if used, must be approved by the Inspection epartments having jurisdiction.

224. **Fishing wire** (*Popular Electricity*, Apr. 7, 1912) is tempered eel wire of rectangular cross-section. It is a grade of wire that used sometimes for rset steels and can be btained at corset facries and at electrical ipply houses. A fishg wire is termed a snake" by some wireien. See Table 227. that a fishing wire ill slide readily past nall obstructions, hooks iould be bent in its ends s shown in Fig. 165. efore bending, the ends iould be annealed by eating them to a red eat and allowing them cool slowly. A small rass knob riveted to the nd of a fishing wire Fig. 166), is better than hook as regards the ase with which the wire an be pushed through onduit. Where fishing s difficult, it is someimes necessary to push wo "snakes" with hook nds into the wire way, one from each of the outlets, as shown in Fig. 65. The wires must be worked back and forth and twisted around ntil the two hooked ends engage. Then one wire can be pulled into

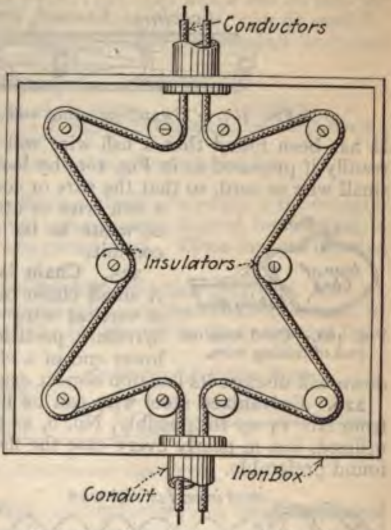


FIG. 164.—Supporting conductors in a vertical conductor run.

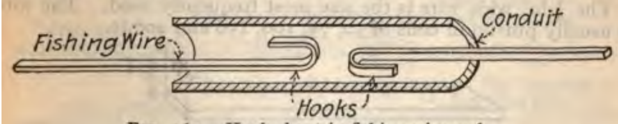


FIG. 165.—Hooks bent in fishing wire ends.

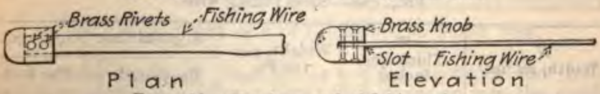


FIG. 166.—Knob on end of fishing wire.

ie duct with the other. The Swan fishing wire for conduit, shown Fig. 167, has a patented coupling on one end and a patented drawing-in-eye" on the other, which can be made to engage thin conduit, as shown in the illustration, When fishing from two ends, as in Fig. 165, it is often advisable to tie a loop, possibly a foot long, of cord, in the hook of one wire and bend down the hook (Fig. 168). The other wire has an open hook which can be made to engage in the cord loop quite readily.

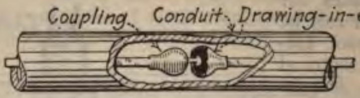


FIG. 167.—"Swan" coupling and drawing-in eye.

It has been found that a fish wire will go through conduit more readily if prepared as in Fig. 169, by loosely winding the end with small wire or cord, so that the wire or cord cannot pull off. Oiling a fish wire or attaching an oil-soaked piece of waste to its end often helps in fishing conduit.

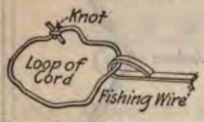


FIG. 168.—Cord loop on end of fishing wire.

225. Chain is used for vertical fishing. A small chain can be made to drop down a vertical wire way with little difficulty. Within a partition, the noise made by the lower end of a chain that is jiggled up and down will disclose its location almost exactly.

226. Galvanized steel wire can be used for fishing. Any size from No. 14 up to, possibly, No. 6, as occasion demands, may be utilized, but in nearly every case the flat steel ribbon wire will be found preferable.

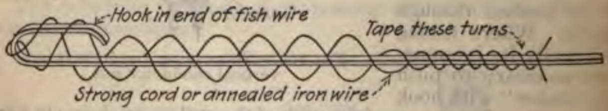


FIG. 169.—Fish wire end prepared with cord.

227. Dimensions of Steel Fish Wire

The ½-in. wide wire is the size most frequently used. The wire is usually put up in coils of 50, 75, 100, 150 and 200 ft.

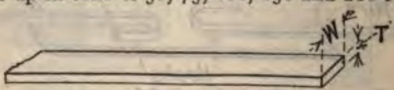


FIG. 170.—Steel fishing wire.

W Width, inches	T Thickness, inches	Weight, per 100 ft.	Approximate price, cents	
			Per pound	Per foot
⅛	0.015	11 oz.	90.0	0.62
⅛	0.030	1 lb. 4 oz.	60.0	0.75
3/16	0.030	1 lb. 14 oz.	60.0	1.13
¼	0.030	2 lb. 8 oz.	60.0	1.50
5/16	0.035	3 lb. 8 oz.	55.0	1.93
⅜	0.035	3 lb. 12 oz.	55.0	2.06

228. **Where conduit cannot be fished with a steel fishing wire** ecause of some obstruction, it is often possible to blow through, ith the mouth or with a plumber's force pump, a ball of cork of a iameter somewhat less than that of the conduit. Attached to he cork ball is a small strong cord (fish line) which can be used for ulling in a length of small wire which, in turn, can be used for rawing in the conductors. Put the ball in the conduit and feed

FIG. 171.—Attachment of conductor to fishing line.

n some string, then blow. With a plumber's pump, a tee is necesary on the end of the conduit; one opening is used for feeding in he string and the other for the pump blast. Close the cord opening hen blowing.

229. **In drawing wire into conduit** (*Practical Engineer*, Apr. 17, 912), it is a mistake to use so much force that the wire cannot be withdrawn. Conduits should be big enough so that excessive force

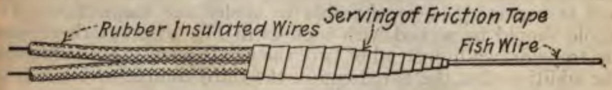


FIG. 172.—Attachment taped over.

s not necessary. Duplex No. 14 conductors can often be pushed through "easy" runs. Small conductors (No. 14 and No. 12) can be pulled in with the fish wire. Fig. 171 shows how they can be attached to the fish wire and Fig. 172 how the attachment should be served with tape to render pulling easy. It spoils any fishing wire to draw in with it conductors that pull hard.

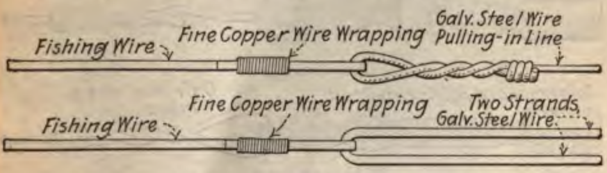


FIG. 173.—Attachment of pulling-in line to fish wire.

For conductors larger than No. 12 and No. 14, unless the "pulls" re "very easy," a pulling-in-line which is drawn into the conduit with the fish wire should be used for hauling in the conductors. No. 10 or No. 12 B.W.G. galvanized steel wire makes a good pulling-in-line and is probably better for heavy work than rope. Two trands can be used if necessary. Braided cord is better than wisted rope for a pulling-in-line, because when tension is applied, the rope tends to untwist. Sash cord is satisfactory for light work. Galvanized steel pulling-in-wire can be attached to fish wire as in Fig. 173.

Three or four links from a chain of no greater diameter than the line should be made up in the end of a rope or cord pulling-in-line. Wires to be drawn in or a fish line can be attached to the links (Fig. 174). One stranded conductor can be attached to a pulling-in-line as in Fig. 175. The attachment should be taped over to make it smooth. If two conductors are to be pulled in, one of them is "made up" into a loop in the end of the pulling-in-line, as shown in Fig. 175. The insulation is trimmed from this conductor for

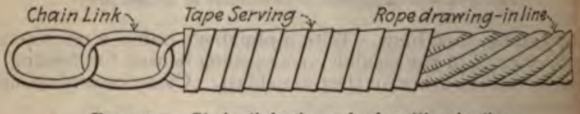


FIG. 174.—Chain links in end of pulling-in line.

6 in. or more and the bared end of the other conductor is made up about the first one, forming a long tapering connection. If a hard pull is expected, it is advisable to solder the connection. The whole should be served with tape as in Fig. 172. If three wires are to be drawn in instead of two, the attachment is the same with the addition that the bared end of the third conductor is made up around the other two. The diameter at any section of the attachment must not exceed the over-all diameter of the wires and the attachment should be in the form of a conical wedge. It is sometimes necessary to cut off, possibly, half of the strands of the bared ends and make up only the strands that remain to insure that the attachment will be of sufficiently small diameter.

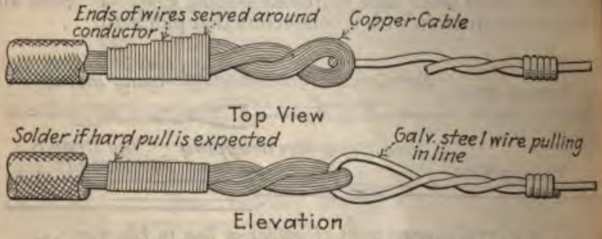


FIG. 175.—Attachment of stranded conductor to pulling-in line.

230. Force for pulling in conduit is, in the case of easy pulls, supplied by men. Tackle blocks are permissible for heavy pulls. Cranes can often be used very effectively where they are available. Snatch blocks can be used to guide the pulling-in-line to some point where it can be either pulled with the crane hook or by the crane in traveling along its runway. A lever can be used for hard pulls by either repeatedly fastening the pulling-in-line to the le ing it with a pair of pliers and then prying against the the lever. Only a short pull is possible with each setting ession of settings and prys is necessary to draw the con-

feeding conductors into conduit, care must be taken go in symmetrically and without lapping or twisting. luctor crosses another it may make a "hump" that will the conduit. blown into con- s pulling easier. ient way to get red soapstone icts is to place bow, place the he conduit and on the elbow. d soapstone rubbed on the as they are conduits where re hard.

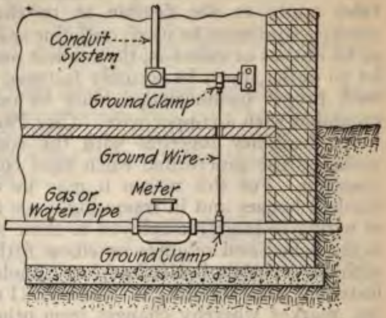
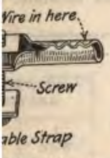


FIG. 176.—Method of installing ground on conduit system.

nduit systems rounded by at- ground clamp to a conduit of a and connecting it by a ground wire with a similar ched to a water or gas pipe outside of the meter. The be soldered in the clamps. All parts of the conduit st be in good electrical contact. It may be necessary to le enamel from fittings or from conduit threads to effect conduit system is not grounded and one side of the cir- in contact with the conduit, an electrical path may be if the other side of the circuit happens to be grounded. (The neutral wire of a three-wire system is usually grounded.) The electrical path thus completed might be through damp wood or a contact with a gas pipe. A fire might result. With the conduit well grounded such a short-circuit would blow a fuse and thereby reveal itself. With combination fixtures the gas pipe should be in firm electrical contact with the conduit system at each outlet box.



The "Amer- table ground

233. Wire for grounding conduit must er, at least No. 10 B. & S. gage, where the largest wire in conduit is not greater than No. 0 B. & S. gage. It e greater than No. 4 B. & S. gage where the largest ined in conduit is greater than No. 0 B. & S. gage. must be protected from mechanical injury.

excellent ground clamp (the American made by the *ectric Company*, Philadelphia) is shown in Fig. 177. *able* and is made in four sizes. No. 1 fits $\frac{3}{8}$-in., $\frac{1}{2}$-in.,

$\frac{3}{4}$-in., and 1-in. conduit or pipe. No. 2 fits 1 $\frac{1}{4}$-in., 1 $\frac{1}{2}$-in., and 2 and No. 3 fits 2 $\frac{1}{2}$-in. and 3-in.

235. Flexible metallic conduit (*Standard Handbook*) may used for all kinds of wiring; being in some cases prefetable to conduit. Its installation is much easier and quicker than the stallation of rigid conduit, the latter coming in short pipe len whereas the former may be had in lengths of 50 to 200 ft. depen on the size of the conduit. Practically the same *Nat. Elec. C* rules apply to the flexible as to the rigid conduit. Rubb covered wire must be used; outlet or switch boxes must be inst at all outlets or switches; the conduit must be continuous from let to outlet, must be securely fastened to the boxes and provi with proper bushings and must be permanently and effecti grounded with a copper wire. (See Par. 233.)

Its flexibility together with the continuous length proce make its use practicable when rigid conduit would be out of question. For this reason it may be employed to advantage finished houses and in frame buildings in place of the other fo of wiring so largely employed in these structures. The condu easily fished and requires no elbow fittings. These may be with the conduit itself; but care should be exercised in prop fastening the conduit at elbows. (Fig. 180.) Fittings are the market whereby changes from other forms of wiring may easily made to flexible conduit wiring. Iron plates should be to protect the conduit from nails, where it passes through slot floor beams or studding.

235A. Greenfield Flexible Steel Conduit

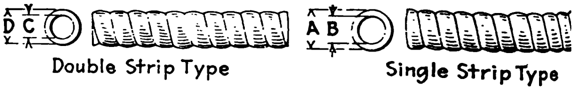


FIG. 178.—"Greenfield flexible steel conduit.

SINGLE-STRIP TYPE

B Nominal inside diameter in inches	A Approximate outside diameter in inches		Weight per 100 ft. in pounds	Approximate feet in coil	List price per 100 ft.	Largest wire accommodate 1 wire	2 wires
$\frac{5}{16}$	0.523	$\frac{17}{32}$	24	250	$5.00	....	....
$\frac{3}{8}$	0.605	$\frac{39}{64}$	30	250	7.50	....	....
$\frac{1}{2}$	0.875	$\frac{7}{8}$	55	100	10.00	8	12
$\frac{3}{4}$	1.079	1 $\frac{3}{32}$	75	50	13.00	2	10
1	1.312	1 $\frac{5}{16}$	122	50	21.00	00	0
1 $\frac{1}{4}$	1.59	1 $\frac{19}{32}$	170	50	31.00	200,000	3
1 $\frac{1}{2}$	1.875	1 $\frac{7}{8}$	188	25–50	42.00	400,000	1
2	2.375	2 $\frac{3}{8}$	263	25–50	57.00	800,000	200,000
2 $\frac{1}{2}$	3	3	306	25	70.00	....	....

DOUBLE-STRIP TYPE

C	D							
5/16	0.485	1/2	20	250	$5.00	....	....	.....
3/8	0.61	5/8	34	250	7.50	....	....	.....
1/2	0.92	59/64	68	100	10.00	8	12	.....
3/4	1.18	1 3/16	95	50	13.00	2	10	12
1	1.49	1 1/2	144	50	21.00	00	0	8
1 1/4	1.75	1 3/4	182	50	31.00	200,000	3	5
1 1/2	2.06	1 1/16	217	25–50	42.00	400,000	1	3
2	2.56	1 9/16	265	25–50	57.00	800,000	200,000	00

36. **Installation of Flexible Steel Conduit and Flexible Steel ored Conductors.**—Where exposed they may be clamped to surface wired over either with pipe hooks or with pipe straps. ere concealed they can be fished into place just as any other con-led conductors are fished in.

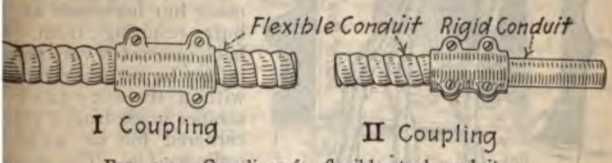


FIG. 179.—Couplings for flexible steel conduit.

37. **Flexible steel conduit is joined** with clamps as illustrated Fig. 179. Short lengths can be coupled to longer pieces with clamp of *I* and waste thereby prevented. The clamp at *II* used for coupling rigid to flexible conduit.

FIG. 180.—Elbow clamp.

FIG. 181.—Connector for attaching flexible steel conduit to an outlet box.

238. **Where elbows are formed in flexible conduit** some pro-ion must be made to prevent the conduit from straightening out ereby preventing the withdrawal of the conductors. Pipe aps can be used in some cases and in others an elbow clamp ig. 180) can be applied.

239. **Flexible steel armored conductors and flexible steel nduit** *can be connected* **into steel boxes** with the connector *strated in Fig. 181.* The fitting shown is of Sprague manu-

facture and is formed from sheet steel and galvanized. It clamped to the armor with a bolt which insures good electri connection between armor and steel box. Fig. 182 shows flexil steel conduit connect into an outlet box.

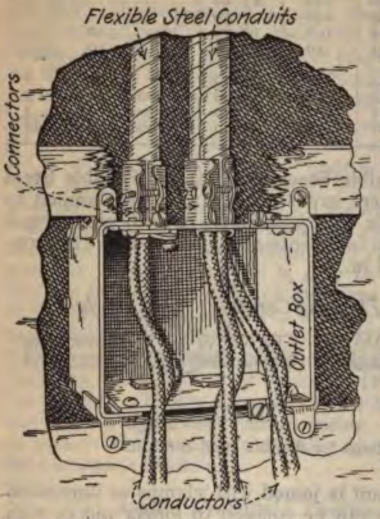


FIG. 182.—Flexible steel conduit outlet box.

240. To cut flexil steel conduit a fine ha saw should be us Special vices can be p chased which have a s across their jaws to gu the saw blade, the cond being held between groo in the jaws.

241. For reaming fl ible steel conduit a spe reamer (Fig. 183) has b made but inasmuch as burr resulting from hack-saw cut is very sm it can be readily remo with a three-corner scraper made from a thr cornered file or with ordinary file. The rea illustrated is for condui $1\frac{1}{4}$ in. or less diameter.

242. Fish plugs pulling in flexible cond (Fig. 184) are furnisl by the conduit manufacturer for $\frac{3}{8}$-in., $\frac{1}{2}$-in. and $\frac{3}{4}$-in. double a single flexible conduit. After the conduit has been cut off squ in a vice with a hack-saw the fish plug is screwed into the tube and the fish or drawing-in wire attached to the plug for pulling in.

243. Flexible steel armored conductor (Fig. 185) (*Standard Handbook*) consists of rubber-covered wire protected from injury and to a certain extent from dampness by two layers of flexible steel armor. The cable may be obtained leaded or unleaded, both being protected with the steel armor. The leaded cable differs from the unleaded in that it has a lead covering between the wire and steel armor to protect it from excessive dampness. Both the unleaded and leaded cables are made with single and multiple conductors of almost any gage wire. The leaded armored cable is approved and can be used for all classes of work, open or concealed, in fire-proof or non-fire-proof buildi and during or after construction. The unleaded cable is appr

FIG. 183.—Reamer f flexible conduit.

can be used, open or concealed, in non-fire-proof buildings pro-d they are not subject to moisture.

ıe proper way to install armored cables in new buildings is to holes in the joists and partitions and to lace the cable in the : manner as wires in concealed knob-and-tube work; but it ld always be looped from outlet to outlet. Where the cable aced in slots nails are liable to be driven into it and not being proof, it must be protected at such points with 0.125-in. iron :s. None of the cable should be installed until the roof and are in position. In running between joists and at outlets

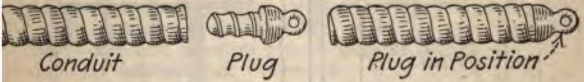


FIG. 184.—Plug for pulling-in flexible conduit.

:able should be securely fastened if possible with pipe hooks or ›s, so that in case the lock-nuts or bushings should fall off at :ts, the fastenings will prevent the cable from pulling out of the and becoming lost between the joists or studs.

ıe wires should extend about one-half a foot beyond the outlet in order to permit the proper connection of fixtures and switches, ›me cities unleaded armored cable is not permitted to be plas-l in brick walls or on metal partitions; but where allowed it ld be cemented in place and allowed to stand several days re the walls are plastered so that the cable will be protected

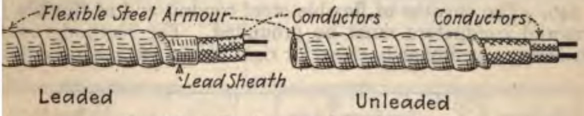


FIG. 185.—Steel armored conductors.

ı the dampness caused by the wet plaster. The unleaded : should not be run under tile or cement floors until after these : been laid because of the dripping water. Armored cable is best substitute, not including rigid conduit, for concealed ›-and-tube work and also for molding work.

4. **Manipulating Flexible Steel Armored Conductor.**—It ld never be spliced except at outlets. Many methods of :ning cable in outlet boxes are in vogue. Outlet bushings are widely used. Outlet and switch boxes specially adapted for ›le armored cable are on the market. Many special cutters ›n the market. The armor should be cut square so as not to : sharp corners which cut into the insulation of the wires.

5. **Steel Armored Conductor for Old Building Wiring.**—It be used to great advantage in this work. An advantage essed by it is that it can be run with almost utter disregard to *›ntact with pipes* or other materials and can be fished for long *ıces.* Its own weight is sufficient to carry it down partitions

and it is stiff enough to fish between joists without the use fish wire. It can also be installed quicker and with less cu of walls, floors, etc., than can wires in flexible tubing or cond knob-and-tube work, and although a trifle more expensiv makes a better job. Care should be taken in setting outlet not to depend on laths to hold them because almost invariab

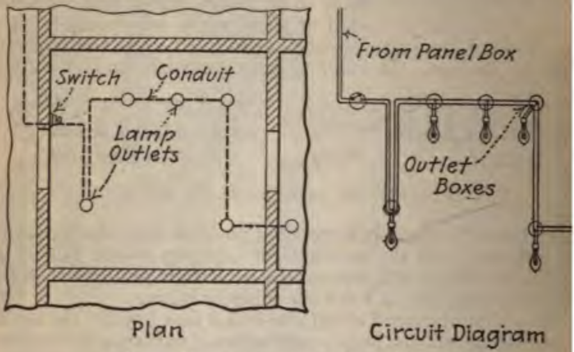


FIG. 186.—Loop system of conduit wiring.

hanging and straightening fixtures, they are pulled loose i securely fastened to a joist, stud or backboard. Fixture s should be fastened to boxes with stove bolts, riveted over the

246. The sheaths of flexible steel conduit and of flexible armored conductors must be grounded. The methods use grounding are similar to those for rigid conduit which are desc

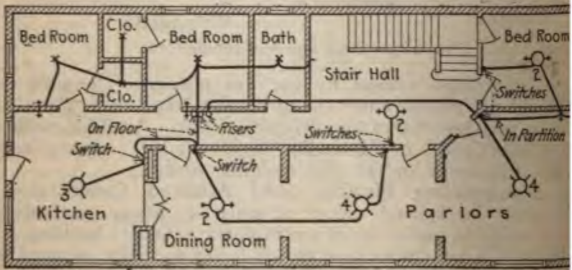


FIG. 187.—Example of loop system of wiring in a flat.

on another page. Suitable clamps which are required hold steel sheaths in position in outlet boxes, serve to complete an trical connection through the box. Where a group of these fle steel armored conductors or conduit enters a wooden panel all of the sheaths must be bonded together with a copper No. 4 or larger, soldered to them, which connects to ground

7. **The loop system of wiring** is nearly always used where uit is concealed. (See Figs. 186 and 187.) The conductors to each outlet and the use of junction boxes is thereby avoided. es should be made only in junction boxes and the boxes should ys be available for inspection.

ELECTRIC LIGHT WIRING

8. **The maximum incandescent lamp load permissible on branch circuit** is, except in special cases, 660 watts. That is, ng should ordinarily be so arranged that no set of incandes- lamps requiring more than 660 watts (16 sockets), whether ped on one fixture or on several fixtures or pendants, will be ndent on one cut-out. Permission may be given in special s, for departures from the rule. Although a branch circuit ing ten 66 watt lamps would satisfy the requirements, it is not lly the practice to connect more than 8 or 12 incandescent lamp ets to any one branch.

as-filled lamps to a capacity of 1320 watts (32 sockets) may be ndent on one cut-out *provided* No. 14 wire is carried directly the keyless sockets or receptacles.

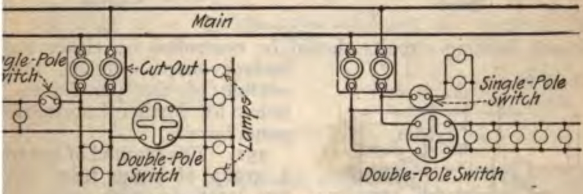


FIG. 188.—Connections of lamps to circuit.

9. **The Connection of Lamps to Circuits.**—The principles out- in Fig. 188 are general. The lamps on the circuit extending cally downward from the cut-out at the left of the illustration d burn as long as the main was alive. The other lamps are rolled by either single-pole or double-pole switches. Single- switches should not be used for the control of loads exceeding watts. Three-way switches are considered the equivalent of e-pole switches in this respect.

o. **Panel-box panels** are illustrated in Figs. 189, 190 and 191. nel provides a means of connecting (through fuses) the branch its to a main. Switches may be used as in Fig. 189, in both main and branch circuits, or switches may be omitted, as ig. 191. Whether or not switches should be provided, is mined by conditions. Many satisfactory installations are peration without switches, but switches are of great conven- for opening the circuits, for replacing fuses, or for testing. eneral, knife switches in branch circuits should not be used hrowing on and off lights, as they are not usually of suffi- y strong construction to stand up long in such service.

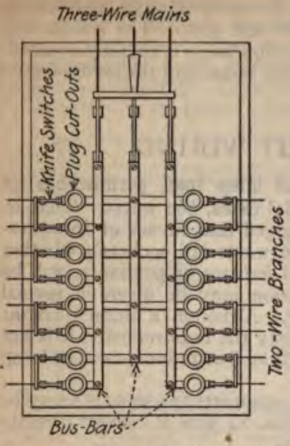


FIG. 189.—Three-wire distributing panel.

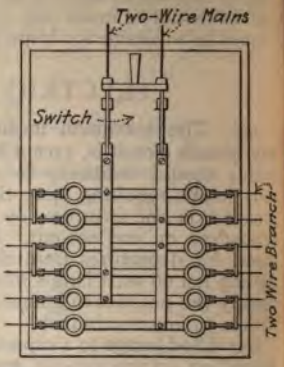


FIG. 190.—Two-wire distributing panel.

Branch lighting circuits should be controlled by either flush or surface snap switches, mounted outside of the panel box. See index for further information on panel boxes.

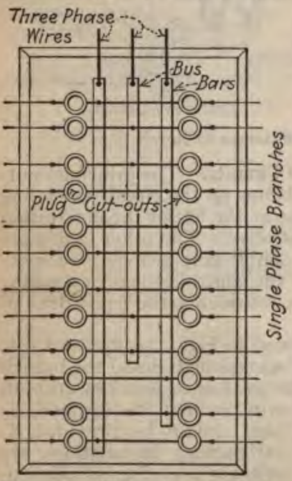


FIG. 191.—Three-phase to single-phase distributing panel.

251. The method of controlling a group of lamps from either of two locations, with snap or flush switches, is shown in Fig. 192. Two special "three-way" switches, of either the flush or surface type which can be readily purchased, are required. This scheme of wiring is much used for hall lights, so they can be controlled from either the first or second floor. Either of the schemes of wiring described in connection with Fig. 192 may be employed.

252. The method of controlling a group of lamps from either of two locations, with knife switches, is shown in Fig. 193. The method of *I* is preferable if both switches are near the lighting circuits, because it is economical of wire. If both switches are far from the lighting circuit, the method of *II* may be preferable. Where one of the switches is far from the circuit, there is not much choice. In any case where there is a question, draw diagrams approximately to scale, and which method is preferable will be evident. The method of *II* cannot be used with direct-current arc lamps, because throwing the switches will

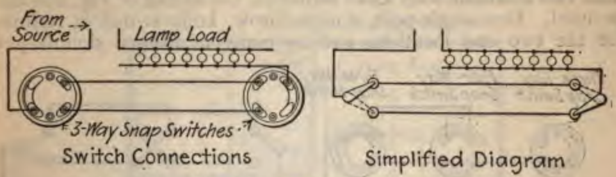


FIG. 192.—Circuits controlled from two locations.

reverse their polarity. Snap or flush switches are preferable to knife for two-location control, because a person may leave a knife switch open.

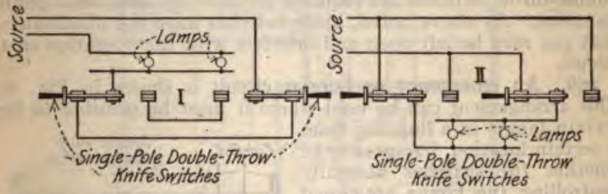


FIG. 193.—Circuit controlled from two locations with knife switches.

253. Two-location control with double-pole switches is shown in Fig. 194. This or some similar method must be adopted where the load exceeds 660 watts, as a greater load than this should not be controlled with single-pole switches.

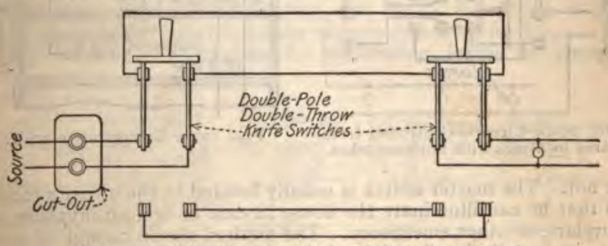


FIG. 194.—Double-pole-switch, two-location control.

254. The method of controlling a group of lamps from any one of more than two locations, with flush or snap switches, is shown in *Fig. 195.* Special switches made for the purpose are required. A *"three-way"* switch is used at each end of the circuit, and many additional "four-way" switches are necessary as there are additional control locations. This method is also much used for wiring for hall lights, so that all can be controlled from any floor.

255. **For controlling a group of lamps from any one of more than two locations with knife switches,** the wiring of Fig. 196 may be used. One single-pole, double-throw, knife switch is required for the two end locations and as many additional double-pole,

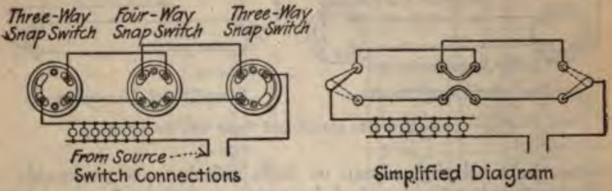


FIG. 195.—Circuit controlled from three locations.

double-throw switches are required as there are additional control locations. As above noted, knife switches have the disadvantage that one may be left open and interfere with the operation of the circuit.

256. **An emergency or burglar circuit** is shown in Fig. 197. This arrangement can be used where it must be possible to light certain lamps in a building from a certain location, irrespective of whether the switches normally controlling the lamps are closed

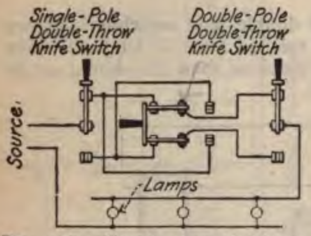


FIG. 196.—Circuits controlled from three locations with knife switches.

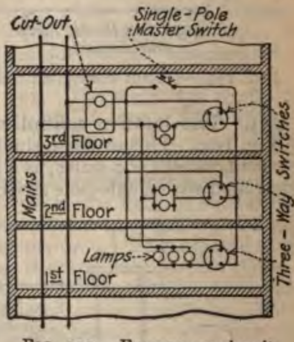


FIG. 197.—Emergency circuit.

or not. The master switch is usually located in the owner's room, so that he can illuminate the house in case of fire, an invasion by burglars, or other emergency. The method shown cannot be used for an installation involving more than 660 watts' capacity of incandescent lamps, because this is the maximum capacity that is permitted on a single-pole switch. Where a load of more than 660 watts is involved, two or more single-pole master switches can be applied, and each used for an independent emergency circuit;

or a double-pole or triple-pole switch can be installed and each pole used for an independent circuit. In some cases to control hall lights, it is necessary to substitute "four-way" for "three-way" switches. Fig. 198 shows a method of arranging an emer-

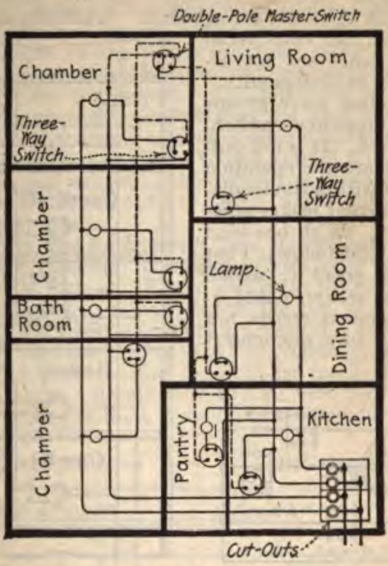


FIG. 198.—Emergency switch wiring in an old building.

gency switch in a building that has already been wired. The dotted lines represent the wiring that should be added to the existing wiring, to provide for the emergency switch feature.

257. Electrolier switches for controlling lamps in groups,

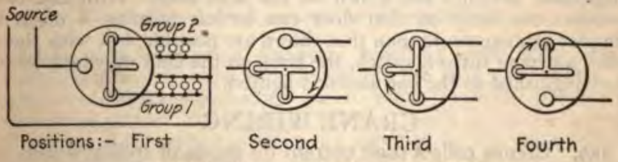


FIG. 199.—Two-circuit electrolier switch.

which control is often necessary in room lighting where there is a dome or electrolier having several distinct circuits, are wired as shown in Figs. 199 and 200. Special snap switches, which are made of either the flush, pull, or surface type, are necessary. With the two-circuit switch, Fig. 199: With the switch handle in the first position all lamps are off—in the second position only those of *group* 1 are on—in the third position those in both groups are on—in the fourth position only those in *group* 2 are on. Then with the next quarter turn of the switch the first position is again assumed and all lights are extinguished. While the same principle is always used, all commercial electrolier switches are not arranged exactly as illustrated.

For controlling three groups of lamps, a three-circuit switch, Fig. 200, is used. It is not possible to illustrate the operation of this switch with a simple diagram, and different makes operate differently. With one kind the operation is as follows: First turn connects *group* 1; second turn connects *groups* 1 and 2; third turn connects *groups* 1, 2 and 3; fourth turn disconnects all lamps.

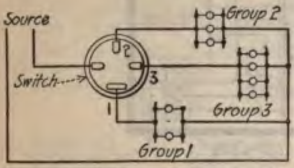


FIG. 200.—Three-circuit electrolier switch.

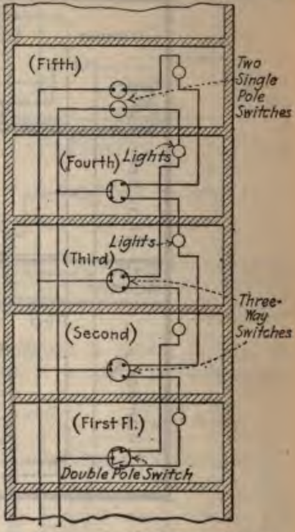


FIG. 201.—Stairway wiring.

258. **A circuit arrangement for stairway lighting** is shown in Fig. 201, whereby one can illuminate the landing that he is on and the one above or below him, as he goes up or comes down the stairs. The switch at each landing must be operated in passing. Two single-pole switches are shown on the fifth floor. With the two switches the lamp on that floor can be left burning if desired. Simpler arrangements than that shown are possible, but with them when a person turns a switch, the lamp on the floor on which he is, is extinguished as the one ahead is lighted.

CRANE WIRING

259. **Cranes collect their current** by means of trolley wheels or shoes which bear against copper trolley wires or structural steel conductors that are erected parallel to the crane runway. The location of the conductors is determined by conditions. Sometimes the crane builder specifies that the conductors must be located in a certain position; and in other cases the purchaser selects and specifies the position of the conductors and the crane manufacturer

arranges the current collectors on the crane accordingly. Probably the best location for the collector conductors on a bridge crane runway, is between the flanges of and parallel to one of the crane girders. Here the conductors are out of the way, well protected and can be readily supported. It is not often that they are erected in any other position. Occasionally the trolley wires can be supported from the roof trusses above the crane runway, and are installed similarly to the trolley wires for trolley cars. A pole collector with a wheel at its upper end, exactly like a trolley car pole but much shorter, is used. Where the spacing between roof trusses is very great this method may not give good results, because of the wire swinging and the trolley coming off. (Much of the following material on Crane Wiring is from an article on that subject, which was written by the compiler of this book and printed in *American Machinist*, Oct. 17, 1912, under the pen name of Ernest G. Bradshaw.)

260. Trolley wire for cranes is hard drawn copper, the same as used in electric traction. Hard drawn wire must be used to prevent excessive stretching. Round wire is erected where the method of support adopted does not involve the use of trolley ears for holding it at intermediate points between the ends of the run. Where trolley ears are used "Fig. 8," or preferably, grooved trolley wire should be used, because they can be readily held in screw-clamp trolley ears. Round wire can be used with trolley ears, but the ear flanges of these must be hammered down around the

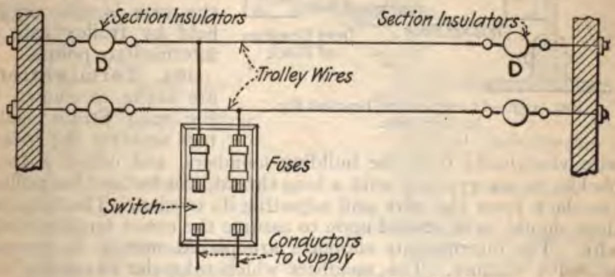


FIG. 202.—Crane wiring service switch.

wire, a time consuming operation requiring some skill; also, a round-wire ear introduces a hump on the wire and makes the trolley wheel jump and draw an arc when the wheel passes over the raised place. Either 0, 2/0, 3/0 or 4/0 wire is usually required. The wire size required is ordinarily specified by the crane builder, but in any case it should be large enough that the voltage drop in it will not much exceed 3 or 4 per cent. of the line voltage with all of the crane motors operating at full-load.

261. A crane service switch (Fig. 202) should be installed for *feeding every crane* circuit. A fused switch is most frequently *used to provide* overload protection, although in important installations, where reliability is essential—where equipment must be placed back in service after an accident, in minimum time—circuit-breakers are used. From an electrical standpoint, the best location for the service switch is at the center of the run. In practice, however, it should be placed where it can always be reached from a ladder running to the floor and so the operator can open his circuit when he leaves his machine.

262. Methods of supporting crane trolley wires differ with conditions. If the crane is provided with hook-shoe collectors (Fig. 203), which slide along under and carry the weight of the trolley wire, the wire is rigidly held only at the terminations at the ends of the run, and is kept from sagging by intermediate, insulating brackets, like those shown in Fig. 203. If trolley wheel current collectors are used (and they probably provide the best means of collecting current), the tension in the wire is taken by the terminations, and the wire is also rigidly held by trolley ears at intermediate points.

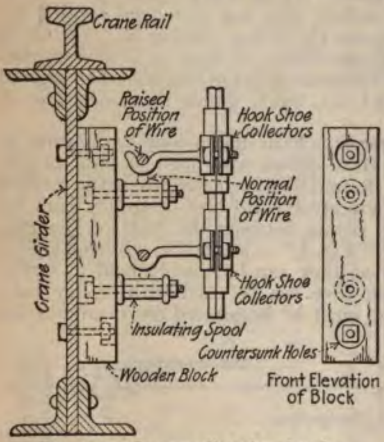


FIG. 203.—Intermediate bracket for trolley wire.

263. Terminations are made as shown in Fig. 204. Strain insulators separate the trolley wire electrically from the building members, and either a turn-buckle, or an eye-bolt with a long thread, can be used for pulling the slack from the wire and adjusting its tension. The terminations should be depended upon to assume the entire tension of the wire. The intermediate supports are placed merely to prevent excessive sagging. The members which take the stresses of the eye-bolts at the terminations should be very substantial, or thoroughly braced, because on them depends the reliability of the entire installation. The eye-bolts, turn-buckles and strain insulators should be not smaller than the $\frac{5}{8}$-in. size.

264. Intermediate supports for crane trolley wires, the supports installed between the terminations to prevent sagging, can be arranged as shown in Figs. 203, 205 and 206. The bracket of Fig. 203 is, as above outlined, applicable only where the crane has hook-shoe collectors. The block of wood that supports the insulating spools should be thoroughly dry and treated with an *insulating paint.* The bolt holes in it should be deeply countersunk, *to eliminate the* possibility of grounds. The spools can be of dry, *painted wood*—where the Underwriters will permit—but should be f porcelain. Porcelain tubes with porcelain knobs at the ends to orm flanges will do. The length of the insulator between flanges hould be at least 4 in. Spools turned from fiber are sometimes used. The spools should be so arranged that there will be at least a ½-in. learance between them and the hook-shoe when it passes along.

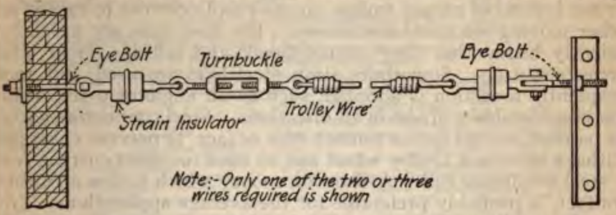


FIG. 204.—Trolley supports at ends of run.

In a fire-proof building, where the crane has trolley wheel collectors, the wires can be supported by trolley ears as in Fig. 205. The wooden supporting block must be thoroughly painted and the bolt holes in it deeply countersunk, to prevent the possibility of grounds. Tap bolts, screwing in from the rear, support the screw-

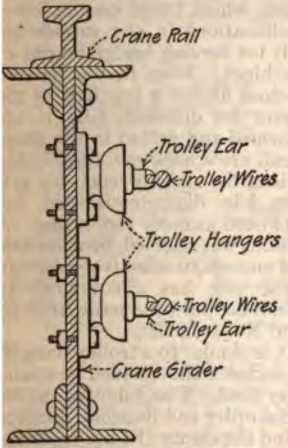


FIG. 205.—Trolley ear supports.

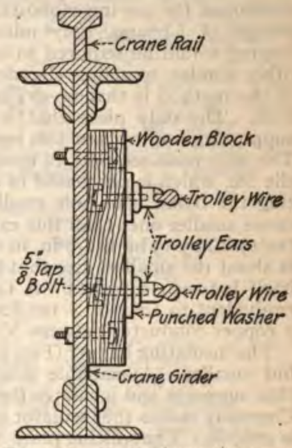


FIG. 206.—Trolley hanger support.

clamp trolley ears which seat against washers. "Figure-8" or, preferably, grooved trolley wire is used. The wire should be drawn tightly at the terminations and the ears should be installed every 8 or 10 ft.

For an out-door crane, or for applications where the Underwriters have jurisdiction, the wires can be supported as shown in

Fig. 206. Standard street railway type trolley hangers and ears are used, which provide excellent insulation. The hangers can, provided a proper location of the trolley wires results, be bolted directly to the crane girder.

265. Trolley rails of structural steel are being used to some extent instead of copper trolley wire to supply current to cranes and other moving electrical machinery. The steel rails are made sufficiently heavy that they cannot break and fall as copper wires occasionally do. Sometimes strap steel bars are used, but more frequently a section is adopted, such as an angle or a tee, which has considerable stiffness in all directions. Steel conductors should be painted, except on the contact edge or face, to prevent corrosion. Either a shoe or a trolley wheel can be used to collect current from a steel conductor rail. A shoe or spoon, which makes a rubbing contact, is probably preferable for the average application. Trolley-wheel collectors that travel at high speeds are not successful for current collection from steel conductors, because the wheel tends to bounce and jump from the rigid rail at joints and uneven places. There are almost numberless ways in which steel conductor rails can be arranged and supported. The arrangement described in the following paragraph is typical.

266. An installation of a structural steel tee conductor or trolley rail is shown in Fig. 207. While the arrangement illustrated was developed for serving mono-rail cranes, which travel on the lower flanges of I-beams, only minor modifications in the supporting forging would be required to adapt it for serving bridge cranes or other similar traveling electrical machines. Note that a feature of the method is that no drilling or close fitting is required in the field. The only piece that is different for different jobs is the supporting forging, but this can be formed and drilled in the shop. The only tools required to erect the rail are a hack-saw for cutting the tee, which is purchased in 30-ft. lengths, and a wrench for setting the bolts. No bolt smaller than $\frac{5}{8}$-in. diameter is used, because smaller ones than this can be twisted asunder too easily. A tee $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. in dimensions was selected, because this is about the smallest size that is rigid enough to effectively sustain itself between supports. A tee of this size has a conductively equivalent to that of a 109,800 cir. mil copper conductor, that is, a copper conductor between No. 0 and No. $\frac{2}{0}$ in size.

The insulating hanger (Fig. 207, *II*), is similar to a trolley hanger, but smaller. A mallable iron bell encloses the molded material that supports and insulates the hanger stud. The Johns-Manville Company makes the insulator to special order and its mold number is 4689-B. The splicing plate (*IV*) and the clamp (*V*) are castings, preferably malleable iron, and the only machine work on them is the drilling and tapping of the holes. The section insulator (*VI*) consists of two castings, a fiber dividing-block and two wrought-iron clamping plates. Directions for spacing the insulating supports when erecting the conductor are given on the illustration. *The terminal lug* (*VIII*) is forked instead of annular, so that it can be readily disconnected for isolating circuits for testing without taking out a bolt.

267. In computing the resistance of steel trolley rails, the area, in square inches, of the section involved, can be taken from

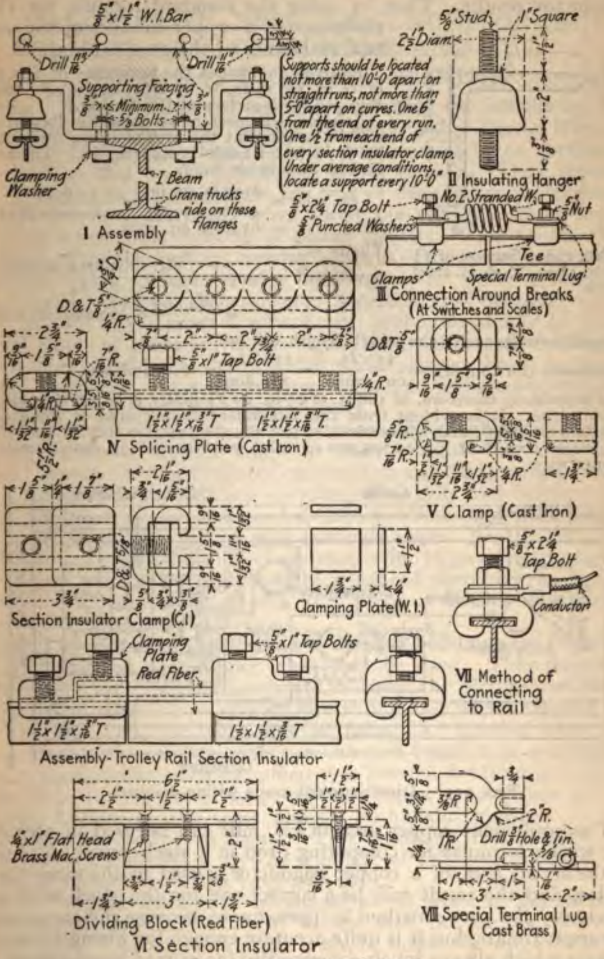


FIG. 207.—Steel trolley rail.

one of the steel company's handbooks, such as are issued by the Cambria and Carnegie steel companies; the area in cir. mils can then be obtained by using the rule given below. By dividing this area by 6.14, which is the approximate ratio of the resistance of mild steel to that of copper, the equivalent copper area of the steel conductor results. Then by using the standard formula for the resistance of a copper conductor, the actual resistance of the steel is obtained.

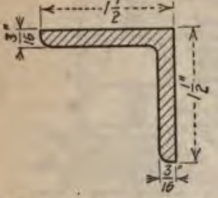


FIG. 208.—Section of $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in. × $\frac{3}{16}$ in. steel angle.

Example.—What is the resistance of 160 ft. of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle? (See Fig. 208 for a picture of the section.)

Solution.—By referring to a handbook, it will be noted that the area of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle is 0.53 sq. in. Then to find its area in cir. mils:

$$\text{cir. mils} = \frac{\text{area in sq. in.}}{0.0000007854} = \frac{0.53}{0.0000007854} = 674{,}800 \text{ cir. mils.}$$

Then:

$$\text{equivalent in copper} = \frac{\text{cir. mils area of steel}}{6.14} = \frac{674{,}800}{6.14} = 109{,}800 \text{ cir. mils.}$$

Then the resistance of the 160 ft. length will be:

$$\text{Resistance (for copper)} = \frac{11 \times \text{ft.}}{\text{cir. mils}} = \frac{11 \times 160}{109{,}800} = 0.016 \text{ ohms.}$$

The resistance, therefore, of 160 ft. of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle is 0.016 ohms. It is evident from the equivalent copper area of the steel (109,800 cir. mils), that the conductivity of the steel section will lie between the conductivities of No. 0 (105,500 cir. mils) and No. 00 (133,100 cir. mils,) copper wire.

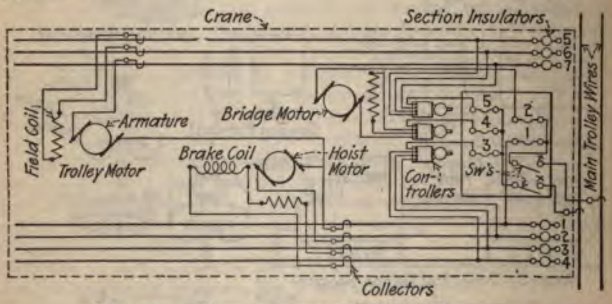


FIG. 209.—Direct-current crane wiring diagram.

The equivalent copper area in cir. mils can be used in any of the wiring formulas for computing drop in a steel conductor, just as the actual area of a copper conductor is used in the same formulas, and the result will be a correct one for the steel section. Obviously the above method is approximate, because the constants are approximate, but it is quite accurate enough for wiring computations which always involve necessarily inaccurate assumptions.

268. A crane wiring diagram is given in Fig. 209, which is typical for a direct-current, three-motor, traveling bridge crane. Variations in crane wiring and control schemes are practically number-ess. For direct-current cranes, series motors are almost invariably used, while for alternating-current cranes, wound rotor motors are used.

SIGNAL WIRING—BELL, ANNUNCIATOR, BURGLAR-ALARM, TELEPHONE AND ELECTRIC GAS LIGHTING WIRING

269. **Brief of Underwriters' Rules Covering the Installation of Telephone, Call Bell, and Similar Circuits** (*Factory Mutual Wiring Rules*).—The arrangement of these wires should be as carefully planned as that of the lighting or power circuits. They should be so placed as never to be in the way of fire streams or ladders. Where possible, the signal wires about the yard should be kept entirely away from lighting or power circuits. This avoids the liability of the two systems crossing if breaks occur and of dangerous currents being conducted into buildings over wires ordinarily considered harmless. Where the arrangement is of necessity such that crosses might occur if wires broke, protectors should be provided near the point where the signal wires enter each building. Protectors should also be provided on all foreign lines, such as public telephone or fire-alarm wires, and on all private lines which are liable to receive lightning discharges.

Where signal circuits are operated from electric-lighting or power circuits with or without lamps or other resistors in series, the signal circuits must be insulated on porcelain and the same construction followed as for lighting circuits. The bells and buttons or switches must be of non-combustible materials and held away from the supporting surface with porcelain knobs.

No signal wire should be closer than 2 in. to any electric light or power wire unless additionally insulated therefrom by some firmly fixed non-conductor such as a piece of flexible tubing or, preferably, a porcelain tube.

270. **In installing signal wires in finished buildings** the rubber-covered twisted pair copper wires may be used. They may be run along the top of the baseboard or along the picture molding. Where it is desirable to conceal the wiring and where expense is no consideration, the wires may be fished like lighting wires in concealed work. Where wires are bunched together in a vertical run, a fire-resisting covering sufficient to prevent fire from traveling from floor to floor, must be provided. Signal or telephone wires cannot be run in the same conduit with lighting wires. (The material that follows on Signal Wiring is largely from a series of articles on that subject, by the compiler of this book, printed in *Popular Electricity* during 1912 and 1913.)

271. **Signal wires may be supported on wood in dry places with metal staples** (Fig. 210) driven into the timber. Never fasten more than one wire under a staple, unless the wires are first protected with a tape wrapping. In damp places ordinary staples rust and eat through the insulation. Electrolytic action may ensue, whereby the wire will be eaten through. It is very difficult to drive round top staples in straight; hence staples having

square tops, of a style narrower than the ordinary double pointed tacks, should be used. Zinc coated staples are preferable to coppered ones. Insulating saddle staples (see illustration *II*), are probably as cheap in the long run as the ordinary metal ones, as two wires can be safely held under one saddle staple, and time is thereby saved. Insulating saddle staples secure the wire well at turns and prevent the metal from cutting into the insulation. In stringing a long run, a saddled staple at the end will hold the slack until the intermediate staples are placed.

272. Cleats of compressed, impregnated wood (see Fig. 210) are good for supporting a twisted pair conductor in an exposed place,

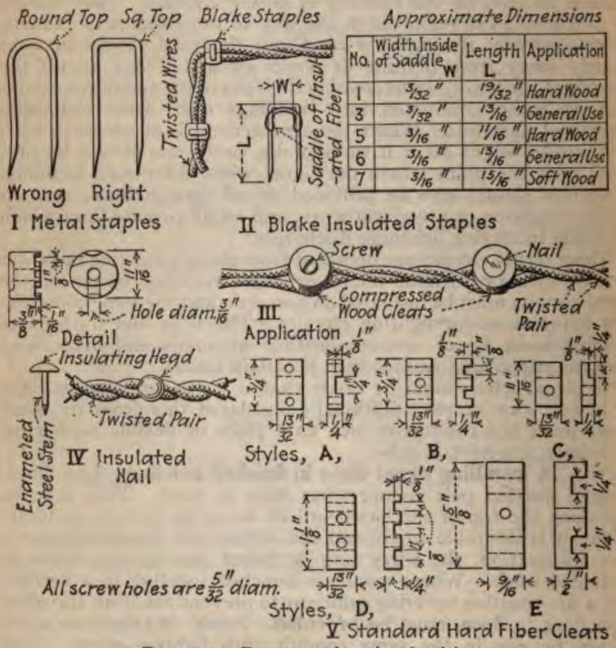


FIG. 210.—Fasteners for signal wiring.

as they are very neat in appearance. Either nails or screws can be used to hold them. The compressing of the wood prevents the cleats from splitting. They are particularly useful for runs over plastered surfaces, and in other places where staples cannot be used. When stringing long runs of wire, compressed wood cleats at the run ends will hold the slack until the intermediate cleats are placed. These wood cleats cost less than those of either porcelain or fiber. They can also be used to support single wires, one wire under a cleat.

273. **Insulated nails** (Fig. 210, *IV*) having a metal stem and a head of insulating material, are used for supporting twisted pair conductors, and while they are cheap, they do not support the wires as well as does the wood cleat. They do not hold a single wire well and do not properly hold back slack in long runs. The nails are made in different lengths and with heads of different colors to match surroundings.

274. **Hard fiber cleats** (Fig. 210, *V*) are used where one or more single conductors are to be supported, but are not as good as the wood cleats, although they cost more. It is sometimes necessary to use them where the wire supported is too large for the standard wood cleat.

275. **Wire for bell work** in dry places is usually No. 18 copper, double cotton covered and paraffined. Where more than two or three bells are connected to the circuit, or where the circuits are long, No. 16 wire should be used. No. 14 is frequently used for battery wires. Rubber covered twisted pair wires, like those used for interior telephone wiring by the telephone companies, can often be used to advantage in damp places or where the circuits are exposed. No. 20 wire, although sometimes used, is too small for reliable work. Annunciator and twisted pair wire is made with insulating coverings of different colors, so one can be selected that will match the surroundings, and, thereby, be inconspicuous. Cables of annunciator wire, which can be obtained with practically any number of conductors from 2 up to 200, are very convenient and economical for large installations. In perfectly dry locations, a cable having a paraffined, braided cotton covering can be used, but if it is to be exposed to dampness a lead covered cable should be installed. By having the cable conductors covered with braids of different colors, the conductors can be readily identified. A kind of weather-proof wire called "damp-proof," is quite satisfactory for exposed wiring in damp places. It is more expensive than annunciator wire, but it has a better appearance when installed.

276. **The installation of signal wiring in wooden framed buildings** requires great care. The conductors are so weak mechanically, so poorly insulated and there are frequently so many of them, that if work is not systematically and thoroughly erected, trouble invariably results. The wires can be supported in unfinished houses by fastening them to the studs and joists with staples. In finished houses wires can be run behind a base board or under the molding at its top; or by prying up a floor board the wires can be placed under it. A saw cut, into which the wires can be dropped, can be made in any joist that lies across the path of the wire. Wires can be run on the tops of picture moldings.

277. **In fishing for vertical wires** a piece of small chain 2 ft. long is attached to a length of strong cord. The chain and cord is pushed through a hole bored for the wire at the top of the partition, and the noise made by the chain when the cord is pulled up and down, will indicate the location of any obstruction. With the obstruction located, the baseboard or floor board can be taken out and a hole can be bored or some other means adopted to provide a pocket whereby the chain can be reached.

278. The steel fish bit (Fig. 211) is a useful tool in installing signal wires. The bit has a hole in its end. After the bit has been bored through an orifice, the wire to be drawn through is made up through the hole and the wire and bit are together drawn back through the orifice. The use of a fish wire is thereby eliminated. In a floor or ceiling, the orifice having been bored, it may be more convenient to first withdraw the bit and then to thread the wire through the hole at the end of the bit, and to push the bit back through the hole. Good bits of this type are so tempered that they will drill through wood, masonry, wrought iron or structural steel.

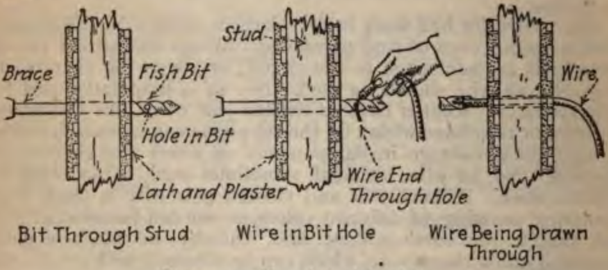


FIG. 211.—Use of steel fish-bit.

279. Electric bell circuits are shown in Fig. 212. Many of these are quite simple but are included so that all will be together for the electrician's reference. Two ordinary vibrating bells will not work well together in series, so, when it is necessary to connect two or more in series, one should be a single stroke bell, as in *IV*. A multiple arrangement *II* is preferable to a series arrangement, and the batteries for a multiple arrangement are more effective if connected in multiple. Try a series and a multiple arrangement of cells and ascertain which works best. Where several signal bells must be located together, gongs of different types (*VI*), each of which gives a different sound, can be used, In operating bells from an electric light circuit, incandescent lamps (*VII* and *VIII*) can be used for resistance. An ordinary bell usually requires about 0.1 amp. for its operation, and enough lamps should be used to cut down the current to this value. It is best to connect the bell in multiple with a lamp, as at *VII*, as thereby the arcing at the vibrating contact is minimized. At least one lamp should be connected in each side of the circuit at the cut-out, to prevent difficulties if a ground should occur on the bell circuit. Bells with platinum contacts are preferable for all services, but are expensive. A differential or short-circuiting bell (Fig. 215) can be used with good results, with lamps in series, on lighting circuits or high voltage battery circuits.

280. **Return-call bell circuits** for different services are shown in *Fig. 213.* With these, when a station is signaled, the party called can signal back by pressing his button. As a general proposition, ound return circuits are undesirable, as one ground on one of the rmally ungrounded wires may render the system inoperative; rthermore, there are often "stray" currents from electric railay circuits flowing in the earth, which may interfere with the operan of the bell circuits. With the arrangement of Fig. 213 *VII*, en the calling station is the one at the single stroke bell, the

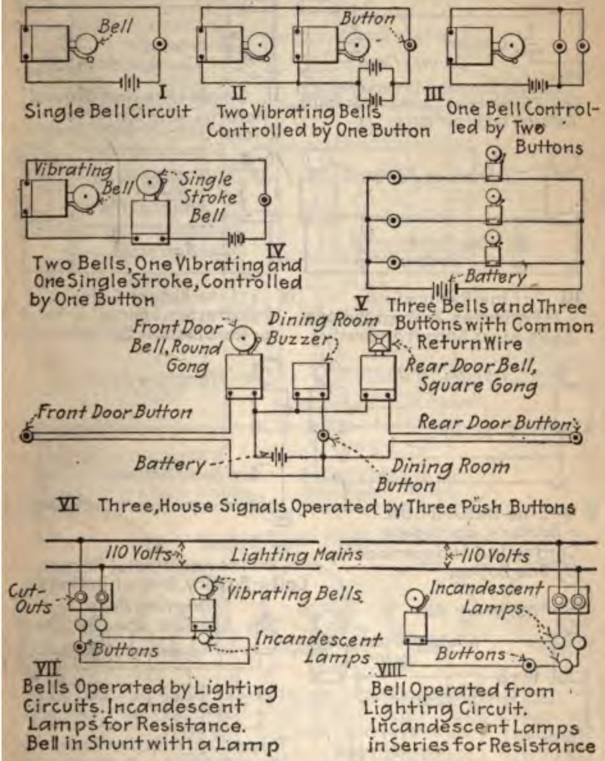


FIG. 212.—Elementary electric bell circuits.

ller may be sure that the called station is ringing, because it is e vibrating bell at that station that causes the single stroke bell ring.

281. Apartment house and speaking tube bell wiring circuits e shown in Fig. 214. One battery serves for all stations. Freently *a larger sized* wire is used for the battery wire, which supes *all of the* stations, than for the other wiring.

282. Electric bells of different types are shown in Fig. 215. The vibrating bell is the one commonly used. The single stroke bell can be used in series with a vibrating bell, which will open and

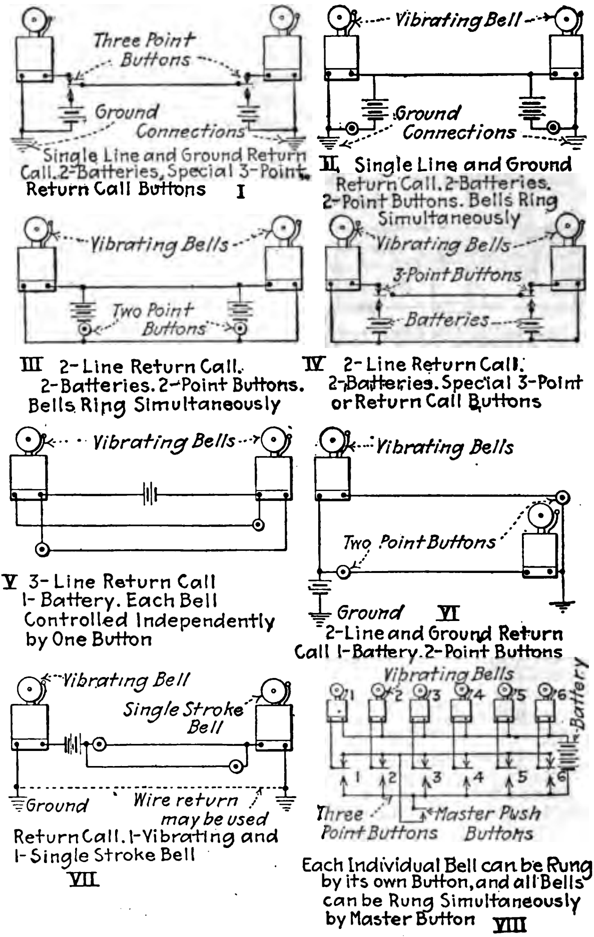


FIG. 213.—Return call and master button electric bell circuits.

close the circuit, and thereby make the single stroke bell also operate. *It is* essential for satisfactory operation, that the natural *periods of* vibration of the armatures and tappers for both bells, be the same. If the armatures, tappers and springs of both are the same in weight, dimensions and construction, the natural

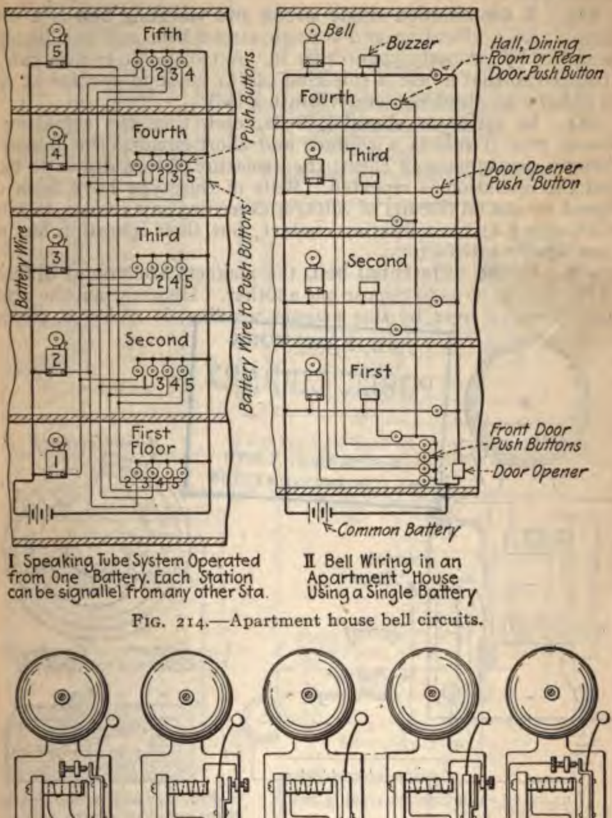


FIG. 214.—Apartment house bell circuits.

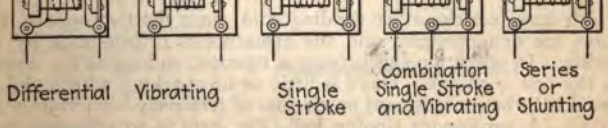


FIG. 215.—Electric bells of different types.

periods of vibration will be the same; small differences will not *appreciably* affect satisfactory operation. A vibrating bell can be changed into a series bell by so adjusting the vibrating contact screw that the circuit will not be opened when the armature is drawn over.

283. **A combination single stroke and vibrating bell** is a combination of a vibrating and a single stroke bell, and can be used as either by properly connecting it. A two point switch can be arranged so that a bell of this kind can be made to operate at will, as either a single stroke or a vibrating bell.

284. **In series or shunting bells,** each time the armature is drawn over it makes a contact and short-circuits the magnets, thereby demagnetizing them; the armature spring draws it back and the operation is repeated. Bells of this type have been designed for use on circuits of voltages exceeding say 5 volts, to minimize arcing at the vibrating contact, but their operation has not been wholly satisfactory.

285. **In the differential bell,** the magnets are wound differentially, that is, so as to oppose one another. Hence, when the armature is drawn over by one magnet winding, it makes a contact

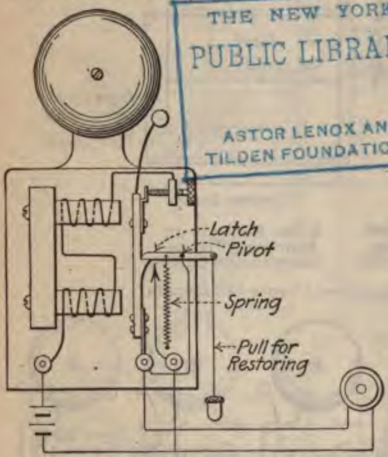


FIG. 216.—Continuous ringing bell.

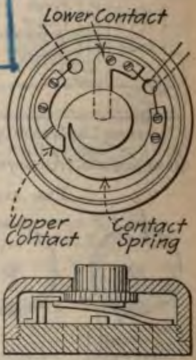


FIG. 217.—Double contact, three-point or return call push button.

which energizes the other winding, and, since the two oppose, the cores are demagnetized and the armature is drawn back by its spring. In operation this process is repeated so long as the circuit to the bell is closed. There is little or no sparking with a differential bell; hence it is used on circuits of relatively high voltage.

286. **A continuous ringing bell** (Fig. 216) is so arranged that *when the button* is pressed and the circuit closed through the bell, *the armature* is drawn over and the latch released and pulled down *against its contact* point by a spring or by gravity. This con-

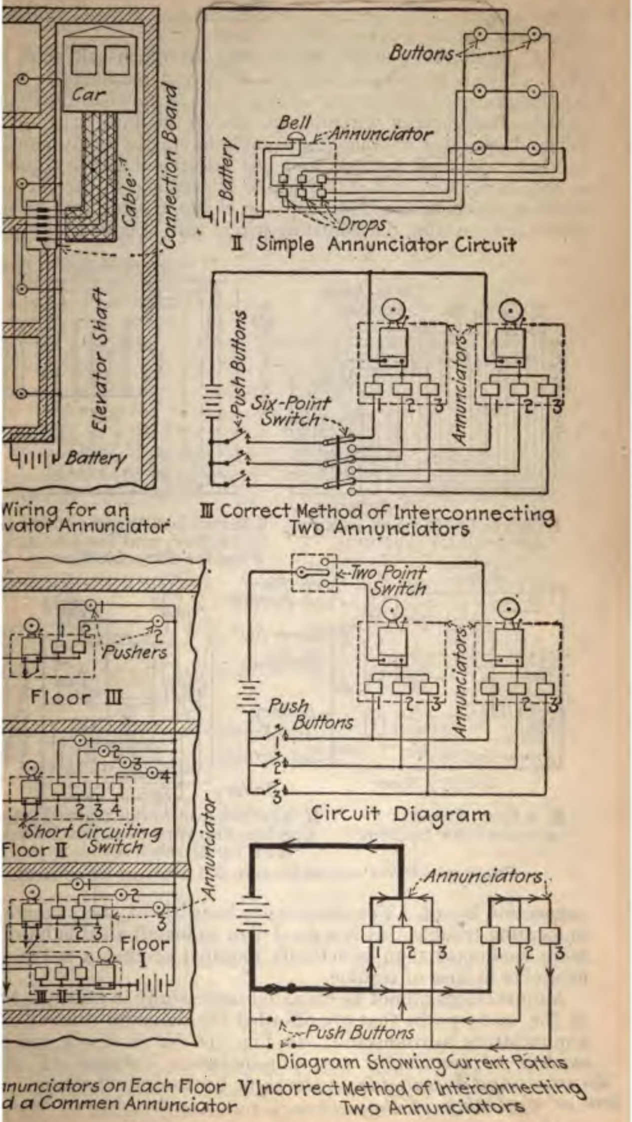


FIG. 218.—Annunciator circuits.

nects a shunt circuit around the button, and the bell continues to ring until the latch is restored by hand.

287. **A double-contact, three-point or return-call push button** (Fig. 217), is used in return-call bells and annunciator circuits. Applications of push buttons of this type are shown in the diagrams.

288. **Annunciator circuits** are shown in Figs. 218 and 219. With an elevator annunciator a cable having as many conductors as there are push buttons and one additional battery conductor is required. One end of this cable is attached to the car and the other is made fast midway up the elevator shaft and should be connected to the push-button wires with binding posts on a

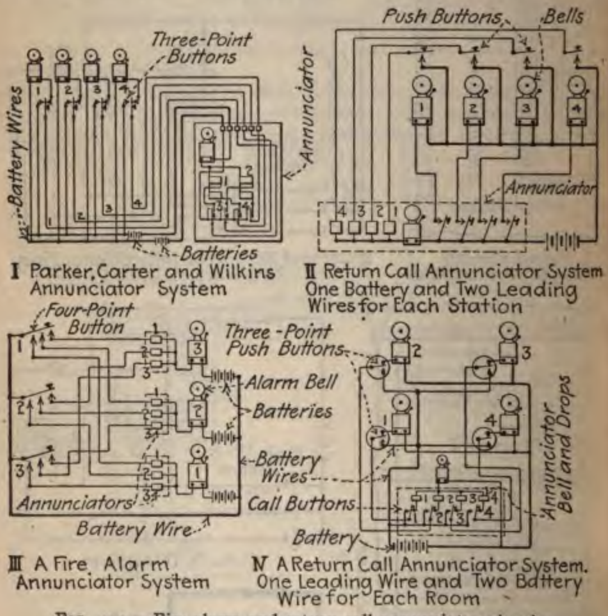


FIG. 219.—Fire alarm and return call annunciator circuits.

connection board. The connection board is of great convenience in locating trouble. It is a good plan to install a cable having one more conductor than is actually required so that a spare will be available in case of trouble.

Annunciators cannot be operated successfully in multiple because of the many paths that are afforded the signaling current through annunciators so connected. In Fig. 218 *III* is shown one correct method of connecting two annunciators installed at different locations and operated from the same buttons and battery. Either one or the other of the annunciators can be thrown into service th the six-point switch. If two annunciators are to operate nultaneously the drops of one must be connected in series with e drops of the other. In *V* is shown an incorrect method of nnecting two annunciators. With it, when one button is pressed ere are several paths for the current and it will divide and flow shown in the lower diagram and may, unless the annunciator ljustments and battery strength are just right, throw all of the ops. Annunciators connected in accordance with this method ill ultimately give trouble.

The method of connection of *IV* is used where attendants are gnaled from annunciators located in different parts of the buildg during certain periods of the day and from a centrally located nnunciator at other times. Either the local annunciator bells the common annunciator can be shunted out when necessary ith the short-circuiting switches shown. Fig. 219, *I* shows a iagram of a Parker, Carter & Wilkins return-call annunciator ystem. With this system there is a considerable saving in wire s only one direct wire is required from a room to the annuniator. Two common battery wires are around the house.

Fig. 219, *II* and *IV* show two methods of accomplishing the same nd. That of *II* is probably preferable for the average installaion because (1) the signaling current does not pass through any utton except that being pressed, (2) single-contact, not doubleontact push buttons are used and (3) only one battery wire is arried to the rooms.

With the fire alarm system, *III*, when any one of the switches s closed all of the annunciator stations are signaled.

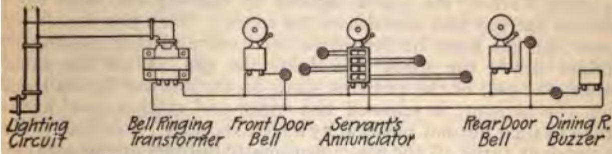


FIG. 220.—Application of a bell-ringing transformer.

289. Bell-ringing transformers (Fig. 220) should always, where iere is alternating current, be used for operating signaling systems ich as those for bell and annunciator service. A well-made ell-ringing transformer will last forever. Consult the local inector as to his installation requirements before putting in a bellnging transformer, as there have been misunderstandings in regard this matter. The Code Rules specify that the transformers all be of special design and that the primary wiring shall be inalled in accordance with the rules for light, power and heat iring and that the secondary wiring shall be installed in accordice with the rules for signal system wiring. It is well to try out bell-ringing transformer with any instrument that is to be opered by it, that has coils of many turns (such as an annunciator) fore final connections are made, because the impedance of these ls to the alternating current sometimes "chokes" the current and renders operation less satisfactory than would be expected judging from the secondary voltage rating of the transformer. A well-designed bell-ringing transformer requires practically no energy for its operation and will not start an ordinary watt-hour meter either when it is idle or when it is furnishing ringing current for an electric bell such as is usually installed in residences.

290. **There are two systems of electric gas lighting: The multiple and the series.** Series systems may be further subdivided into those operating from induction coils and those operating from frictional or static electric machines. The multiple system is the most common. The series system, which is best adapted for large auditoriums where many lights are used in groups, is seldom now used because such places are almost invariably lighted by electricity.

291. **The operation of the multiple system** is evident from Fig. 221. One battery terminal is grounded, or preferably, connects to a common battery wire. The other battery terminal connects through the spark coil to the terminals on the burners. If a common battery wire is used each burner must be insulated from the gas fixture with a rubber nipple. To light the gas, it is either first turned on or is turned on automatically by the burner mechanism and then further movement of the burner mechanism draws a wire wiper, which connects to one side of the battery, across an insulated wire hook which is mounted on the burner tip and which connects to the other side of the circuit. When the wiper leaves the hook a spark is drawn which lights the gas.

292. **Burners of different forms** are shown in Fig. 221. With the stem burner, the gas is lighted by turning the stem which turns on the gas and also draws the spark. With the simple pull burner the gas must be turned on by hand and then pulling the pendant draws the spark and lights the gas. With the rachet burner, one pull of the pendant turns on the gas and lights it and when the pendant is released the wiper and ratchet-pawl are returned to their normal position by a spiral spring. A second pull of the pendant turns off the gas. Automatic burners are so arranged that with them the gas can be lighted or turned off by pressing a button at any one of one or more control stations which can be located at any reasonable distance from the burner. Two insulated wires are required with each automatic burner where the gas pipe is used as a return and three wires are necessary where a non-grounded return is used.

293. **Spark coils** are necessary in electric gas lighting systems to insure that the spark at the burner will be "fat" enough that it will light the gas. The "fat" spark is produced by reason of the self-induction of the coil which acts to momentarily increase the voltage of a circuit enormously, through the coil when the circuit is broken. A spark coil for gas lighting usually consists of about 6 layers of No. 14 or No. 16, double-braid cotton-covered wire wound on a core $\frac{3}{4}$ in. in diameter consisting of a bundle of soft *iron wire.* The coils are made in various lengths of from 8 in. to *12 in.* An 8 in. or a 10 in. coil of No. 16 wire is about right for the average gas lighting installation. A spark coil can be either pur-

chased with or equipped with a relay attachment (Fig. 222). The relay closes a bell circuit when there is a short-circuit on the system and the bell rings and gives an alarm. The bell can be operated from the gas lighting battery as indicated by the dotted lines but it is better practice to use a separate battery, as shown in the full

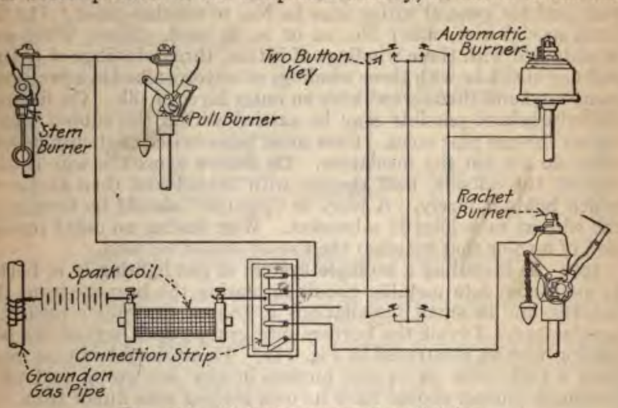


FIG. 221.—Multiple system of gas lighting.

lines, as the cells of the main battery used for such a purpose are liable to be exhausted much more rapidly than the others.

294. A connection strip (Figs. 221 and 222) whereby the leading wires running to the different burners or groups of burners can be disconnected from the battery for testing or in case of trouble should be provided in all gas lighting systems of any consequence.

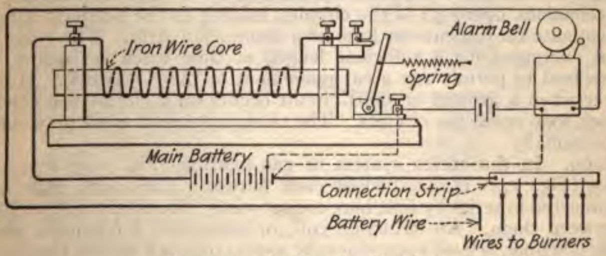


FIG. 222.—Spark coil with relay.

Such a strip may consist of a group of single-point switches or a strip of metal connected to the battery on which the ends of small metal straps normally bear. Each strap is pivoted at its outer end so it can be swung out of connection with the strip and the leading wires to the burners are connected to the pivoted ends.

295. Batteries for gas lighting should be of the open-circuit type and should have low internal resistance. Only cells of the very best grade should be used. A battery of 6 sal-ammoniac cells in combination with a spark coil will make a good spark.

296. Wire for gas lighting systems, from the battery to the fixture and for general wiring may be No. 16 weather-proof. On fixtures special wire, either No. 22 or 24, is used. These wires can be obtained with three windings of cotton, three windings of cotton and one of silk or with three windings of cotton soaked in a fire-proof compound and then served with an outer layer of silk. On fixtures the wire where possible may be carried within the tubing which covers the gas pipe stem. Care must be exercised that corners and edges do not cut the insulation. On fixture arms the wire is carried on the outside, held thereto with thread and then shellaced which holds it nicely. A helix or "pig-tail" should be formed in the wire at each joint in a bracket. Wire having an outer insulation of a color that matches the fixture should be used.

297. In installing a multiple system of gas lighting it is better to use a complete metallic circuit insulating the burners from the fixtures, but in small installations a ground (gas-pipe) return is satisfactory. Divide the burners into groups each served by one leading wire as illustrated in Fig. 221. There should not be more than 6 pull, stem or ratchet burners in any one group and each automatic burner should have its own leading wire direct from the battery. The National Electrical Code rules for installing gas lighting systems are the same as for other signal circuits operating at pressures of less than 10 volts. Electric gas lighting equipment cannot be installed on fixtures having both gas and electric lights.

298. An automatic cut-out should be installed in gas lighting systems of any consequence to protect the battery from grounds or short-circuits. In the cut-out the battery wire is connected to the coil of a relay which, when energized, permits a clockwork to operate. If the clockwork operates long enough it, through a mechanism, opens all of the circuits, leading to the burners, which terminate on the cut-out base or a connection strip. The relay is not energized for a sufficient length of time when a burner is operated to permit any great movement of the clockwork. However when a ground or short-circuit occurs on a circuit the clockwork soon opens the circuits. The clock movement must be wound occasionally.

299. In the series system of gas lighting (Fig. 223) a spark gap (Fig. 224) is installed at each burner. The spark gaps are connected in series by fine, bare copper wires (No. 26 gage) stretched between them. An induction coil, or sometimes a frictional electric machine, is used to produce the sparks or small arcs at the gaps. About 15 gaps may be allowed for every inch of spark or arc that the induction coil is capable of producing. The gaps are arranged in groups and each group is connected on a separate circuit after a method similar to that illustrated for multiple gas lighting. The gas is turned on and then the induction coil, it being in operation, is connected successively to the different groups, creates arcs at the gaps and lights the gas. Burners can often be arranged close ıer so that one will light from another in which case a spark required on only one burner of a group so arranged. The vires connecting burners should not be carried closer than $1\frac{1}{4}$ metal work. Where this separation is impossible the wire l be encased in glass tubing. The voltage is very high and

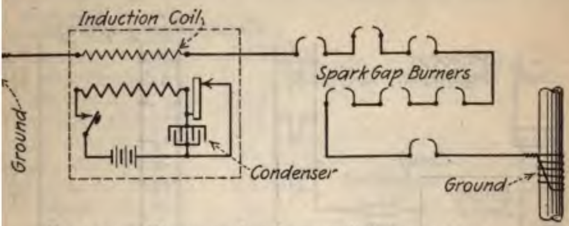


FIG. 223.—Diagram of series gas lighting system.

ıgh insulation is essential. The condenser in the induction for minimizing the spark at the vibrator.

. **Burglar alarm systems** (*Standard Handbook*) are simply cations of call bell systems; the bell circuit being closed when- . door, window, transom or skylight, etc., is opened. More ate alarm systems entail the use of an annunciator indicating window or door, ıas been opened; tinuously ringing silent test switch w that every win- door, etc., in the has been properly ; switch for test- ll and battery; a ıl switch for cut- ut the alarm sys- luring the day or ver it is not re- l; lock switches dmitting persons proper keys with- unding the alarm; ments for light- an incandescent or gas-jet auto- ally when the sounds so that the

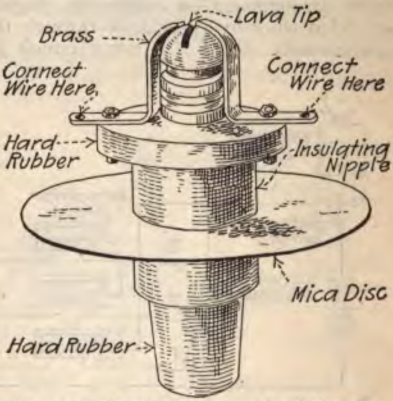


FIG. 224.—Spark gap burner for series gas lighting.

ıciator drop may be visible, and numerous other refinements. chief requisite of an alarm system is the certainty of action apparatus and contacts. Since the apparatus may stand ıs and even years without being called into action, rubbing ts, German silver springs, etc., are largely employed. Wires, contacts, etc., should be concealed and should be installed in a first class manner.

301. **There are two classes of burglar alarm systems: open circuit and closed circuit.** In open-circuit systems the circuit or circuits to doors and windows throughout the building are normally open and when the circuits are closed by a door or window being

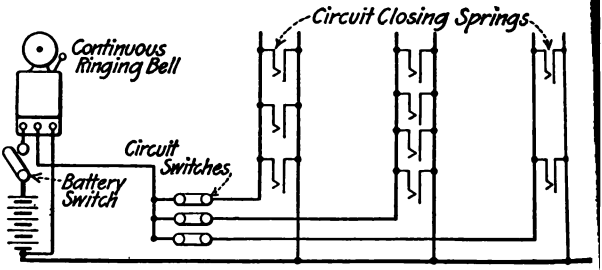


FIG. 225.—Simple open-circuit burglar-alarm system.

opened the alarm is sounded. In closed-circuit systems the circuit throughout the building is normally closed and current is flowing in it. When it is opened the alarm is sounded.

302. **Open-circuit systems** are shown in Figs. 225, 226 and 227. Some arrangement—a continuous ringing bell or drop—must be provided whereby the circuit through the alarm bell will remain continuously closed if a house circuit is closed instantaneously

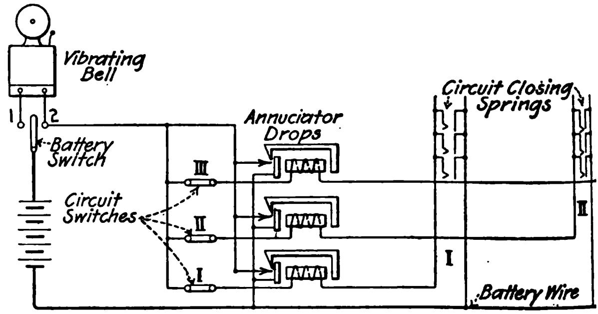


FIG. 226.—Open-circuit burglar-alarm system with alarm annunciator.

In setting the system for the night, the battery switch and the circuit switches are all opened. Then the battery switch is closed and the circuit switches are closed one at a time thereby locating any circuit on which there is trouble or on which a window may have been left open. Open-circuit systems are usually installed in preference to closed-circuit because of their simplicity.

303. One objection to the open-circuit system is that if the wires should be cut no protection is afforded, the alarm being then inoperative. When properly installed, however, the cutting of wires is a very rare occurrence. To guard against this possibility, a closed-circuit system may be installed in connection with the open-circuit system, the window, door and other contacts being arranged to open the circuit of a relay which thereby makes contact with the bell circuit. This system will give the alarm when the wires are cut, or when the closed-circuit battery is run down, or when a window, door, etc., has been opened. A straight closed-circuit system may also be installed.

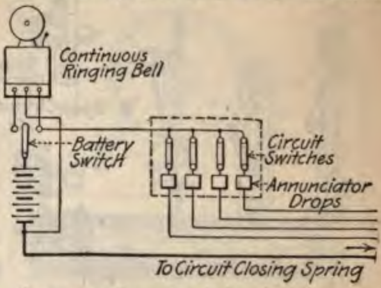


FIG. 227.—Open-circuit burglar-alarm system using an annunciator in combination with a continuous-ringing bell.

304. Closed-circuit systems are more sensitive than open circuit but are more liable to disarrangement. Fig. 228 shows an installation with two house circuits but usually one house circuit suffices. Fine bare copper wire (No. 24 gage) can be used for the house circuits and may be strung in front of doors, windows and objects to be protected so that its breakage will open the circuit and set off the alarm. Gravity cells are used for the closed-circuit battery and Le Clanche cells for the open-circuit battery.

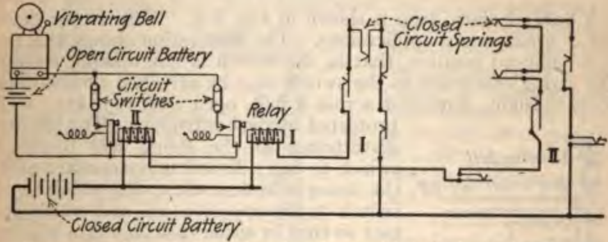


FIG. 228.—Closed circuit burglar alarm with two alarm circuits.

305. Burglar alarm fittings are shown in Fig. 229. Fig. V shows burglar alarm attachments for protecting windows, skylights, blinds, etc. A wire or string is attached to the ring and is drawn so as to break the contact. Further tension on the wire or string or its severance will establish the contact and give the alarm. Alarm springs for shades are shown in Fig. VI. The string of the shade is attached to the arm or hook so as to break the contact. Any interference with the setting makes contact and gives warning of intruders. A lock burglar alarm switch is shown in Fig. VI This is placed on the door frame so that persons with proper k can enter without giving the alarm. Turning the key opens bell circuit.

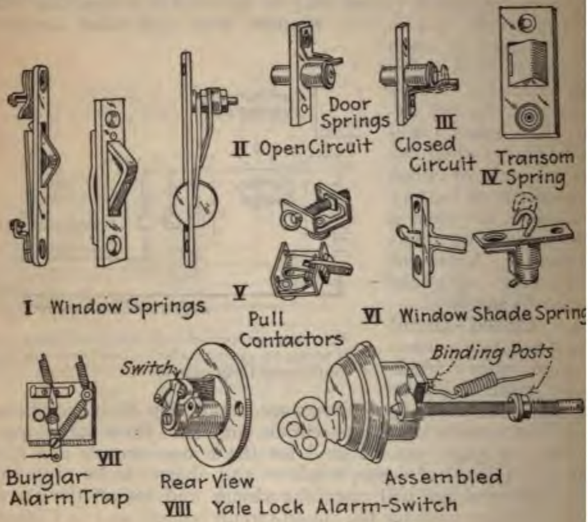


FIG. 229.—Burglar-alarm fittings.

A burglar alarm trap is shown in Fig. VII. This simple de has a great many applications. The illustration shows the in a balanced position, that is, the switch is not making con The string connected to the switch may be attached to a win door, skylight, stretched across a hall, open doorway, etc., t protected against intruders. The sligl disturbance of the string will draw switch to one side and make contact a the string is broken the spring will draw switch to the opposite side and make tact so that in either case an alarm is gi An auto-drop or constant-ringing att ment is shown in Fig. 230. The bell ci is closed automatically and is kept cl as long as desired. The drop is place the bell circuit and when the circu closed by a push button, door or wir spring, the circuit-closer drop is operated by an electromagnet keeps the circuit closed until the drop is raised again.

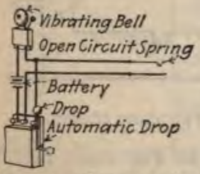


FIG. 230.—Constant ringing attachment.

Instead of contacts in windows, doors, etc., electric mat sometimes used. An invisible electric mat is placed und

er floor covering and which when trod on or touched by
nds an alarm or signal in any part of the house by
bell circuit
ns windows
open for
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31) may be
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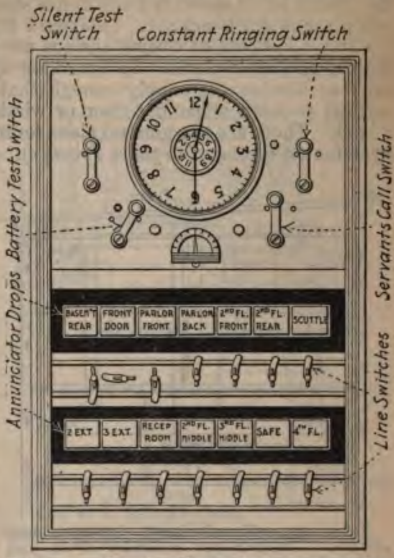
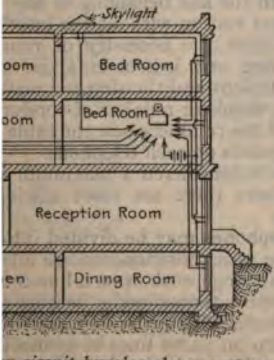


FIG. 231.—Burglar-alarm clock annunciator.

installation
alarm sys-
circuit) is
. 232. It is to be understood that all the windows in one room are connected in multiple so that only one drop on the annunciator is required for each room. Fig. 233 shows the arrangement of a simple, closed-circuit, burglar-alarm system. All the contacts are arranged to open the closed-circuit when disturbed; this releases the armature of the relay which is instantly drawn by the spring to complete the bell circuit and give the alarm. This arrangement requires the use of both



n-circuit burglar-alarm system.

nd open-circuit batteries, and while a trifle the mor
e most reliable system that can be installed.

this system the alarm is given, the room indicated and the lamps throughout the building turned on whenever the circuit is opened. In closed-circuit systems a resistance should be placed in the circuit when the alarm is not set. (*Standard Handbook.*)

Circuit opening or closing springs are usually placed in window frames and door jambs. In installing springs be careful that the door or window fits snugly enough that the spring will lie in its normal position when the door or window is closed.

308. There are two general plans for installing interior telephone systems (*American Telephone Practice*). One is to install a switchboard at some central point to which all lines radiate and at which they are connected as desired by an operator. The switchboards and instruments are of the types made for small exchanges.

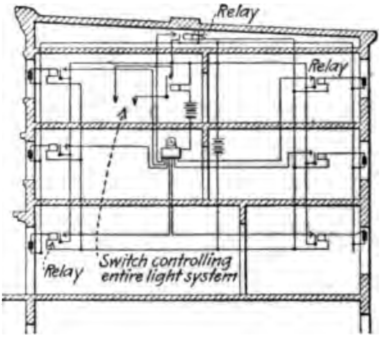


FIG. 233.—Closed-circuit burglar-alarm system. Annunciator indicator room and switch throws on all lights.

The second plan involves the use of an intercommunicating or house system in which the instrument at each station is placed on a separate line, the line belonging to each station passing through all of the other stations. By means of a switching device arranged at each station, the party at any station may, at will, connect his telephone with the line belonging to any other station and call the party at that station without the intervention of an operator. This plan involves the necessity of running at least one more wire than there are instruments in the exchange through each one of the stations and the simplest way to do this is to run a cable having the requisite number of conductors through each of the stations, all of the conductors in the cable being tapped off to the switch contact points on each telephone.

From 12 to 20 stations is considered a maximum for intercommunicating systems. Where there are more stations a switchboard should be installed.

309. Local battery telephones may be divided into two classes series and bridging. The series instruments are adapted for use on single station lines in exchange work or on a line connecting only two instruments. This type is termed series because the generator and bell are connected in series with each other and further because it was formerly the practice on party lines to connect such instruments in series in the line. The bridging instruments are so called because the generator and ringer are separately bridged across the line and in party line work it is common to connect such instruments in multiple on the line.

ɔther floor covering and which when trod on or touched by sounds an alarm or signal in any part of the house by ie bell circuit neans windows left open for n and protec- ɔbtained.

Clock burglar *Standard Hand-* g. 231) may be automatically t sections at ined times. y also be fitted nstant ringing servants' call ı incandescent an attachment natically light- whole house in an alarm. are provided g each circuit e annunciator; g the bell and for testing the

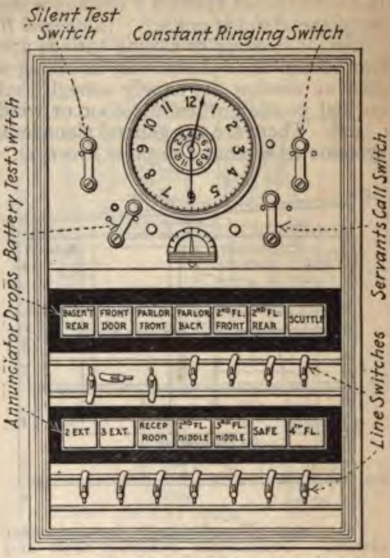


FIG. 231.—Burglar-alarm clock annunciator.

The installation lar alarm sys- n circuit) is Fig. 232. It is to be understood that all the windows in one room are connected in multiple so that only one drop on the annunciator is required for each room. Fig. 233 shows the arrangement of a simple, closed-circuit, burglar-alarm system. All the contacts are arranged to open the closed-circuit when disturbed; this releases the armature of the relay which is instantly drawn by the spring to complete the bell circuit and give the alarm. This arrangement requires the use of both

-Open-circuit burglar-alarm system.

uit and open-circuit batteries, and while a trifle the more *is the most reliable* system that can be installed. In is called an "automatic shunt" for the generator, their function being to cut out the resistance of the generator armature from the circuit at all times except when the generator is in use.

311. The circuit of the bridging telephone is shown in Fig. 234, *II*. In this, the arrangement of the receiver, induction coil, transmitter and battery are identical with that in the series telephone. The ringer, however, is bridged permanently across the line and the generator is placed in a circuit across the line which is normally open but which is closed automatically by a spring when the generator is operated. The magnets of the ringer or bell are wound with many turns of fine wire. This gives them great impedance. The talking currents, which are high-frequency alternating currents, do not, therefore, pass through the ringer coils. The ringing currents can readily pass through the ringer coils and cause them to operate.

312. The circuits of an assembled bridging telephone are shown in Fig. 234, *IV*. As the ringer and the transmitter are mounted on the door of the instrument box the connection between them and the other parts of the apparatus is made through the hinges as shown. Note that the circuits are identical with those given for the elementary bridging instrument.

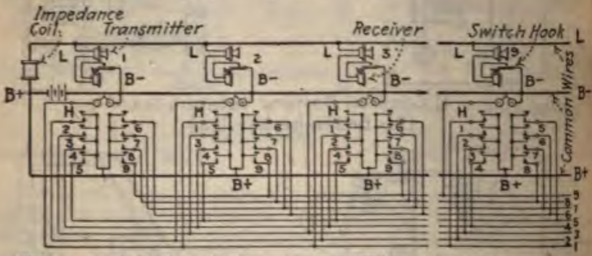


FIG. 235.—Selective-ringing, common-talking, private-line system.

313. A simple intercommunicating system which permits of but two parties talking simultaneously is shown in Fig. 235. As furnished by the Western Electric Company, the bells are wound to 10 ohms resistance insuring minimum draught of current from the battery and long battery life. The transmitter and receiver are of high resistance and the impedance of a coil through which battery is supplied to the transmission circuit prevents the shunting of talking currents through the battery. The use of high-resistance transmitters and receivers insures that the most distant instrument will receive practically as much as those near the batteries. The wall instruments are quite similar in external arrangement to that of Fig. 242, but are furnished in the surface type only. Desk instruments can also be supplied.

314. The circuits of an ordinary lever switch intercommunicating system are shown in Fig. 236. One station calls another by the turning of a magneto generator, the switch lever having first been moved into contact with the button corresponding to mber of the station desired. The disadvantage of the system that the switch lever must always be returned to the "home" tton or endless confusion from cross signals will result.

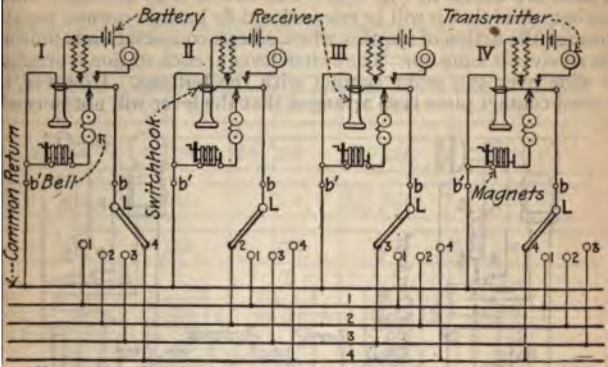
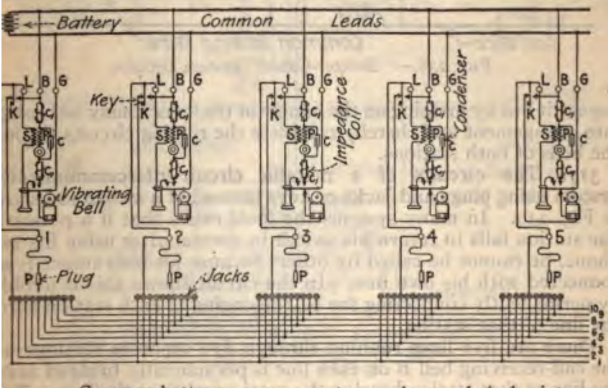


FIG. 236.—Circuit of lever switch intercommunicating system.

315. **The circuits of a common-battery, common-return plug d jack intercommunicating system** are shown in Fig. 237. The ring for 10 stations is shown but only 5 of them are indicated. ie plug is inserted in the jack corresponding to the station wanted



. 237.—Common-battery, common-return, plug and jack, intercommunicating system.

d a pressure of the key rings the wanted station's bell. Impedce coils are inserted in the primary circuits to reduce cross talk *l the transmitter* is bridged by a condenser which provides a *l circuit for the* talking currents set up by the transmitter.

The plug must be removed after a conversation, or cross ringing will result.

316. The circuits of the Holtzer-Cabot intercommunicating system are shown in Fig. 238. The switch is so arranged with a ratchet wheel that it will be released and fly back to normal position through the action of a spring when, after a conversation is finished, the receiver is hung up. The switch lever at each station is arranged to slide over and make contact with the buttons. However, the curved contact piece is so arranged that the lever will not normally

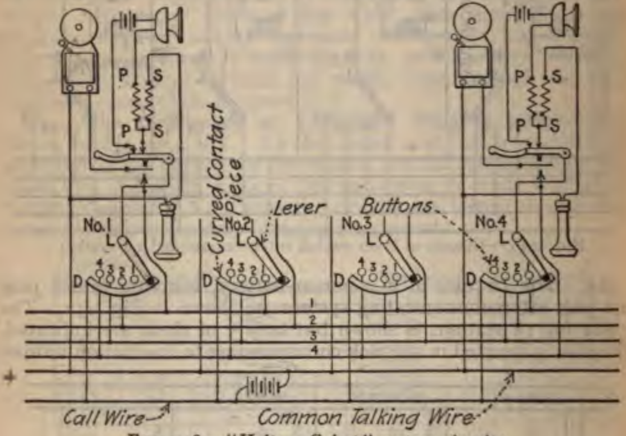


FIG. 238.—"Holtzer-Cabot" system circuits.

engage it but by pressing on the handle of the lever it may be brought into engagement and thereby complete the ringing circuits through the bells of both stations.

317. The circuits of a metallic circuit intercommunicating system using plugs and jacks or keys instead of a switch are shown in Fig. 239. In many systems the fault exists that if a person at one station fails to return his switch to normal after using his telephone, he cannot be called by others because his instrument is not connected with his own line. In the circuit shown this is avoided by permanently connecting the bell belonging to each station across the line of that station.

There are five lines running through five separate stations and the call-receiving bell *B* on each line is permanently bridged across the line at that station bearing the same number as the line. Two-point spring jacks are provided at each station for each line and the subscriber's telephone set and generator may be switched into the circuit of any line by inserting the plug in the proper jack. Thus if a party at Station No. 1 desires to call Station No. 5, the plug at station No. 1 would be inserted in jack No. 5 and the generator operated. This would ring the bell at Station No. 5 and the party at that station would respond by inserting the plug in his own home jack. When through talking, if the party at Station No. 1 left his plug in connection with line No. 5, no harm would be done

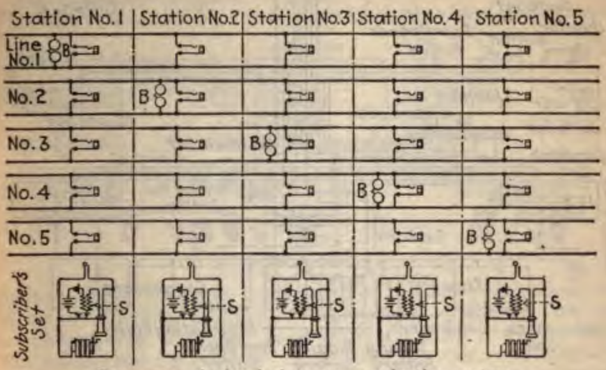


FIG. 239.—A plug-in intercommunicating system.

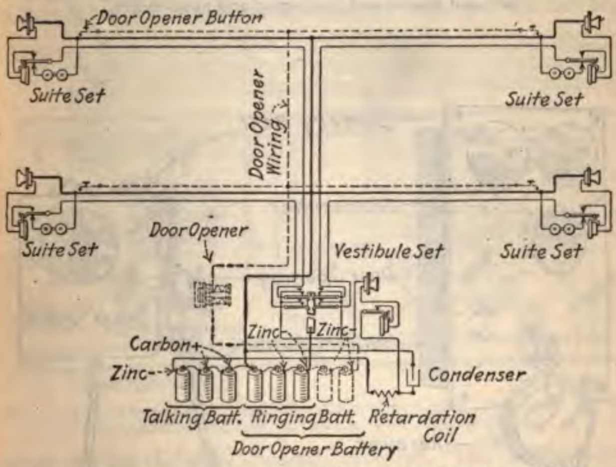


FIG. 240.—Apartment house system giving service between vestibule and apartments.

as other parties could operate the call bells of either line, No. 1 or No. 5, just as well with the plug inserted as with it out.

Instead of using plugs and jacks, as shown in Fig. 239, to effect the connection of the telephones with the various lines, a mor

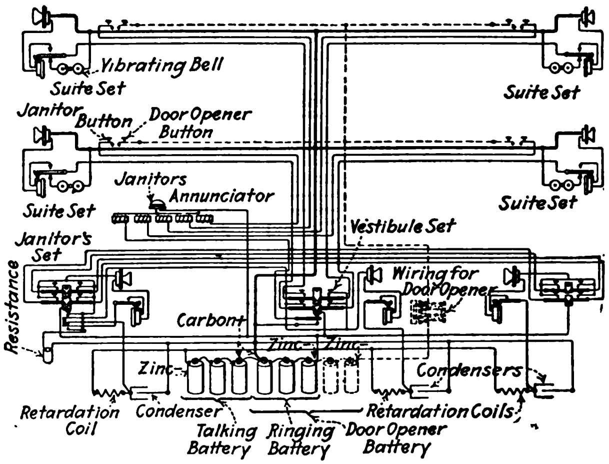


FIG. 241.—System giving service between vestibule and apartments, vestibule and janitor and tradesmen and apartments.

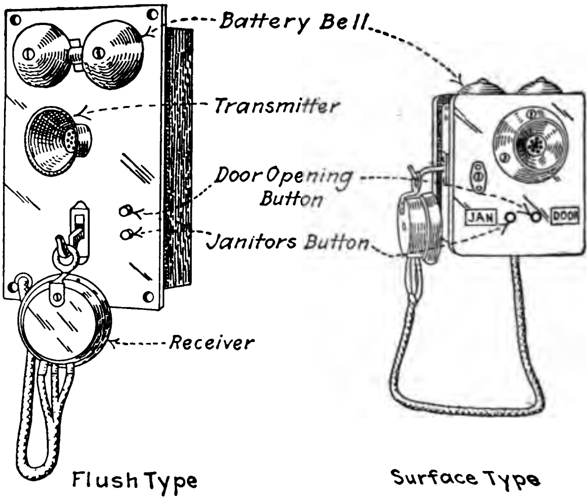


FIG. 242.—Apartment-house suite telephones.

convenient arrangement, described hereinafter, involving, however, the same principle, is to employ push buttons or keys. The proper connection with these is made by pushing a key instead of inserting a plug in a jack.

318. Apartment house telephone system circuits are shown in Figs. 240 and 241 which are recommended when the installation of a

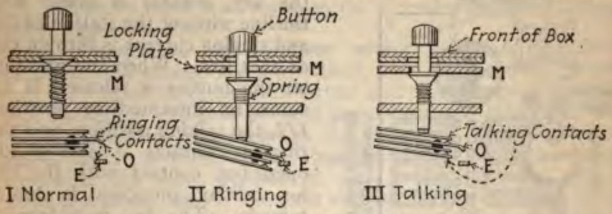


FIG. 243.—Positions of intercommunicating key.

private branch exchange is not justified. These illustrations show Western Electric Company's Interphone systems. The suite telephones (Fig. 242) may be of either the flush or surface types. The talking battery is fed through retardation coils, so in installation where there is provision for simultaneous conversation between two stations, there cannot be cross talk. The receiver and transmitter in the telephones are in series, an induction coil not being

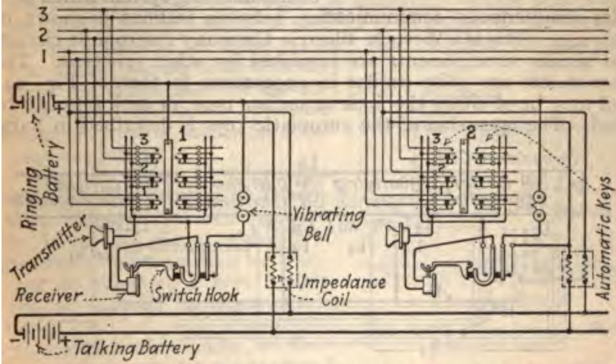


FIG. 244.—Automatic-key intercommunicating sets. Any two or more stations on the system can converse simultaneously.

necessary for the short distances involved. The calling buttons on the telephones make connections as described in paragraph 319. Where a janitor's set is installed, the annunciator for it is similar to ordinary annunciators. One janitor's equipment can be made to serve any *reasonable* number of vestibules and apartments by *making proper modifications.* The bells in the apartments are *wound to 10 ohms* and the resistance of the janitor's annunciator drop plus that of his bell is 10 ohms, which insures minimum draught of current from the battery and maximum battery life. Ordinary electric bells have about 2 or 3 ohms resistance.

319. The operation of the keys in an interphone instrument is shown in Fig. 243. When the button is pressed all the way down as at *II*, the ringing position of the key, contact is made with the line wires of the station called and ringing current is thrown out on that line. When the pressure on the button is released, it assumes an intermediate position, *III*, the talking position, and the ringing contacts *o* and *e* are open but contact with the line for talking purposes is maintained. The key is automatically held in this intermediate position by a locking plate *m* until this plate is actuated by the operation of any other button in the telephone which releases the key so that it assumes its normal position as shown at *I*.

FIG. 245.—Flush-type vestibule, janitor's or tradesman's set.

320. An automatic key intercommunicating system which permits simultaneous communication between stations is shown in Fig. 244. This is a Western Electric Company Interphone circuit, but similar arrangements are furnished by other concerns. The instruments are quite similar in appearance to that of Fig. 245 and may be of either the flush or surface type, or desk sets can be used. The operation of the automatic keys is described in para-

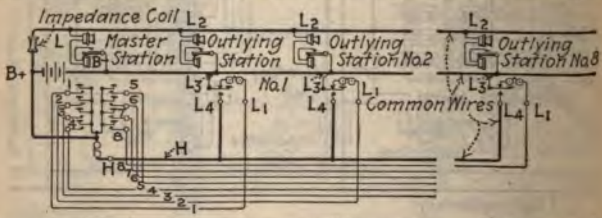


FIG. 246.—Selective-ringing, common-talking system Outlying stations cannot intercommunicate.

graph 319. Wiring between stations may be full metallic as shown or common return. Full metallic is recommended and instruments are arranged for it, but can be easily altered by the wireman for common return. Circuit arrangements can be provided insuring secret service between certain stations. Three or more parties can converse with each other at once by depressing the proper calling buttons.

321. An arrangement wherein the master station can call any outlying station but the outlying station can call only the master station is shown in Fig. 246 which gives the Western Electric circuit. In general this is similar to the scheme of Fig. 235. The arrangement is used in schools, factories, stores, banks and offices where an executive communicates with subordinates and they with him, but where there is no occasion for the subordinates communicating with each other.

322. Conductors for telephone wiring (*Standard Handbook*) are usually of rubber-covered, twisted pair, copper wire, but the work may often be done much better and cheaper, particularly in large buildings, with lead-covered paper-insulated cable such as is used by telephone companies in the subways. These cables are smaller for the same number of wires and are less costly than cables containing the same number of wires rubber-insulated. Paper cables less than 3 in. in diameter and containing as many as 600 pairs can be obtained. Of course with this type of cable all the terminals of the cable or its branches must be made with lead-covered, silk-and-cotton insulated cables, as the paper insulation will not stand handling when exposed. Where the terminal is in a damp location the run should be made with rubber-covered wire. Shafts are preferable to iron conduit for carrying the main riser cables, as it is a difficult matter to make splices between the riser cables and the floor terminal cables if the former are run in conduit.

323. In installing telephone cables or conductors for a system a few spare pairs should always be included. Where this is done the installation of additional stations is inexpensive. Instruments having provision for more stations than required for the initial installation should be used to obviate the replacement of the instruments which is otherwise necessary when additional stations are put in.

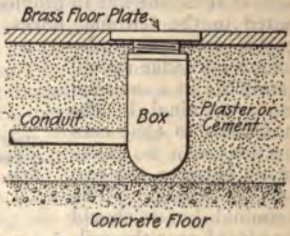


FIG. 247.—Signal-circuit, floor-outlet, box.

324. In wiring for telephones and signaling systems in department stores (*Standard Handbook*) or in other places where it is desirable to have outlets for counters or on desks, a very flexible system may be installed as follows: Lines of ½-in. galvanized pipe may be laid under the floor from the riser shafts and arranged to checker the floor (Fig. 248) in such a manner that all parts of the floor are within short range of the outlet points. Connection boxes (Fig. 247) may be installed at intervals of 50 ft. into which the lines of conduit are bushed. These boxes should be large enough and square and should be fitted with tight-fitting brass cover-plates flush with the surface of the finished floor. Service outlets through which connections may be extended to telephones, bells, etc., may be located approximately 10 ft. apart throughout the entire system. From these outlet-tees and the vacant sides of the connection boxes, wires may be fished under the floor to any desired point. The tees in the conduit may be entirely concealed beneath the floor and made accessible through removable sections of the flooring above them. The tees may be normally plugged, and may be fitted with outlet bushings when connections are to be made through them.

The connections for these low voltage circuits may be made through 2-in. conduit risers located in the same space as the lighting risers. Special interconnected panels (Fig. 249) should be provided at every floor through which branch connections to the underfloor conduit system may be easily made. The interchanging of connections may also be made at these panels. This system may be used for all telephone, bell and signal wires.

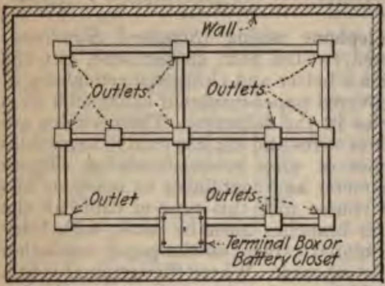


FIG. 248.—Conduit system for signalling installation.

325. For wiring large office buildings for telephones (*Standard Handbook*) a very economical and satisfactory system can be arranged as follows: One or more terminal boxes are provided on each floor at points adjacent to vertical pipe-shafts. Elevator shafts can frequently be used for this purpose. From the basement one or more cables are extended up through these shafts. Branch taps of sufficient size to provide for service on each floor are terminated in the terminal boxes. The riser cables and the service cables from the telephone exchange should terminate in a common main terminal in the basement so that connections can be easily made between the two sets of cables. The terminal boxes should be placed near the ceiling and wide shell molding should be provided in the halls for carrying the wires from the terminal boxes to the rooms. A smaller molding should also be provided for carrying the wires in the individual rooms.

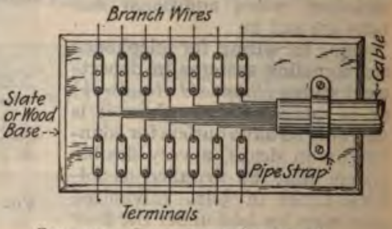


FIG. 249.—Interconnection board.

Where the wires enter the room from the hall, a piece of ¾-in. conduit should be furnished for carrying the wires through the partition. This conduit should be either lined with insulating material or the sharp edges around the inside of the pipe should be rounded off. Where it is necessary to run across the ceiling of a hall in order to avoid either carrying the exposed wires across the finished ceiling, or making a circuitous run around the hall to reach the rooms on the opposite side from the floor terminal, conduit should be installed across the ceiling before the plastering is completed for the purpose of carrying a small branch cable to provide for such lines.

326. **When wiring large hotels and apartment houses for telephones** (*Standard Handbook*) it may be taken for granted that one telephone will be required in each room of a hotel and one for each apartment in an apartment house. In office buildings, a number of telephones may be required in one room, and a very flexible system of wiring must be installed. In hotels the wiring involves the running of a pair of wires from each room to a common center near the switchboard which is usually located on the first floor. Provision should also be made so that the cable of the telephone company carrying the trunk lines may run from the switchboard to the outside of the building. A 2-in. conduit is usually large enough for this purpose, but the local telephone company which usually installs the wires after the race ways are in place should be consulted.

From the telephone switchboard a cable is run through the vertical pipe shaft. The size of this cable diminishes as it extends up through the building. At each box a tap is terminated of sufficient size to provide wires for all telephones on that floor. From the terminal boxes on each floor twisted pairs of rubber-insulated wires are run through the conduits to locations in each room.

A very simple manner of wiring apartment or hotel buildings for telephones is to place a terminal box on each floor convenient to a vertical pipe shaft. From this terminal box a ½-in. conduit is run to a designated location in the wall of each room. The height of the outlet should be 4 ft. 10 in. from the finished floor. This conduit should not be over 50 ft. long and should have not more than three bends with a minimum radius of five inches. Any conduit 100 ft. long should be not less than 1 in. in diameter; ½-in. conduit should be provided for a maximum of two pairs of wires; ¾-in. conduit for five pairs, and 1-in. conduit for ten pairs. In extending the conduit from the terminal box to rooms, it is possible to use one run of larger conduit to supply a number of rooms, rather than run small conduit to each room. Where the floor area is large and the number of telephones required is great, it may be found economical to install more than one terminal box on a floor.

327. **In relatively small apartment houses** where only one telephone is required in each apartment, it is an easy matter to run a vertical conduit up through each tier of apartments and provide an outlet in each apartment. Individual pairs of twisted rubber covered wire can then be pulled from the switchboard through the conduit for each telephone. The individual wires can be carried in a cable from the bottom of the risers to the switchboard.

328. **The number of telephone wires to be provided** in a building depends, of course, on the building and the class of business for *which it is to be used.* A rough average is one pair per 200 sq. ft. *of floor space in* financial buildings, and one pair for every 300 sq. *ft. of floor space* in commercial buildings.

DESIGN OF INTERIOR WIRING INSTALLATION

329. **Factors Affecting Wiring Lay-outs** (*Standard Handbook*).—In conduit work the space available often dictates that the feeders be split up into two or more feeder lines. Conduit larger than 2 in. in diameter is not easily handled, and even if the run were such that 2-in. conduit could be easily installed, it would be preferable to install smaller conduit and divide the feeders so as to guard against complete shut down should anything happen to the feeders. Very often the mistake is made of installing feeders just large enough to carry the present load, and when additions are called for the feeders are overloaded and additional feeders must be installed at great expense. The same is true of branch circuits. The maximum allowance of 660 watts on branch circuits should not be used up. Frequently a larger lamp may be substituted for a 16-c.p. lamp; in fact, this is very easily done because of the fact that the lamp socket will take any size of incandescent lamp up to 500 c.p. and circuits are thus easily overloaded. It is usual to connect up about 400 watts so that fans, etc., may be connected afterward without overloading the circuit.

330. **In selecting a system for wiring for light** one should be used whereby 110 volts or thereabouts can be impressed on the lamp terminals. Nominal 110-volt incandescent lamps, including those of voltages of from say 90 volts to 125 volts, are more efficient, cheaper and have longer lives than those for higher voltages. Lamps of nominal voltages of about 50 volts are seldom used now and require excessive expenditures for copper conductors. The three-wire system is much more economical of copper than a two-wire system, therefore should be used for feeders and mains in installations of any consequence; then the two-wire system is used for branches. Three-phase systems can be used for lighting as elsewhere described (see index) and can be used to advantage in industrial plants where the use of constant speed motors makes the use of the three-phase system desirable.

331. **The method to use for wiring a building** is determined by conditions. *For residences:* Exposed work on knobs and cleats is cheap and safe but seldom used because of its unsightliness. Molding work is sometimes used in old buildings but does not look well. The knob and tube method can be used when the building is being wired while under construction or in wiring an old building. It is a low-cost method and quite safe. Either rigid or flexible conduit or steel armored conductor wiring are best and also most expensive. In many communities, conduit or steel armored conductor wiring are the only methods permitted for concealed work. Flexible steel armored conductors provide the best and safest installation for wiring old buildings. *For business and public buildings* of frame or of brick and frame construction the above suggestions for residence wiring apply. For fire-proof buildings the rigid, wrought-iron conduit method is used almost exclusively.

332. **In planning the wiring for a residence** secure the floor plans of the building or, if it is a small one, inspect the building. Decide first where the meter is to be located, as the point of entrance

to the building should be as close to the meter as possible. Some central station companies specify where meters shall be located. Often the meter can be located and the service wires enter in the cellar, as in Fig. 250. A kitchen is a poor location for meters because they will get greasy and collect dirt. Where the service wires enter between the first and second floors a good location for the meter is in a rear hall or in the pantry. Meters should not be located in attics or where the readers must climb stairs to reach them. A basement or a first floor entrance is the best.

The meter location having been determined, ascertain how many lamp outlets there will be, the current taken at each, and where

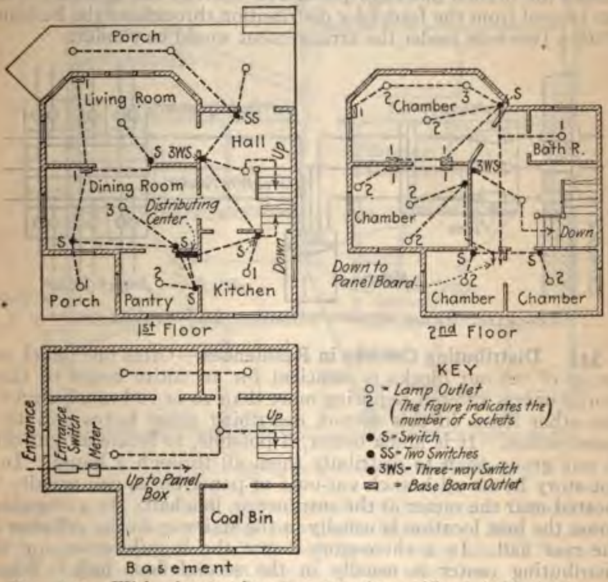


FIG. 250.—Wiring lay-out in a two-story house (Conduit Method).

the outlets will be located. Decide on the location of the distributing center as directed in another paragraph. Divide the outlets into groups requiring less than 660 watts, each group to be fed by a branch circuit from the distributing center. No branch circuit feeding incandescent lamps can have a load in excess of 660 watts connected to it and it is better to so subdivide the outlets that no branch circuit will have an initial load greater than about 440 watts which allows 220 watts for growth. Fig. 250 shows the subdivision of branch circuits radiating from a distributing center *throughout a house.* Locate the switches. Calculate the size of *feeder that will* be required in accordance with directions give elsewhere herein. If load exceeds 660 watts it is best to use a three-wire service. Incandescent lamp branch circuits are usually of No. 14 wire unless they are over 100 ft. long when wire at least as large as No. 12 should be used. No. 14 is the smallest size permitted by the *Code*. Figs. 250 and 252 show plans for conduit jobs, with non-conduit jobs the arrangement would be the same except that splices could be made elsewhere than in outlet boxes.

333. **The wiring in a residence between the entrance and the distributing center** is shown with a three-wire feeder in Fig. 251. A fused entrance switch is always inserted in the feeder circuit immediately inside of the building, then comes the meter and finally the branch blocks or panel box whereby the branch circuits are tapped from the feeder for distribution throughout the building. With a two-wire feeder the arrangement would be similar.

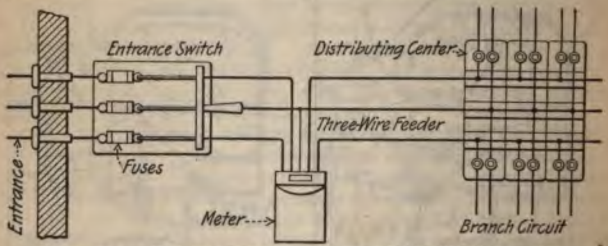


FIG. 251.—Wiring between entrance and distributing center.

334. **Distributing Centers in Residences.**—Often one panel or a group of cut-out blocks is sufficient for an entire house of three stories or less and not requiring more than 10 or 12 branch circuits. See other items in this section describing panel boxes and their construction. It is much better, if possible, to locate all cut-outs in one group than to distribute them all through a house. In a one-story house all branch cut-outs or panel boxes can usually be located near the meter at the entrance or in a hall. In a two-story house the best location is usually in the stairway to the cellar or in the rear hall. In a three-story house the best location for the distributing center is usually in the second floor hall. Where there are more than three stories, distributing centers can be effectively located on every third or second floor. Fig. 252 shows the wiring plan and distributing center in a one-story residence. Closets are considered very unsafe locations for distributing centers.

335. **Things to Consider when Laying Out Residence Wiring** (*National Electric Light Association Bulletin*).—*Three-way switches* should be used to control the hall lights on two or more floors from any floor. *A double-control switch* can be installed in any room whereby a portion or all of the lamps in the room can be lighted or extinguished with this same switch. *Wall switches* should be located so that the door which they are near will not cover them when they are open. *A master switch* for throwing on all of the lights in the

se in case of accident can be located in the owner's bed room. *loset door switch* can be inserted in the jamb of a closet door :reby a lamp in the closet will be automatically lighted when door is opened. Through the use of a chain pull socket for closet lamp, waste of electricity can be avoided when the door pen. *Switches for front porch and lower hall lamps* should be ited conveniently near the door so one can reach in from the side, with the door partially open, and turn them on or can, :n inside, open the door with one hand and turn the switch with

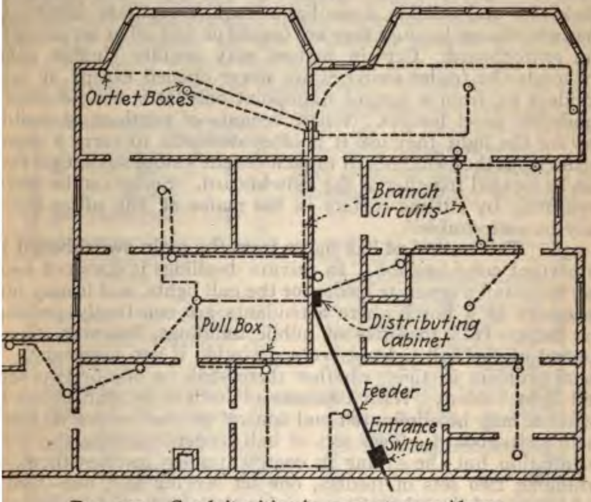


FIG. 252.—Conduit wiring in a one-story residence.

other. *A cellar beacon light*, a small red lamp near the cellar p switch, can be arranged to remain lighted so long as the ar lamps are burning. *Bathroom lamp outlets* should be so inged that shadows will not be cast against windows.

36. There are five points that must be considered in designing wiring lay-out for a large building (*Knox, Electric Light Wiring*) :y are:

. *Control of groups of receivers (other than hall or night lights) n the main switchboard.*

. *Control of hall lights from the main switchboard.*

. *Maximum load that should be served by one feeder.*

. *The best maximum limit for the size of the feeder conductors.*

. *The proportion of the total voltage drop that can be allowed in ers and mains.*

ach of these items will be separately considered in the following graphs. By a receiver is meant any device that consumes rical energy.

337. Control of groups of receivers (other than hall or night lights) from the main switchboard. Where it is desirable to control a group of receivers from the main switchboard in the basement, a separate feeder must be carried from it to each group to be so controlled. Usually the feeder system can be laid out without regard to the control of the room lights, because, as a rule, they do not have to be controlled from the switchboard. It is usually advisable to have each of the lower floors, up to and including the ground floor, on a separate switch as these floors often require light when the others do not. Special lighting appliances such as sign, clock dial and outside dome lights require separate feeders from the switchboard because they are turned on and off at set times from the switchboard. Certain motors may require similar control. In hotels the feeder switches are never opened except in case of accident so, from a control standpoint only, it is not necessary to subdivide hotel feeders. Where tenants of portions of buildings pay for the light they use it is often desirable to carry a separate feeder from the switchboard to each tenant's suite so that all meters can be located together at the switchboard. Suites can be metered separately by cutting meters in the mains at the suites but this may be undesirable.

338. The control of hall lights from the main switchboard is an important consideration. In private dwellings it does not usually pay to install a separate feeder for the hall lights, and it may not be necessary in a hotel where attendants are constantly passing in the halls. In a majority of public buildings, however, separate control of the hall lights is very desirable if not necessary. The usual problem is, then, whether there shall be one or two sets of hall light feeders. With two sets of feeders for hall lights local switches may be eliminated and control effected entirely from the main switchboard. Two sets of hall feeders increase the cost of installation but the saving in energy usually justifies them. By arranging two sets of feeders, one set serving say, one-third the hall lights and the other the remaining two-thirds, the smaller group can be used for dark days and for an all-night circuit and a saving in energy will result. Where there are two sets of hall lights thus controlled the wiring of outlets should be such that there will be a uniform distribution of light whichever set is lighted. Where tenants pay for the energy used in their suites a separate feeder for the hall lights is indispensable.

339. Maximum Load that Should be Served by One Feeder.—It is impossible to give a hard and fast rule covering this feature. The total load in the building, the available space for the switchboard, the method of control desired and the cost all influence a decision. The load should always be somewhat subdivided to localize trouble and so that, in an isolated plant, the engineer can disconnect portions of the load, while he is getting another machine on the line, when the load comes on suddenly.

340. Best Maximum Limit for the Size of Feeder Conductors.—On a basis of cost alone it is usually cheaper to run a few large conductors than a great number of small ones. It does not pay, however, to use conductors larger than 1,000,000 cir. mils. When eater capacity is required it is cheaper to subdivide, so that several nductors will have the aggregate capacity required. For alter- ting currents, conductors larger than 700,000 cir. mils are not sirable because of skin effect. Often the space available for nductor runs makes it necessary to use small conductors. Each se must be decided on its merits.

341. The Proportion of the Total Voltage Drop that can be al- wed in Feeders and Mains.—Distribution of drop is discussed in other section and it is there stated that it is usual to confine certain oportions of the drop to the feeders, certain proportions to the ains and certain proportions to the branches. As the allowable ltage drop determines the size of a feeder or main it is evident at the lay-out of feeders and mains for any given job will in a easure depend on the drop distribution. Where the load on an incandescent lighting feeder exceeds 660 to 1000 watts, a three-wire feeder should be used to insure good voltage regulation and maximum economy of copper.

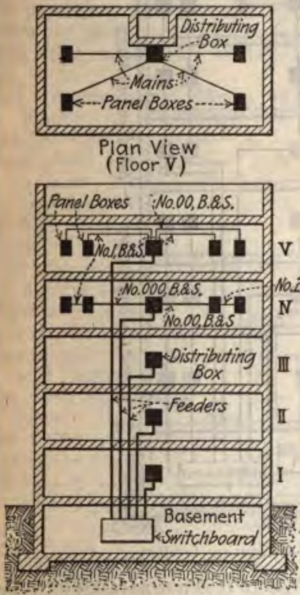


FIG. 253.—Individual feeder to each floor.

FIG. 254.—One feeder serving three floors.

342. To design the wiring lay-out for a large building make a ectional-elevation drawing of the structure and a plan drawing of ach floor. Indicate the receivers (lamps and motors) on the lans *and then locate* panel boxes so that, in general, *no lighting anch circuit will be* much over 100 ft. long or have a load much *eater than 400 watts.* While 660 watts is allowable it is well to provide the 220 watts spare capacity. Panel boxes shou placed so that they can be readily reached and so that the b circuits, mains and feeders can be run to them. Compute th on each panel box and indicate it on the drawing at the box.

Now lay out the mains and feeders. First decide wheth hall or public lights will be controlled separately, or togethe the private lights from the main switchboard because this f affects the arrangement of the feeders and possibly that of the Next decide (note conditions outlined above affecting this m whether there should be a separate feeder to each floor as i 253, or whether several floors or portions thereof will be ser

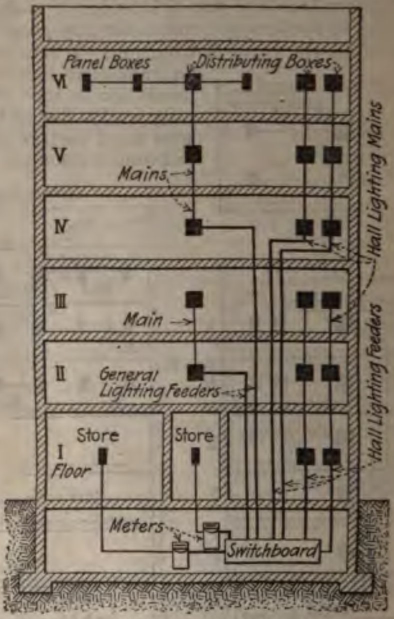


FIG. 255.—Two sets of lighting feeders.

one feeder (Figs. 254 and 255). Where it is not necessary arately control the loads on the different floors and where t ductor size will not be prohibitively large, the cheapest and bly the best arrangement is to serve several or possibly al with one feeder. Usually the only limit to the number o that may be served with one feeder is the refinement of that is required from the main switchboard. It is fre necessary to make several tentative lay-outs and compu before the most desirable arrangement is found. Make a te arrangement of mains and feeders and compute the c

given elsewhere. If the tentative scheme does not
:tory lay out another and try that. Motors, and
ɪtors, unless very small, should be served by inde-
:rs.

ɪples of feeder, main and panel-box lay-outs in large shown in Figs. 253 to 257. These are shown to illus-
es rather than actual installations but each method
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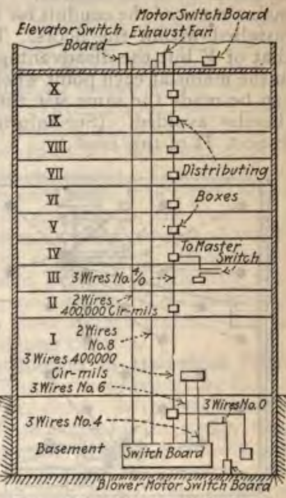


FIG. 256.—An actual feeder lay-out.

ers and Mains to of Buildings.—In
rering large areas,
boxes per floor may
These panel boxes
served by a separate
ıl wire ways are con-
257) or it may be
tall but one riser to
d distribute through
ains to the panel
floor as in Fig. 254.
tion where the feed-
ins are all vertical
: no feeder runs in
The construction of the building and the flexibility of
:d largely determine these points. An excellent ar-
one with a feeder to each floor, Fig. 253, wherein
ontrol and good voltage regulation are assured. The
;. 254, one feeder serving three or more floors, is prob-
en used. It costs somewhat less than the feeder-per-
but does not provide equal flexibility of control nor
voltage regulation. The feeder and main arrange-
255 will also give good results if the main connecting
on boxes is made of the same size wire throughout,
the installation of fuses in series. (See a discussion
r, as applied to the mains connecting a number of
n the same floor, which is given in a following para-
ıetimes a single main is made to serve all the panel
ilding as in Fig. 256, but as a general proposition this
many eggs in one basket" and results in inflexible
particular case must be decided on the basis of cost

345 Distribution to Panel Boxes on Floors.—(See above paragraph.) Often in buildings covering a small area one panel box per floor for general lighting is sufficient. Fig. 253, floors *V* and *IV* show an arrangement of mains from the distributing box to the panel boxes that may be used where the distributing box is located at about the center of the building. The lay-out on floor *V* is the best because with it trouble is localized, and very uniform pressure at panel boxes is assured. Where, as shown in *V*, subdivided mains are used the conduit for them will be small and can be readily installed within the floors. The method of *IV* is cheaper than that of *V* but the disadvantage is that fuses are required in series in the mains at each point where the wire size changes. The mains can be made the same size throughout at increased cost and fuses thereby avoided. (See information on mains and tapered mains in Sect. II of this book.)

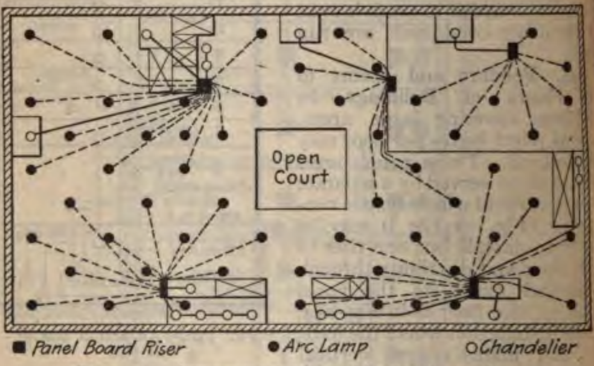


FIG. 257.—Arrangement of panel boxes on one floor.

Where the feeder to a floor rises at one side of the building the mains from the distributing box to the panel boxes may be arranged as in Fig. 254, floors *IV*, *V* and *VI*. The lay-out of *VI* is objectionable because there must be a fuse in series with the main in every panel box. By using two-wire sizes as in *V* instead of four the number of series fuses is reduced to two. The best arrangement is that of *IV* because with it there are no series fuses and troubles are localized. Fig. 257 shows a lay-out on a floor that is served by four panel boxes, each fed by a vertical riser.

346. Shop Wiring Design.—The design of the conductor system between the generating station and the shop buildings of an industrial plant that generates its own power is treated in another section and a general comparison of the distribution methods that may be involved is there given. The wiring for the lighting circuits within the shop is laid out on the same general basis as for other buildings as herein outlined. The lighting, feeder, main distribution center and panel box lay-outs are about the same for other buildings. For groups of motors, circuits independent of the lighting circuits should be provided unless the motors are very small. These independent circuits should extend preferably from the generating station or at least from the entrance through the building to points wherever there are motors.

In general, the factors affecting the design of interior feeder and main lay-outs for power circuits are the same as given in Paragraph 336. Often in a one-story shop or on each of the floors of a several story shop the best method of serving the motors is to carry a single main the entire length of the shop. The motors can then, through fuses and switches, be connected to this main. A single main on each floor suffices for a narrow shop. Where the shop is wide, several parallel mains so located that no motor is very far from some one of them may be installed. Often a ring main running around just inside of the shop walls (see Fig. 124 Par. 233) provides a good arrangement. The branches from the main can be carried down the walls and under the floor to the motors. In a shop of several stories, unless the motor load is very small, it is a good plan to run separate power mains from the entrance to the building to each floor but any of the feeder and main arrangements shown for lighting circuits in Figs. 253 to 256 can be used. However the lay-outs for power conductors should be, and usually are, much more simple than those for lighting conductors. A simple arrangement is usually possible because a close voltage regulation is not so important with power as with lighting circuits.

347. **Wiring for Electrical Distribution in Industrial Plants.**—Standard practice of one large concern is described by Geo. R. Terry, in *Electrical World*, June 23, 1912. With large motors, each of which takes a considerable percentage of the energy transmitted over a main, separate motor and lighting mains are preferable. But with many small and mixed sizes of motors which are liable to removal and which consume a relatively small proportion of the power of the mains, one system of feeders and mains for motors and lamps appears to work out to greater advantage as any one motor is seldom large enough to cause interruption of service on the mains.

The feeders are carried through buildings on roof trusses supported on porcelain cleats, strain insulators being used at turns and ends. The cleats merely hold the conductors in line and out of contact with the trusses. When circuits pass through the yards from building to building they are carried on glass insulators supported on steel bents attached to the building side walls or roofs. The general rule for work inside of buildings is to run all circuits of wires larger than No. 8 B. & S. gage open above the roof truss line and in conduit below. All circuits of No. 8 and smaller wire are always in conduit.

INTERIOR WIRING COSTS

348. **Cost of Interior Wiring** (*Lectures on Illuminating Engineering*, Johns Hopkins University, October and November, 1910).—*Prices of labor and material differ in different localities and at different times.* It is, therefore, difficult to state even approx

mately what the cost of interior wiring for lighting should be. In large cities, these variations are not extreme and it is possible to state the limits within which the cost, expressed in terms of the usual contractor's price per outlet, should lie. The figures given below apply to interior wiring of all classes, from the small residence up to the large hotel or office building. They cover the portion of the work from the main source of supply, assumed to be at the building line. In case the building is lighted from its own plant these figures will apply to the portion of the installation lying between the lamps and the plant switchboard. No lamps, fixtures or reflectors are included in these prices which are for work installed as building is being constructed:

Exposed wiring, $1.50 to $1.60 per outlet.

Wire in wooden molding, $2.00 to $2.50 per outlet.

Concealed knob and tube wiring, $2.50 to $3.00 per outlet, with $1.00 added per switch outlet.

Wiring in iron conduit, $4.50 to $5.00 per outlet.

Wiring in iron conduit in concrete buildings, $5.00 to $6.00 per outlet.

In the above, switches and base-board plugs are considered as outlets when the iron box is included. If the switch and plate are also to be furnished, approximately $1.00 per outlet of this nature should be added. For the larger installations in modern buildings the price of $7.00 per outlet, including all wiring and feeders up to the lighting fixture, has been found to be a fairly close figure.

348A. Knob and Tube Wiring In Finished Buildings

PRICES TO CONSUMER FOR DIFFERENT NUMBERS OF OUTLETS, SINGLE FLOOR CONSTRUCTION

No.	Cost	No.	Cost	No.	Cost	No.	Cost	No.	Cost
5	$15.85	17	$37.40	29	$57.20	41	$77.82	53	$100.82
6	17.85	18	39.05	30	58.85	42	79.75	54	102.85
7	19.85	19	40.70	31	60.50	43	81.75	55	104.77
8	21.85	20	42.35	32	62.15	44	83.60	56	106.70
9	23.85	21	44.00	33	63.80	45	85.50	57	108.62
10	25.85	22	45.65	34	65.45	46	87.45	58	110.55
11	27.50	23	47.30	35	67.10	47	89.37	59	112.47
12	29.15	24	48.95	36	68.75	48	91.30	60	114.40
13	30.80	25	50.60	37	70.40	49	93.22	....	....
14	32.45	26	52.25	38	72.08	50	95.15	....	....
15	34.10	27	53.90	39	73.97	51	97.07	....	....
16	35.75	28	55.55	40	75.90	52	99.00	....	....

Add as per following for outlets under other than single floors and for hardware and drop cords.

Under double flooring otherwise than hardwood. Second or third story.

Ceiling outlet.. $1.00 extra.

Switch outlet for any center outlet...................... 1.00 extra.

Under hardwood flooring, single, double or triple. Second and third story.

Ceiling outlet.. $3.00 extra.

One switch outlet for any center outlet.................. 3.00 extra.

Additional on same gang for same center outlet......... 1.50 extra.

Switches, hardware and drop cords as per following:

Push button switches, each	$1.00 extra.
Push button 3-way switches, per set of two switches	2.75 extra.
Porcelain base switches, each	.35 extra.
Porcelain base Edison receptacles, each	.35 extra.
Baseboard flush plate receptacles, each	1.15 extra.
Drop cord, key sockets each	.60 extra.
Drop cord, chain sockets, each	.75 extra.

Above from tables prepared for use of new business solicitors by the Central Station Development Company, of Cleveland, Ohio.

349. Prices of Wiring Old Buildings—Cottages.—(Commonwealth Edison Co., Chicago. From *Data*, November, 1911.) The prices are those charged the customer. This list is called special schedule "E" and is for 1-story cottages with open attic.

Seven to twelve lights	$35.00
Thirteen lights	39.00
Fourteen lights	41.00
Fifteen lights	43.00
Sixteen lights	45.00
Seventeen lights	47.00

Prices of wiring for switches and receptacles as given in 352 must be added. Prices of fixtures not included. The prices are based on concealed flexible conduit work, except in basement where rigid conduit is used.

350. Prices of Wiring Medium Grade Old Buildings.—The following prices are those charged the customer by the Commonwealth Edison Co., Chicago, and published in *Data*, October, 1911. The prices are for lamp outlets in flats of semi-fire-proof construction, renting for from $25.00 to $40.00 per month and in houses renting for from $20.00 to $50.00 per month. Schedule applies only to old houses having double floors of hardwood on pine. Prices of wiring for switches and receptacles from 352 to be added to the list prices. Prices are based on concealed flexible conduit work, except in basement where conduit is installed exposed on the ceiling.

Lights	Cost		Lights	Cost		Lights	Cost	
	Class "A" building 2 story	Class "B" building 3 story		Class "A" building 2 story	Class "B" building 3 story		Class "A" building 2 story	Class "B" building 3 story
10	$50.00	$70.00	28	$92.00	$116.00	46	$138.00	$173.50
11	52.00	72.00	29	94.00	118.00	47	140.00	176.50
12	54.00	74.00	30	96.00	120.00	48	143.00	179.50
13	59.00	81.00	31	98.00	122.00	49	148.00	186.50
14	61.00	83.00	32	100.00	124.00	50	151.00	190.00
15	63.00	85.00	33	102.00	126.00	51	154.00	193.50
16	65.00	87.00	34	104.00	128.00	52	157.00	197.00
17	67.00	89.00	35	106.00	130.00	53	160.00	200.00
18	69.00	91.00	36	108.00	132.00	54	163.00	203.00
19	71.00	93.00	37	113.00	143.00	55	166.00	206.00
20	73.00	95.00	38	116.00	146.50	56	169.00	209.00
21	75.00	97.00	39	119.00	150.00	57	172.00	212.00
22	77.00	99.00	40	122.00	153.00	58	175.00	215.00
23	79.00	101.00	41	125.00	156.50	59	178.00	218.00
24	81.00	103.00	42	128.00	159.50	60	181.00	221.00
25	86.00	110.00	43	130.50	162.50	61	186.00	226.00
26	88.00	112.00	44	133.00	165.50	62	189.00	229.00
27	90.00	114.00	45	135.50	168.50	....	....	.....

351. Cost of Wiring High-grade Old Buildings.—Prices charged the customer by the Commonwealth Edison Co., Chicago. From *Data*, November, 1911. The prices are for lamp outlets in high-class apartments and medium-sized residences with hardwood finish throughout, renting for $50.00 per month. Prices of fixtures not included. Prices of wiring for switches and receptacles from 352 must be added. Prices are based on concealed flexible conduit work in buildings with a hardwood floor over one of pine.

Lights	Cost		Lights	Cost	
	Class "C" building 2 floors	Class "D" building 3 floors		Class "C" building 2 floors	Class "D" building 3 floors
10	$ 75.00	$ 88.00	36	$161.00	$182.00
11	78.00	91.00	37	166.00	189.00
12	81.00	94.00	38	169.50	193.50
13	89.00	99.00	39	173.00	198.00
14	92.00	102.00	40	176.50	202.50
15	95.00	105.00	41	180.00	207.00
16	98.00	108.00	42	183.00	211.00
17	101.00	111.00	43	186.00	215.00
18	104.00	114.00	44	189.00	219.00
19	107.00	117.00	45	192.00	223.00
20	110.00	120.00	46	195.00	227.00
21	113.00	123.50	47	198.00	231.00
22	116.00	127.00	48	201.00	235.00
23	119.00	130.50	49	206.00	242.00
24	121.00	134.00	50	210.00	246.50
25	126.00	141.00	51	214.00	251.00
26	129.50	145.00	52	218.00	255.50
27	133.00	149.00	53	222.00	260.00
28	136.50	153.00	54	226.00	264.50
29	140.00	157.00	55	229.50	268.50
30	143.00	161.00	56	233.00	272.50
31	146.00	164.50	57	236.50	276.50
32	149.00	168.00	58	240.00	280.50
33	152.00	171.50	59	243.50	284.50
34	155.00	175.00	60	247.00	288.50
35	158.00	178.50	....	....	....

352. Cost of Wiring Old Buildings—Switch Outlets, Switches and Extras.—The following prices to the customer are those of the Commonwealth Edison Co., Chicago (*Data*, Nov., 1911) and are to be added to the price given for outlets in the three preceding tables. Wiring is concealed and in flexible conduit.

Cost of wiring for switch outlets					
Class	A	B	C	D	E
Single pole..........	$3.00	$3.50	$4.25	$4.50	$2.50
3-way..............	4.50	5.00	5.75	6.00	4.00

In addition to the above prices for wiring switches, additional prices switches, etc., will be as follows:

...sh push button single pole	$1.00	Drop cord (without canopy)..	.75
...ndard snap single pole....	.50	Water-proof floor receptacle.	3.00
...tomatic door switch......	1.50	Flush baseboard receptacle...	1.50
...ay flush switch..........	1.00	Standard wall socket........	.50
...ay snap switch..........	.50		
...op cords, including spun ...ass canopy cord, and socket	1.00		

...353. Cost of Knob-and-Tube and Conduit Work.—Work done ...St. Paul, Minn. Costs are those to the customer and are for ...w work. (*Electrical World*, Jan. 28, 1909.)

...b number	Knob-and-tube			Iron conduit	
	Number of outlets	Total cost	Cost per outlet	Total cost	Cost per outlet
1	120	$247.00	$2.06	$423.00	$3.53
2	80	147.00	1.84	251.00	3.14
3	72	158.00	2.19	248.00	3.44
4	66	136.00	2.06	213.00	3.23
...Average	....	....	2.04	....	3.26

Average excess cost of conduit above knob-and-tube work is ... per cent.

354. A day's work for a wireman and helper in erecting mold-...g, on surfaces where holes must be drilled and plugged to sup-...rt it, is the running of 100 ft. (Auerbacher).

355. The division of cost of a conduit job will be approximately ...follows: Labor, 40 per cent.; conduit, 22 per cent.; wire, 18 ...r cent., and incidentals, switches, outlets, etc., 20 per cent. ...*lectrical World*).

356. Cost of double-braided rubber-insulated wire in place ...conduit. (*Nelson S. Thompson, Electrical World*, Sept. 9, ...11.) Costs do not include conduit.

Single conductors			
...ize A.W.G.	Cost per 1,000 ft.	Size A.W.G. & cir. mils	Cost per 1,000 ft.
Solid		Stranded	
16	$15.00	1	$101.30
14	18.60	0	128.00
12	21.70	00	156.00
10	25.85	000	184.25
Stranded		0000	217.00
8	35.40	250,000	275.00
6	48.25	300,000	327.00
4	62.65	400,000	405.00
3	75.25	500,000	500.00
2	82.00		
Duplex conductors			
14	$30.00	10	$40.25
12	34.00	8	49.25

357. Cost of Conduit in Place (New Building)

½ in. size	$ 8.50 per 100 ft.
¾ in. size	10.25 per 100 ft.
1 in. size	13.75 per 100 ft.
1¼ in. size	18.25 per 100 ft.
1½ in. size	22.00 per 100 ft.
2 in. size	30.60 per 100 ft.
2½ in. size	47.00 per 100 ft.
3 in. size	60.00 per 100 ft.

358. Cost of Conduit Elbows in Place

2 in. size	$ 1.00 each
2½ in. size	1.25 each
3 in. size	4.00 each
4 in. size	10.00 each

359. Estimating Costs of Conduit Installations.—The Treasury Department of the United States uses the following methods and values for computing the costs of conduit wiring in federal buildings. (*Nelson S. Thompson, Electrical World*, Sept. 9, 1911.) The figures are for high grade work in fire-proof buildings. The material is taken off accurately from the drawings. The total amounts of conduit and wire are the lengths scaled from the plan plus the following: Number of ceiling outlets×2 ft.; number of bracket outlets×10 ft.; number of switch outlets×10 ft.; number of baseboard outlets×4 ft.; number of two-gang switches×15 ft., and number of three-gang switches×20 ft. Table 357 shows the cost of conduit in place. For the cost of underground service connections in place and for work in old buildings where walls and ceilings are cut and plaster must be replaced, 50 per cent. should be added to the tabulated values.

The cost of all kinds of outlet boxes in place is 25 cents each in new buildings and is 50 cents in old buildings where plaster must be repaired. The cost of large junction boxes in place is 5 cents per pound. Plug receptacles in place cost $1.30 each. Single pole snap switches in place cost $1 each. Fixture studs cost 5 cents each in place; outlet bushings 5 cents each in place; lock-nuts 1 cent each in place. One should estimate 3 bushings and 3 lock-nuts per outlet.

The average total cost of lighting systems complete in place in eastern sections of the country is about $12 per outlet; in the West and South the cost will be about $15 per outlet, and in the extreme West the cost per outlet will be $20. The number of outlets upon which these figures are based does not include switch outlets, but only the actual lamp outlets. In old buildings the cost of the conduit and wiring work is $20 to $25 per outlet and $30 in the extreme West.

360. Miscellaneous wiring costs for first class conduit work in fire-proof buildings. (*Nelson S. Thompson, Electrical World*, Sept. 9, 1911.) Busbars for switchboards, in place 50 cents per pound; structural steel work, in place, for switchboards, 10 cents per pound; blue Vermont marble, 2 in. thick, $2 per square foot; slate panels, 1¼ in. thick, 50 cents per square foot; drilling holes, slate and marble, 25 cents each; labor on switchboard panels in ıop, $25, and on the job, $12 each; tablets and cabinets, complete ı place, $5 per switch. One should ascertain if possible the actual ›st of cabinets and tablets and add $1 per circuit for installation. tandard floor outlet boxes (such as are used in United States ederal buildings) cost $3 each in place; telephone cabinets in place uch as are used in federal buildings) cost $20 each.

Motor connections, 5 h.p. and under, $2 per horse-power; ıotor connections, 10 h.p. up, $1 per horse-power; freight and rayage, 3 per cent. of total cost of material and labor; railroad ıre, depending on location of the job; board and lodging, depend- ıg on location of the job; superintendence, 1 per cent. of total ›st of materials and labor, and profit, 20 per cent. of total cost of ıaterials and labor.

ELECTRIC SIGN WIRING

361. **Methods of Wiring Electric Signs** (*Data on Electric Signs*, 'he National Electric Light Association).—Lamps burning in ıultiple may be connected either two-wire or three-wire, as shown ı Fig. 258. In series wiring, lamps may be connected either in traight series or multiple-series, as shown. Where transformers

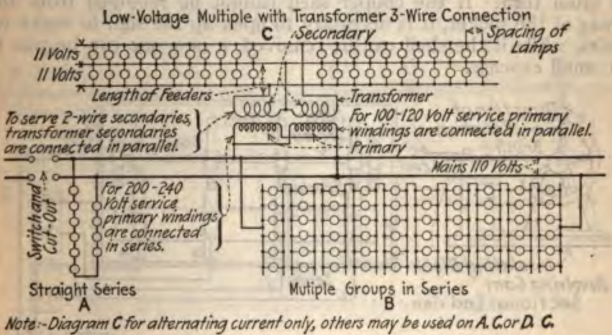


FIG. 258.—Methods of connecting sign lamps.

see section on Transformers for information on sign transformers) re used to obtain low voltage, lamps may be connected either wo-wire or three-wire as in standard multiple wiring, the trans- ormer reducing the voltage from the regular 110- or 220-volt ircuits to the voltage required by the lamp. The ordinary ıultiple wiring can be changed to straight series wiring by merely lipping the alternate connections between lamps (Fig. 259).

In a large sign any combination of series or multiple-series ıay be used. With straight series wiring, should one lamp in he series burn out, all the lamps in that series will be out. If he lamps are connected in multiple-series, the failure of one lamp ›es not cause any of the other lamps to go out. However, there should be not less than eight to ten lamps in each multiple g... or the failure of one lamp will cause too much current to ... through the other lamps of the same group, thus shortening ... lives.

362. **Sockets for Electric Signs.**—Any standard weather-p... socket manufactured for sign use is satisfactory providing it ... been approved by the Underwriters and has been shown to ... thoroughly weather-proof. A socket with an extending porce... cap which protects the base of the lamp from water is desi...

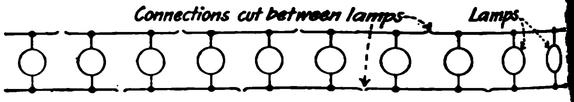


FIG. 259.—Method of changing sign wiring from multiple to series.

in that it gives a longer life to the lamp. A removable cop... shell is desirable inasmuch as there is a certain amount of w... from the taking of the lamps out of the sign for cleaning or ren... ing, and as the workmen are in the air, they cannot be as car... as they would be under ordinary conditions and the copper s... is often torn. If the copper shell cannot be removed from t... front of the socket, it is necessary to open up the sign to make r... pairs, while if the shell can be removed, a new one can be put ... at small expense.

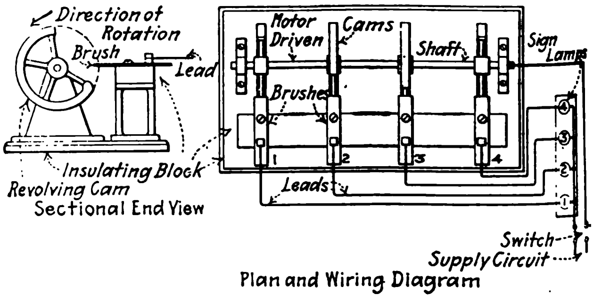


FIG. 260.—The elementary sign flasher.

363. **The principle of the sign flasher** is illustrated in Fig. 260. Cams or a drum are mounted on a shaft that is rotated by a small electric motor. The circumferences of the cams or of the drum are so cut that, in the brush-type flashers, the brushes will make contact only during certain predetermined portions of a revolution and thereby complete the electric circuit through the sign lamps only during that period. In the carbon-type flashers the cams, instead of carrying current and making and breaking the contacts directly, operate to open and close carbon-break ...

nes which control the sign lamps. The possible variations rangement of cams and drums for producing different effects almost numberless.

Current Carrying Capacities of Flashers.—Double-pole ers are made in four sizes that will carry respectively 15, 30, 60 amp. per switch. Single-pole carbon flashers are made will carry 5 amp. per switch. Brush type flashers are rated m 2 to 5 amp. on each brush and are not reliable for greater nts. Non-carbon, double-pole-switch flashers are made for nts of 15 amp. and greater but it is claimed by some manufac- that 15 amp. should be the maximum because no knife switch successfully break greater currents continuously.

Wiring and Installing Brush Type Flasher.—Fig. 261 s the wiring for a sign for "spelling" out. The neutral wire

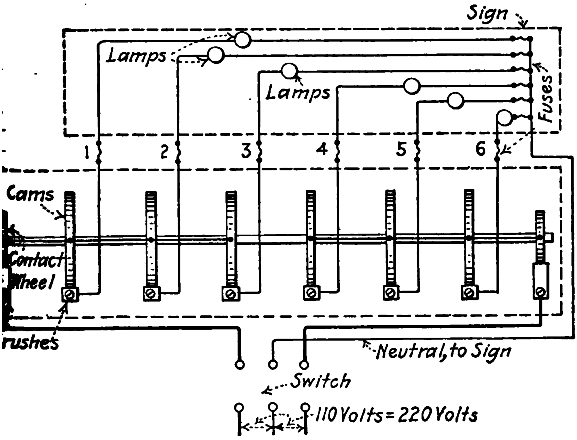


FIG. 261.—Wiring of three-wire brush-type flasher.

me main on a two-wire system) runs direct to the sign through customary cut-outs, and the outside "legs" (or remaining main two-wire system) run to the flasher as a common feed. From flasher one wire is run to each individual letter through the omary cut-outs. In the case of a double face sign, two like rs can be connected in multiple and regarded as one circuit, ided the load which one switch of the flasher is designed to r is not exceeded.

ways install so that the copper brushes are at the front of flasher. Follow the general installation directions given for on flashers in another paragraph.

6. **Wiring diagrams for carbon sign flashers** (*Reynolds Dull ler Co., Chicago*) are given in Fig. 262. Unless otherwise ed *flashers are furnished* requiring a wiring arrangement like

that at *III*. The load is balanced by running the neutral around the machine, to the cut-outs, breaking only the outside "legs" on a 220–110-volt system. While this method of wiring is entirely feasible, is no harder on the contacts, and permits the use of a cheaper flasher, it is technically a violation of the insurance rules, which specify that all circuits of more than 660 watts must be broken double pole. If the load is absolutely balanced it would break double pole at 220 volts, and the lamps would be in series, but if the load is not exactly balanced there would be single-pole breaking. In other words, it is a double break and again it is not, according to circumstances. The use of this machine wired in this way should be taken up with the local inspector. If he is disposed to take a broad view of the matter he will undoubtedly permit

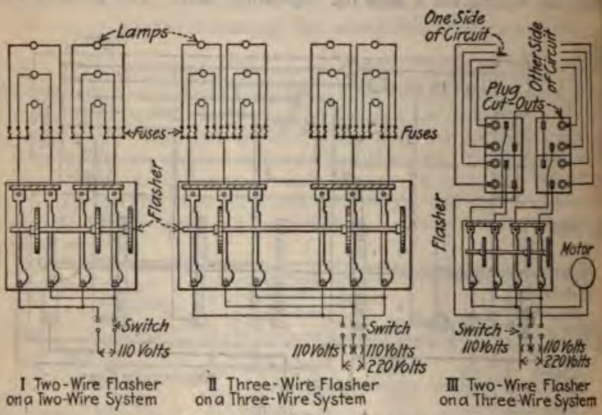


FIG. 262.—Wiring diagrams for carbon sign flashers.

its use, as it is just as safe as any other way, but if he should insist on an absolute observance of the code, it is probable that he would not permit it.

367. In installing and wiring a carbon flasher (*Reynolds Dull Flasher Co.*, Chicago) run the mains to the upper bridge of the flasher, and run the sub-mains to the sign and to the terminals on the base of the machine. The sub-mains are divided into the small circuits either in the sign or as close thereto as possible to save the cost of wiring. Each small circuit into which the sub-mains are divided should be protected with fuses and some inspectors may require that the sub-mains also be protected with fuses where they leave the flasher.

Place the flasher on a wood shelf, 15 in. wide and 10 in. longer than the slate base, in such manner that the carbons are in the front, the motor at the left with the commutator side to the front. The shelf should be covered with asbestos and if the machine is in a basement or out of sight, cover it with an iron or fire-pro

: and if to be run in plain view, it should be covered with a glass e. Run all wires through bushings in the shelf close to the base he machine.

Do not screw either flasher or motor down tight but leave an hth of an inch clearance under the heads of the screws. The of a show window, a board partition, or anything that acts as ounding board will increase the noise three-fold and when it is cessary to install in such places, arrange an extra set of rubbers der the shelf also.

368. **Some "Dont's" to Observe in Installing Sign Flashers** *eynolds Dull Flasher Co.*).—DON'T start the flasher without exnining it for damage in transit. Give a few turns by hand and e that everything works perfectly free and easy and that the ades fit into the forks properly.

DON'T install the flasher in the bottom of a box where it is not cessible. Place it on a shelf, run the wires down through the elf close to the base and turn a cover upside down over it.

DON'T install hind-side foremost. The carbons should always be the front.

DON'T run with a tight belt. Practically no power is required. un the belt just as loose as it will stay on.

DON'T run your flasher backward. Looking at it from the switch le, the main shaft should run from you on the top.

DON'T run the flasher over ten revolutions per minute nor less an six.

DON'T fail to instruct your customer about oiling.

DON'T connect up a carbon machine single pole.

DON'T overload any switch on a flasher.

369. **Wiring for the so-called "high-speed" effects** (*Reynolds ull Flasher Co.*, Chicago) such as running fountains, rising smoke,

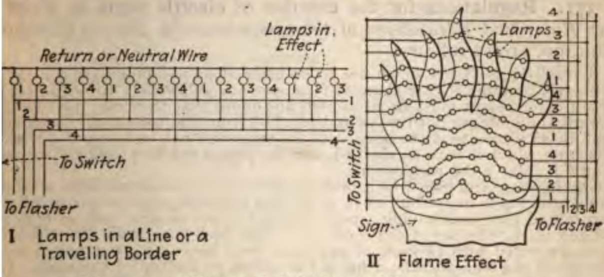


FIG. 263.—Wiring of "High-speed" effect signs.

mes, traveling borders and revolving wheels are wired as indicated Fig. 263. The diagram at *I* is for the effect where the sign nps are in a single line and the same general arrangement is d for a traveling border. For a fountain effect number the ps at the beginning of each stream and so continue to the end ne stream and where several streams run parallel all the lamps in one horizontal row can be connected to the same branch as though they were one lamp. Traveling borders on an ordinary 3 ft. × 10 ft. sign should have lamps spaced about 6 in. apart. In a fountain 15 ft. high the lamps should be about 9 in. apart. Fig. 263, II, shows the wiring diagram for smoke, flame, steam, dust and running water effects. Avoid a "straight-across" arrangement of lamps as the resulting effect will be unnatural.

370. The wiring for a flashing illuminated sign, that is, a painted sign which is successively illuminated (by lamps carried in a reflector trough above it) and darkened by the lamps being extinguished is shown in Fig. 264. Lamps should be 16 c.p. and mounted not more than 12 in. apart in the reflector which should preferably be of the silver backed type. For flashing in colors but three can be used, namely: red, clear and amber. Other colors such as green, blue, etc., are too dense to produce a good effect and little light will throw down more than 8 ft. A carbon type flasher should be used.

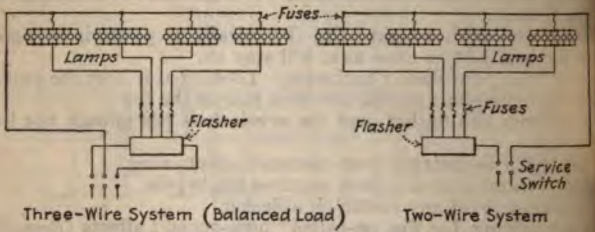


FIG. 264.—Wiring for flashing sign.

371. Regulations for the erection of electric signs as given in the *Rules and Regulations of the Commonwealth Edison Company*, Chicago, are as follows:

Accessibility.—Signs which are to be cleaned or re-lamped from a ladder must not be hung higher than 30 ft. above the sidewalk. All signs placed at a greater height must be so located and hung that they may be swung in toward the building both ways and reached from the windows. Such signs shall be so placed that the bottom of the sign shall not be below the window sills from which it is to be cleaned, and the top of the sign shall not be more than 6 ft. above the window sill.

Guy Lines.—Any sign which must be cleaned or re-lamped from a ladder, and whose top is more than 18 ft. above the sidewalk, shall be provided with two sets of guy lines having separate attachments on sign and on building. All guy lines, whether of chain or cable, shall be hot galvanized. Sectional signs, provided with two sets of guy lines, shall have one set attached to the bottom of the sign and the other set attached to the top of the sign. Guy lines shall be placed at such an angle with the horizontal that the signs will not be raised up and the weight taken from the main supporting chain by strong wind.

Strong Backs.—In case it is not convenient to provide a sign with guy lines on each side, the sign shall be held rigid from swinging by means of a stiff rod or strong back connected to the top of the sign.

Expansion bolts shall be of the lead wedge expansion type, $\frac{3}{8}$ in. in diameter by 3 in. long, and shall be firmly set in holes drilled into a masonry wall. If the wall is of brick, the hole shall be in the center of a hard, firm brick. All soft or loose bricks must be avoided. If a solid brick cannot be found the guy line must be attached to a bolt passing through the building wall *urnbuckles.*—Eye bolts and hooks which screw into turnbuckles shall e holes drilled through their ends and shall be provided with a split pin to vent unscrewing.

Iinge Bolts.—Hinge bolts shall be provided with lock nuts or split pins.

Bushings and Collars.—Swaying signs shall be attached to their cranes by igers passing over iron collars placed on the crane and provided with an minum lining. A bearing for these aluminum-lined collars shall be placed on the crane, and shall consist of solid aluminum collars with flanges at one l. The aluminum collars shall be placed upon the crane with the unnged ends facing each other, and shall be rigidly attached to the crane and of such size that the aluminum-lined iron collars shall have a snug fit, but free enough to permit the sign to oscillate.

Cross Plates.—Cross plates to which guy lines are attached shall be bolted the sign with two short, snug fitting bolts, which shall be riveted over after ts are put on. These bolts shall be large enough to support the sign witht danger of breaking or shearing, and shall not be smaller in diameter than n. The plates shall be of such a width that the distance between bolts ill not be less than one-third the distance between the holes where the guy es are attached.

Feed Wires.—Swaying signs supported from a crane shall have stranded d wires between building and sign. Feed wires which are not run through crane shall be attached to insulated support on the crane near its base, d from this support connect to the sign with a drip loop extending 3 in. low the sign outlet. Wherever feed wires pass through an iron plate or rough the side of an iron pipe the opening shall be protected by a porcelain ameled bushing.

ELECTRIC HEATING DEVICE INSTALLATION

372. **Special outlets for heating devices** are frequently reuired. Outlet plates, similar to that of Fig. 265, provided with ceptacle, switch and indicating lamp socket are regularly manuctured for currents as great as 20 amp. Keyless brass sockets ve a maximum rating of 6 amp. The ordinary pull-chain and y sockets have a maximum rating 2½ amp. Standard separable tachment plugs are approved for 0 watts at 250 volts, or 10 amp. a 110-volt circuit. Where ordiary key sockets are used for witching on and off heating deices they soon wear out under the ction of the arcs formed in breakg the relatively heavy currents. nap or knife switches should lways be used for heating deices. Specially constructed, asbestos-covered, flexible cords are ecified for all heating devices requiring more than 250 watts.

FIG. 265.—Indicating heater receptacle.

373. **An approximate rule for the wattage of an electric heater heat a room** is to allow 1½ watts of heater input (maximum) r cubic foot of air space for shops, factories, halls, churches and ntral stations and 2 watts per cubic foot of air space for average oms. The direction of exposure, the number of windows and e *quality of building construction*, and other things, all have *earing on the matter* so the values given are approximate only *average conditions of building and climate.*

374. Power and Current Taken by Heating Devices (*Electrical Solicitor's Handbook*)

Domestic devices

Device	Watts consumed	Amperes taken at 110 volts
Broilers, 3 ht.	300 to 1,200	2.7 to 10.9
Chafing dishes, 3 ht.	200 to 500	1.8 to 4.6
Cigar lighters	75	0.7
Coffee percolators for 6-in. stove	100 to 440	0.9 to 4.0
Corn poppers	300	2.7
Curling-iron heaters	60	0.6
Double boilers for 6-in., 3 ht. stove	100 to 440	0.9 to 4.0
Flatiron (domestic size), 3 lb.	275	2.5
Flatiron (domestic size), 5 lb.	400	3.6
Flatiron (domestic size), 6 lb.	475	4.3
Flatiron (domestic size), 7.5 lb.	540	4.9
Flatiron (domestic size), 9 lb.	610	5.6
Frying kettles, 8 in. diameter	825	7.5
Griddle-cake cookers, 9 in. by 12 in., 3 ht.	330 to 880	3.0 to 8.0
Griddle-cake cookers, 12 in. by 18 in., 3 ht.	500 to 1,500	4.6 to 13.7
Heating pads	50	0.5
Instantaneous flow water heaters	2,000	18.2
Nursery milk warmers	450	4.1
Ovens	1,200 to 1,500	10.9 to 13.7
Plate warmers	300	2.7
Radiators	700 to 6,000	6.4 to 5.5
Ranges: 3 heats, 4 to 6 people	1,000 to 4,515	9.1 to 40.1
Ranges: 3 heats, 6 to 12 people	1,100 to 5,250	10.0 to 47.5
Ranges: 3 heats, 12 to 20 people	2,000 to 7,200	18.2 to 65.5
Shaving mugs	150	1.4
Stoves (plain), 4.5 in., 3 ht.	50 to 220	0.5 to 2.0
Stoves (plain), 6 in., 3 ht.	100 to 440	0.9 to 4.0

Commercial devices

Device	Watts consumed	Amperes taken at 110 volts
Annealing furnaces	200	1.8
Bar or barber's urns, 1 to 5 gals., 3 ht.	200 to 1,700	1.8 to 15.5
Baker's ovens, 30 to 80 loaves	6,000 to 10,000	54.5 to 91.0
Cigar lighting	75	7
Dental furnaces	450	4.1
Glue pots	110 to 880	1.0 to 8.0
Hat irons (small)	200	1.8
Hatter's iron, 9 to 15 lb.	450	4.1
Instrument sterilizers	350 to 500	3.2 to 4.6
Laboratory apparatus flask heaters	500	4.6
Machine irons, 12 to 18 lb.	770	7.0
Pitch kettles, 12 and 15 in., 3 ht.	300 to 1,500	2.7 to 13.7
Polishing irons, 3.5 to 5.5 lb.	330 to 450	3.0 to 4.0
Radiators (various sizes)	700 to 6,000	6.4 to 54.6
Sealing-wax pots, 0.5 and 1.5 pt.	175 to 300	1.6 to 2.7
Shoe irons	200	1.8
Soldering irons (various sizes)	100 to 450	1.8
Soldering pots, 4 to 10 lb. capacity	200 to 440	0.9 to 4.0
Tailor's iron, 12 to 25 lb.	660 to 880	6.0 to 8.0
Vulcanizers for automobile tires	100 to 450	0.9 to 4.0

375. **Luminous radiators or air heaters,** which are sometimes called convectors, can be used for room heating. From the standpoint of energy utilization a heater of one type is as efficient as a heater as the other since in any electrical heating device all of the electrical energy put into it is transformed into heat. Luminous radiators, which throw off radiant heat, are suitable for quickly warming any portion of one's body. The radiant heat rays will warm only a material which is opaque to them. They pass through air without heating it and are not affected by air currents. They may heat air indirectly by heating objects in contact with air, the objects transmitting the heat to the air. As a general proposition luminous radiators are not suitable for warming large spaces.

Air heaters or convectors heat the air passing over the heated surfaces of the convector. Convectors should be so arranged that there is an effective circulation of air through and around them. A single, large capacity heater in a room will not heat it as effectively as several small capacity heaters having the same aggregate capacity. Heaters should be preferably placed under or near windows.

376. **To estimate the wattage of an electric heater to heat a room** the following approximate formula has been used. It is based on the assumption that the inside temperature is to be 70 deg. fahr. and the outside temperature is about 12 deg. fahr. below zero.

$$\text{Watts required} = 5S + 50W + 0.5A$$

Wherein, $S=$ sq. ft. of wall surface exposed exclusive of window surface, $W=$ sq. ft. of window or glass surface exposed, and $A=$ cu. ft. of air space in the room. Where the inside and outside temperatures vary much from those above assumed, the wattage required will be (approximately) correspondingly more or less in proportion to the difference between the inside and outside temperatures.

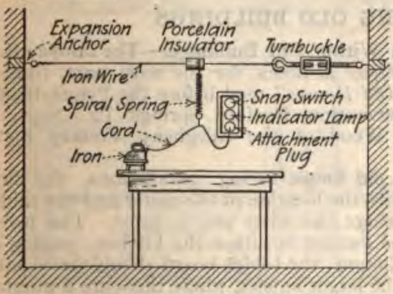


FIG. 266.—An electric iron installation.

FIG. 267.—Method of supporting spring.

377. **A method of supporting the conducting cord of an electrically heated iron** (*Electrical World*, May 4, 1911) is shown in *Fig. 266. The spring is fastened with an* "S" hook (see Fig. 267) *to a porcelain insulator* which is arranged to slide back and forth

on a wire. As the iron is pushed to and fro the porcelain insulator follows its movements and, as the spring will stretch, ironing can be done over a considerable area. The conducting cord is supported well out of the way of the operator. Spiral springs are usually furnished by the manufacturers with all sadirons.

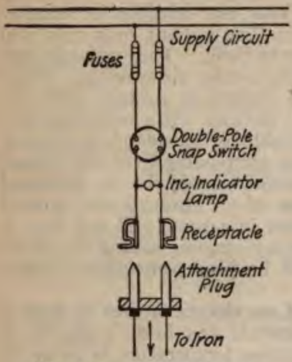


FIG. 268.—Wiring diagram.

The iron wire is made up in a screw eye, inserted in the wall at one end and into one eye of a small turnbuckle at the other end which provides means for keeping the wire tight. The hook end of the turnbuckle engages with a screw eye inserted in the wall. It is well to arrange the iron wire somewhat to the rear of the line along which the iron will be used. This is done to prevent the cord from striking the hand of the ironer.

378. **A method of wiring an electric iron** is shown in Figs. 266 and 268. An incandescent lamp of small candle-power is connected across the branch circuit to the iron on the iron side of the double-pole switch. So long as the switch is closed and the iron connected to the supply source the lamp will glow and indicate the fact that the iron is "alive." This device not only tends to make the operator careful in his use of energy, but it assists in preventing the fires that are sometimes caused by an electric iron being left on a wooden ironing board while connected to a supply source.

WIRING OLD BUILDINGS

379. **Information on Wiring Old Buildings.**—The information herein given on this subject is taken, for the most part, from a paper "*The Wiring of Old Houses*" read before the Pennsylvania Electric Association Convention, Bedford Springs, Pa., Sept. 3, 1912, by Howard H. Wood of the Allegheny County Light Company.

380. **In laying out old house wiring installations,** the first things to be considered are the location of the meter and the tablet board, and the point where the wires are to enter. The meter loop should generally be located in either the kitchen, pantry or cellar. In the smaller houses, the tablet board should be located near the meter, and in the larger houses, where there are a number of branch circuits, at the central point of distribution, *i.e.*, at some point on the second floor, preferably the hall. The point of entry should be located with reference to the accessibility of the service connection.

381. **Typical Wiring Plan of an Old Building.**—Fig. 269 shows the routes taken by the wires, to chandeliers and switches, within

valls and under floors. The point of entry for the mains in this case s the kitchen, on the outer wall of which is located the main switch, he fuse block, and the meter. The connected load being less than

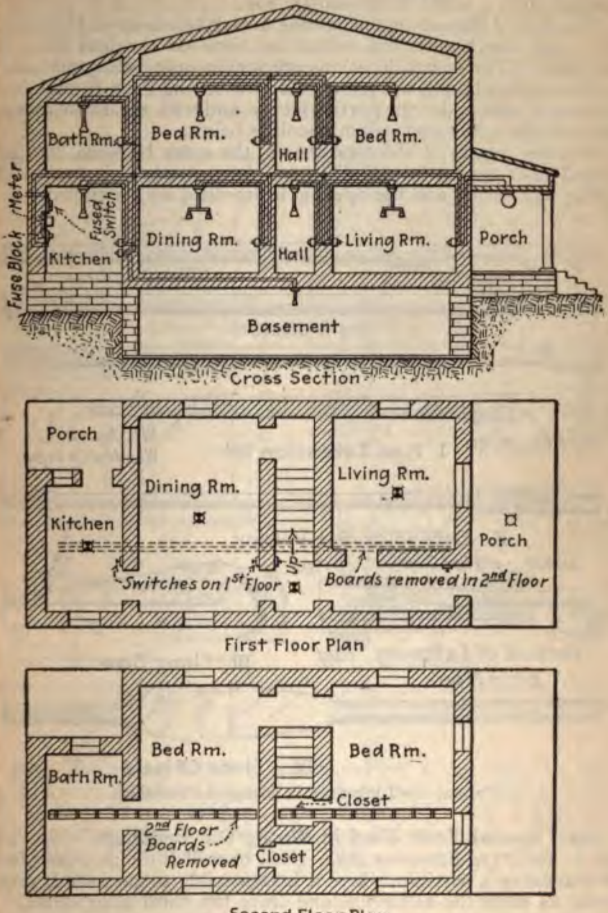


FIG. 269.—Wiring of a five-room house.

i60 watts, or the equivalent of 12 lamp outlets, only one circuit is ecessary. *Double-pole switches are shown, as they are required certain cities in installations where combination gas and electric* fixtures are used. Single-pole switches, installed in accordance with Code rules, are practically as good for the average installation. The methods of carrying conductors to single-pole switches will be obvious from a study of the illustration.

The dotted lines show the flooring boards taken up on the second floor, and the fixture and switch locations on the first floor are indicated. The switch locations are within easy fishing distance.

The flooring boards are removed on the second floor in such locations as to pass under one partition only, and with regard to accessibility of the outlet and switch openings below.

In many houses of the type shown, the space between roof and second floor ceiling is sealed, in which case a hole is cut in the ceiling of a closet, and the opening is provided with a trap door.

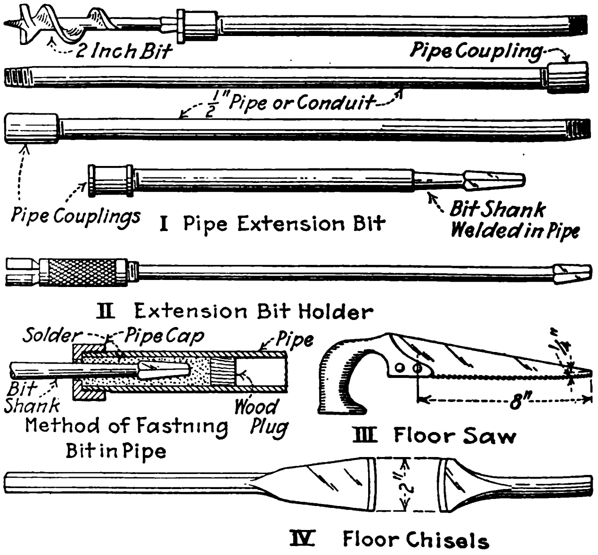


FIG. 270.—Tools used in wiring old buildings.

382. Special Tools Used in Wiring Old Buildings. (See Fig. 270.) (*a*) *Pipe Extension Bit.*—Used to drill through cross pieces or headers in a partition where it is impossible to get over or under them, as from the cellar up, and from the third floor down. A 2-in. bit is used, making a hole large enough to take four pieces of flexible tubing. Cases are known where boring has been done from the cellar to the third floor successfully, although the necessity for this is very rare. Fig. 271 illustrates the application of this device. A bit brace can be used for turning it or if the space is restricted a pipe wrench can be used.

(*b*) *Floor Saw.*—Used in removing flooring boards, made short enough so that it cannot be pushed through the plaster of the ceiling below. The blade is ¼ in. wide at the point and approximately 8 in. long with a handle similar to a key hole saw.

(*c*) *Floor Chisels.*—Used in removing the flooring boards. The chisels are from 12 to 24 in. long and 2 in. wide at the point.

(*d*) *Extension Bit Holder.*—Used in a bit brace for drilling holes in joist. They are 2 to 3 ft. long, and enable wireman to drill holes in a recess, or in places where a long bit would be needed. By coupling two of the holders together, the wireman can drill circuit holes in joist while standing, which renders the work much easier, where there are a number of holes to be drilled.

Mouse.—Used in locating cross pieces, and finding clear spaces in partitions. Is made up of a length of twine with a piece of lead or other heavy material on its end.

Snake.—Used in fishing wires through partitions or under floors; made of rectangular or round steel wire.

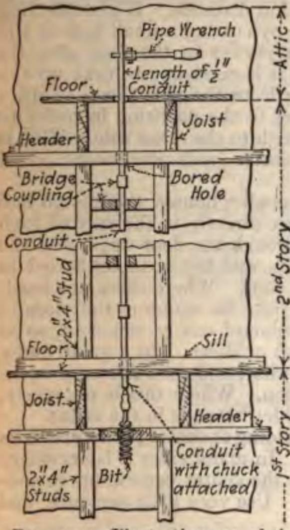


FIG. 271.—Illustrating use of the pipe extension bit.

FIG. 272.—Methods of locating cleats to support floor boards that have been removed.

383. Removing Flooring Boards.—First a slot must be made in the seam between flooring boards of sufficient size to enable the floor saw blade (Fig. 270) to be inserted. This is best done with a sharp, narrow chisel having a ⅝-in. blade. Then the saw blade is inserted, and the tongue at the junction of the flooring boards is sawed off the full length of board to be removed. The wireman can tell when he reaches the joist at which he wishes to end his cut. At this point the chisel blade is placed, with the flat part across the board at edge of the joist, and another small slot made. Then the board is sawed off even with the joist, and can be easily removed with a floor chisel (Fig. 270). When the board is replaced, a cleat is nailed to joist (Fig. 272) for the board to rest on, and then the board is nailed down, or better yet, screw down, so that, if it is necessary to get at the wires again, it can be done with little trouble. When fastening down the flooring, two nails or screws should be put in each joist. When only one nail is used, the board is liable to squeak when walked over. To insure a substantial job, any floor board that is removed should be long enough to bridge at least two joists.

384. Fishing to Center Outlets.—A great deal depends on the layout of the house. Almost invariably the joists are run parallel to the street. If the house is one with a side or center hall on the second floor, the circuits can be run the length of the hall, necessitating the removal of two boards for that distance. Wires can then be fished from the center of the room by cutting a small hole at the chandelier location, or by cutting a pocket in the floor directly above the location of the outlet. If it is necessary to take up the boards in the floor at some distance from the partitions, another pocket will have to be taken up close to the partition in order to drop the switch loops, and to go through to the other side. This is necessary when the hall is in the center, with the rooms to be wired on each side.

If, as is the case with some of the smaller houses, there is no hall on the second floor, and the rooms are directly in the rear of each other, the boards can be taken up through the door-ways, and the wires dropped to the switches, outlets, and to the tablet board in the kitchen very readily. (See Fig. 269.) Where there are hard-wood floors, the wires must be fished from the center of the room to a closet, or to a point where the baseboard can be removed, so as to get into a partition going either up or down. In a great many cases, it is necessary to drop to the cellar, and then come up again in another location for the switch loop. Where this is necessary, the most convenient place for the tablet board is in the cellar.

384 A. When plaster-of-Paris molding or center pieces are to be drilled, the Syracuse bit is the best. In many cases it is necessary to first saw off the lower portion of the center decoration to provide a flat surface to front the drill. Use very little pressure, and have the drill very sharp.

385. Wiring for Switch Loops.—In a great many cases, the bringing out of the switch loops at outlets at a proper distance from floor is the most difficult part of wiring old houses, on account of the cross pieces or bridges sometimes found in partitions. The method to be used must be determined by the wireman on the job, according to the conditions found. Following are some of the methods used:

First, with his mouse, he finds if the runway is clear; if so, the rest is easy. But, if he finds there are cross pieces, he locates their position by measurement with the mouse, and marks the location on the wall. If the cross pieces are above the proper positions for the switch, he will probably use one of the following methods of getting around it:

(a) Remove the door stop strip from the frame of the doorway (Fig. 273), bore through on each side of the cross piece, and cut a recess in the inside of the frame, then fish the wires around.

(b) If on the second floor, and there is no partition directly

above, the wireman can use a pipe extension bit (Fig. 270, *I*), drilling one hole large enough to fish the switch loop through.

(*c*) If the cross piece is not too far above the proposed location of the switch, holes can be drilled on a slant from switch opening.

(*d*) Remove the wall paper directly over the cross piece, which can easily be done, especially in an old house where there are several thicknesses of paper, either dry or by dampening it. This can be done by cutting an X through the paper at the point over which the opening is to be made, and bending the paper back, but taking care not to bend it enough to crease it. Then cut a hole smaller than the paper removed, and bore holes or cut away the cross piece

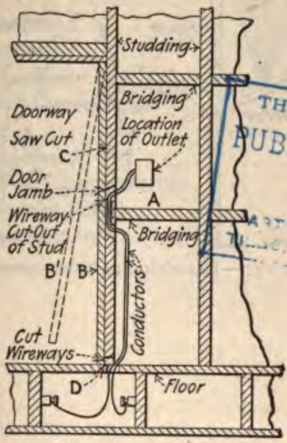


FIG. 273.—Carrying wires around a bridge.

enough so that the wires will pass. If there is a figure or flower where the cross piece is located, the same can be cut out with a sharp knife, and, after the hole is plastered up with plaster of Paris, the paper can be replaced very neatly. A careful man usually performs this operation very successfully.

(*e*) Sometimes a wireman will attempt to remove these cross pieces, when he can get at them from above, by putting a piece of pipe down between the partition, and hitting with a heavy hammer. This method is liable to cause damage to the plaster by bulging or breaking it out, and is not recommended.

(*f*) When a switch must be located on a brick wall, it is necessary to run wires in rigid or flexible steel conduit. The wall must be channeled, and the conductor buried in it, and the groove replastered. At the point where the metal terminates under the floor a suitable outlet fitting must be provided.

386. **Examining Partition Interiors.**—With a pocket flashlamp and a little mirror the interior of a wall or partition which woul

ordinarily be inaccessible can be inspected (Fig. 274). The mi
is introduced in the outlet hole and the flashlamp and eye are
behind it as illustrated. The mirror reflects the light of the l
onto the place to be illuminated, at the same time reflecting
image back to the eye. (William Sprunt, *Electrical World*, Ma
1912.)

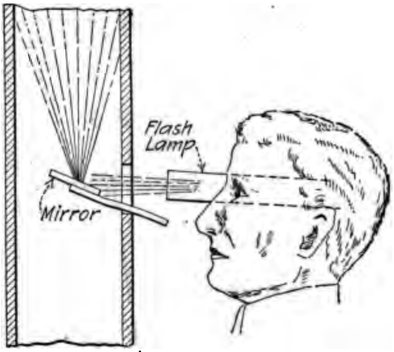


FIG. 274.—Examining partition interior.

SECTION V

TRANSFORMERS

GENERAL

1. **The term stationary or static transformer** (*Standard Hand-ook*) as ordinarily applied, refers to an apparatus for changing the oltage or current in an alternating system from one value to another ith an inverse change respectively in the value of the current or oltage.

1 A. **A step-up transformer** is a constant potential transformer connected that the delivered voltage is greater than the supplied oltage.

1 B. **A step-down transformer** is one so connected that the elivered voltage is less than the supplied; the actual transformer ay be the same in one case as in the other, the terms step-up and ep-down relating merely to the application of the apparatus.

1 C. **A constant-potential transformer** (Fig. 1) consists essen-ally of three parts: the primary coil which carries the alternating urrent from the supply lines; the core of magnetic material in hich is produced an alternating magnetic flux; and the secondary oil in which is generated an e.m.f. by the change of magnetism the core which it surrounds.

Generally the primary is the high-tension winding and it is com-osed of many turns of relatively fine copper wire, well insulated withstand the voltage impressed on it. The secondary winding composed of few turns of heavy copper wire capable of carrying onsiderable current at a low voltage.

2. **The most important application of constant-potential trans-rmers** is for raising the voltage of an electric transmission cir-uit so that energy can be transmitted for considerable distances ith small voltage drop and small energy loss. (See Sections I and [for a more complete discussion of this matter.)

3. **The Theory of Operation of the Constant-potential Trans-rmer.**—(See Fig. 1.) It has been shown in Section I that turns wire wound on an iron core have self-induction. When an alter-ating voltage is applied to such turns a current flows through them at generates a counter voltage or e.m.f. that opposes the applied oltage. From formulas, the transformer designer can compute ist how many turns are necessary for a transformer of a given ze so that it will generate a counter voltage equal to the applied oltage. So, in designing the primary winding of the transformer Fig. 1, the designer would select such a number of turns for the rimary winding that the counter voltage generated by it would e 2,200 volts. Hence, when the primary winding is connected to 2,200-volt circuit, it generates a counter voltage of practically ,200 and no appreciable current flows. A small current, the excit-g current, just enough to magnetize the core, does flow but it is *small that it* can be disregarded in this discussion.

Since the primary and secondary windings are on the same core, the magnetic flux generated by the magnetizing or exciting current flowing in the primary winding also cuts the turns of the secondary winding and generates in them an e.m.f. This e.m.f. will be, in accordance with a well-known law, opposite in direction to that impressed on the primary. If the secondary circuit is open no current can flow in it but if it is closed a certain current, proportional to the impedance of the secondary circuit, will flow. This current, because of the direction of the e.m.f. generated in the secondary, will be in such a direction that the magnetic flux produced in the core by it will oppose the flux due to the primary winding. It will therefore decrease the effective or resultant flux in the core by a small amount which will decrease the counter e.m.f. of the

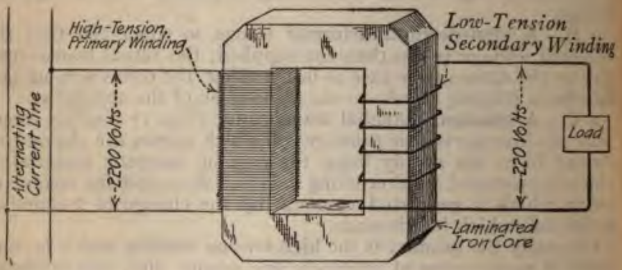


FIG. 1.—The elementary transformer.

primary winding and permit more current to flow into the primary winding. As noted elsewhere, the ratio of the number of turns in the primary winding to the number of turns in the secondary winding determines the ratio of the primary to the secondary voltage.

If the voltage impressed on the transformer is maintained constant the voltage of the secondary will be nearly constant also. When more current flows in the secondary there will be a corresponding increase in primary current. As the load on a transformer increases, the impressed voltage remaining constant, there is actually a slight drop from the no-load voltage of the secondary due to certain inherent characteristics of the transformer, but in a properly designed device this drop will be very small. Although the construction and elementary theory of the transformer are very simple, a theoretical explanation of all of the phenomena involved in its operation is very complicated. Only the principal features have been described. Some minor, though very important, considerations that would complicate things have not been treated.

4. The ratio of the primary to the secondary turns determines *the ratio of* the primary to the secondary voltage. For example, *for transforming* or "stepping-down" from 2,000 volts to 100 volts *the ratio of* the turns in the windings will be 20 to 1. The currents the primary and the secondary windings will be, very closely, versely proportional to the ratio of the primary and secondary ltages because, disregarding the small losses of transformation, e power put into a transformer will equal the power delivered it. For example, considering a transformer with windings ving a ratio of 20 to 1, if its secondary winding delivers 100 amp. 50 volts the input to its primary winding must receive almost actly 5 amp. at 1,000 volts. The imput and output are each ractically) equal and each would equal (almost exactly) 5,000 tts.

5. **The terms "high-tension winding" and "low-tension nding" are preferable** to the terms "primary winding" and econdary winding" because a high-tension winding may be the imary in one case and the secondary in another. But if the mes "high-tension" and "low-tension" are used there can be confusion.

6. **The efficiency of a transformer** is, as with any other device, e ratio of the output to input or, in other words, the ratio of e output to the output plus the losses. As a formula it may be pressed thus:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Copper loss} + \text{Iron loss}}$$

7. **The copper loss of a transformer** is determined by the sistances of the high-tension and low-tension windings and of the ads. It is equal to sum of the watts, I^2R losses in these comnents at normal load.

8. **Performance of Distributing Transformers.**—The table ows about average values for 2,200 to 220–110-volt, 60-cycle ansformers and is not particularly representative of any certain anufacturer's line.

va.	Watts loss		Per cent. efficiency				Per cent. regulation				Per cent. exciting current
	Iron	Copper	Full load	¾ load	½ load	¼ load	100% P.F.	90% P.F.	80% P.F.	70% P.F.	
½	15	13	94.7	94.4	93.2	88.8	2.6	2.73	2.62	2.5	8.0
1	20	24	95.8	95.7	95.0	92.0	2.4	2.51	2.41	2.25	5.5
1½	24	33	96.4	96.4	95.8	93.5	2.2	2.4	2.35	2.3	4.0
2	29	40	96.7	96.7	96.2	94.1	2.0	2.25	2.23	2.2	3.6
2½	32	51	96.8	96.9	96.5	94.7	2.05	2.42	2.45	2.4	3.3
3	33	57	97.1	97.2	96.9	95.4	1.92	2.31	2.38	2.35	3.0
4	37	70	97.4	97.5	97.4	96.0	1.81	2.55	2.75	2.85	1.9
5	43	82	97.5	97.6	97.5	96.3	1.7	2.35	2.51	2.6	1.8
7½	57	110	97.8	97.9	97.7	96.7	1.55	2.4	2.6	2.8	1.7
0	70	140	97.9	98.0	97.9	96.9	1.47	2.32	2.6	2.7	1.65
5	95	192	98.1	98.2	98.1	97.2	1.35	2.2	2.42	2.58	1.5
0	123	255	98.1	98.2	98.1	97.3	1.35	2.6	3.0	3.25	1.3
5	138	305	98.2	98.3	98.3	97.5	1.3	2.6	3.0	3.3	1.25
0	158	370	98.3	98.4	98.3	97.6	1.29	2.75	3.2	3.5	1.15
7½	175	415	98.4	98.5	98.5	97.9	1.18	2.9	3.43	3.8	1.05
[illegible]	239	520	98.5	98.6	98.5	97.8	1.14	2.7	3.22	3.57	1.0

9. **The iron loss of a transformer** is equal to the sum of t[he] losses in the iron core. These losses consist of Eddy or Foucau[lt] current losses and hysteresis current losses. Eddy current loss[es] are due to currents generated by the alternating flux circulati[ng] within each lamination composing the core and they are minimiz[ed] by using thin laminations and by insulating adjacent laminatio[ns] with paint. Hysteresis losses are due to the power required [to] reverse the magnetism of the iron core at each alternation and i[s] determined by the amount and the grade of iron used for the la[m]inations for the core.

10. **Transformer Ratings.**—Transformers are rated at th[eir] kilovolt-ampere (kva.) outputs. If the load to be supplied b[y a] transformer is at 100 per cent. power factor the kilowatt (kw[.]) output will be the same as the kva. output. If the load ha[s a] lesser power factor, the kw. output will be less than the kv[a.] output proportionally as the load power factor is less than 1[00] per cent.

For example: A transformer having a full load rating of 100 kva. [w]safely carry 100 kw., if the 100 kw. is at 100 per cent. power factor or 90 [kw.] at 90 per cent. power factor or 80 kw. at 80 per cent. power factor.

11. **Capacities of Transformers for Operating Motors** (*Gene[ral] Electric Company*).—For the larger motors the capacity of [the] transformers in kilovolt-amperes should equal the output of [the] motor in horse-power. Thus a 50-h.p. motor requires 50 kva. [of] transformers. Small motors should be supplied with a somewh[at] larger transformer capacity, especially if, as is desirable, they [are] expected to run most of the time near full-load, or even at slig[ht] overload. Transformers of less capacity than those noted [in] table 12 should not be used even when a motor is to be run at o[nly] partial load.

12. **Capacities of Transformers for Induction Motors.**

(*General Electric Company*)

Size of motor horse-power	Kilovolt-amperes per transformer		
	Two single-phase transformers	Three single-phase transformers	One three-pha[se] transformer
1	0.6	0.6	....
2	1.5	1.0	2.0
3	2.0	1.5	3.0
5	3.0	2.0	5.0
7½	4.0	3.0	7.5
10	5.0	4.0	10.0
15	7.5	5.0	15.0
20	10.0	7.5	20.0
30	15.0	10.0	30.0
50	25.0	15.0	50.0
75	40.0	25.0	75.0
100	50.0	30.0	100.0

13. **Regulation on Inductive and Non-inductive Load** (*Gen[eral] Electric Company*).—While with a non-inductive load such as i[s]

:ent lamps the regulation of transformers is within about 3 per t., with an inductive load, the drop in potential between no-load full-load increases to, possibly, about 5 per cent. If the motor l is large and fluctuating, and close lamp regulation is important, desirable to use separate transformers for the motors.

4. **The oil used in transformers** (*Standard Handbook*) performs important functions. It serves to insulate the various coils n each other and from the core, and it conducts the heat from coils and core to some cooler surfaces where it is either dissipated he surrounding air or transferred to some cooling medium. It is lent that the oil should be free from any conducting material, hould be sufficiently thin to circulate rapidly when subjected to erences of temperature at different places, and it should not be table until its temperature is raised to a very high value.

lthough numerous kinds of oils have been tried in transformers, he present time mineral oil is used almost exclusively. This s obtained by fractional distillation of petroleum unmixed with other substances and without subsequent chemical treatment. ood grade of transformer oil should show very little evaporation oo deg. Cent. and it should not give off gases at such a rate as to duce an explosive mixture with the surrounding air at a tempera- below 180 deg. cent. It should not contain moisture, acid, li or sulphur compounds.

t has been shown by Mr. C. E. Skinner that the deteriorating ct of moisture on the insulating qualities of an oil is very marked; sture to the extent of 0.06 per cent. reduces the dielectric ngth of the oil to about 50 per cent. of the value when it is free n moisture; but there is very little further decrease in the ectric strength with an increase in the amount of moisture he oil.

ry oil will stand an e.m.f. of 25,000 volts between two 0.5-in. bs separated by 0.15 in. The presence of moisture can be ected by thrusting a red hot nail in the oil; if the oil "crackles" er is present. Moisture may be removed by raising the tem- ature slightly above the boiling point of water, but the time sumed (several days) is excessive. The oil is subsequently sed through a dry-sand filter to remove any traces of the lime ther foreign materials.

5. **Bell-ringing transformers** are referred to in the section on *rior Wiring* under *Bell Wiring*.

SINGLE-PHASE CONNECTIONS

6. **Connections for standard distributing transformers** are wn in Figs. 2 and 3. Distributing transformers of medium small capacity are almost invariably arranged, as shown, with primary and two secondary coils. By making the necessary nges in the primary-coil connections they may be used on nary circuits of either 1,100 or 2,200 volts and their secondary dings can be so connected as to deliver 110 or 220 volts or for a 220-volt, three-wire circuit. For changing the connections

of the primary coils a block is provided within the transformer case. The connections of the secondary coils are made, either by splicing the secondary leads or with connectors, outside of the transformer case. Distributing transformers are also made for primary voltages of 1,040 or 2,080 and corresponding secondary voltages

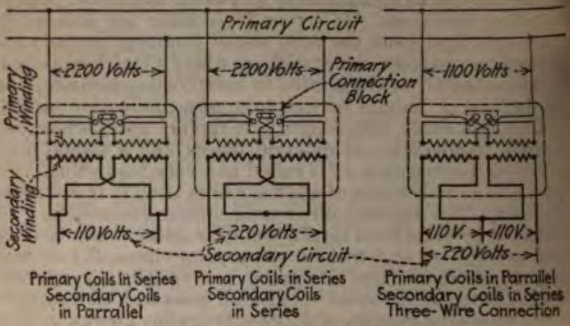


FIG. 2.—Connections of standard distributing transformers.

of 115 and 230 and have an approximate ratio of 9 or 18 to 1. Front and rear views of a Westinghouse distributing transformer are shown in Fig. 3 *A*.

17. **Transformer connections for three-wire secondary service** are shown in Figs. 2, 3 and 4. In the arrangement Figs. 2 and 3

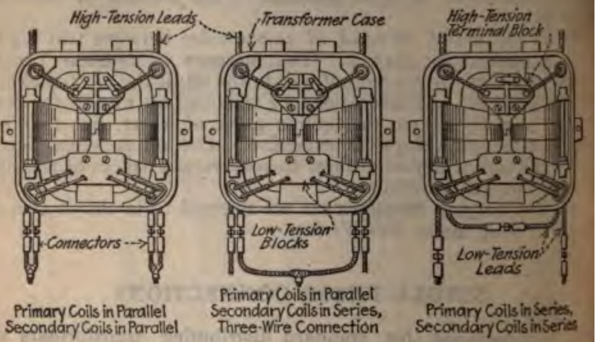


FIG. 3.—Method of interconnecting transformer secondaries with connectors.

one transformer only is used. Its secondary windings are connected in series and a tap is made to the point of connection between the two windings, providing 220 volts between the two outside wires and 110 volts on each of the side circuits. The transformer should have a capacity equal to the load to be supplied and the three circuits should be carefully balanced. If the three-wire circuits are decidedly unbalanced, the transformer should have a capacity equal to twice the load on the most heavily loaded of the two side circuits.

In Fig. 4 two transformers are shown connected to serve a three-wire circuit. The three-wire load should be balanced as nearly

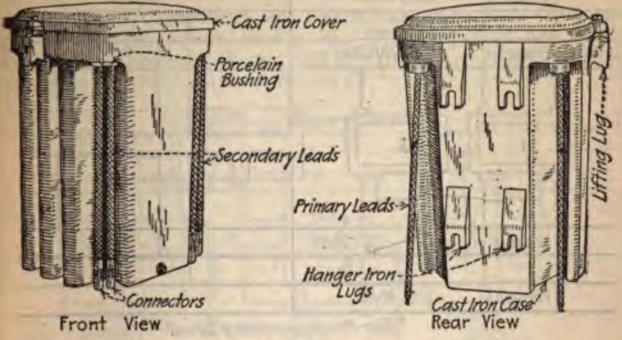


FIG. 3A.—Standard distributing transformer.

as possible and where it is very nearly balanced each transformer should have a capacity equal to one-half of the total load. If the load is badly unbalanced, each transformer should have a sufficient capacity equal to the load on its side of the circuit. See discussion of "Parallel Operation."

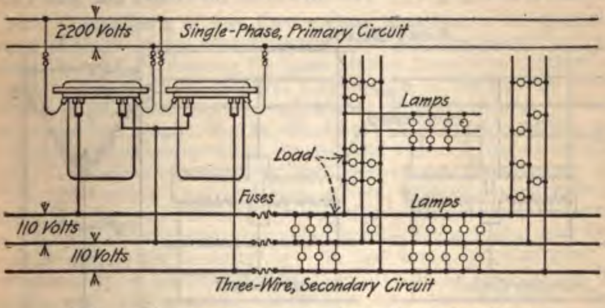


FIG. 4.—Two transformers serving a three-wire circuit.

TWO-PHASE CONNECTIONS

18. Transformers connected to four-wire, two-phase circuits *are shown in Fig. 5.* As a rule two-phase primary lines are four-wire as shown and to such a four-wire line the transformers are connected to each of the side circuits as if each side circuit were a single-phase circuit not having any connection with the other. The total load should be so divided between the phases that the loads on each will be equal as nearly as possible. Each trans-

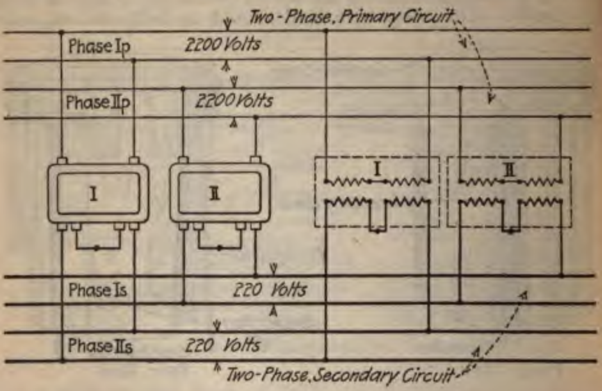


FIG. 5.—Transformers, two-phase to two-phase, four wire, connection.

former should be designed for line voltage and will carry line current. Each transformer should have a kva. capacity equal to one-half of the kva. load that is served by the two transformers.

18 A. Transformers connected to three-wire, two-phase circuits are shown in Fig. 5 *A*. The current in the center line wire (*AA*)

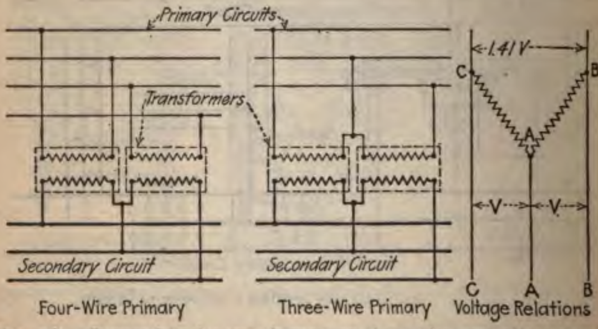


FIG. 5A.—Connections for transformers on three-wire, two-phase circuits.

is 1.41 the current in either of the outer wires. Each transformer has line voltage impressed on it and carries one-half the total load. A General Electric Co. publication comments thus: "Considerabl unbalancing of voltage at the end of a transmission line or cable is experienced with the three-wire, two-phase system due to the mutual induction between phases. Where the power factor is low, a still worse regulation is obtained, making satisfactory operation difficult. Very few systems now operate on this plan and practically all of them could be improved by the use of some other system."

19. **Mixed connections are sometimes made with two-phase transformers** as shown in Fig. 6. With improper connections such as those shown, difficulty will be experienced in the operation of motors and they may not run at all.

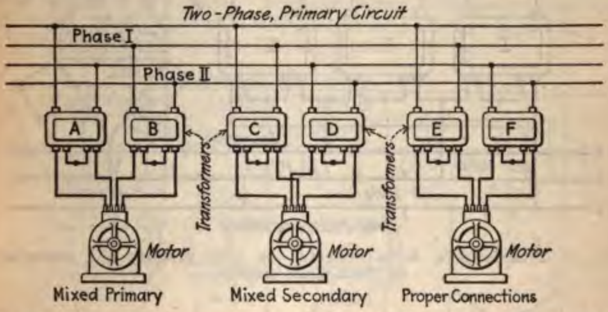


FIG. 6.—Correct and incorrect connections for transformers serving two-phase motors.

THREE-PHASE CONNECTIONS

20. **Comparison of one three-phase transformer as against a group of single-phase transformers** (*Standard Handbook*) that may be employed for obtaining the same service have been summed up by Mr. J. S. Peck as follows: Advantages of three-phase transformer: First, lower cost; second, higher efficiency; third, less floor space and less weight; fourth, simplification in outside wiring, and fifth, reduced transportation charges and reduced cost of installation. The disadvantages of the three-phase transformer are: First, greater cost of spare units; second, greater derangement of service in the event of break-down; third, greater cost of repair; fourth, reduced capacity obtainable in self-cooling units; and fifth, greater difficulties in bringing out taps for a large number of voltages. It is considered that the three-phase transformer has certain real and positive advantages over the one-phase type, while its disadvantages are chiefly those which result in the event of break-down—an abnormal condition which occurs at rarer and rarer intervals as the art of transformer design and manufacture advances.

21. ***Transformers with both primary and secondary coil delta (Δ) connected*** *are shown in Fig. 7.* All three of the transformers are *connected in series* in a closed circuit and each line wire is connected

to the connection between two of the transformers. The voltage imposed on either the primary or secondary of the transformer is the primary or secondary line voltage, respectively. The current in either winding = line current $\div \sqrt{3}$, or line current $\times$ 0.58.

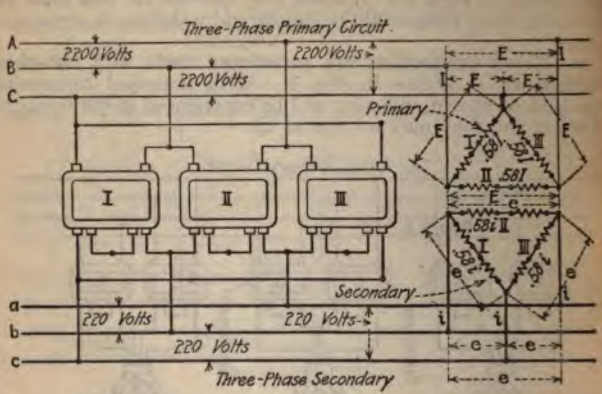


FIG. 7.—Transformers, delta-connected on both primary and secondary on three-phase circuits.

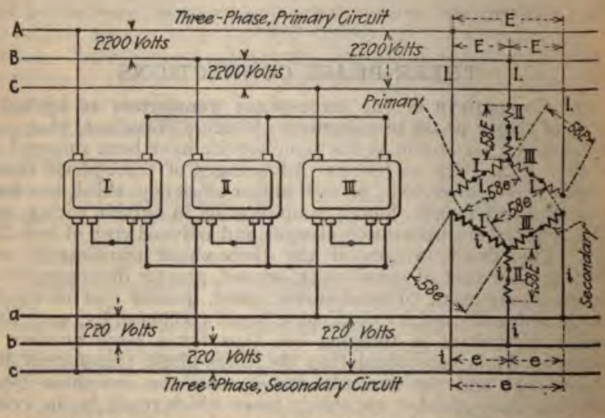


FIG. 8.—Transformers, star-connected on both primary and secondary on a three-phase circuit.

The kva. capacity of each transformer should be equal to one-third the total kva. of the load to be served. The total kva. load transmitted by a balanced three-phase line = 1.73 IE (where I

line current in each line wire and E is the voltage between w
Therefore, the kva. capacity of each transformer shoul
73 $IE \div 3 = 0.58\ IE$.

22. **Transformers with both primary and secondary star-connected,** from a three-wire primary circuit, are shov Fig. 8. The current in each transformer winding is the sar the line current and the voltage imposed on each winding = voltage $\div \sqrt{3}$ = line voltage $\times$ 0.58. The kva. capacity of transformer should be equal to one-third the total kva. of the to be served. The total kva. load transmitted by a bal three-phase line $= 1.73\ IE$ (where I is the line current in eacl wire and E is the voltage between wires). Therefore, the capacity of each transformer should be $1.73\ IE \div 3 = 0.58\ IE$. The star-star connection is seldom used.

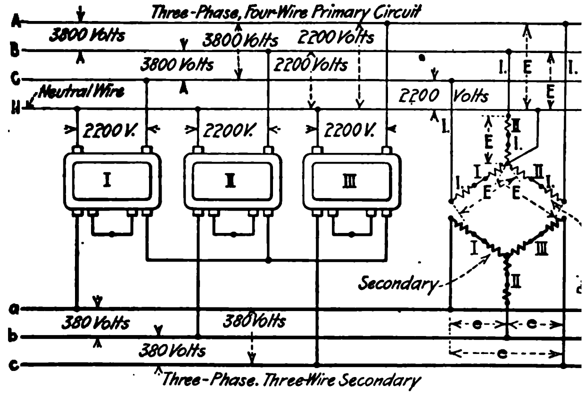


FIG. 9.—Transformers, star-connected on both primary and seconda three-phase circuits (four-wire primary circuit).

The same grouping except that the primary circuit is four is shown in Fig. 9. In thus connecting transformers from a wire, primary circuit it should be remembered that each r hand primary terminal connects with a line wire and each left- terminal connects with the neutral wire or the reverse, respecti The voltage and current relations are shown in the illustratioı

23. **Transformers delta-connected to the primary circuit star-connected to the secondary circuit** are shown in Fig Any group of transformers can be connected with either primary or secondary coils connected in either star or delta. the primary delta-connected and the secondary star-conn as shown, the secondary voltage will be 1.73 times what it wou if it were delta-connected. For example, in the illustration transformers are assumed to have a 10 : 1 ratio) with a secondary connection the secondary line voltage would be 2,20 = 220 volts, but with a star or Y secondary connection the sec

voltage is $220 \times 1.73 = 380$ volts. It should be noted that with a delta-connected primary an increase of 15 per cent. in the primary voltage and a star secondary connection will make the secondary voltage twice what it would be with delta-connection and normal primary voltage.

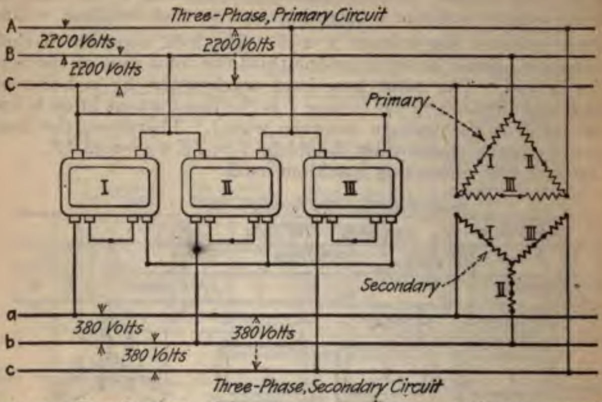


FIG. 10.—Transformers, delta-connected, primary and star-connected secondary.

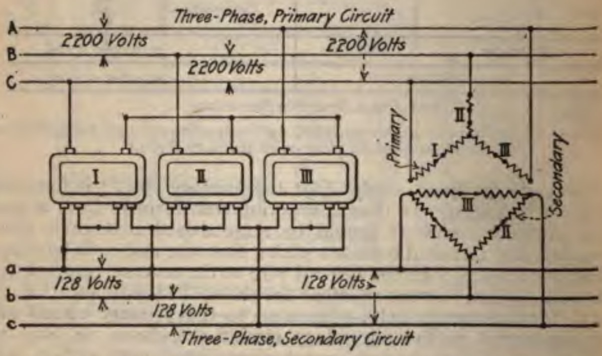


FIG. 11.—Transformers, star-connected primary and delta-connected secondary.

24. **Transformers star-connected primary and delta-connected secondary** are shown in Fig. 11. This is the reverse of the grouping described in 23 and the secondary voltage will be but 0.58 times as great as if both secondary and primary were star-connected.

25. **The Three-phase V- or Open-delta Connection** (Figs. 12 d 13).—Line voltage is impressed on each transformer and line rrent flows in each transformer coil. This method is considerably ed for motors but has the objection that if one of the transformers comes inoperative the three-phase circuit served will be fed by t one transformer and hence will be inoperative. (The *Reversed-connection* is indicated at the primary side in Fig. 13.)

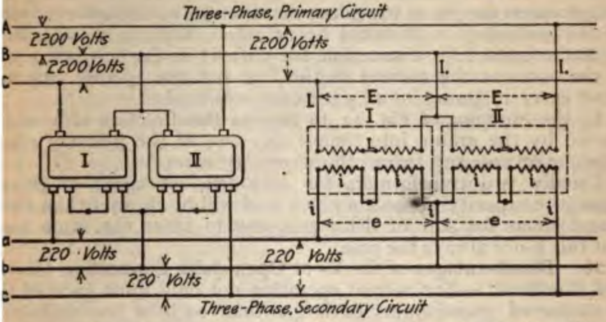


FIG. 12.—Transformers, V- or open-delta primary and secondary (three-ire, three-phase primary circuit and three-wire, three-phase secondary rcuit).

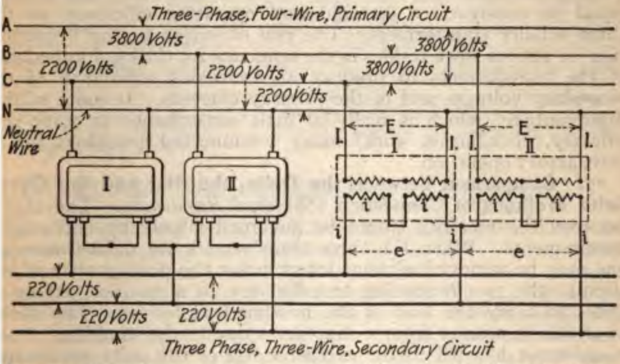


FIG. 13.—Transformers, primary connected in reversed- V and secondary - connected (four-wire, three-phase primary circuit and three wire, three-iase secondary circuit).

The combined capacity of two transformers (*Gear and Williams*), nnected by this method and serving a given load should be 15.5 *r cent. greater than* the combined capacity of three transformers, *'ta- or star-connected* and serving the same load. For instance *hree 5-kva.* transformers (total capacity 15 kva.) are required for a certain installation and they are replaced by two $7\frac{1}{2}$-kva. transformers (total capacity 15 kva.) the two transformers will be overloaded by 15.5 per cent. at a full load of 15 kw. at 100 per cent. power factor.

For example, assume that in a three-transformer installation the current in the secondary line is 17.3 amp. This imposes a load of 10 amp. on the transformer secondary coils. At 200 volts this is 2 kw. per transformer or 6 kw. in all. If, now, two 3-kw. transformers are put in to replace the three 2-kw. units the capacity of the secondary coils would be 15 amp. But, as above noted with the open-delta connection the current in the secondary coi is the same as the current in the line and the 15-amp. windin must carry 17.3 amp. or 15.5 per cent. overload.

In the grouping of Fig. 12, to reverse the direction of a moto served by the group, interchange any two of the primary phas wires or reverse any two of the secondary wires.

Usually two transformers for open-delta grouping of prope aggregate capacity to serve a given load will be cheaper than thre transformers for star or delta grouping to serve the same load but this is not always the case.

26. Disadvantages of the V- or Open-delta Connection (*Stand ard Handbook*).—For normal operation not only must each of th V-connected transformers be larger than each of the delta-con nected transformers, but the two transformers must have a com bined rating 15.5 per cent. greater than the three transformer This fact taken alone does not represent a disadvantage of th V-connection, because the two larger transformers are exactl equal in constructive material and operating efficiency to th three smaller transformers. The real objection to the V-connec tion for serious work resides in the tendency for the local impedanc of the transformers to produce an enormous unbalance of th secondary voltages and of the primary currents. In spite of th disadvantage (which is really of little consequence in 2,200-vo primary, distribution work) many V-connected groupings are i satisfactory operation.

27. Comparison between the Delta, the Star and the Open delta Methods of Connection (*Standard Handbook*).—The choi between the methods would be governed largely by the servi requirements. When the three transformers are delta-connecte one may be removed without interrupting the performance of th circuit—the two remaining transformers, in a manner, acting i series to carry the load of the missing transformer. The desi to obtain immunity from a shut-down due to the disabling of or transformer has led to the extensive use of the delta connectio of transformers, especially on the low-potential delivery sid It is to be noted that in case one transformer is crippled the oth two will be subjected to greatly increased losses.

Thus, if three delta-connected transformers be equally loade *until* each carries 100 amp., there will be 173 amp. in each extern *circuit wire*. If one transformer be now removed and 173 am continues to be supplied to each external circuit wire, each of t *remaining* transformers must carry 173 amp., since it is no ries with an external circuit. Therefore, each transformer must ow show three times as much copper loss as when all three transrmers were active, or the total copper loss is now increased to a alue of six relative to its former value of three.

A change from delta to Y in the secondary circuit alters the ratio f the transmission e.m.f. to the receiver e.m.f. from 1 to $\sqrt{3}$. n account of this fact, when the e.m.f. of the transmission ciruit is so high that the successful insulation of transformer oils becomes of constructive and pecuniary importance, the threehase line sides of the transformers are connected in "star" and he neutral is grounded. However, most of the circuits operating t 100,000 volts or more are not grounded and the transformers re joined in "delta" and insulated for the full e.m.f.

See also **26** regarding properties of an open-delta connected roup.

28. Comparative Cost of Transformers for Different Groupings or Three-phase Service.—The following table shows the costs f the single-phase transformers, of proper capacities for either a elta or an open-delta grouping and of a three-phase transformer o serve a 75-kva. installation.

Method of connection or grouping	Number of transformers required	Capacity of each transformer, kva.	Aggregate capacity	Cost per transformer	Aggregate cost
Delta (Δ)	3	25	75	$213	$639
Open Delta (V)	2	40	80	312	624
Three-phase transformer	1	75	75	546	546

[1] The theoretical aggregate capacity of two single-phase transformers or open-delta grouping for a 75-kva. three-phase load would be (see 25) $5 \times 1.15 = 86.3$ kva. or $86.3 \div 2 = 43.2$ kva. per transformer. The nearest ommercial capacity to 43.2 kva. was 40 kva., which gives an aggregate apacity of 80 kva. which is sufficiently close to the theoretical requireent for practical work.

SPECIAL TRANSFORMER CONNECTIONS

29. Transformers connected for transforming from threehase to two-phase or the reverse are illustrated in Fig. 14 which hows what is known as the Scott connection. The transformers equired are special and each has a lead brought out from the iddle point of the high-tension winding and a special voltage tap arranged giving 86.6 per cent. of the high-tension winding. Jsually two transformers just alike are purchased so that they ill be interchangeable. These special transformers can be purhased from any of the large manufacturers. Those shown are Vestinghouse transformers. Two standard single-phase transormers for such service should have an aggregate kva. rating $5\frac{1}{2}$ per cent. greater than their group or nominal rating.

30. *T-Connected* Transformers for Transforming from Threeiase to Three-phase (*Standard Handbook*).—A method of emoying *two* transformers in three-phase transformation which practically overcomes the disadvantages of the V-connectio and possesses considerable merit, is found in the T-connecti As indicated in Fig. 16, one transformer is connected across b tween two of the line wires while the other is joined between t third line wire and the middle point of the first transformer. T current in the primary coil of each transformer is the same in val as that in the primary coil of the other, and the secondary curre in the two transformers are likewise equal in value. The volta impressed across one transformer is only 86.6 per cent. of th across the other so that if each transformer is designed especia

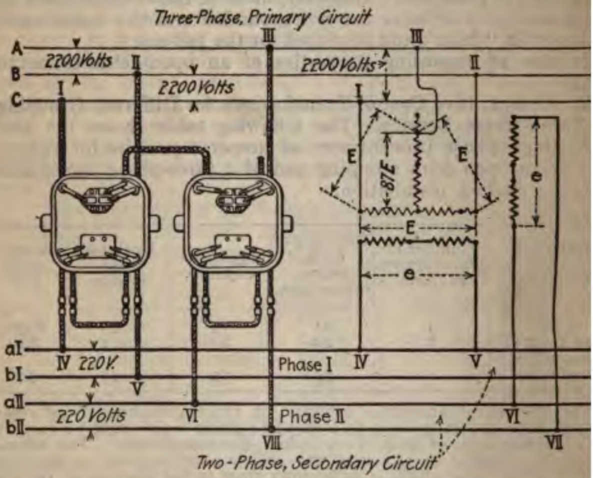


FIG. 14.—Transformers connected for three-phase to two-phase tran mation.

for its work one will have a rating of EI and the other a ratin 0.866 EI, where I is the current in each line wire and E is e.m.f. between lines. The combined rating will therefore be 1. as compared with 1.732 EI for three one-phase transformers c nected either Δ or Y, or with 2,000 EI for two V-connected tr formers.

30 A. **Requisites for Transformers for T-Connection.**— two transformers should possess the same ratio of primary secondary turns and a tap is brought out from the central p of one of the transformers. It is not essential that the for transformer be designed for exactly 86.6 per cent. of the volt of the latter; the normal voltage of one can be 90 per cent. of other, without producing detrimental results. Moreover, tr formers designed for the same normal e.m.f. and intended fo connection can be T-connected with considerable improve in service.

In comparing the T-connection with the Δ- or the Y-
a (*Standard Handbook*), it is to be noted that each con-
:complishes the transformation without sensible distortion
relations. The T-connection allows the neutral point
:hed equally as well as does the Y-connection. The Δ-
n, however, is the only one capable of transforming in
ies with one disabled transformer. With reference to its
maintain balanced phase relations, the T-connection
etter than the V-connection.
;gregate kva. rating of two T-connected transformers
15½ per cent. greater than the nominal kva. rating of
.

**:planation of the Transformation from Three Phase to
ie** (*Standard Handbook*).—Assume the simple case of a
e of power of 30,000 watts at 100 volts, three phase, to
rmed (without loss) to 30,000 watts 100 volts, two phase,
5. Assuming now that the load is balanced on the two-
:, there will be 15,000 watts per phase, or 150 amp. at
Since the three-phase power is represented as $\sqrt{3}\,IE$
, where I is
t per line wire
the e.m.f. be-
: wires, I must
3.2 amp. be-
as been taken
lts.
vn in Fig. 15,
phase coils of
former must
ned for 100
173.2 amp.
three-phase
e other trans-
nust be de-
r 86.6 volts
amp. The
through the
D, divides
a part (86.6

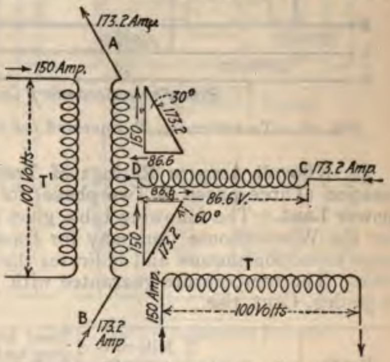


FIG. 15.—Three-phase to two-phase transformation.

:s through *DA* and an equal part (86.6 amp.) passes
lly through *DB;* thus the magneto-motive force of these
nts has a resultant of zero, and it has no effect upon the
so far as transformer T′ is concerned. The coil, *A D B*,
total value of current of 173.2 amp. throughout all of its
: the current in one-half is 60 time-degrees out of phase
in the other half.
to say the 173.2 amp. in one half is made up of a load
150 amp. in leading time-quadrature with which is 86.6
le that in the other half is made up of a load current of
in lagging time-quadrature with which is a superposed
86.6 amp. The magnetizing effect of the 173.2 amp.
e, 150 amp. and the current in the two-phase side of

transformer T′ is 150 amp. In the *T*-transformer the magnet[o]motive force of 173.2 amp. in 86.6 per cent. turns is just equ[al] to that of 150 amp. in 100 per cent. turns; these two currents a[re] directly in time-phase opposition, and the apparatus operates [in] all respects like a one-phase transformer. The phase relati[ons] and the relative values of the several components of currents a[re] shown in the vector diagram of Fig. 15.

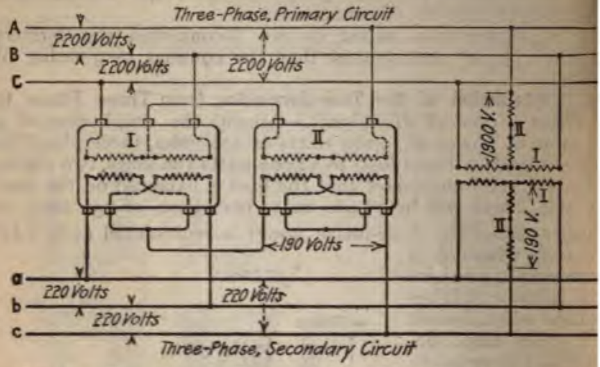


FIG. 16.—Transformers, T-connected for three-phase transformation

32. Kilovolt Ampere Ratings of Transformers for Scott Co[n]nection (Three-phase to Two-phase) for Serving a Given Hor[se]power Load.—The following table gives the ratings recommend[ed] by the Westinghouse Company for transformers serving squirr[el] cage induction motors and indicates the efficiency of the instal[la]tion. The temperature guarantee with performances as shown [is] a 50 deg. Cent. rise.

Horse-power of motor	Number of transformers	Kilovolt-ampere capacity of each transformer	Total kilovolt-ampere load imposed on the group of two transformers when motor is operating at full load	Efficiency of b[oth] of transforme[rs] with full-loa[d] on motor
½	2	½	0.75	92.8
1	2	½	1.35	94.5
2	2	1	2.40	95.2
3	2	1½	3.4	95.9
5	2	2½	5.5	96.4
7½	2	4	8.1	97.0
10	2	5	10.7	97.2
15	2	7½	15.7	97.4
20	2	10	20.9	97.6
30	2	15	31.5	97.8
40	2	20	42.0	98.0
50	2	25	51.0	98.0
75	2	37½	77.0	98.3

$$\text{Kva. on each transformer} = \frac{\text{h.p.} \times 746 \times 1.08}{(\text{eff} \times \text{P. F. of motor})}$$

$$\text{Efficiency} = \frac{\text{kva. on transformer}}{\text{kva. transformer loss} + \text{kva. on transformer}}$$

33. Booster transformers (*Electric Central Station Distributing Systems*, Gear and Williams, *Van Nostrand Co.*).—Ordinary distributing transformers applied as illustrated (Fig. 17), are used where it is necessary to raise by a fixed percentage, the voltage delivered by a line, as is necessary when transformer ratios do not give quite the right voltage or when line drop is excessive. A booster raises the voltage of any primary circuit in which it may be inserted by the amount of the secondary voltage of the booster. (See Fig. 17.)

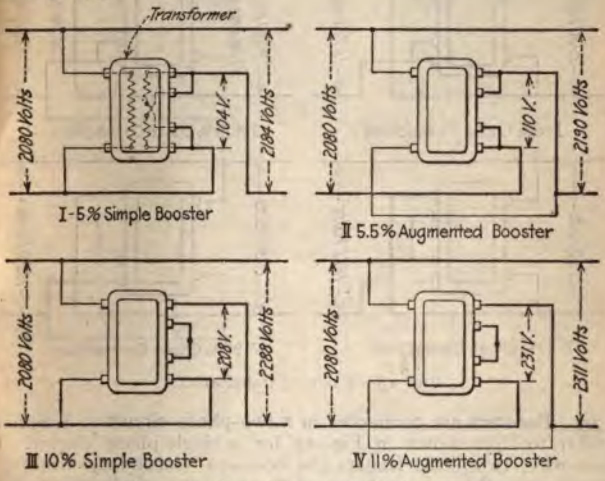


FIG. 17.—Transformers used as boosters.

Examples.—On a long, single-phase, 2,080-volt lighting branch so heavily loaded that the pressure drops more than the amount for which the normal regulation of the feeder will compensate, a 110-volt transformer inserted in the line as a booster will raise the pressure of the primary branch on the load side of the booster by 110 volts. This raises the secondary pressure 5.5 volts on all of the transformers beyond the booster.

With 440-volt service supplied by star-connected, 230-volt transformers, a 10 per cent. booster in each phase raises the normal pressure of 230–400 volts to 253–440 volts.

The connections for a simple booster are shown in Fig. 17 *I*, the line pressure being raised from 2,080 to 2,184 volts or 5 per cent. The connection at *II* is that for an augmented booster in which the line pressure is raised from 2,080 to 2,190 volts, because the primary of the booster is connected across the line on the far side and the boost r is boosted as well as the line. This gives an increase of 5.5 per cent. in the line pressure.

Fig. 17 *III*, *shows a* 10 *per* cent. simple booster and IV an augmented *11.1 per cent. booster.*

The transformers shown in Fig. 17 have a 10 or 20 to 1 ratio and the percentages shown apply only to transformers of this ratio. If boosters having a ratio of 2,080 to 115–230 are used the percentages are increased about 10 per cent. Fig. 17 *I* would then become 5.5 per cent.; *II*, 6.05 per cent.; *III*, 11.1 per cent.; *IV*, 12.2 per cent.

34. **The proper connection of the secondary for a booster or choke transformer** must usually be determined by trial for a transformer of any given type, but once determined, any transformer of the same type may be connected in the same manner. The connections shown in Figs. 17 and 18 are correct for transformers of the principal makers.

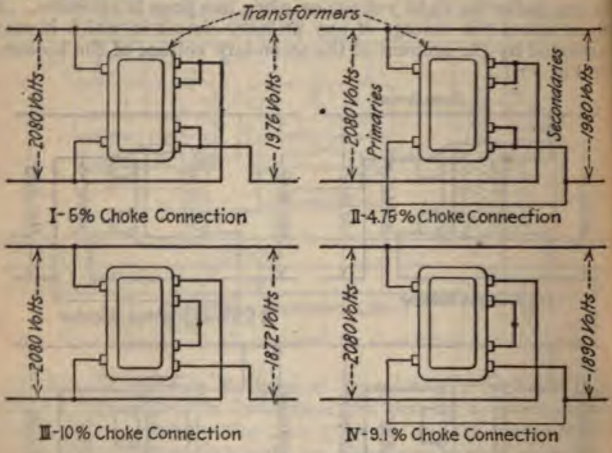


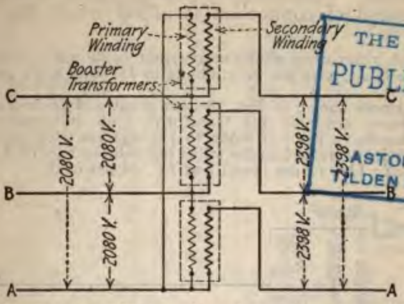
FIG. 18.—Choking transformers.

35. **Boosters are connected in a two-phase circuit** in a manner similar to that shown in Fig. 17 for a single-phase circuit. In three-wire, two-phase feeders the boosters (secondary windings) are cut into the outer wires and the primary windings are connected between the middle and the outside wires.

36. **Booster transformers in three-phase circuits are connected** as shown in Fig. 19 (*Gear and Williams, Van Nostrand Co.*).—The insertion in any phase wire of the booster voltage affects two phases. The boosting and choking effects, with transformers of various ratios, with the boosting transformers used in one, two or three phases are expressed in percentage of the primary voltage in the table of 37.

37. **Voltage Boosting and Choking Effect of Transformers Connected in Three-phase Circuits** (*Electric Central Station Distributing Systems*, Gear and Williams, *Van Nostrand Co.*).—Values in the body of the tables are the percentages that the voltages will be increased or decreased respectively by the insertion of booster or choking transformers, of different ratios, in one, two

:, of the phase wires. Transformers are connected for as shown in Fig. 19. The letters *AB*, *BC* and *CA* refer ree phases of Fig. 19.



19.—Booster transformers in a three-wire, three-phase circuit.

	Boosting											
	10 to 1			20 to 1			9 to 1			18 to 1		
r	AB	BC	CA	AB	BC	CA	AB	BC	CA	AB	BC	CA
	10.0	10.0	5.3	5.00	0.00	2.65	11.0	0.0	5.8	5.5	0.00	2.9
B	15.3	10.0	5.3	7.65	7.65	2.65	16.8	5.5	5.8	8.4	2.75	2.9
C	15.3	15.3	15.3	7.65	7.65	7.65	16.8	16.8	16.8	8.4	8.40	3.4
	Choking											
	10.0	0.0	4.6	5.0	0.0	2.3	11.00	0.00	5.06	5.5	0.00	2.53
	14.6	10.0	4.6	7.3	5.0	2.3	16.06	11.00	5.06	8.3	5.50	2.53
C	14.6	14.6	14.6	7.3	7.3	7.3	16.06	16.06	16.08	3.03	8.03	8.03

An arrangement of standard transformers, connected as nsformers, and boosters to provide 2,080 volts from a e, three-phase system is shown in Fig. 20. This is taken ear and Williams' "*Central Station Distributing Systems*" *Vostrand Co.*). The installation served was a 300-kw., lt, three-phase motor and the source of energy was a e, Y-connected system operated at about 2,160 volts beach phase wire and neutral or 3,740 between phases.

nly transformers available were six, 50 kw., units, having coils wound for 1,040 or 2,080 volts and secondary coils or 230 volts. By connecting these transformers for 1,040 the primary and arranging two in series from each phase neutral with secondaries in parallel, it was possible to tap or circuit off at half the line pressure. The line pressure t 3,740, the additional voltage required to provide 4,160 secured through the use of a 9 to 1 booster in each phase.

39. Choking Transformers (Gear and Williams in *Electric Central Station Distributing Systems, Van Nostrand Co.*).—When the secondary is connected in reverse order the transformer becomes a "choke," depressing the line pressure instead of raising it. This method of connection is useful where less pressure is desired.

Examples.—A 5 per cent. choke connection is shown in Fig. 18 *I*, a 4.75 per cent. choke in *II*, a 10 per cent. choke in *III* and a 9.1 per cent. choke in *IV*.

The transformers shown in Fig. 18 have a ratio of 10 or 20 to 1 and the percentages shown are only for transformers of that ratio. If choking transformers having a ratio of 2,080 to 115–230 are used, the choking percentages would be decreased to the following values: Fig. 18 *I*, 5.5 per cent.; *II*, 5.24 per cent.; *III*, 11 per cent.; and *IV*, 10 per cent.

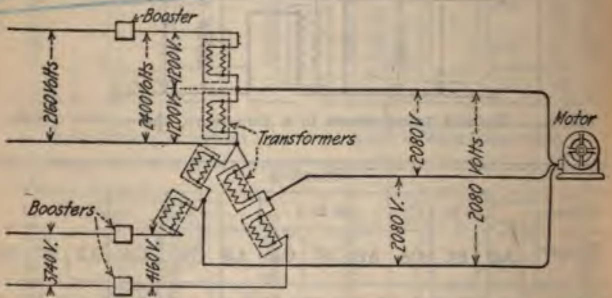


FIG. 20.—Arrangement of standard transformers, connected as auto-transformers and boosters to provide 2,080 volts from a four-wire, three-phase system.

40. There are certain precautions that should be observed in the installation of boosters (Gear and Williams, *Electric Central Station Distributing Systems*), to protect them from injury. The booster secondary is in series with the line and current is drawn through its primary windings in proportion to the load on the line. If the primary of the booster is opened while the secondary is carrying the line current the booster acts as a choke coil in the main circuit. This causes a large drop of pressure in the booster, imposing upon its secondary windings a difference of potential of two to five times normal. Under these conditions the insulation of a 2,000-volt transformer may be subjected to a pressure of 10,000 to 20,000 volts or more depending upon the load carried by the main circuit at the time.

If a fuse is used in the primary its blowing creates the above condition and the arc holds across the terminals of the fuse block until it burns itself clear. It has often been observed that where boosters have been "protected" by fuses in this way, the transformer has burned out shortly after the blowing of its primary fuses if not at the time.

41. Booster Cut-out (Gear and Williams).—In connecting or disconnecting a booster the main line should be opened before putting it in or out. If service on the line cannot be interrupted, or if it is desired to switch the booster in or out at certain times, it may be done with a series arc cut-out as in Fig. 21. The operation of the cut-out simultaneously opens the primary and short-circuits the secondary of the booster. The switch must be of a type having a positive action so that arcing will not damage its contacts at the moment the secondary is short-circuited. The arc cut-out must have sufficient carrying capacity to carry the main-line current when the booster is shunted out and standard series arc cut-outs should not be used where the line current is likely to exceed 20 to 25 amp.

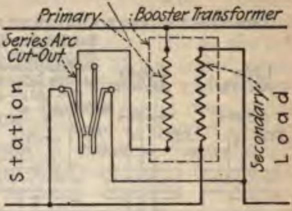


FIG. 21.—Series arc cut-out for a booster.

When the augmented booster is used the terminals of the primary winding of the transformer which goes to the cut-out should

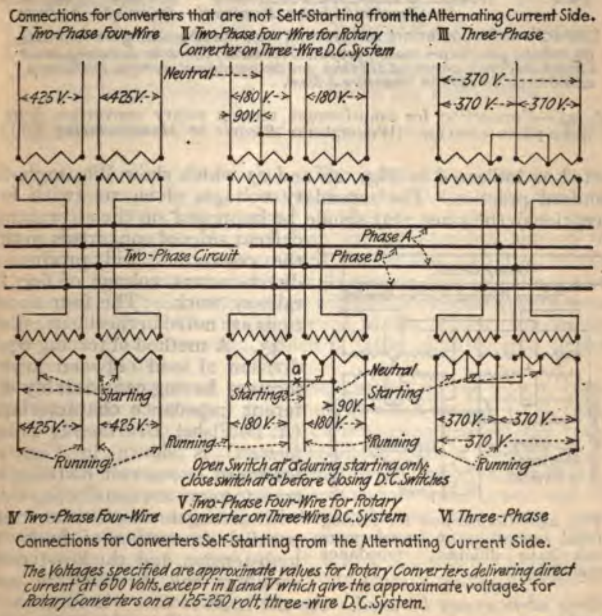


FIG. 22.—Connections for transformers serving rotary converters from a two-phase system. (*Westinghouse Electric & Manufacturing Co.*)

be connected to that terminal of the cut-out which is shown as not being in use in Fig. 21.

42. Transformers for serving rotary converters may be con-

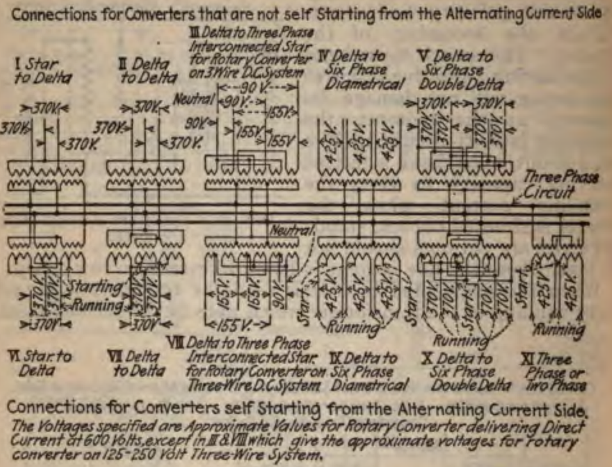


FIG. 23.—Connection for transformers serving rotary converters from a three-phase system. (*Westinghouse Electric & Manufacturing Co.*)

nected as indicated in Figs. 22 and 23 which show Westinghouse standard practice. The secondary voltages given are (with four exceptions) the ones that should be impressed on the alternating-current sides of converters so that the converters will produce a direct-current voltage of 600 for railway work. The four exceptions are noted in the illustrations.

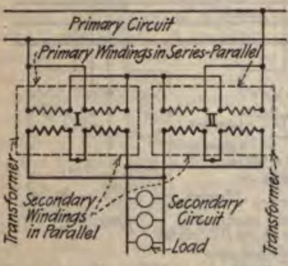


FIG. 24.—Connection for forcing parallel operation of transformers which have different impedance characteristics.

43. A method of forcing equal division of load between transformers having considerably different impedance characteristics (A. D. Fishel, *Distributing Transformers*) is shown in Fig. 24. Standard, 2,200-volt distributing transformers are usually provided with arrangements for the series-parallel connecting of both the high-tension and the low-tension windings and therefore the connections shown can be used. As the high-tension windings are in series the currents in the primary windings will be the same, hence the transformers will be equally loaded.

44. Transformer Connections for Obtaining 250 and 400 Volts from a 1,150-volt Line for Starting and Running a Motor (H. W. Young, *Electric Journal*).—The motor is a 20-h.p., 60-cycle machine. To supply 20 h.p. will require approximately 20 kw., which, in three transformers, corresponds to approximately three 7.5-kw. units. If these are connected to give a 5 to 1 ratio, 1,150 volts on the primary will give 230 volts for the secondary. If the transformers are connected with the high-tension windings in delta and the low-tension windings in star, as shown in Fig. 25 *I*, the ratio of the three-phase transformation will be 1,150 to 400 as desired, and by using the middle point of the low-tension windings, 200 volts will be available for starting the motor. Usually such motors will start very satisfactorily on one-half voltage.

As another solution: Two 15-kw. and two 3-kw. transformers may be connected in V with one 15-kw. and 1-kw. transformer on each leg, as shown in Fig. 25 *II*. With one of the 15-kw. transformers connected with a ratio of 2.5 to 1, 1,150 volts high tension

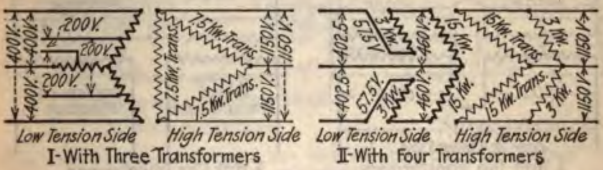


FIG. 25.—Connections for obtaining 250 and 400 volts from a 1150-volt line.

will give 460 volts low tension. The 3-kw. transformers should then be connected to give a ratio of 20 to 1, so that 1,150 volts will give 57.5 volts low tension. If the 15- and the 3-kw. transformers be connected in parallel on the high-tension side to the 1,150-volt line and in series on their low-tension windings, so that the 3-kw. transformer winding will oppose that of the 15-kw. transformer, the resultant voltage will be 460 minus 57.5 or practically 400 volts. The middle point of the 15-kw. low-tension transformer gives 230 volts, which is fairly close to that desired for starting the motor.

Note that the normal low-tension current of the 15-kw. transformer at 400 volts is 37.5 amp., and 30 amp. for the 3-kw. transformer at 100 volts, so that the current capacities of the transformers are sufficient for the three-phase load of 20 kw. at 400 volts, which correspond to approximately 29 amp. (20,000 ÷ 1.73 × 400). Obviously, two 7.5-kw. or one 10-kw. transformer and one 5-kw. transformer might be substituted for the 15-kw. transformer and the 3-kw. transformer might be replaced by a 4-kw., a 5-kw., or two 1.5-kw. transformers, if any of these are available.

45. Obtaining 7.5 kw. at 500 Volts from a 60-cycle 1,000-volt Circuit with Standard Transformers (H. W. Young, *Electric Journal*).—As the high-tension voltage of the standard 1,050-vo transformer is substantially that required and the frequency n mal the problem is one of determining a method for obtaining the secondary voltage of 500. The 500 volts may be secured by connecting two transformers in series (Fig. 26 *I*) the sum of the voltages of which will be that desired. If, then, a 5-kw. transformer connected as shown for 1,000 to 400 volts be used in combination with a 1.5-kw. transformer with a ratio of 1,000 to 100 the low-tension windings in series will yield 500 volts and the high-tension windings in parallel 1,000 volts as desired.

The current required on the low-tension side is 15 amp. (500× 15=7.5 kw.) which is the normal current for the 1.5-kw. unit but corresponds to a 600-kw. unit with a 400-volt secondary. That is, the 5-kw. unit will be overloaded 20 per cent. This is permissible as the iron loss is considerably reduced due to the lower voltage.

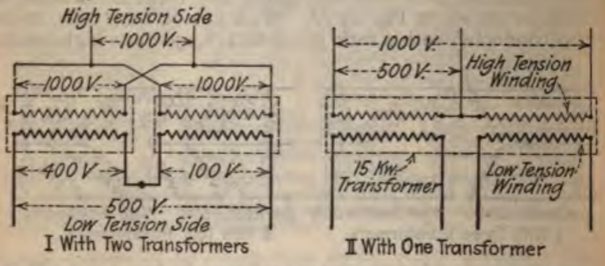


FIG. 26.—Connections for obtaining 500 volts from a 1000-volt circuit.

Instead of the 5-kw. unit, two 3-kw. units might be connected at a ratio of 1,000 to 400 with both high-tension and low-tension windings in parallel and these in turn might be connected in series on the low-tension side, with the 1.5-kw. transformer above referred to, and in parallel on the high-tension side.

Another method would be to employ a 15-kw. transformer as an auto-transformer (Fig. 27 *II*) using only the high-tension winding. In this case, 1,000 volts would be impressed over the high-tension winding when 500 volts could be taken from one-half of the winding as shown. With this arrangement the 1,000- and the 500-volt circuit are in electrical connection which may be undesirable.

46. Transforming from 360 Volts to 2,400 Volts with Standard Transformers (H. W. Young, *Electrical Journal*).—The arrangement described hereinafter (Fig. 27) was devised for the emergency supply, of a town four miles distant, from a 360-volt generator serving rotary converters. A standard transformer at 120 volts with a 20 to 1 ratio, or at 240 volts with a 10 to 1 ratio gives 2,400 volts high tension. (These voltages are considerably higher than normal although permissible in cases of emergency.) It is evident that 120+240=360. That is if two transformers are used with their high-tension windings in parallel for 2,400 volts and their low-tension windings in series, one connected for 240 an the other for 120 volts, the group will operate at a ratio of 360 volts to 2,400 volts. The transformers were thus connected and energy was efficiently transmitted the four miles at 2,400 volts. Note that full-load current for the 10-kw. transformer at 240 volts corresponds to the current of the 5-kw. transformer at 120 volts, thus permitting the operation of the transformers in series on the low-tension side as indicated.

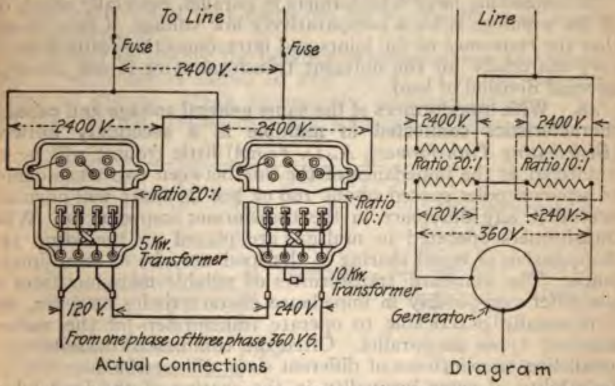


FIG. 27.—Feeding a 2,400-volt line with standard transformers from a 360-volt source.

PARALLEL OPERATION

47. Parallel Operation of Transformers.—Transformers will operate satisfactorily in parallel (Fig. 28), that is, with their

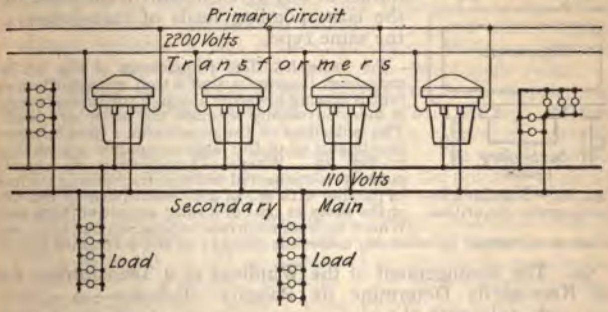


FIG. 28.—Transformers banked or operating in parallel.

high- and low-tension windings respectively connected directly *to the same circuits* provided—(1) they have the same ratio of *transformation*, (2) the same voltage ratings and (3) approximately the same regulation. If the low-tension voltages are different the transformer having the highest voltages will circulate current to those of lower voltage and cause a continuous loss. If transformers connected in parallel do not have the same regulation they will not share the total load in proportion to their ratings. The greater share of the load will be taken by the transformer having the best regulation.

In connecting large transformers in parallel, especially when one of the windings is for a comparatively low voltage, it is necessary that the resistance of the joints and interconnecting leads does not vary materially for the different transformers or it will cause an unequal division of load.

48. With transformers of the same general voltage and capacity characteristics connected in multiple in a secondary network (*Distributing Transformers*, A. D. Fishel) little trouble will be encountered as the impedance of the line between two transformers on separate poles spaced about 100 or 200 ft. apart will normally neutralize any difference in the transformer impedances. When transformers operated in multiple are placed on the same pole the question of equal sharing of the load may be of some importance. The standard transformers of reliable manufacturers do not differ very widely in impedance characteristics however, and it is usually practicable to operate transformers of the various standard types in parallel. Often the commercial desirability of paralleling transformers of different sizes will overbalance the undesirability of some inequality in the sharing of the load which might result.

49. Polarity of Transformers.—The windings of a transformer are usually so connected to the leads extending out through the case that the direction of flow of the alternating current or the polarity of the transformer at any given instant is the same in all the corresponding leads of transformers of the same type.

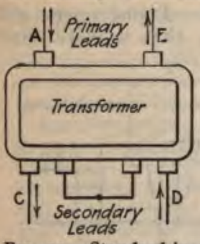


FIG. 29.—Standard instantaneous po.arities.

For example: The transformer of Fig. 29 is so connected internally that at an instant when current is flowing inwardly through the primary lead *A* it flows outwardly through the secondary lead *C*. The polarities of the single-phase transformers of practically all of the large companies are as shown in Fig. 29. Where a transformer of a certain polarity is connected without transposing its leads, in parallel with one of a different polarity the effect is the same as that of a short-circuit on both units. Where such an incorrect connection has been made it can be corrected by reversing either the primary or the secondary leads.

50. The Arrangement of the Windings of a Transformer does not Necessarily Determine its Polarity.—Polarity—so called—has to do only with the plan or arrangement adopted in bringing the leads out of the case. Interchanging the positions of the leads that extend through the bushings in the case will change the polarity of the transformer.

51. Tests for Polarity of Single-phase Transformers.—Where a standard transformer of known correct polarity and of the same io and voltage as the transformer to be tested is available : following simple method can be used:—Connect together ig. 30 *I*) the high-tension and the low-tension leads as if for paral- operation, inserting a fuse in one of the secondary leads. If th transformers are of the same polarity, no current will flow in : low-tension windings and the fuse will not blow. If the trans- mers are of opposite polarities the low-tension windings will ort-circuit each other and the fuse will blow. The fuse should sufficiently small that there can be no possibility of injuring : transformers.

A method of testing for polarity of single-phase transformers h a voltmeter is shown in Fig. 30, *II*. Connect the trans- mer as shown. Make successively voltmeter readings V, V_1, 1 V_2. If the transformer has standard polarity, $V+V_1$ will

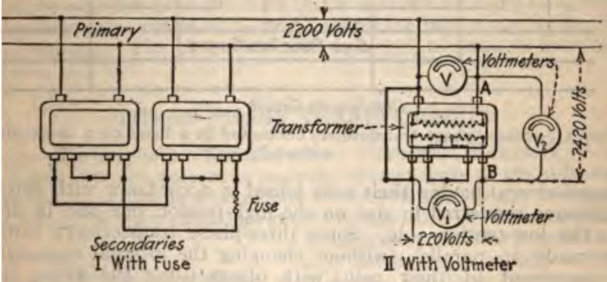


FIG. 30.—Testing transformers for polarity.

ual V_2. If the transformer is of non-standard polarity V_2 will ual $V-V_1$. For example, in Fig. 30, *II* the transformer is of ndard polarity and the primary line voltage, V (2,200 volts) is the secondary transformer voltage V_1 (220 volts) equals : voltage between A and B or 2,420 volts. With an incorrect larity the voltmeter V_2 would read (2,200 − 220) 1,980 volts.

52. **Polarity of Single-phase Transformers Connected in nks on Three-phase Circuits** (W. M. McConahey, *Electric urnal*, July, 1912).—A standard star-delta connection with six gle-phase transformers is shown in Fig. 31. The polarity of *No.* s the reverse of that of the other five. If the polarity of all six insformers were the same, *No.* 6 would be connected in a man- r similar to that of *No.* 3 instead of having the connections of e winding reversed. If the polarity of all the transformers is e same, all banks should be connected to the line in exactly the me manner. It is possible to connect one bank differently from e others and still secure parallel operation but this is not advisable, cause it is liable to lead to confusion and trouble. It is best to opt one scheme of construction and to adhere to it.

53. **Some Three-phase Transformers can be Paralleled and me cannot** (W. M. McConahey, *Electric Journal*, July, 1912).— ransformer having its coils connected in delta on both high-

tension and low-tension sides cannot be made to parallel with one connected either in delta on the high-tension and star on the low-tension or in star on the high-tension and in delta on the low-tension side. However, a transformer connected in delta on the high-tension and in star on the low-tension can be made to parallel with

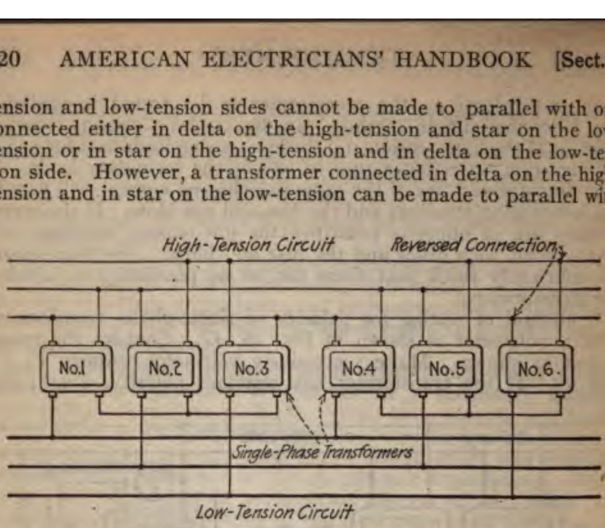


FIG. 31.—Single-phase transformers connected in a bank on a three-phase circuit.

transformers (having their coils joined in accordance with certain schemes) connected in star on the high-tension side and in delta on the low-tension side. Some three-phase transformers cannot be made to parallel (without changing the internal connection arrangement of their coils) with others using the same type of connections for the two windings. For example, a transformer connected delta to delta may have its coils so interconnected that it will not parallel with another transformer connected delta to delta. By changing the internal connections between the coils, however, it will be possible to bring out the terminals in such a way that parallel operation can be obtained.

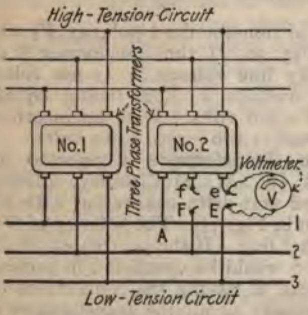


FIG. 32.—Testing three-phase transformers for parallel operation.

54. How to Determine whether or not Three-phase Transformers will Operate in Parallel.—If the transformers are available connect them as indicated in Fig. 32 leaving two leads on one of the transformers unjoined. Test with a voltmeter across the unjoined leads. If there is no-voltage between *E* and *e* or between *F* and *f* of transformer *No. 2* the polarities of the transformers are the same and the connections can be completed and the transformers put in service.

If a voltage difference is found between E and e or between F

l *f* or between both, the polarities of the transformers are not same. Then connect transformer lead *A* successively to mains 2 and 3 and at each connection test with the voltmeter be-een *e* and *f* and the legs of the main to which lead *A* is not con-cted. If with any trial connection the voltmeter readings be-een *f* and *e* and either of the two legs is found to be 0 (zero) the nsformer will operate with leads *f* and *e* connected to those two s. If no system of connections can be found that will satisfy s condition the transformer will not operate in parallel without nges in its internal connections and it may be that it will not erate in parallel at all. See another paragraph on this subject.
For a very complete discussion of this subject and the descrip-n of a method whereby it can be determined by voltmeter tests ether or not two three-phase transformers which cannot be ought together for a practical test will or can be made to operate parallel, see article in *Electric Journal* for July, 1912, by W. M. cConahey. The above material is largely abstracted from this icle.

THREE-PHASE TRANSFORMERS

55. **Three-phase Transformers** (*Standard Handbook*).—Al-ough there are numerous possible arrangements of the coils and res in constructing a polyphase transformer yet it may be stated at a polyphase transformer generally consists of several one-phase transformers with separate elec-tric circuits but having certain magnetic circuits in common. A three-phase transformer is illus-trated in Fig. 33 together with the component one-phase trans-

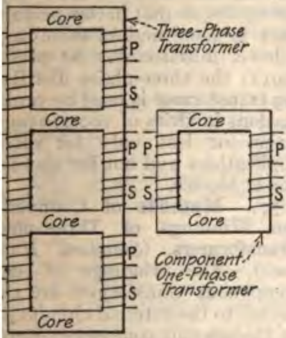


FIG. 33.—Three-phase core-type transformer.

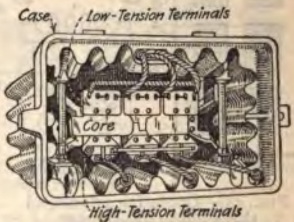


FIG. 34.—Interior view of a Westing-house three-phase transformer.

rmer. It will be observed that a three-phase transformer re-ires three times as much copper as the one-phase component ansformer, but less than three times as much iron. Thus in mparison with three individual transformers the three-phase it is somewhat lighter and more efficient. Each component nsformer operates as though the others were not present, the of one transformer combining with that of an adjacent transformer to produce a resultant flux exactly equal to that of each one alone. Fig. 34 shows the interior of a Westinghouse three-phase transformer.

56. Application of Three-phase Transformers (A. D. Fishel).—For central stations of medium sizes, three-phase transformers are rarely superior to single-phase except where the larger sizes can be applied in which cases the transformers are normally installed in sub-stations or central stations. The chief reason for this is the non-flexibility of a three-phase transformer. It is usually purchased for a particular size and type of load, and if that load should be changed, the transformer, representing a comparatively heavy investment, remains on the hands of the central station, whereas a single-phase transformer of one-third the size, could usually be adapted for some other service.

This feature becomes of less importance as the central station increases its size, and three-phase transformers for purely power service are now being used by a considerable number of the large central stations of this country. The three-phase transformer costs less to install and the connections are simpler, points that are of importance in connection with outdoor installations. The fact that a failure of a three-phase transformer would interrupt service more than the failure of one single-phase transformer in a bank of three, is of little importance because of the comparatively few failures of modern transformers. On the other hand, especially for 2,200 volt service, the single-phase transformer has been carried to a high degree of perfection, and is manufactured in much larger quantities, so that better performance is usual and in some cases, a lower initial cost. At present (1912) the three-phase distributing transformer is used by central stations in cities of 100,000 population or less only for special applications and not for standard power service.

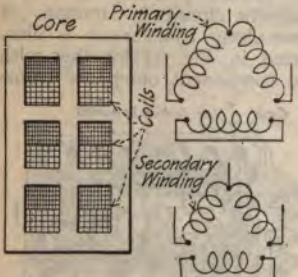


FIG. 35.—Operating a damaged three-phase transformer.

57. Methods of Connecting the Windings of Three-phase Transformers (*Standard Handbook*).—The windings of each component transformer are connected to the external circuits just as though this component were a one-phase unit; that is, the primaries may be connected either Y or delta. Moreover the relative advantages of the Y-connection and the delta-connection are quite the same with one three-phase transformer as with three one-phase transformers. The delta-connection is advantageous in some cases in that if the windings of one phase become damaged by short-circuiting, grounding or through any other defect it is possible to operate with the other phase windings V-connected.

58. In operating a damaged three-phase transformer on two coils it is necessary to separate the damaged transformer windings electrically from the other coils, as indicated in Fig. 35. The high-potential winding of the damaged phase should be short-circuited upon itself and the corresponding low-potential winding should also be short-circuited upon itself. The winding thus short-circuited will choke down the flux passing through the portion of the core surrounded by them without producing in any portion of the winding a current greater than a small fraction of the current which would normally exist in such portion at full load.

AUTO-TRANSFORMERS OR COMPENSATORS

59. The Auto-transformer (*Standard Handbook*).—The most efficient and effective method of operating a stationary transformer (when the ratio of transformation is not too large) is as an auto-transformer; that is with certain portions of the windings used simultaneously as the primary and the secondary circuit. The electrical circuits of a one-phase auto-transformer (sometimes called a "compensator" or a "balance coil") are indicated in Fig. 36. The auto-transformer has only one coil a certain portion of which is used for both the high-tension and the low-tension winding. The number of turns of this coil is the same as would be required if it were used exclusively for the high-tension winding and a separate additional coil were used for the low-tension winding. Moreover, when the ratio of transformation is 2 to 1 or 1 to 2, the amount of copper in the one coil is exactly the same whether it is used as an auto-transformer or as a high-tension coil of a two-coil transformer of the same rating. Not only is there less copper required for an auto-transformer than for a two-coil transformer but less iron is needed to surround the copper.

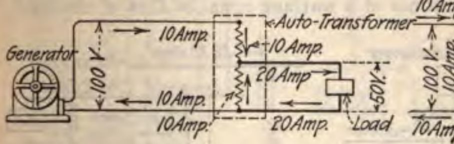


FIG. 36.

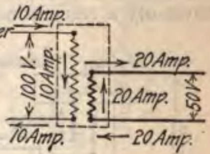


FIG. 37.

FIG. 36.—Electric circuits of a 1-kw., single-phase auto-transformer.
FIG. 37.—Electric circuits of a 1-kw., single-phase, two-coil transformer equivalent to the auto-transformer of Fig. 36.

Referring again to Fig. 36 it is to be noted that the one-coil is designed for 10 amp. throughout and for a total e.m.f. of 100 volts. Evidently the voltage per turn is uniform throughout, so that to obtain 50 volts it is necessary merely to select any two points on the continuous winding such that one-half of the total number of turns is included between them. The load current of 20 amp. (required for 1,000 watts at 50 volts) is opposed by the superposed 10 amp. of primary current, so that even in this section of the coil *the resultant current* is only 10 amp.

If an ordinary two-coil transformer had been used, the circuits *would have been* as noted in Fig. 37, while the required constructiv material would have been approximately as indicated in Fig. 38 *I*. So far as concerns its constructive material, a 1-kw., 2 to 1 ratio auto-transformer is the equivalent of a 1 to 1 ratio 0.5 kw., two-coil transformer as shown in Fig. 38, *II*. The latter transformer requires about 14 lb. of copper and 28 lb. of iron as compared with about 22 lb. of copper and 34 lb. of iron for the transformer of Fig. 38, *I*. Moreover, the losses of the auto-transformer are correspondingly less than those of a two-coil transformer.

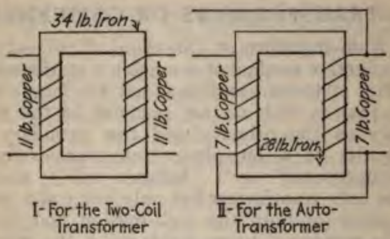


FIG. 38.—Comparison of constructive material required for a transformer and for an auto-transformer.

60. Standard Transformers used as Auto-transformers.—The applications shown in Figs. 39 and 40 are from Gear and William's *Central Station Distributing System*. The connections of Fig. 39, *I* are those for providing a 110-volt distribution on a 220-volt system. The load is assumed as 20 amp. The arrow-heads and figures indicate the distribution of current in the windings. Obviously a transformer of a wattage equal to that of the load, is

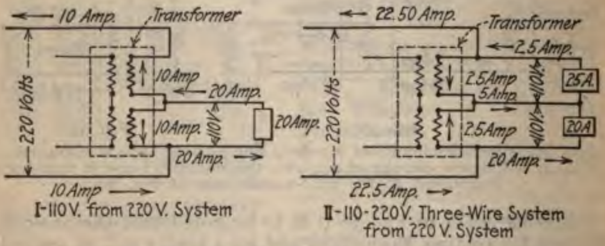


FIG. 39.—Standard transformers used as auto-transformers.

required. At *II* the connections for a 110–220-volt three-wire system are shown. The transformer winding carries only the unbalance of current in the two sides of the system. The transformer secondary winding need be only large enough to carry the largest unbalance that is likely to occur. In the methods of both *I* and *II* the transformer primaries are left open and are not used. Figure 40 shows other arrangements. At I is a connection arrangement that can be used in a 440-volt plant where 110–220-volt lighting is required. Two transformers are connected in series with their secondary windings in series and their primary windings in parallel. It is important that the primaries be in parallel as the second transformer will, if the primaries are left open, act as a choke to the lighting current. For a 110–220-volt system as shown, transformers each of capacity equal to the load are required. A similar 110-volt distribution system requires that the

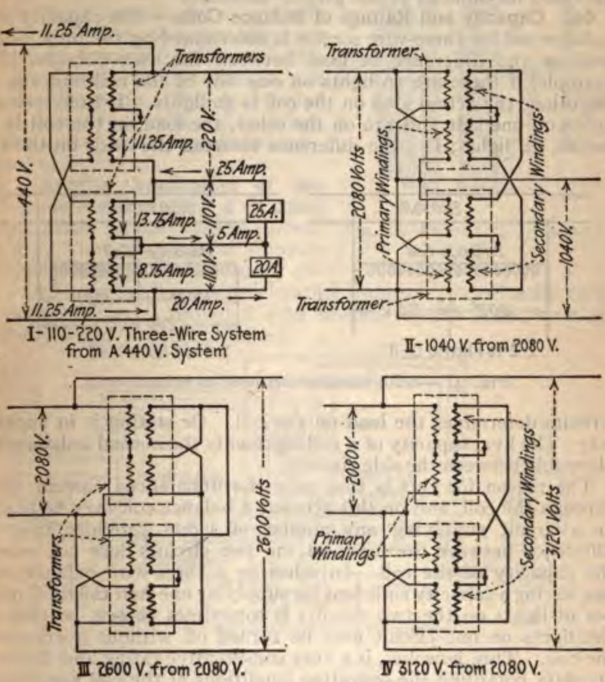


FIG. 40.—Standard transformers used as auto-transformers.

transformer on the side on which the lights are connected have a capacity of 1.5 times the load and the other one must carry half the load, making the total capacity twice the load.

Figures 40, *II*, *III* and *IV* show respectively methods whereby 1,040, 2,600 or 3,120 volts can be secured from a 2,080-volt system by the use of two transformers in series on the primary side and in multiple on the secondary side.

61. A common application of the auto-transformer **is as a** ***balance coil*** in a three-wire distribution from a two-wire suppl as indicated in Fig. 41, *I*. In this diagram the supply is at 200 volts, two-wire and a 2 to 1 ratio auto-transformer allows the distribution to be at 100+100 volts, three-wire. In Fig. 41, *II* the supply is at 100 volts, two-wire, while a 1 to 2 ratio auto-transformer permits distribution at 100+100 volts, three wire.

When used on a 220-volt two-wire circuit to provide a three-wire, 110-volt system, the balance coil maintains balanced voltages between the two sides of the system regardless of load conditions provided its capacity is not greatly exceeded.

62. Capacity and Ratings of Balance Coils.—The capacity of a balance coil for three-wire service is determined by the unbalanced load or the difference in load between the two circuits. For example, if there are 50 lights on one side of the coil and 100 on the other, the actual load on the coil is 50 lights. If there are 200 lights on one side and 150 on the other, the load on the coil is, as before, 50 lights; *i.e.*, the difference between the loads on the two

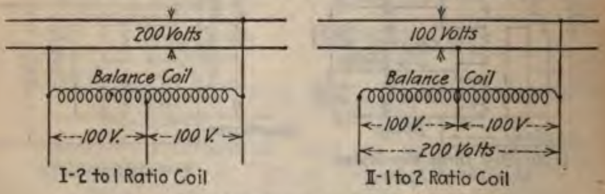


FIG. 41.—Auto-transformers used as balance coils.

circuits determines the load on the coil. Or stating it in another way: The kva. capacity of a coil represents the normal unbalancing allowable between the side circuits.

The reason for this is that only the unbalanced current flows through the coil, and on this account a balance coil may be placed on a circuit supplying any number of lights, provided that the difference between the loads on the two circuits does not exceed the capacity of the coil. In selecting a three-wire balance coil, one having a capacity sufficient for supplying one-half the total number of lights on the two circuits is sometimes chosen, so that all the lights on one circuit may be turned off without overloading the coil. This, however, is a very conservative rating and if accurate data regarding the operating conditions of the coil are obtainable, a smaller size may frequently be used. It is probably more frequent practice to consider that the unbalance will be 10 per cent. and for this condition a coil of a capacity equal to 10 per cent. of the total load on both side circuits is used. But even with the above conservative rating, the balance coil is lower in first cost, lighter in weight and much more efficient in operation than a transformer with separate primary and secondary windings. The kva. rating of a five-wire balance coil represents the maximum unbalancing allowable between any two side circuits.

The internal losses in the balance coil, both in the iron core and in the windings, are much less than in a two-coil transformer to equivalent service. This comparison between the two-coil transformer and the balance coil holds in a general way for all classes of service, regardless of the ratio of transformation.

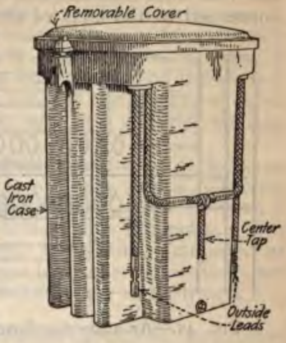


FIG. 42.—Westinghouse balance coil.

63. Commercial balance coils are usually oil cooled and mounted in transformer cases (Fig. 42). The coil most in demand is one for supplying a 110–220 volt three-wire circuit from a 110- or a 220-volt main. Coils for 440 to 220 volts are frequently furnished. Balance coils for supplying five-wire circuits are occasionally made. They may be for use on 440-volt circuits and have two outside and three intermediate leads, a total of five in all.

64. Another application of the auto-transformer is as a starting compensator for alternating-current motors. The compensator supplies a reduced voltage to the motor circuits while the machine is accelerating from rest. Ordinarily each auto-transformer is provided with several taps so that a number of low voltages may be obtained.

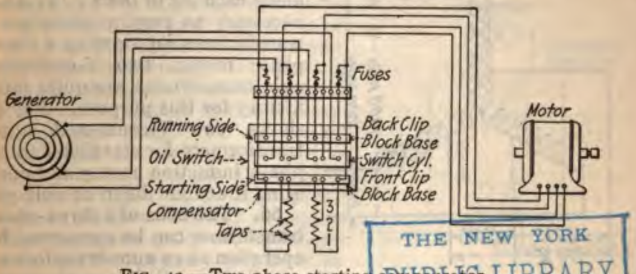


FIG. 43.—Two-phase starting compensator.

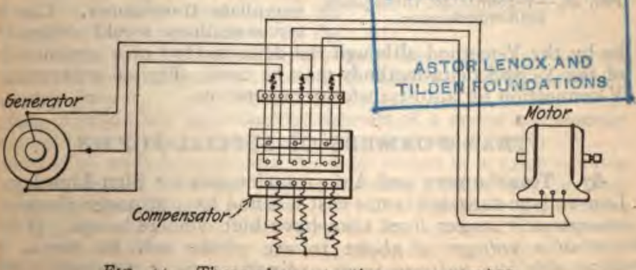


FIG. 44.—Three-phase starting compensator.

65. A starting compensator arrangement for a tw induction motor (*Standard Handbook*) is shown in Fig. 43. are two auto-transformers, the two separate phase lines connected to the ends of the separate auto-transformer wi

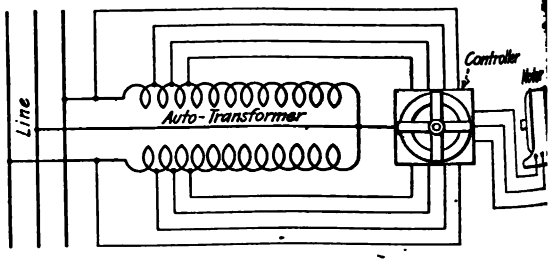


FIG. 45.—An auto-transformer, three-phase, starting compens

During the starting period the motor is connected between the ends and two intermediate taps. Fig. 44 shows a compensator arrangement for a three-phase induction moto three auto-transformer windings are Y-connected and low points are permanently along each leg of the Y. necessary to employ thr transformers for starting phase motor; two V-co auto-transformers are qui factory for this purpose. shows two V-connected transformers for starting phase induction motor a ating it at four different

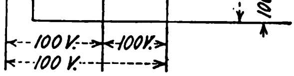


FIG. 46.—Y-connected, three-phase auto-transformer.

66. The coils of a thre transformer can be conn operation as an auto-tran equally as well as can t one-phase transformer. terconnections would o be by the Y-method although the delta-method or a com of the Y- and delta-methods may be used. Fig. 46 rep Y-connection for auto-transformer operation.

TRANSFORMERS OF SPECIAL FORMS

67. Transformers and Auto-transformers for Sign Li *Low-voltage* tungsten lamps cost less and have stronger *consequently* longer lives than have high voltage lam *lamps* of a voltage of about 10 are widely used for *produce* this low voltage from ordinary 110- or 220-

ts, small transformers or auto-transformers, especially made e purpose by several manufacturers, are used. The transrs are sometimes called economy coils and the auto-transrs are sometimes called compensators. The transformer is, neral, to be preferred to the auto-transformer because with ansformer the secondary circuit is insulated from the primary removes the liability of trouble from grounds on the secondffecting the primary and largely removes the liability of shock the high-voltage secondary circuit. See material on sign g in another section.

e transformers are made of capacities of from 250 to 2,000 s. As the normal voltage on a low-voltage sign is relatively low it is desirable that the length of conductor between a sformer and its lamps be maintained at a minimum. This ccomplished by using several small transformers mounted at erent points on a sign rather than one large one. Slate bases are uired by local rules in certain cities for sign transformers and o-transformers.

8. **The current transformer** (*Standard Handbook*) sometimes orrectly referred to as a "series transformer," considered elecally, and omitting any reference to the change in its design to omplish its specific duty, differs from the shunt or potential nsformer merely in the method of use. The latter transformer rdinarily supplied with a constant impressed voltage, the load ng changed by varying the impece (load) of the total secondary uit, while the total impedance of secondary circuit of the former nsformer is normally held constant the change in load is due to a ultaneous change in the primary rent and e.m.f. In the shunt nsformer the actual ratio of the nary to the secondary current is minor importance while every rt is made to so design the appaus that the ratio of the secondary ver to the primary power is as rly unity as possible. In the ign of a series transformer no ught whatsoever is given to the io of the primary and secondary watts but attention is concented on the endeavor to obtain a definite ratio of secondary to nary amperes.

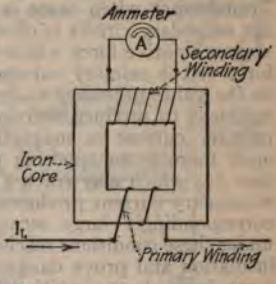


FIG. 47.—Elementary series transformer.

9. **The electric and magnetic circuits of a series transformer** conveniently be represented by the diagram shown in Fig. 47, ere it is used for reducing the line current to a value suitable measurement by a low reading ammeter, which may be thorhly insulated from the main circuit. Note that the current ugh the ammeter, *A*, is less than the line current IL by the cor urrent and the exciting current, taken in proper phase relatio

Application of the Current Transformer.—When an alt rating current is so large that to connect measuring or operating instruments directly in the circuit would be impracticable, or when the voltage is so high that to do so would be unsafe, the current transformer provides a means of reproducing the effect of the primary current on a scale suited to the instrument and of insulating the instrument from the main circuit. It is a special development of the transformer principle in which a constant ratio of primary to secondary current is the important consideration instead of the usual constant ratio of primary to secondary voltage.

Current transformers are used with alternating-current ammeters, wattmeters, power-factor meters, watthour meters, compensators, protective and regulating relays, and the trip coils of circuit-breakers. It is standard practice in this country to design current transformers (regardless of their capacity or ratios of transformation) to supply a full-load secondary current of 5 amp.

For example: If a 600-amp. current transformer has a ratio of 120 : 1, that is, when a current of 600 amp. flows in the primary circuit 600 ÷ 120 = 5 amp. will flow in the secondary circuit.

Measuring instruments for use with these transformers are so designed and are provided with scales such that they give a full scale deflection when 5 amp. flows through them and normally relays trip on a 5-amp. secondary current. One current transformer will supply three or four instruments with operating current without appreciably affecting accuracy.

71. **It is Unsafe to Open the Secondary Circuit of a Current Transformer when there is any Current in the Primary.**—When the secondary circuit is closed the current in this circuit creates a magnetomotive force which is in opposition to the magnetomotive force of the primary current and the core flux is thereby limited to the value necessary to generate in the secondary coil an e.m.f. sufficient to produce therein a current only slightly less than the primary current in magnetizing effect. When the secondary is open there is no opposing magnetomotive force for limiting the core flux which may reach a high value. Thus even a small value of primary current produces an excessive value of core flux and a correspondingly large secondary e.m.f. The secondary voltage under these conditions reaches a value which may both damage the insulation and prove dangerous to life. Absolutely no harm can come from short-circuiting the secondary terminals of the series transformer, and this method is used when it is necessary to insert or disconnect instruments in the secondary circuit.

72. **The Constant-current Transformer** (*Standard Handbook*).—The operation of low-voltage arc or incandescent lamps in parallel on a constant potential system necessitates a prohibitive expenditure for conducting material when the area to be lighted is extensive and the lamps are widely separated. For such service it is the common practice to operate the lamps which are connected in series with a constant current. The constant-current transformer is a special form of apparatus which converts alternating current at a constant potential of any value to a constant (alternating) current with a voltage varying with the load. It consists of a primary coil upon which the constant voltage is impressed, a secondary coil (or

oils) movable with respect to the primary, and a core of low nagnetic reluctance. It depends for its regulation upon the magetic leakage between the primary and secondary coils.

Consider first the primary coil; with constant e.m.f. impressed ipon this coil the total magnetism within the coil will be practically onstant under all conditions. The e.m.f. generated in the secondry will depend upon the strength of the field which it surrounds. n all types of stationary transformers the secondary current is pposite in general time-direction to the primary, so that not only s there a repulsive thrust between the two coils but there exists a onsiderable tendency for the magnetic lines from the primary o be forced out into space without penetrating the secondary. n the ordinary constant potential transformer the repelling action etween the two currents is prevented from producing motion of he coils by the rigid mechanical construction, while the proximity of the primary and secondary coils limits the magnetic leakage.

In the constant-current transformer, however, the repelling action is utilized to adjust the relative positions of the primary and secondary coils; when the coils are widely separated the paths for the leakage lines are increased and the lines which the secondary surrounds are fewer than when the coils are quite near together. The counter weights mechanically attached to the movable coil (or coils) are so arranged that when the desired current exists in the secondary coil (independent of its position along the core) the weights are just balanced. An increase in the current increases the repulsion and causes the coils to separate. With any current less than normal, the repelling force diminishes and the primary and secondary coils approach each other thereby restoring the current to normal. The primary can be wound for any reasonable potential (say as high as 10,000 volts) while the secondary can be wound for the voltage required for operating the arc lamps—from 15 to 200 or more lamps.

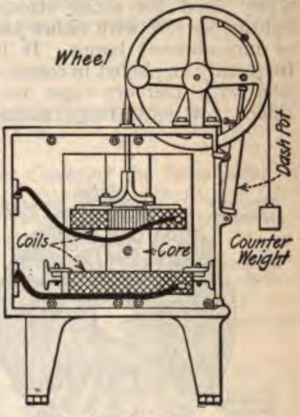


FIG. 48.—Constant-current transformer.

73. Mechanical Construction of the Constant-current Transformer.—The magnetic circuit of a constant-current transformer is usually of the "shell" type, the three limbs being placed vertically. In small sizes (Fig. 48) one of the coils is arranged in a fixed position while the other is movable. In some of the larger sizes there are two fixed primary coils and two movable secondary coils, while in others both the primary and secondary coils are movable. In any event he gravitational action on the movable coil or the gravitational ction of one movable coil against another to which it is mechanically interconnected, is counter-balanced accurately with an excess or deficiency just equal to the repulsive thrust of the primary and secondary coils at the desired load current. By the use of cam mechanisms for the counter-weights, or of eccentrically placed extra weights, the excess force of the counter-weights may be arranged to be equal to the variable repulsive thrust corresponding to a constant value of current in the coils at all positions of the movable coils. In fact, the transformer may be adjusted to regulate for a current of constant value at all loads or for one which either increases or decreases with increase of loads, while both the real value of the load current and its rate of change with the variation in load may be adjusted at will. In order to prevent any "hunting" action of the movable coils each transformer is sometimes equipped with a dash-pot. (See Fig. 48.)

74. Commercial constant-current transformers are built for natural air cooling or for immersion in oil. Oil has proved an excellent medium for insulation, cooling and lubrication. This type of transformer is extensively used for series street-lighting service with either arc or incandescent lamps. It is frequently employed in connection with mercury-vapor rectifiers for operating series-connected direct-current lamps. The efficiency of a constant-current transformer is high, being about 96 per cent. at full-load for a 100-lamp transformer. The power factor which depends upon the magnetic leakage, is low at all loads; it reaches about *80 per cent.* at full-load and decreases therefrom in almost direct *proportion* to the decrease in load.

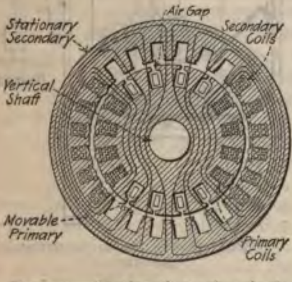


FIG. 49.—Section through a single-phase, induction-type, potential regulator.

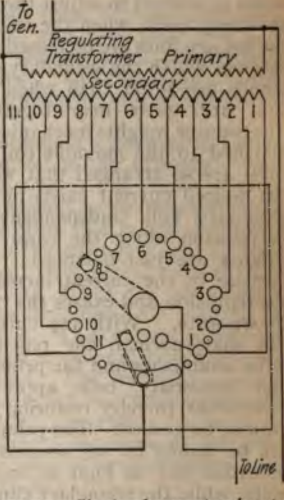


FIG. 50.—Single-phase, step-by-step type potential regulator.

75. The induction regulator (Fig. 49) is a special type of transformer, built like an induction motor with a coil-wound secondar which is used for varying the voltage delivered to a synchronous converter or alternating-current feeder system. In comparison with a variable-ratio transformer it possesses the advantage of being operated without opening the circuit and without short-circuiting any transformer coil. The primary of the induction regulator is subjected to the constant voltage of the supply system, the delivered voltage obtained from the secondary winding being varied by rotating the primary structure through a certain number of degrees with reference to the secondary structure. The primary structure is normally stationary, although it is movable either automatically or by hand for the purpose of varying the secondary voltage.

76. **The step-by-step potential regulator** is merely a stationary transformer provided with a large number of secondary taps and equipped with a switching mechanism for joining any desired pair of these taps to the delivery circuit according to the e.m.f. required. A diagram of the circuits of a regulator of this type is shown in Fig. 50. In comparison with the induction type of regulator the step-by-step type is less noisy in operation, requires less magnetizing current and is more rapid in action. However, it provides only a limited number of voltage steps and may give trouble from arcing at the switch contacts.

INSTALLATION OF TRANSFORMERS

77. **Brief of Underwriters' Rules Covering the Installation of Transformers** (*Factory Mutual Fire Insurance Companies' Wiring Rules*).—Where transformers are to be connected to high-voltage circuits, the local Inspection Department should always be consulted before work is begun or the apparatus is purchased, as it is necessary in many cases for best protection to life and property, that the secondary system be permanently grounded, and this cannot be done unless provision is made for it when the transformers are built.

Transformers should always be located outside of buildings, unless special permission is given to put them inside. In general, it is dangerous to locate transformers with oil-filled cases inside, as it is entirely possible for a break-down of insulation to ignite the oil, which may result in a very stubborn fire. For the same reason, the placing of these transformers on roofs is also objectionable.

Even transformers which are not oil cooled may contain a considerable amount of combustible material which, if ignited, would make a hot fire, especially if the cases are ventilated as is customary with these types of transformers. Moreover a burn-out in the windings may cause dense smoke, which might easily be mistaken for a fire and cause fire streams to be thrown into the building, with a resultant water damage. They can, therefore, be permitted *inside of buildings only* after the circumstances have been carefully *considered and* the necessary safeguards provided.

78. Size and Capacity of Transformer Fuse Wire

(Westinghouse Electric & Manufacturing Co.)

Capacity amperes	18 per cent. German silver wire	Capacity amperes	Aluminum wire
$\frac{1}{2}$ to $\frac{3}{4}$	No. 36	4 to 10	No. 24
$\frac{3}{4}$ to 1	No. 30	5 to 10	No. 24
1 to $1\frac{1}{4}$	No. 30	10 to 15	No. 23
$1\frac{1}{4}$ to $1\frac{1}{2}$	No. 30	15 to 20	No. 22
$1\frac{1}{2}$ to $1\frac{3}{4}$	No. 30	20 to 25	No. 21
$1\frac{3}{4}$ to $2\frac{1}{4}$	No. 26	25 to 30	No. 20
$2\frac{1}{4}$ to $2\frac{3}{4}$	No. 26	30 to 50	No. 19
$2\frac{3}{4}$ to 4	No. 26	....	....

79. Sizes of Primary Fuses Recommended for Transformers of Different Ratings

(General Electric Company)

Transformers kva. capacity	Primary volts	
	1,100–1,200 Amperes rating	2,200–2,400 Amperes rating
0.6	1	1
1.0	1	1
1.5	2	1
2.0	2	1
2.5	3	2
3.0	3	2
4.0	5	2
5.0	5	3
7.5	10	5
10.0	10	5
15.0	15	10
20.0	20	10
25.0	25	15
30.0	30	15
40.0	40	20
50.0	50	25

80. Mounting Distributing Transformers.—Units of the smaller capacities are supported on poles on cross-arms in accordance with instructions furnished by their manufacturers. Gear and Williams recommend that, for transformers of capacities larger than 20 kw., double-cross arms should be used at the top as the top arms carry most of the weight. "Where the installation consists of three 15-kw. or larger transformers it is advisable to use a larger-sized cross-arm than the standard. An arm having a cross-section of 4 in. by $5\frac{1}{2}$ in. has been found ample for installations aggregating 90 to 100 kw."

"Where a large amount of power is needed which requires a *number of* 50-kw. units which cannot be conveniently installed *inside of the* building, they can be safely and conveniently installed *on a platform* between two or more poles as shown in Fig. 51. *The use of* units larger than 50 kw. is usually not advisable as the so heavy as to be inconvenient to handle and replacing them in e of a burn-out is a considerable task. A platform for supporting ee 50-kw. units can be built by bolting in gains, between two es, 2–3 in. × 10-in. planks and nailing to them a floor of 2-in. nk."

1. **Methods of Hanging Transformers.**—The methods of unting transformers described and illustrated in the following agraphs were taken from the *Report of the Committee on Overhead e Construction* of the Pennsylvania Electric Association, Sept. 3, 2. H. N. Müller of the Alleghany County Light Company of

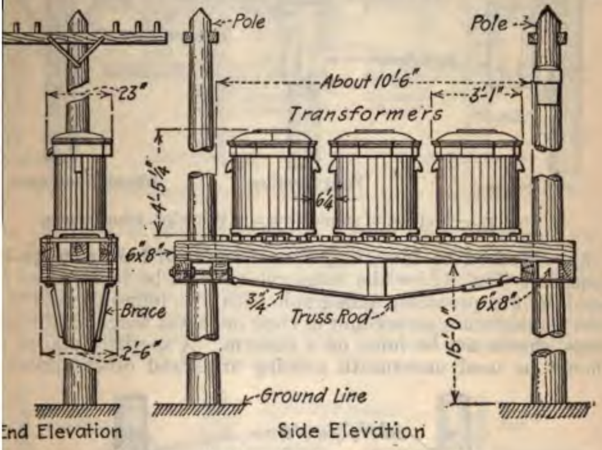


FIG. 51.—Platform for large transformers.

tsburgh was chairman of the committee and the practices out- d are those followed by the Alleghany Company. The methods vide ample clearances for linemen climbing the poles and assure t the wiring will remain in place and not give trouble from short- uits. Platforms are recommended for supporting the larger nsformers because of the accessibility for repairs or replacements t they provide.

2. **Method of Mounting Single Transformers of from 1- to 4- 1. Capacity.**—The transformer should be supported by the hangers furnished by the manufacturer and hung at the central nt on the cross-arm and not out on the arm away from the pole. the bottom of the hanger a section of an arm, not longer than the neter of the pole, should be fastened to the pole with two lag s. The transformer can be hung on the bottom arm, if one is place and supports lines, provided this arm is in the second or a lower one. The primary mains feeding the transformer ld be on an upper arm.

installations where the transformers are more than 4 ft.

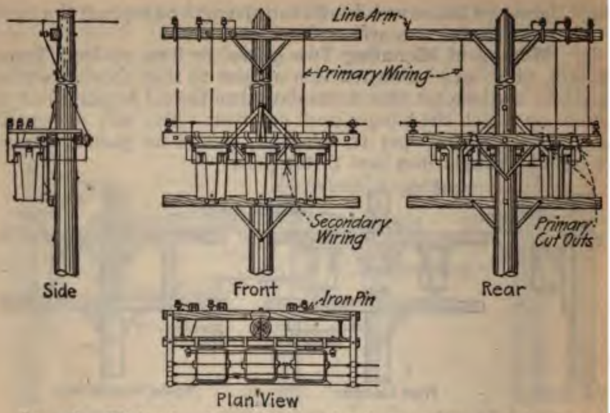


FIG. 56.—Wiring for three 5-kva. or for three 10-kva. transformers.

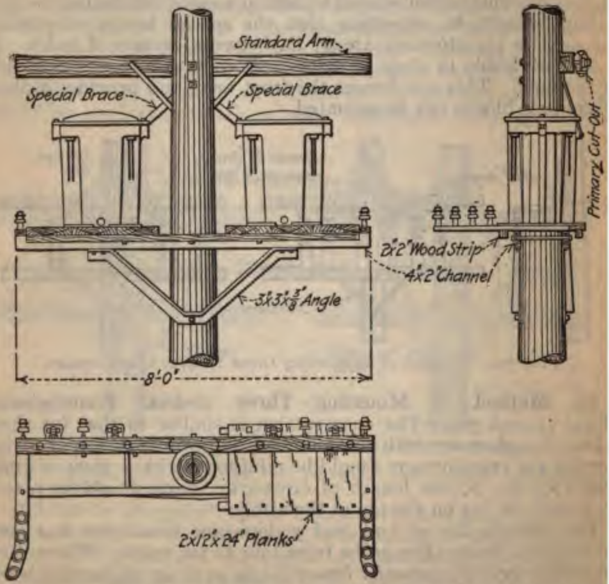
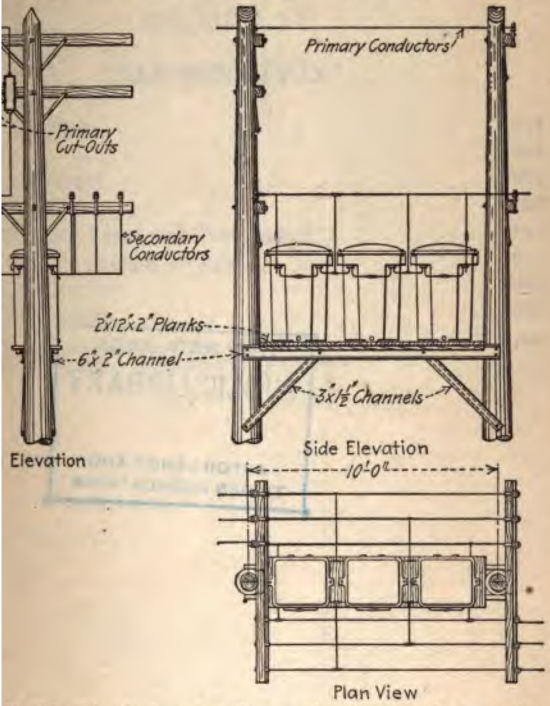


FIG. 57.—Single pole platform for two 20-kva., two 30-kva. or one 50-k transformer.

rovide equivalent mechanical strength will be unnecessary.) insure against a transformer falling off.

[ethod of Mounting Two 20-kva., Two 30-kva. or One Transformer. (Fig. 57.)—For transformers of these capaci- igle-pole platform is recommended. The beams for the should be 4 in. ×6 lb., channel iron 8 ft. long. The ed are a single piece of angle iron $3\times3\times\frac{3}{8}$ in. bent in a



·Double pole platform for three 20-kva., two 50-kva., or three 50-kva. transformers.

Pine or oak planks $2\times12\times24$ in. are to be laid across iel irons for the transformers to rest upon. The wooden is to be held together by a 2×2 in. strip of wood running tside of the channel iron, to which the planks are secured by d screws or 20-penny nails.

[ethod of Mounting Three 20-kva., Three 30-kva., Two r One 50-kva. Transformer. (Fig. 58.)—The poles should *10 ft. apart* on centers. The main channel irons are 6 in. *10 ft. 6 in.* over all. Braces are of 3 in. ×4 lb. channel.

SECTION VI

ILLUMINATION[1]

ıe compiler acknowledges the assistance of Messrs. Chas. R. Riker . Sidney Neu in the preparation of this section.

PRINCIPLES AND UNITS

Physiological Features of Illumination.—In order to under-d the principles of scientific illumination, it is necessary to rstand the mechanism of the eye.

g. 1 (From *Primer of Illumination* copyright by Illuminating neering Society) shows the parts of the eye as they would ar if it were cut through from back to front vertically. In process of seeing, the light s through the cornea, pupil, lens of the eye to the retina, as in a camera light passes ıgh the lens to the sensitized The picture is formed on retina, which is a layer made of the ends of nerve fibers h gather into the optic nerve go directly to the brain.

FIG. 1.—The eye—essential parts shown in section.

optic nerve sends along the picture to the brain. The lens he eye, unlike that of the camera, automatically changes in kness to focus or make a clear image on the retina for seeing at rent distances. This focusing action is called the accommoda- of the eye, and when the light is dim or bad the focusing cle vainly hunts for some focus which may make objects look

Expanded when Illumination is Dim. Contracted to Shut out Excessive Light.

FIG. 2.—Expansion and contraction of the pupil of the eye.

r and gets tired in trying to do it. The muscles which move eye about also get tired in the same way and the result is eye-in, which stirs up pain and headache just as any other over-tired cles of the body may set up an ache.

he iris (*which gives the eye its color*) serves to regulate the unt *of light which reaches the eye.* In very dim light it opens *making the pupil big,* as shown in Fig.2, and in very bright light it shuts up as shown, and thus keeps out a flood of brilliant light which might hurt the retina. The protective action of the pupil is pretty good, but by no means complete, for it seldom gets smaller than shown in the illustration, however bright the light. From a study of Fig. 2 we may deduce:

(a) When trying to see any object, do not allow a light to shine into the eyes, nor face a brightly lighted area. In addition to tiring the retina, the superfluous light causes the pupil to contract, so that less light from the illuminated object reaches the retina. An object which would seem well lighted in a room with dark walls, and no light shining in the eyes, will appear poorly lighted in a bright room with light walls, or when a light is shining in the eyes, simply because the pupil is smaller. This also explains why a higher light intensity is necessary in the day time than at night. It is generally easier to read with the same light source in a room having dark walls than if the walls are light in color—though the total illumination on the page will probably be less. Reflected light from glossy paper produces the same effect as light surroundings. The effect produced by a light shining directly into the eyes is termed *glare.*

(b) A fluctuating light causes the pupil to be constantly changing. This is very tiring to the muscles which control the iris, and if long continued may even work a permanent injury.

(c) The lens of the eye is not corrected, as is a photographic lens, for color variations. It cannot focus sharply red and blue light from the same object simultaneously, although this is ordinarily not noticed. As white light is composed of all colors, it follows that we can see more clearly, *i.e.*, objects appear sharper and more distinct, by a monochromatic light (light of only one color) than by even daylight. The light from the mercury vapor lamps closely approximates this condition.

(d) Illumination should be uniform; otherwise the eye, in continually attempting to adapt itself to the unequal conditions, becomes tired in the same way as with a fluctuating light.

Correct illumination enables one to see clearly with minimum tiring of the eyes. To secure this, all the above conditions must be satisfied.

2. **A line of vision** is a line drawn from a given point to an assumed natural position of the eye of an observer. When a lamp is concealed from the eye of an observer by a reflector the lamp is out of the line of vision of the observer, but if the observer changes his position until he can see the lamp then it is in his line of vision.

3. **Visual Acuity.**—Experiments have shown that if the intensity of illumination is gradually increased the following facts are noticeable: *First*, that a certain definite intensity of illumination is required before the object can be distinguished; *second*, that as the intensity of illumination is increased, the visual acuity is increased in proportion, that is, the object becomes more easily seen, up to a certain intensity of illumination; *third*, that beyond a certain point, increasing the intensity of illumination does not result in a proportional increase in visual acuity. This is shown graphically in Fig. 3. It is therefore apparent that more than a certain amount

of illumination, depending on conditions and purpose, is wasteful, in that it does not make things any more clearly seen.

4. **Effect of Daylight on Illumination.**—Daylight is so much more intense than artificial illumination that it makes artificial lighting appear dim by contrast. Experiments show that when some daylight is present, from 50 to 100 per cent. greater intensity of illumination is required. This is because the eye gets used to the high intensity of illumination on all objects by daylight, and there are no deep shadows to relieve the monotony.

5. **The intensities of natural illumination** (Bell, *Standard Handbook*) vary very greatly, ranging up or down according to relation of the point considered to windows and sunlight. The intensity of the diffuse illumination near a south window may rise to 20 ft-c. or more; with less brilliant exposure it may be 10, or 5 or 3 ft-c., and so on down as one passes to less favorable positions and gets down to fractions of a foot-candle. The illumination, for example, where this paragraph is being written near a west window on a rainy day is about 3 ft-c., while 10 ft. further within the room it has fallen to less than 0.5 ft-c. by which it is difficult to read coarse print. So far as ordinary work goes any illumination above say 2 ft-c. is about equally good. When daylight drops materially below this, one has to resort to artificial light, and there is a strong tendency to use much more than is necessary to the detriment of the eyes. Under a desk lamp an illumination of 10 ft-c. is not an exceptional amount, but it is more than double that which can generally be advantageously utilized by the eye.

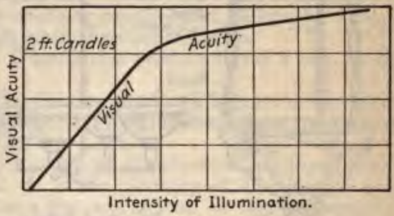


FIG. 3.—Characteristic curve of visual acuity.

6. **Direct lighting** is that wherein the light source is visible and the light is distributed directly from it.

7. **Indirect lighting** is that form wherein the light source is entirely hidden. The light is projected to the ceiling and walls from which it is reflected downward.

7a. **Indirect Compared with Direct Lighting** (H. W. Shalling).—Obtaining a large portion of the illumination indirectly has the following disadvantages as compared with direct lighting.

(1) Lower efficiency; to produce a given illumination requires about twice as much light with indirect lighting as with efficient direct lighting.

(2) More rapid depreciation due to the collection of dirt.

(3) A lower degree of perspective, since sharp shadows are largely eliminated.

(4) An unduly bright ceiling which often gives an unpleasant psychological effect, especially when the opaque unit of the indirect lighting forms a contrast with the brightly lighted ceiling.

8. **The three fundamental quantities upon which the art** illumination is based are:

1. *Intensity*, or luminous intensity, which defines the light-gi power of a source and which is measured in candle-power.

2. *Illumination*, or light-flux density, which is measured in candles.

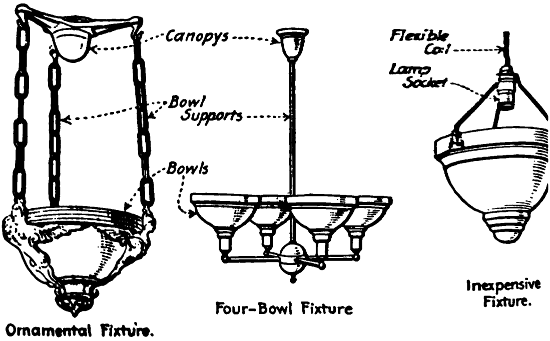


FIG. 4.—Examples of fixtures for indirect lighting.

3. *Intrinsic brilliancy*, which is measured by the lumino tensity per unit of area and in candle-power per square inch.

9. **Candle-power.**—The light-giving power of a lum source is expressed in candle-power. It is determined by comp the lamp either with a standard maintained by the National B of Standards at Washington, D.C., or with a well-seasoned lam has been accurately mea to this standard and serves as a secondary stan A light source generally more light in one dir than it does in another. Fig. 5.) Thus a direct-c arc lamp gives more li an angle 45 degrees bel horizontal than in any direction. The candle of a lamp therefore nothing unless the di is also specified. The c power generally is different in different directions.

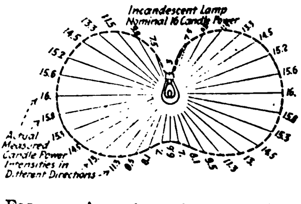


FIG. 5.—Actual candle-power intensities in different directions from a 16-c.p. carbon-filament incandescent lamp.

10. **Mean Horizontal Candle-power.**—The average of the c powers of a lamp in all directions in a horizontal plane is call mean horizontal candle-power. Incandescent lamps were fo rated by their mean horizontal candle-power. Two lamps the same (mean horizontal) candle-power may thus diffe ir light-giving powers above and below the horizon

11. Mean Lower Hemispherical Candle-power.—The average of the candle-power of a lamp in all directions in the lower hemisphere is called the mean lower hemispherical candle-power of the lamp. As applied to incandescent lamps, the lamp is assumed to have the bulb down, base up. This term is of little importance where lamps are to be used with reflectors.

12. Mean Spherical Candle-power.—The average of the candle-power of a lamp in all directions is called the mean spherical candle-power. This term is of most importance as it is an index to the total light-giving power of the lamp in all directions.

13. Foot-candles—Candle-feet—Lux.—The unit of intensity of illumination is the foot-candle or candle-foot. It can be defined in two ways, both of which mean the same: 1 ft-c. is

(1) The intensity of illumination produced by a 1 c-p. source at a distance of 1 ft.

(2) The intensity of illumination produced by one lumen when spread over 1 sq. ft. of surface. The illumination on the interior surface of the sphere of Fig. 6 is 1 ft-c.

The lux is a unit of intensity of illumination employed when using the metric system. It is the intensity of illumination produced by a 1 c-p. source at a distance of 1 m., or that produced by one lumen when spread over 1 sq. m., 1 lux = .0929 ft-c., 1 ft-c. = 10.76 lux.

13A. The efficiency of an electric light source is ordinarily given in *watts per candle,* which means watts per mean horizontal candle-power. However, this method is unsatisfactory in that candle-power is not a true measure of the total light produced by the lamp. Furthermore, as the efficiency, on the above basis, increases, the figure expressing it decreases. A better method of expressing efficiency is in *lumens per watt.*

14. The reduction factor of a light source is the ratio of the mean spherical candle-power to the mean horizontal candle-power. Few sources radiate uniformly in all directions, and since most incandescent lamps have their maximum intensity in the horizontal direction, it is seen that the reduction factor must usually be less than one. According to this definition, the mean spherical candle-power can be obtained by multiplying the mean horizontal candle-power by the reduction factor.

15. Factors for Obtaining Mean Spherical Candle-power

Type of incandescent-lamp light source	Reduction factor
Carbon, oval anchored filament	0.825
Gem 50 watt, 20 c-p. filament	0.825
Gem 100, 125, 187, 250 watt filament	0.820
Tantalum filament	0.790
Tungsten (*Mazda*), multiple, vacuum, 105–125 volts	0.780
Tungsten (*Mazda*), multiple, vacuum, 220–250 volts	0.790
Tungsten (*Mazda C*), multiple, gas filled, nitrogen, 105–125 volts	0.800
Tungsten (*Mazda C*), series, gas filled, for ordinary circuits, 60, 80, 100 c-p.	0.760
Tungsten (*Mazda C*), series, gas filled, for ordinary circuits, 250, 400, 600 c-p.	0.800
Tungsten (*Mazda C*), series, gas filled, 20-amp. circuits, 600 and 1000 c-p.	0.780

16. Economical Intensities of Illumination in Foot-candles

(National Electric Lamp Association)

Application	Foot-candles
Armory or drill hall	3.0
Art Gallery	
White statuary	2.5
Bronze statuary	7.0
Paintings	5.0
Assembly Room	3.5
Auditorium	2.0
Automobile showroom	5.0
Automobile (interior)	1.0
Ball room	3.0
Bank	3.0
Bar room	3.0
Barber shop	2.5
Blacksmith shop	3.0
Billboard	8.0
Billiard room (general)	0.8
Billiard table	5.0
Bowling alley—	
Alley	1.5
Pins	4.0
Cafe (see saloon)	2.5
Carpenter shop	4.0
Court room	2.5
Church	2.0
Club—	
See Hotel, Residence, etc.	
Dance hall	2.0
Depot waiting room	1.5
Desk	4.0
Draughting room	8.0
Engraving	10.0
Factory—	
General illumination only, where additional special illumination of each machine or bench is provided	1.5
Local bench illumination	4.0
Complete (no local) illumination	4.0
Fire Stations—	
When an alarm is turned in	3.0
At other times	1.0
Foundry	3.0
Garage	2.0
Gymnasium	2.5
Hospital—	
Corridors	0.5
Wards (with no local illumination supplied)	1.5
Wards (with local illumination supplied)	0.5
Operating-table	12.5
Hotels—	
Corridor	0.6
Bed room	1.5
Lobby	2.0
Dining room	2.0
Writing room	2.0
Laundry	2.0
Library—	
Stock room	1.5
Reading room (with no local illumination supplied)	3.5
Reading room (with local illumination supplied)	0.7
Machine shop—	
Rough work	6.0
Average work	2.0
Fine work	4.0
Market	3.0
Moving-picture theater	1.5
Museum	3.0
Office (no local lights)	4.0
Pattern shops	4.0
Power house	3.0
Postal service	7.0
Public square	0.8
Reading (ordinary print)	2.0
Reading (fine print)	2.5
Residence—	
Porch	0.2
Hall (entrance)	0.7
Reception room	1.5
Sitting room	1.5
Library	2.0
Dining room	1.5
Kitchen	2.0
Laundry	1.5
Hall (upstairs)	0.5
Bed room	1.5
Bath room	2.0
Cellar	0.6
Store room	0.7
Rug rack	15.0
School—	
Class room	2.5
Assembly room	2.0
Cloak room	0.8
Corridor	0.8
Manual training	3.0
Drawing	5.0
Sewing (light goods)	4.0
(dark goods)	8.0
Shipping room	2.0
Show window[1]—	
Light goods	7.0
Medium goods	15.0
Dark goods	20.0
Sign	8.0
Stable	1.0
Station (railroad)	2.0
Stenographer	5.0
Stereotyping	4.0
Stock room	1.5
Store—	
Art	4.0
Baker	3.0

[1] Depends largely on character of street and other features of location.

17. Economical Intensities of Illumination—(*Continued*)

Application	Foot-candles	Application	Foot-candles
Store—		Store—	
Book	3.5	Piano	4.0
Butcher	3.5	Shoe	3.5
China	2.5	Stationery	3.5
Cigar	3.0	Tailor	4.0
Clothing	5.0	Tobacco	3.0
Cloak and suit	5.0	Street—	
Confectionery	3.0	Business (not including light from show windows and signs)	0.5
Decorator	3.0	Residence	0.1
Drug	4.0	Prominent residence districts	0.2
Dry goods	4.0	Country roads	0.05
Florist	3.0	Studio	4.0
Furniture	4.5	Swimming pool	2.0
Furrier	5.0	Telephone exchange (general)	3.0
Grocery	3.0	Theater—	
Hardware	4.5	Lobby	3.0
Hat	4.0	Auditorium	2.0
Jewelry	4.5	Train sheds	1.0
Lace	3.0	Typesetting	8.0
Leather	3.5	Warehouse	1.5
Meat	3.5	Wharf	1.0
Men's furnishings	3.5		
Millinery	4.0		
Music	3.5		
Notions	3.0		

18. Economical Intensities.—The above intensities of illumination are recommended for various purposes. These intensities enable objects to be seen with all the clearness generally necessary in the places mentioned. Thus, in draughting rooms greater intensity is required than in swimming-pool buildings, because more detail must be brought out. On billboards greater intensity is required than in a library reading room to enable the signs to be read at a great distance.

19. Average Intrinsic Brilliancy of Various Illuminants

Light source	Candle-power per sq. in.	Light source	Candle-power per sq. in.
Moore tube	0.3–1.75	Incandescent lamps:	
Opal-shaded incandescent lamp	0.5–3.0	Tantalum, 2.0 watts per candle	700–800
Frosted electric incandescent lamp	2–8	Tungsten, 1.25 watts per candle	850–1000
Candle	3–4	Tungsten, 1.0 watts per candle	950–1050
Gas flame	3–8	Nernst, 1.5 watts per candle	2200
Oil lamp	3–8	Sun, on horizon	2000
Cooper-Hewitt lamp	10–20	Flaming arc lamp	5000
Welsbach gas mantle	20–50	Calcium light	5000
Acetylene burner	60–100	Open arc lamp	10,000 50,000
Enclosed a-c. arc lamp	75–200	Open arc crater	200,000
Enclosed d-c. arc lamp	100–500	Sun, 30 degrees above horizon	500,000
Incandescent lamps:		Sun, at zenith	600,000
Carbon, 3.5 watts per candle	350–400		
Carbon, 3.1 watts per candle	450–500		
Gem, 2.5 watts per candle	625		

20. Intrinsic Brilliancy.—Lights of greater intrinsic brilliancy than 4 to 6 c-p. per sq. in. produce glare; that is, they tire the muscles and retina of the eye and prevent it from seeing objects clearly. It is well to avoid placing sources of light of greater intrinsic brilliancy than 1 c-p. per sq. in. in the field of vision. Intrinsic brilliancy is total candle-power per unit area of the source of light. Brilliant light sources in the line of vision should be protected by frosted or translucent shades.

21. Flux of Light. Lumen.—For purposes of calculation it is convenient to consider the light given out by any source as a flow, stream or flux from the source outward. The flux generated by a point source of 1 c-p. in a unit solid angle is called one lumen. In Fig. 6, if we assume the square to measure 1 in. on each side and to lie on the surface of a sphere 1 in. in radius, the light of 1 c-p. at the center would generate one lumen in the solid angle enclosed by the lines *abcd*. As the total surface of this sphere is 4π times $1 = 4 \times 3.1416 \times 1 = 12.56$ sq. in., the total flux emitted by a point source of 1 c-p. is 12.56 lumens. A source of 2 mean spherical c-p. would emit $2 \times 12.56 = 25.12$ lumens, and so on.

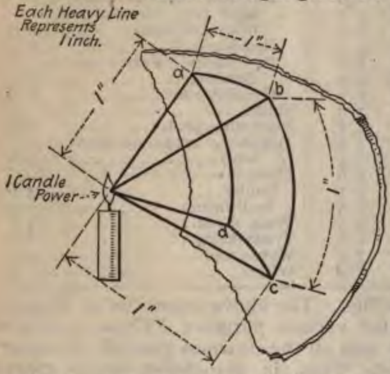


FIG. 6.—Flux of light in unit solid angle.

22. Intensity of Normal Illumination.—The inverse square law can probably be best understood by referring to Figs. 7 and 8. Consider first Fig. 7, in which the light from a light source is directed by a theoretically perfect parabolic reflector. A reflector of this type has, when the light source is properly placed within it, the property of projecting all of the light in perfectly parallel rays or in a beam. With a theoretically perfect reflector and with the light projected through an absolutely transparent medium the quantity of light at any point in the beam, as for instance at A, Fig. 7, would be the same as at any other point in the beam, as B (Fig. 7). Hence the intensity of illumination, or the brightness of the light, would be the same on A as on B. Parabolic reflectors that are used for automobile head lights give a result that approximates this condition. Obviously a perfect parabolic reflector and a perfectly transparent medium are impossible. The brightness of the beam of light projected by an automobile lamp diminishes as the distance from the lamp increases due to the imperfectness of the reflector, to the dirt and smoke in the air and to the reflection and absorption caused by the particles in suspension in the air.

This property of a parabolic reflector is noted merely to show that light is a perfectly tangible thing just as water is and that the amount or volume of light produced by a source is a perfectly definite quantity. The beam of light, projected from a source in a perfect parabolic reflector, through a perfectly transparent medium would extend out an infinite distance and the intensity of light at any point in the beam would be the same.

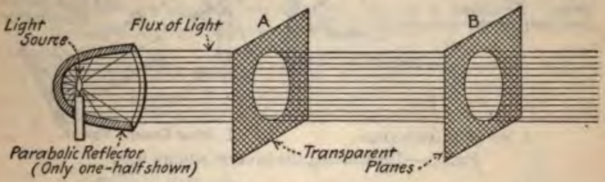


FIG. 7.—Light projected by a parabolic reflector.

Now consider the natural tendency of light (undirected by a reflector) which is to radiate from its source in all directions. It spreads out as it were. Therefore the greater the distance of any point from such a source the lower will be the intensity or brightness at that point. Consider Fig. 8. If the light from source L falls normally or at right angles on a surface A at a distance LA from the source it will illuminate A to a certain intensity or brightness. If instead it falls on a surface B, distant LB (LB being twice LA)

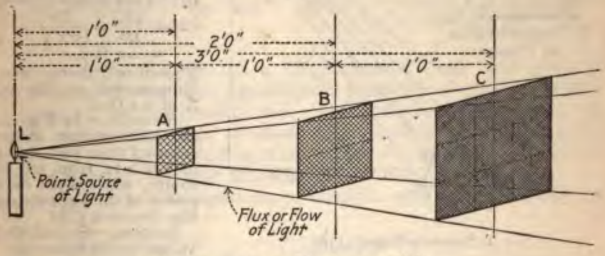


FIG. 8.—The radiation of light.

the same total number of lumens or quantity of light will illuminate a surface twice as wide and twice as high or of four times the area. As the same quantity of light is thus spread out over four times the area the average illumination on B will be but $\frac{1}{4}$ of that on A. If the same quantity of light from the same source falls on surface C (distant LC from L) the flux or beam of light will be spread out over a surface nine times the area of A and the average illumination will be but $\frac{1}{9}$ that on A.

In every case where light is radiated from a point-source to som point the intensity of illumination at the point is inversely prop *tional to the square of the distance of the point from the source.* This law can be expressed as a formula thus:

$$I = \frac{cp}{D^2} \text{ or } D = \sqrt{\frac{cp}{I}} \text{ or } cp = ID^2$$

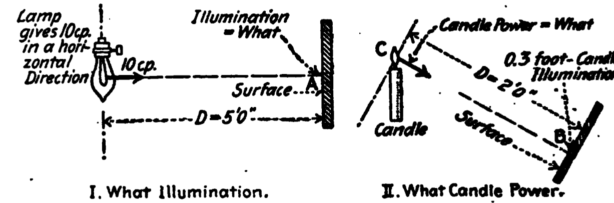


FIG. 9.—Illustrating the inverse square law.

wherein $I =$ the intensity of illumination in foot-candles on a surface normal (at right angles) to the direction of the light rays; cp = candle-power of the light source in the given direction and D is the distance from the source to the surface in feet.

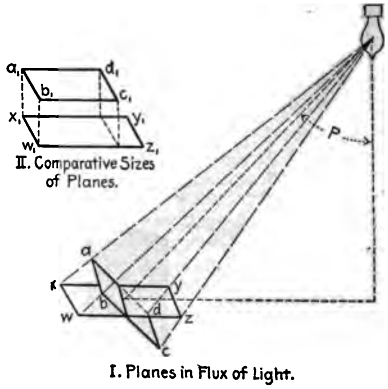


FIG. 10.—Illustrating the theory of the cosine law.

Example.—In Fig. 9, *I*, what is the intensity of illumination at the point *A* on the surface? The lamp produces an intensity of 10 c-p. in a horizontal direction and the surface is 5 ft. from the lamp.

Solution.—Substitute the values in the formula:

$$I = \frac{cp}{D^2} = \frac{10}{5 \times 5} = \frac{10}{25} = 0.4 \text{ ft-c.}$$

Therefore there is an illumination at the point *A* of 0.4 ft-c.

Example.—In Fig. 9, *II*, the illumination at point *B* is 0.3 ft-c. and the surface is 2 ft. from the light source, what is the candle-power of the light source in the direction *CB*?

Solution.—Substitute the values in the formula:

$$cp = ID^2 = 0.3 \times 2 \times 2 = 1.2 \text{ c-p.}$$

Therefore the candle produces 1.2 c-p in the direction *CB*.

23. Limitations of the Inverse Square Law.—Although the inverse square law applies with absolute accuracy only to light emitted from a source so small that it may be considered as a mere point, in practice results are sufficiently accurate if the distance *from the* source to the point at which the light is measured is ten *to fifteen times* as great as the apparent size of the light source.

24. Intensity of Illumination on Horizontal Surfaces. The *Cosine Law.*—(See Fig. 10.) The inverse square law and formula

(Par. 22) indicate how the intensity of illumination, on a surface normal or at right angles to the rays from the source of light, may be computed. Such a surface is indicated by *abcd*, Fig. 10, *I*. The intensity at the center of this surface (*abcd*) would be computed with the formula of 22.

$$I = \frac{cp}{D^2}$$

Now consider the surface *wxyz* which lies in a horizontal plane but which is inclined in relation to the direction of the light from the source. However, the same quantity of light or the same number of lumens (the beam of light included within the pyramid is formed by the dashed lines) illuminates *abcd* as illuminates *wxyz*. *Wxyz* is actually larger than *abcd* as shown at *II*. Since the same

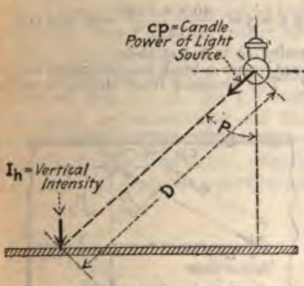


FIG. 11.—Notation for the first cosine law formula.

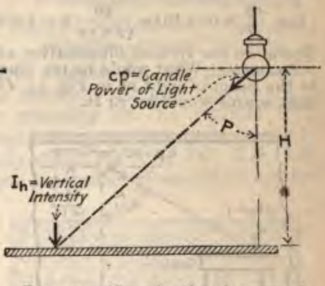


FIG. 12.—Notation for the second cosine law formula.

quantity of light illuminates a larger area in one case than in the other it is evident that the average intensity on the larger area must be less than the smaller one. The reduction in intensity on the area *wxyz* below that of *abcd* is obtained by multiplying the intensity of *abcd* by a factor, the cosine of angle *P*. A table of cosines is given in the first section of this book.

Expressing this statement as a formula using the notation of Fig. 11.

$$I_h = \frac{cp}{D^2} \times \cos P \quad \text{or} \quad D = \sqrt{\frac{cp \times \cos P}{I_h}} \quad \text{or} \quad cp = \frac{I_h \times D^2}{\cos P}.$$

wherein I_h = vertical intensity in foot-candles of the illumination on the horizontal surface; cp = the candle-power of the light source in the given direction, D = distance in feet from the point under consideration to the light source and *cos P* = the cosine of the angle *P* as taken from a table of cosines. (Such a table, condensed, is given in the first section of this book.)

The above formula can be converted into this more convenient form (Fig. 12).

$$I_h = \frac{cp}{H^2} \times (\cos P)^3$$

Wherein the letters all have the same meanings as above except that H = the vertical height in feet of the light source above the horizontal surface illuminated.

25. The value for candle-power (cp) for use in the above formulas should not be taken as the nominal rated candle-power of the light source but should be taken from a photometric curve or from manufacturers' data as the candle-power in the particular direction under considerations as illustrated in following examples.

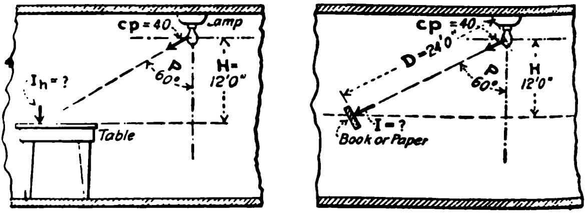
Example.—A lamp is located 12 ft. above a table (Fig. 13, *I*) and in such a position that the angle *P* is 60 degrees. Assume the candle-power of the lamp is 40 in this direction (30 degrees below the horizontal). What is the vertical intensity at the table or in other words what is the intensity of illumination on the table?

Solution.—From the table of cosines in the first section of this book it will be found that cosine (or cos) of 60 degrees = 0.5. Substitute the values from Fig. 13, *I*, in the formula:

$$Ih = \frac{cp}{H^2} \times (\cos P)^3 = \frac{40}{12 \times 12} \times 0.5 \times 0.5 \times 0.5 = \frac{40 \times 0.125}{144} = 0.035 \text{ ft-c.}$$

Therefore the vertical illumination at point *Ih* is 0.035 ft-c.

Example.—What would be the illumination on a book held at right angles to the beam of light as in Fig. 13, *II*? The distance from the book to the light source would be 24 ft.



I Vertical Illumination. II. Normal Illumination.

FIG. 13.—Example of computing vertical illumination.

Solution.—Substitute in the formula of 24:

$$I = \frac{cp}{D^2} = \frac{40}{24 \times 24} = \frac{40}{576} = 0.070 \text{ ft-c.}$$

Therefore the illumination at the point *I* on a book held at right angles to the beam of light would be 0.070 ft-c.

26. The calculation for intensity of illumination on a vertical surface is quite similar to that for a horizontal surface. (See 24. The formula is (see Fig. 14):

$$Iv = \frac{cp}{D^2} \times \sin P \text{ or } \frac{cp}{S^2} \times (\sin P)^3$$

Wherein Iv = the intensity of illumination in foot-candles on the vertical surface; cp = the candle-power of the light source in the given direction; S = horizontal distance in feet from the lamp to the surface and P = angle between the direction of light and the vertical.

27. Caution Regarding the Use of the Preceding Formulas.—It must be understood that illumination intensities derived with the above formulas give the intensity of illumination due to dir light from the light unit, and in practice this derived value is always increased a certain amount by diffusely reflected light. This increase may be relatively large if the ceiling, walls and other objects in the room are light in color and have a high coefficient of reflection, but it is almost negligible in industrial plants, for instance, where the walls may be of dark brick, the roof and girder construction very dark in color, with the space filled with machinery of various sorts.

28. A photometric curve consists of lines, plotted on a polar diagram, which show graphically the distribution of the light about a light source and the candle-power intensities at various directions about the lamp or lamp and reflector. See Fig. 5 and other following illustrations for examples.

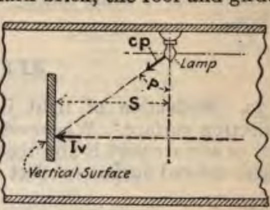


FIG. 14.—Notation for "Illumination on vertical surface" formula.

29. How to Read a Photometric Curve.—In the photometric curve of Fig. 15, *I*, the luminous intensity directly downward is indicated by measuring off this intensity on the vertical to a given scale. Thus, *XA* represents the candle-power intensity directly below the light. Similarly distances *XB*, *XC*, *XD*, *XE*, *XF*, and *XG* represent candle-power intensities given off all around

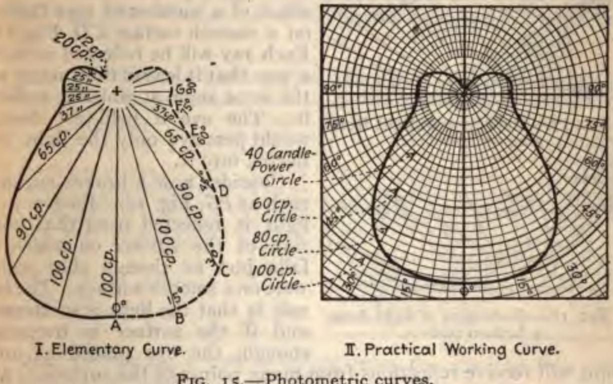


FIG. 15.—Photometric curves.

the light at angles above the vertical of 15 degrees, 30 degrees, 45 degrees, 60 degress, 75 degrees, and 90 degrees. Similarly the candle-power intensities above 90 degrees can be measured off to the given scale along their respective angles. These points are then joined by a continuous line, *G*, *F*, *E*, *D*, etc., and this *line, completed for the 360 degrees, is called the photometric distribution curve of the light.*

Fig. 15, *I*, shows such a completed photometric curve, but in practice it is customary to use circular lines, as indicated on Fig. 15, *II*, to show the scale to which the candle-powers are plotted.

The candle-power intensity of the light-unit can be measured along as few or as many angles as necessary, the accuracy of the resultant curve being largely determined by the number of angles taken.

REFLECTORS

30. **Reflection of light** is the redirecting of light rays by a reflecting surface. Whenever light energy strikes an opaque object or surface part is absorbed by the surface and part is reflected. Light colored surfaces reflect a larger part of the light thrown on them than do dark colored surfaces, whereas dark surfaces absorb a larger part of the light, black surfaces absorb nearly all the light which reaches them. Consider first a smooth surface *AB*, Fig. 16, on which a ray of light *L* falls. This ray will be so reflected in the direction *R*, that the angle *a* is exactly equal to the angle *b*. Consider now the effect of a number of rays falling on a smooth surface *CD*, Fig. 17. Each ray will be reflected in such a way that it leaves the surface at the same angle at which it strikes it. The eye if held as shown would perceive only the light reflected into it.

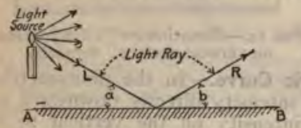


FIG. 16.—Reflection of light from a smooth surface.

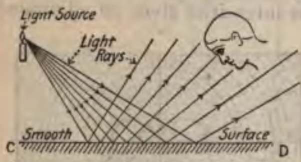


FIG. 17.—Reflection of light from a smooth surface.

FIG. 18.—Reflection of light from a broken surface.

Consider now a broken surface such as *FG*, Fig. 18. Each ray of light is reflected from that portion of the surface on which it falls just as though that point were on a smooth surface. The result is that the light is scattered, and if the surface is irregular enough, the eye placed at any point will receive reflections from many points of the surface. All opaque surfaces except polished surfaces have innumerable minute irregularities like the surface in Fig. 18. This fact alone enables them to be seen.

31. **Reflecting Power of Surfaces.**—Different surfaces reflect different percentages of the light falling upon them. The illumination of a small room having poorly reflecting walls can often be improved by changing the wall coverings, particularly if bare lamps are used. If the room is large or if reflectors are used to throw the light downward so that not much light reaches the walls to be

reflected, a change in the wall covering will have little effect on the general illumination.

32. **The following table of reflection coefficients** (*Art of Illumination, Bell*) is useful in showing the relative reflective value of wall coverings in rooms.

Material	Per cent. reflection	Material	Per cent. reflection
Highly polished silver....	92	Chrome yellow paper....	62
Optical mirrors silvered on surface	70 to 85	Yellow wall paper.......	40
		Light pink paper........	36
Highly polished brass...	70 to 75	Blue wall paper.........	25
Highly polished copper...	60 to 70	Dark brown paper	13
Highly polished steel.....	60	Vermilion paper.........	12
Speculum metal.........	60 to 80	Blue green paper........	12
Polished gold...........	50 to 55	Cobalt blue.............	12
Burnished copper........	40 to 50	Glossy black paper......	5
White blotting paper.....	82	Deep chocolate paper....	4
White cartridge paper....	80	Black cloth.............	1.2
Ordinary foolscap.......	70	Black velvet............	0.4

33. **Absorption** is the loss of intensity or of volume of light that occurs when it passes through a reflecting or a translucent material, or when it is reflected by a reflecting surface.

34. **Absorption of Light by Globes and Reflectors.**—If globes are used on lamps, account must be taken of the light absorbed by the globes in calculating the total candle-power or lumens required. Table 35 gives average values (*Electrical Equipment of the Home—N. E. L. A.*).

35. **Coefficients (per cent.) of Absorption of Globes and Shades**

Material	Per cent. absorption	Material	Per cent. absorption
Clear glass globes.......	5 to 12	Opaline glass globes.....	15 to 40
Light sand blasted globes	10 to 20	Ground glass globes.....	20 to 30
Alabaster globes........	10 to 20	Medium opalescent globes	25 to 40
Canary-colored globes....	15 to 20		
Light blue alabaster globes.	15 to 25	Heavy opalescent globes	30 to 60
		Flame glass globes......	30 to 60
Heavy blue alabaster globes	15 to 30	Signal green globes.....	80 to 90
		Ruby glass globes.......	85 to 90
Ribbed glass globes.....	15 to 30	Cobalt blue globes......	90 to 95

36. **Refraction** is the changing from the straight line, which a light ray normally assumes, that occurs when the ray passes from one medium into another of different density.

37. **An unshaded incandescent lamp** should never be tolerated under any circumstances, unless the bulb is completely frosted, and even then only in such locations as store rooms, etc., where it is desirable to light the entire wall surface, and where the eyes are normally directed away from the location of the lamps. *This is because the lamp filament has a high intrinsic brilliancy; hence looking at it continually with the unprotected eye is apt to permanently injure the eye.*

38. Distribution Curves of Reflectors.—The effect of a reflector in changing the direction of light given out by a light source is best expressed in the form of a distribution curve. Fig. 19 shows such a curve for a bare lamp and for the same lamp with a reflector. The curve represents the light in a single vertical plane through the center of the light unit, and it is assumed that the light in all similar vertical planes is similarly distributed. See **29** "How to read a photometric curve."

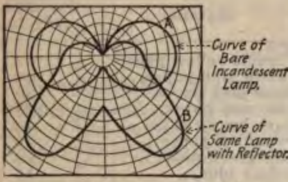


FIG. 19.—Comparison between distribution curve of a bare incandescent lamp with that of the same lamp equipped with a suitable reflector.

39. The area of the distribution curve is not proportional to the amount of light given off. Curve *B*, Fig. 19, represents a smaller total flux, by an amount equal to the absorption in the reflector, than does curve *A*, though it has a larger area. Such a curve as *B* is useful only for determining the intensity of light at any given angle below the horizontal.

40. Extensive, Intensive and Concentrating Reflectors (Fig. 20).—The Holophane Company first classified their reflectors into extensive, intensive and concentrating types, to which was later added the focussing type, the name designating the broadness

FIG. 20.—Typical prismatic glass reflectors.

of distribution as indicated by the distribution curve. These type names have since been adopted by other reflector manufacturers who make reflectors having definite and in general somewhat similar distribution curves, adapted for different mounting heights and spacing distances.

41. Application of Extensive, Intensive, Focussing and Concentrating Reflectors.—In general, focussing reflectors should be used when the distance between lamps is ¾ the mounting height; intensive reflectors should be used where the distance between lamps is about 1¼ times the mounting height; extensive reflectors should be used where the distance between lamps is twice the mounting height. These figures are averages and may not apply to all makes of reflectors. If the best results as to uniformity of illumination are desired, lamps should be suspended from ceilings at such a distance as to give proper ratio of lamp spacing to mounting height, as advised by the reflector manufacturer or as determined by plotting illumination curves.

FIG. 21.—Typical photometric curves of lamps with "extensive" reflectors.

The different types (extensive, intensive, etc.) of Holophane reflector are not, in general, designed to give different illumination results. They are designed to give the same result, each type being suitable for a different condition of height and spacing of lamps.

42. Extensive globes and reflectors (Fig. 20, *I*) distribute the reflected light over a wide angle below the horizontal (see Fig. 21). They are primarily for lighting moderately small rooms (say 12 ft. square) with single units or chandeliers on which the lamps hang pendant. The "extensive" type of distribution will meet the requirements of the following classes of rooms (*National Electric Lamp Association*):

FIG. 22.—Typical photometric curves of lamps with "intensive" reflectors.

1. Rooms in residences where a single light or group of lights centrally located is employed (the distribution of several units hung vertically being approximately the same as that of a single unit).
2. Small offices, waiting rooms, alcoves, etc., where the conditions are substantially as above.
3. Wide hallways having moderate height of ceiling, stock-rooms, workrooms or other cases where even, general illumination is desired from a single line of outlets.

FIG. 23.—Typical photometric curves of lamps with "focussing" reflectors.

Extensive reflectors of the Holophane line give a distribution with the maximum candle-power at about 45 to 50 degrees up from the vertical.

43. *Intensive globes and reflectors* (Fig. 20, II) throw the ligh downward in a rather narrow angle (see Fig. 22). The prima purpose for which the "intensive" type of distribution was designed is that of evenly illuminating large rooms by means of distributed units placed close to the ceiling in the form of squares. This system is used commonly in department and other large stores, in dining halls and restaurants, hotel and club lobbies, large offices, assembly rooms, lodge rooms, halls of moderate dimensions, council chambers, court rooms, etc., where the lights are hung high above the plane of illumination. This method of lighting is seldom used in residences.

Intensive reflectors of the Holophane type have their maximum candle-power at and below 45 degrees.

44. **Focussing globes and reflectors** (Fig. 20, *III*) concentrate the light to a small area, producing greatest intensity of illumination along the axis of the reflector (see Fig. 23). The classes of lighting for which "focussing" reflectors are designed, include the illumination of tables, desks, display windows, store counters (by means of a row of lights placed high and directly over the same) and very high rooms (where they are used in the same manner as the "intensive" type). "Focussing" reflectors give an end-on candle-power approximately $3\frac{1}{2}$ times as great as the lamp's rated horizontal candle-power. The area intensely illuminated is a circle, the diameter of which should be one-half the height of the lamp above the plane of illumination; outside this limit the intensity falls rapidly, but not so abruptly as to give the effect of a spot of light.

Holophane "focussing" reflectors give their maximum candle-powers at about 10 degrees from the vertical.

45. **Concentrating reflectors** throw the light more strongly downward than those of the focussing type, giving in some cases an end-on candle-power of eight times the rated horizontal candle-power of the bare lamp. Higher concentration can easily be obtained but is not generally required commercially.

FIG. 24.—Silvered reflector for indirect lighting.

45A. **Asymmetric Reflectors** are those by which most of the light rays are thrown toward one side of the reflector. This is effected by interior vertical prisms which redirect the light from the side where it is not needed.

46. **Reflectors for Indirect Lighting.**—As manufactured by the National X-ray Reflector Company, a reflector, pointed upward, is placed under the lamp, and all of the light is directed to a light-colored ceiling. The room is illuminated by a reflected light from the ceiling. The result is a widely diffused illumination which resembles daylight; that is, shadows and general effects are similar to diffused daylight coming through a skylight or window. The decoration of the room, especially of the ceiling in which the system is to be used, should be of some light color. For best results the

ceiling should be a light cream or ivory, although somewhat darker shades give very satisfactory results. The walls of the room may be given darker tints, such as light brown, buff or tan. In all cases the lamps used with the system should be clear bulb tungsten. Each lamp has its individual reflector, especially designed, thus insuring the highest possible efficiency.

Many different types of reflectors are used, each adapted to particular conditions. One of these, a distributing type of reflector, is illustrated. Before attempting to suggest fixtures for any particular interior it is well to determine exactly what the conditions are under which the system is to be used, since the size and height of the room, color of walls and ceilings, as well as the location of the electric outlets, all affect the style of equipment that is to be specified. Styles of fixtures employed with this system are shown in Fig. 4. These fixtures are installed in exactly the same way as other electric-lighting fixtures. Some are designed for single lamps, others for multiple units, some types are made of metal, while others are constructed of "Compone" and composition. Special adaptables which may be added to the ordinary arm fixture can be procured. These adaptables hold the reflector in the correct relation to the filament of the lamp and can be readily fitted to arm fixtures that are already in place.

INCANDESCENT LAMPS

47. **Electric incandescent lamps** consist of a filament which is a highly refractory conductor mounted in a transparent glass bulb and provided with a suitable electrically connecting base. In incandescent lamps of the older types the air was, in so far as practicable, exhausted from the space within the bulb and surrounding the conductor (filament), leaving there a vacuum. But in many of the modern lamps this space is filled with an inert transparent gas—like nitrogen, for example. The conductor must have a high melting point or high vaporizing temperature and a high resistance; it must be hard and not become plastic when heated. In vacuum-type lamps the vacuum must be good, not only to prevent the oxidation of the filament, but also to prevent the loss of heat, which would reduce the efficiency. In non-vacuum-type lamps (gas-filled lamps) the gas used must be inert so as not to combine chemically with the filament material. The bulb must be transparent to permit the passage of light, not porous, so that it will retain the vacuum or inert gas, and strong to withstand handling and use.

48. **Classes or Types of Incandescent Lamps.**—There are now June, 1915) but three classes of incandescent lamps on the market, viz.: (1) *Carbon* filament, (2) *Metalized* filament or Gem, and (3) *Tungsten* filament or "Mazda." Several years ago the *tantalum* lamp was quite popular because it was then economical; this was prior to the perfection of the tungsten lamp. The demand for and manufacture of tantalum lamps has practically ceased because of the materially higher efficiency of the tungsten (or Mazda) lamp.

THE CARBON LAMP contains a filament made by carbonizing cellulose thread, forming a filament of pure carbon. Its efficien averages about 3.1 watts per candle. THE METALIZED FILAME OR GEM LAMP contains a carbon filament which has been treated an electric furnace. This treatment imparts certain metall properties to the carbon, thus permitting its operation at high efficiencies than are feasible with ordinary carbon-filament lamp Its efficiency is about 2.5 watts per candle. THE TUNGSTEN MAZDA LAMP has a filament of pure, drawn tungsten wire; s Art. 52.

48A. Voltage and Wattage Ratings of Incandescent Lamps. All incandescent lamps for standard lighting circuits are now rat in watts. The watts rating of every lamp is indicated on its lab On the label is also specified the voltage at which the lamp designed to operate. *The Three-Voltage-Rating* was formerly us but the present practice is to show only one voltage. During t pioneer days of tungsten lamps their performances were somewh uncertain and their first cost was high. Under these conditions t three-voltage-rating was justified inasmuch as it provided a mea whereby light could be readily obtained at minimum cost wi different power rates. Now, however, the lamps are low in pr and their performance is uniform, hence, it appears, the thr voltage-rating is undesirable.

49. The life of an incandescent lamp (that is, the *useful* life) always understood to mean the total hours of burning before t candle-power drops to 80 per cent. of the initial, unless the la becomes useless because of broken filament, or other cause prior this. THE TOTAL OR BURNOUT LIFE of a lamp is the hours burni before failure of the filament.

50. Effect of Voltage Variation on Carbon Lamps

(All values in per cent.)

Volts	Candle-power	Watt per candle	Life
110	169	72.0	15.0
109	161	74.0	18.0
108	153	76.5	21.0
107	145	79.0	24.5
106	138	81.5	29.0
105	131	84.0	34.0
104	124	87.0	40.0
103	118	90.0	48.0
102	111	93.0	60.0
101	106	96.5	80.0
100	100	100.0	100.0
99	95	103.0	120.0
98	90	106.0	147.0
97	85	109.5	175.0
96	80	113.5	200.0
95	75	118.5	270.0
94	71	123.5	355.0
93	67	128.0	450.0
92	63	134.0	545.0
91	59	140.5	650.0
90	55	147.5	760.0

51. 220-volt vs. 110-volt Incandescent Lamps.—A number of 220–440-volt 3-wire direct-current systems have been installed with the idea of saving copper over that required for the 110–220-volt system. A comparison of lamp ratings shows that the 220-volt lamp—whether carbon, metallized or tungsten—has a much lower efficiency than the 110-volt lamp, costs more, and cannot be secured at all in the smaller sizes. Unless the load is composed so largely of motors that the lamp efficiencies and costs are overbalanced—which is not usually the case in these installations—it will be found that the saving effected by the use of 110-volt lamps will overbalance the saving in copper or the convenience effected by the higher voltage system.

52. Tungsten or Mazda Lamps.—The filament of the tungsten lamp is composed of pure metallic tungsten. When the lamps were first manufactured, the finely divided metal was mixed with a binder and squirted through a die, the binder afterward being burned away. As so made, the filaments were hairpin shape, and a number of them were connected in series in each lamp. At present the metal is drawn through dies, the same as any other wire, the final drawings being through diamond dies. The filament has a high tensile strength, is quite elastic and reasonably flexible, and the filament in each lamp is continuous, producing much better efficiency and greatly improved life. The modern lamps are capable of standing the abuse that may be accorded carbon or metallized lamps, and are very greatly superior to those originally produced, standing any reasonable amount of vibration without breakage. Unless accidentally broken, the lamps will easily average 1,000 hr. useful life. In fact, the efficiency ratings have been increased repeatedly (*i.e.*, the watts per candle decreased) in order to keep the average lamp from exceeding the rated life too greatly. The useful life of vacuum lamps has also been greatly increased by the addition of certain elements which absolutely prevent, except in case of impaired vacuum, the blackening of the globes, which was formerly so common.

It is possible to substitute tungsten lamps for either the obsolete carbon or the metallized filament lamps to give an equivalent candle-power with a saving of at least 60 per cent. in the energy consumed, or to consume an equivalent amount of energy with an increase of at least 60 per cent. in the light produced. The saving effected by the use of tungsten lamps, especially by substituting the larger size lamps for many smaller lamps, is of great importance.

The efficiencies of modern vacuum tungsten lamps range from about 1.3 watts per candle for the 10-watt lamps up to 0.9 watt per candle for the 250-watt lamps. The average for all sizes is about 1.3 or 1.4 watts per candle.

53. Tungsten Lamp Characteristics.—The positive temperature characteristic of the metallic filament makes the tungsten lamp much less sensitive to voltage variation than the carbon or even the metallized carbon filament. The resistance of the filament *is very much lower* when cold than at its operating temperature. *This causes it to take* an abnormal current when first turned on, causing the light intensity to increase very rapidly, producing the well-known "overshooting" of tungsten lamps. This is especially noticeable when both carbon and tungsten lamps are controlled from the same switch, the white light from the tungsten lamps appearing an appreciable interval of time before the yellower light of the carbon lamps. The changes produced by this characteristic of the tungsten lamp by changes in voltage are given in 56.

53A. Gas-filled, Tungsten Incandescent Lamps.—Until recently it has been the practice of lamp manufacturers to exhaust the bulbs of incandescent lamps to an almost perfect vacuum. It has, however, been demonstrated that it is possible to operate tungsten wire filaments at higher temperatures in a bulb containing an inert gas. The presence of this inert gas in the bulb retards the evaporation of the filament. The convection currents—hot-gas currents—carry any particles evaporated to the upper portion of the bulb where they are deposited but where they absorb very little useful light. The filaments of these lamps are coiled and mounted in a compact manner to prevent their being cooled appreciably by the passage of the rising gas. These gas-filled tungsten lamps are referred to by some manufacturers as *Mazda C* lamps to distinguish them from the vacuum tungsten lamps which are now called *Mazda B*. The gas-filled lamps operate at considerably higher efficiencies than do the vacuum lamps but are so designed as to give the same useful life, viz., 1,000 hr. It is the usual practice to make the gas-filled lamps with pear-shaped bulbs having long glass necks. The efficiencies range from 0.80 watt per candle for the 100-watt multiple lamp to 0.45 watt per candle for the 1,000-c-p., 450-watt street series lamp.

53B. Mazda or Tungsten Lamp Illumination Data
(*Multiple Lamps*)

Watts	Efficiency watts per candle	Mean horizontal candle-power	Efficiency spherical candle-power per watt	Efficiency lumens per watt	Total lumens	Reduction factor per cent.
Straight-side type (vacuum), 105–125 volts						
10	1.30	7.7	0.60	7.54	75	78
15	1.15	13.0	0.68	8.52	128	78
20	1.10	18.2	0.71	8.91	178	78
25	1.05	23.8	0.74	9.34	234	78
40	1.03	38.8	0.76	9.52	381	78
60	1.00	60.0	0.78	9.80	588	78
100	0.95	105.0	0.82	10.32	1,032	78
150	0.90	167.0	0.87	10.89	1,634	78
250	0.90	278.0	0.87	10.89	2,723	78
Straight-side type (vacuum), 220–250 volts						
25	1.20	20.8	0.66	8.27	207	79
40	1.12	35.7	0.71	8.86	354	79
60	1.10	54.5	0.72	9.02	541	79
100	1.06	94.3	0.75	9.37	937	79
150	1.00	150.0	0.79	9.93	1,490	79
250	0.95	263.0	0.83	10.45	2,613	79

53B. Mazda or Tungsten Lamp Illumination Data
(*Multiple Lamps*).—(*Continued*)

	Efficiency watts per candle	Mean horizontal candle-power	Efficiency spherical candle-power per watt	Efficiency lumens per watt	Total lumens	Reduction factor per cent.
			Pear-shape type (gas filled), 105–125 volts			
00	0.80	125.0	1.00	12.57	1,257	80
00	0.75	267.0	1.07	13.40	2,680	80
00	0.70	429.0	1.14	14.36	4,310	80
00	0.70	571.0	1.14	14.36	5,745	80
00	0.70	714.0	1.14	14.36	7,180	80
50	0.65	1,154.0	1.23	15.47	11,600	80
00	0.60	1,667.0	1.33	16.76	16,760	80

;4. **The tantalum lamp** had a filament composed of metallic ıtalum. It had an efficiency of about 2 watts per candle. This ıp is not satisfactory for use on alternating current as the filament :omes beady and breaks after a short life. The demand for this ıp has practically ceased, it having been superseded by the more cient and rugged tungsten lamp.

;5. Characteristics of Metallized Filament or Gem Lamps
(All values in per cent.)

Per cent., change in	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
ts..........	95.0	96.0	97.0	98.0	99.0	100
peres........	95.8	96.7	97.5	98.4	99.2	100
tts..........	91.0	92.8	94.6	96.4	98.2	100
,............	75.1	79.6	84.4	89.4	94.8	100
P.C.........	121.0	116.6	112.2	108.0	103.7	100
:............	265.0	217.0	176.0	147.0	120.0	100
ts....................		101.0	102.0	103.0	104.0	105.0
peres.................		100.8	101.6	102.4	103.2	104.1
tts...................		101.8	103.6	105.5	107.3	109.3
,.....................		105.3	110.3	114.9	120.4	126.2
P.C...................		96.5	94.0	92.0	89.0	86.5
:.....................		83.0	68.0	59.0	50.0	43.0

56.' Characteristics of Tungsten (Mazda) Lamps
(All values in per cent.)

Per cent., change in	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
ts..........	95.0	96.0	97.0	98.0	99.0	100
peres........	97.1	97.7	98.3	98.9	99.4	100
tts..........	92.4	93.9	95.5	97.1	98.5	100
,............	83.6	86.7	90.0	93.3	96.6	100
P.C.........	110.3	107.9	105.7	103.7	101.8	100
:............	212.0	181.0	154.0	132.0	115.0	100
ts....................		101.0	102.0	103.0	104.0	105.0
peres.................		106.6	101.1	101.7	102.2	102.8
tts...................		100.6	103.2	104.6	106.1	107.5
'.....................		103.4	107.0	110.0	114.4	118.2
'.C...................		98.1	96.3	94.5	92.8	91.1
....		86.0	74.0	64.0	56.0	48.0

57. **Bases for Incandescent Lamps** (See Fig. 28).—Standard nomenclature in this respect has been changed recently. One of the important changes is the substitution of the term "Screw" for "Edison" as applied to bases. The term "Bayonet" base has been adopted in place of the term "Ediswan" base. The classifying adjectives, "Medium" and "Mogul" have been adopted in place of the words "Large" and "Street Series" which were formerly

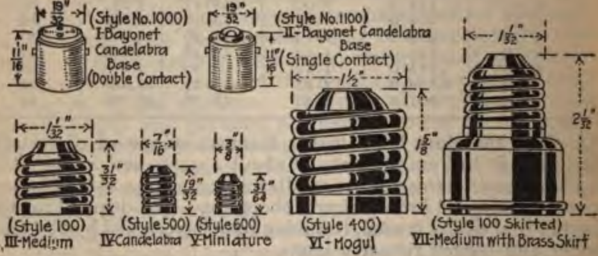


FIG. 28.—Different sizes of "screw" lamp bases.

used. Lamp bases may be divided into three general classes, as the base in a general way determines to which of the three styles the lamp belongs. 1. *Medium bases*, generally used with large lamps. 2. *Small bases*, generally used with candelabra and miniature lamps. 3. *Mogul bases*, generally used with street series lamps.

ARC LAMPS

58. **Carbon Arc Lamps.**—If two pieces of carbon are connected to an electric circuit and brought together, current flows through them. As the contact between the two pieces is poor, due to the nature of the materials, considerable heat is developed at that point. If the two carbons are now slowly separated, the resistance of the contact increases until the heat developed becomes sufficient to vaporize the end of one or of both of the carbons. This vapor forms a conducting path for the current after the carbons are separated and the current flows through this vapor, forming an electric "arc."

59. **Open and Enclosed Electric Arc Lamps.**—When the air can come freely in contact with the arc, the carbons are burned away very rapidly. This is the case with open arcs, which term includes those having a large globe into which air can enter freely. To prevent the rapid oxidation of the carbons and also to make the arc more steady, an inner globe, almost air tight, is provided on all modern carbon arc lamps. This globe and the "gas check" or cap are so designed that just enough air is admitted to burn up the carbon vapor so that it will not deposit on the globe. The increase in life of carbons that results from enclosing the arc is indicated in 60.

60. Representative Arc Lamp Data.—(*Wickenden*)

NOTE.—Values of watts per mean lower hemispherical candle-power approximate for open carbon arcs and magnetite arcs with clear globes, enclosed carbon arcs with opalescent inner globes and for flame and regenerative arcs with opal globes.

Type of lamps	Open or enclosed	Electrodes	Hours per trim	Amperes	Terminal volts	Arc volts	Terminal watts	Arc watts	Terminal power factor.	Watts per m.l.h. c-p.
D.-c series carbon arcs.	Open.....	+Upper, solid or cored. −Lower, solid.	9 to 12	9.6	50	47	480	450	....	0.6
	Open.....	+ Upper, solid or cored. − Lower, solid.	9 to 12	6.6	49.5	47	325	310	....	0.7
	Enclosed..	+ Upper, solid or cored. − Lower, solid	100 to 150	6.6	72.0	68	475	450	....	0.9
A.-c. series carbon arcs.	Enclosed..	One solid. One cored...	70 to 100	7.5	75.0	72	480	450	0.85	1.8
	Enclosed..	One solid. One cored...	70 to 100	6.6	77.0	72	425	400	0.85	2.0
D.-c. multiple carbon arcs.	Enclosed..	+ Upper, solid. − Lower, solid.	100 to 150	5.0	110.0	80	550	400	....	2.25
	Enclosed..	+ Upper, solid. − Lower, solid.	100 to 150	3.5	110.0	80	385	280	....	2.35
A.-c. multiple carbon arcs.	Enclosed..	One solid One cored...	70 to 100	6.0	110.0	72	430	375	0.65	2.40
	Enclosed..	One solid. One cored...	70 to 100	4.0	110.0	72	285	250	0.65	2.60
D.-c. flame arcs.	Open.....	Mineralized inclined....	10 to 16	8.0	55.0	45	440	360	....	0.45
	Open.....	Mineralized inclined....	10 to 16	10.0	55.0	45	550	450	....	0.40
	Open.....	Mineralized vertical....	10 to 16	8.0	55.0	38	440	304	....	0.45
	Open.....	Mineralized vertical....	10 to 16	10.0	55.0	38	550	380	....	0.40
Regenerative...	Semi-enclosed.	− Upper carbon. + Lower carbon, mineralized.	70	5.0	....	70	....	350	....	0.26
A.-c. flame arcs	Open.....	Mineralized inclined....	10 to 16	8.0	55.0	47	374	338	0.85	0.60
	Open.....	Mineralized inclined....	10 to 16	10.0	55.0	47	467	423	0.85	0.55
	Open.....	Mineralized vertical....	10 to 16	10.0	55.0	40	467	360	0.85	0.55
Magnetite......	Open.....	+ Copper. − Metallic oxide.	150 to 180	4.0	80.0	78	320	312	....	0.70
	Open.....	+ Copper. − Metallic oxide.	70 to 100	6.6	80.0	78	528	515	....	0.45

The carbons of an enclosed carbon arc lamp should burn 100 hr. on alternating current and 150 to 180 hr. on direct current if properly operated. Also as the air is excluded the carbons can be burned farther apart, resulting in better light distribution.

To secure satisfactory operation of an enclosed arc, however, care is necessary in the selection of carbons, both as to exact size and quality. Sufficient air must be admitted to unite with the carbon vapor as it is given off or it will deposit on the globe; too much air will greatly decrease the life per trim. If the diameter is not right, either too great or too small, air will be admitted through the gas check. If the quality of the carbon is poor, a deposit will form on the inner globe and discolor it.

61. Flame Arc Lamps.—Any of the ordinary carbon arcs can be made to flame by increasing the arc length or the current density. Such a flame gives off little or no light and hence is disadvantageous. By feeding into the arc certain metallic salts the arc flame can be made to produce light—the color varying with the metal used. Calcium—especially calcium fluoride—produces a yellow-colored light of very high efficiency. Strontium salts produce a reddish color and barium and titanium salts a brilliant white, at a somewhat reduced efficiency. The metallic salts are introduced into the flame by using either carbons cored with a mixture of soft carbon with the desired salt or salts or an electrode impregnated throughout with the desired compound. The carbons may be vertical, and co-axial as in the ordinary arc, but in most open-flame lamps they are inclined in a V-shape. There is thus no obstruction to the light below the horizontal. The arc burns in a cup-shaped economizer of a refractory material, which serves as a reflector, to shield the arc from air currents, and to prevent it from running up the carbons. A small magnet just above the economizer serves to "blow" the arc downward into a bow shape.

62. The open-flame carbon arc is dirty, giving off offensive fumes, and is very costly to maintain on account of the short life of the carbons, which are quite expensive. These defects have been overcome by enclosing the arc in an air-tight chamber.

63. Candle-power of Inclined Electrode Flame Arc Lamps.—The light from this type of lamp is given off at its greatest intensity in a direction nearly under the lamp. This is excellent for display lighting but not so satisfactory for street illumination and for this purpose the light distribution from the lamp is modified with a suitable reflector.

64. Long-burning or Enclosed Flame-carbon Arc Lamps.—Several manufacturers have recently placed on the market flame arc lamps constructed on the principle of the enclosed carbon lamp, *i.e.*, having an enclosed arc chamber from which free access of air is prevented. Some of these lamps have a burning life of as much as 100 hr. per trim. The globe is kept free from the deposit of soot by arranging the air circulation and condensing chambers in which the fumes deposit. These lamps preserve the advantage of the flame arc lamp—high light efficiency—and do not have most of its objectionable features.

he **enclosed flame arc lamp,** the arc of which is essen-t of the ordinary open flame arc lamps, has a burning rim of 100 hr. and compares favorably in candle-power ency with the short-burning open-flame arc lamp. To ng burning life of the carbons, the arc is enclosed in a to which the supply of air is limited, as in the case of the enclosed arc lamp. In the flame-carbon lamp, however, ncy is reduced very little by the enclosure.

agnetite, Luminous, or Metallic Flame Arc Lamps.—several makes of lamps on the market using one electrode that requires very infrequent renewal, and one of metallic These lamps combine the principles of the carbon arc lame arc, in that both the arc stream and the electrodes ly luminous. These ve the peculiarity that ative electrode burns nile the positive elec-consumed very slowly. ts these lamps to direct-ircuits. The negative of these lamps is a r conductor when cold efore a conducting wire ly run through its cen-rry current to the arc, ode serving principally ply of substance to be the arc. In one make np the negative is placed ttom and in another at

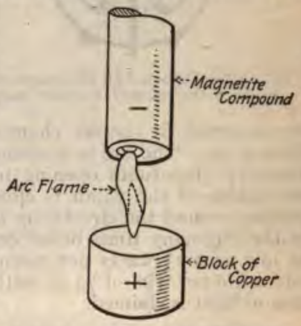


FIG. 29.—Electrodes of metallic flame lamp.

gative electrode (Fig. 29) or cathode has a life of 160 to . The arc flame is brightest near the negative electrode eases in brilliancy and volume as it nears the positive Mechanisms in these luminous lamps feed the negative intermittently by restriking the arc. When the current n on the feeding magnets are energized, bringing the together and striking the arc. A shunt magnet con-ound the arc acts when the voltage caused by lengthening c is sufficiently increased. This closes a contact which uits the arc, causing the feeding magnets to strike the with sufficient force to dislodge any drops of slag which accumulated.

agnetite arc is well adapted for series operation with low (Wickenden.) The four-ampere lamp, designed for series at 80 volts per lamp, has been widely used for street on. The 6.6-amp. lamp has a much higher efficiency newhat shorter life per trim.

tensified Arc Lamps.—By using special, small diam-ons and a high-current density in these lamps, the tem-of the arc is considerably increased, and the ends of both ecome incandescent, giving an increased light efficiency

current, passing from the positive electrode to the negative, vaporizes some of the mercury and causes the vapor to become luminous.

70. **The Arc.**—It being practically impossible to pass an alternating current through a mercury arc, the mercury vapor lamp is therefore essentially a direct-current lamp, and gives its best results when operating on direct current. By providing two anodes, and an auto-transformer, the lamp can be operated, however, on alternating current, using the principle of the mercury rectifier, and alternating-current lamps are regularly marketed and satisfactory in operation.

71. **Quality of light** from a mercury vapor lamp is peculiar. It contains no red rays, and has a peculiar bluish-green color, which greatly distorts the color values of objects viewed by it. For work in which it is not necessary to distinguish color values, two advantages are claimed by the maker. *First*, due to the absence of red rays, it is easy on the eyes, since these rays are the least effective in producing vision, and, owing to their heating power, are irritating and fatiguing to the retina. This is offset by the great preponderance of ultra-violet rays which are claimed by some to be harmful, although this has not been established experimentally. *Second*, the approximately monochromatic nature of the light promotes acuity of vision, *i.e.*, objects are seen more sharply and details are more easily discernible than by white light. The lamps are chiefly useful for drafting, photography, and for lighting large manufacturing areas.

PRINCIPLES OF ILLUMINATION DESIGN

72. **General Principles of Illumination.**—The general purpose of illumination is to enable things to be easily seen. As things are seen by the light reflected from them into the eye, it is necessary to have the lighting units of such number and intensity and so arranged as to make the things it is desired to see most easily seen. To do this, account must be taken of the effect of illumination on the eye. Before attempting to lay out an illumination scheme one should be familiar with the facts outlined under *Physiological Features of Illumination*, Paragraph 1.

73. **Location of Lights.**—No general rule can be given for location of lights for general illumination. It is always desirable to so distribute the units that uniform illumination will result. Where the number and location of lighting outlets is not determined by architectural considerations, or by the arrangement of the furniture and fixtures, it is desirable to arrange the lighting outlets in the form of squares or rectangles. It is important that the units be placed at the centers of the squares and not at the corners. Fig. 32 shows this method of locating outlets which is bad because it gives a very low intensity of illumination near the walls, as compared with that at the center of the room. Fig. 33 shows the correct way of locating outlets in the centers of the squares. In certain cases, notably in office lighting, it may be desirable to pl

the outer rows of outlets somewhat nearer the side walls of the room than would be the case if symmetrically arranged as shown in the diagram, to avoid shadows.

For a given ceiling height, the smaller the squares, the less intense will be any shadows produced. The higher the ceiling, the larger the squares can be. As a general rule the side of each square should about equal the height of the ceiling. For offices that have no desk lighting the squares should be smaller, say $\frac{3}{4}$ the height of the ceiling, to reduce shadows; for stores the squares can be a little larger.

If the room is divided by partitions, each enclosure should be treated as a separate room.

Where the ceiling is divided into panels or broken up by girders, the size and location of these often determine the spacing of the lights. In such cases it is advisable to space the lighting units symmetrically according to the decorations and girders and select lamp sizes and reflectors adaptable to such spacing.

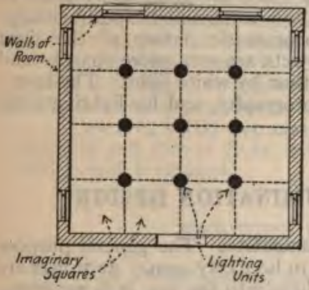


FIG. 32.—Wrong arrangement of lighting units.

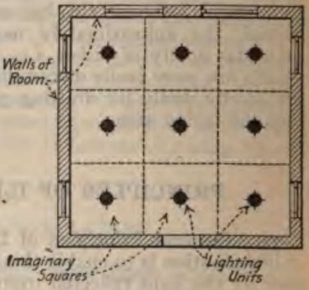


FIG. 33.—Correct arrangement of lighting units.

74. Desirable Sizes of Squares.—In lighting large offices, where individual desk lights are not employed, the squares should be comparatively small in order to have the light on any one desk coming from many units, thus merging the shadows and decreasing the glare due to regular reflections from the desk. In stores, the squares need not be so small. The size of the squares bears no relation to the intensity of illumination, but only to the evenness of illumination and depth of shadows. The following table gives the sizes of squares desirable for various spaces for direct lighting. The table cannot be strictly adhered to in all cases, and it is better not to use with the smallest ceiling height in each line the largest size square available for that height. In office lighting with no desk lights, the squares should never be made so large that extensive reflectors are necessary to obtain uniform illumination. (*Holophane Company.*)

Kind of room	Ceiling height	Desirable length of side of square
Armories	12 to 16 ft.	12 to 16 ft.
Auditoriums	12 to 16 ft.	12 to 16 ft.
Public halls	over 16 ft.	15 to 26 ft.
Rinks	over 16 ft.	15 to 26 ft.
Stores	8 to 11 ft.	8 to 11 ft.
Stores	11 to 15 ft.	10 to 16 ft.
Stores	over 15 ft.	14 to 22 ft.
Offices with individual desk lights	10 to 20 ft.	12 to 18 ft.
Offices without individual desk light	9 to 12 ft	7 to 11 ft.
Offices without individual desk light	12 to 16 ft.	9 to 14 ft.
Offices without individual desk light	over 16 ft.	11 to 18 ft.

75. **A spacing chart for prismatic reflectors** is shown in Fig. 34. Knowing either the spacing or mounting height, the correct reflector and its proper mounting height or spacing can be determined at a glance, or vice versa.

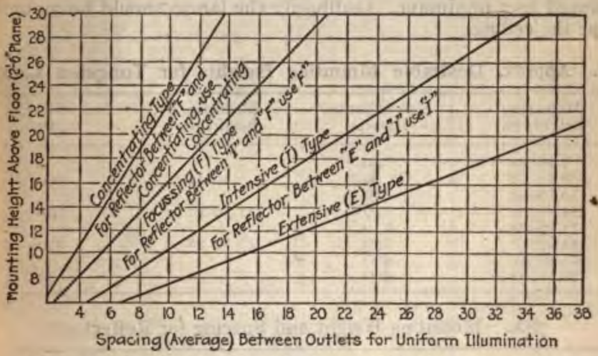


FIG. 34.—Spacing chart for reflectors. (*Holophane Company.*)

EXAMPLE.—Consider an installation for which a spacing distance of 14 ft. has been selected. With this spacing distance extensive type reflectors call for a mounting height of about 9½ ft. above the floor. This is obviously too low to secure the best diffusion and minimum shadows, so reference is made to the diagonal in Fig. 34 representing the intensive type, and a mounting height of 13½ ft. is found. This gives a distance from ceiling to socket of about 1 ft. with a 15-ft. ceiling.

75A. **Spacing for indirect and semi-indirect lighting** is determined largely by the ceiling height. The distance between units should not, in general, exceed 1¾ times the height of the ceiling above the plane to be lighted, draughting rooms and offices where close work is performed should have closer spacings.

76. **Mounting height** usually means the distance from the center of the lamp to the plane of illumination, but it may mean the mounting height above the floor, that is, the height from the floor to the lamp.

77. *Considerations Relating to the Height and Type of Ceiling or Roof of the Area Illuminated* (*Electric Journal*).—In a manu-

facturing area, the direct system is almost invariably employed and the lamps mounted within a foot or two of the ceiling or on stringer boards which span the space between the lowest members of roof trusses at intervals where rows of lamps are deemed necessary. High mounting is desirable because then the lamps are out of the way of cranes, are less liable to be broken, the glare is reduced to a minimum and in the case of a light ceiling there is more reflection and better diffusion of light. The lamps should be lowered in locations where there is horizontal overhead belting, to the level of the bottom of the belting; otherwise a portion of the light is ineffective. It may be necessary, for the same reason, to install two or three units in an area where the conditions would otherwise warrant one unit.

In office lighting the direct, indirect, or semi-indirect system may be used. With the direct system the lower intensity lamps, such as the 60-watt unit, give most satisfactory results. This is due to the fact that the glare and inconvenience from shadows is reduced to a minimum. Ordinarily the lamps should be mounted near the ceiling.

78. Approx. Desirable Mounting Heights for Tungsten Lamps

Mounting height, ft.	Size of lamp, watts	Mounting height, ft.	Size of lamp, watts
7 to 10	40		
8 to 12	50	7 to 12	60
10 to 14	80		
12 to 16	100	11 to 16	100
14 to 20	150		
17 to 27	250	16 to 28	250
25 to 35	400		
30 to 40	500	28 to 40	500

78A. Mounting Height and Spacing for Reflectors

Type of reflectors	Ratio : $\frac{\text{spacing}}{\text{height}}$ (Multiply mounting height by following to obtain spacing of lamps)	Ratio : $\frac{\text{height}}{\text{spacing}}$ (Multiply spacing by following to obtain mounting height)
Extensive	2.00	0.50
Intensive	1.25	0.80
Focussing	0.75	1.30
Concentrating	0.50	2.00

DISTRIBUTING REFLECTORS are not designed for any particular spacing. Use them for spacings wider than *extensive* where uniform or even illumination is not necessary, as in stock-rooms, warehouses and the like.

NOTE.—Where conditions call for reflectors between any two of the above types, use the more concentrating of the two. For example: If a reflector midway between an *intensive* and a *focussing* is indicated by the computations, use the *focussing* type.

79. Total Lumens given by Clear, Regular Bulb Multiple Lamps *(Correct from Incandescent Manufacturers' Data Sheets, June, 1915)*.—The amount of light radiated by any electric lamp is a perfectly definite and measurable quantity, the value of which depends upon the wattage of the lamp and the efficiency at which the lamp is burned. The unit in which quantity of light is measured is called the *lumen*.

In the following table are given the values of the total lumens radiated by each of the incandescent lamps in most common use for lighting purposes. The figures given in this table are correct for lamps operating at normal voltage with the efficiencies which are standard at this date. Use of table is explained in par. 85.

Rated watts	Mazda B or tungsten (vacuum)		Mazda C or tungsten (gas filled)		Tantalum		Gem	Carbon	
	105–125 volts	220–250 volts	105–125 volts	220–250 volts	100–130 volts	200–260 volts	100–130 volts	100–130 volts	200–275 volts
10	75	......	......	......	......	......	......	......	......
15	128	......	......	......	......	......	......	......	......
20	178	......	......	......	......	......	52	50	......
25	234	207	......	......	126	......	......	84	......
30	......	......	......	......	......	......	104	96	......
35	......	......	......	......	......	......	......	......	84
40	381	354	......	......	222	......	162	......	......
50	......	......	......	......	277	252	208	175	......
60	588	541	......	......	......	......	249	210	170
80	......	......	......	......	443	403	337	......	......
100	1,032	937	1,257	......	......	......	422	349	......
120	......	......	......	......	......	......	......	419	341
150	1,634	1,490	......	......	......	......	......	......	......
200	......	......	2,680	2,388	......	......	......	......	......
250	2,723	......	......	......	......	......	......	......	......
300	......	......	4,310	3,770	......	......	......	......	......
400	......	2,613	5,745	5,282	......	......	......	......	......
500	......	......	7,180	6,970	......	......	......	......	......
750	......	......	11,600	......	......	......	......	......	......
1,000	......	......	16,760	......	......	......	......	......	......

80. The three methods, in general use, of calculating illumination are:—(1) The Flux-Of-Light Method. (2) The Watts-Per-Square-Foot Method. (3) The Point-By-Point Method. Each has its applications and none is suitable for all problems. Only methods (1) and (2) will be discussed in this book. Method (2) is in reality a modification of method (1).

81. All of the methods of calculating illumination give approximate data. They really provide nothing more than reasonably accurate estimates which must be supplemented by the judgment of an experienced designer to afford dependable results. In laying out an illumination installation it is always a good plan to initially install in each outlet a lighting unit of a wattage somewhat larger than that that the estimates indicate necessary. In case there is too much light, a lamp of smaller wattage can be used in each outlet.

82. Calculation by the "Flux of Light" Method.—The simple method of laying out general illumination is by this meth

Knowing the intensity desired (16 and 17) on the surface to b minated and its area, the total flux or lumens required to pr that average illumination is readily computed:

$$lumens = \frac{Area\ (sq.\ ft.) \times Intensity\ (foot\text{-}candles)}{Constant}$$

or expressing the same thing in letters

$$F = \frac{S \times I}{c} \text{ and } S = \frac{F \times C}{I} \text{ and } I = \frac{F \times C}{S}$$

Wherein F = the total flux in lumens from all of the light sc that illuminate the area; S = the area illuminated in square I = the average intensity in foot-candles over the entire are C = constant from **84**. Knowing the total lumens required, it i possible to determine how many lighting units of a certain s what size of lamps of a given number are required to provide t quired flux (lumens). The lumens generated in a given lam be found from the table in par. **79**.

83. Illumination Constants.—The "flux of light" method culation is based on the assumption that a certain proportion light generated in a room is thrown on the surfaces to be illumi Some of it is thrown on the walls and ceiling, and of this only is reflected to the illuminated plane. The following table indi approximately, the percentage of the light generated that re the illuminated plane under different conditions.

84. Average Illumination Constants, Per Cent. Lumens E ive, or Efficiency of Utilization.—If the number of total lumen duced by a light source be multiplied by the value (expressed decimal) for the conditions applying given below, the numb lumens effective in lighting the area will be the result. (See

Ceiling	Light	Light	Medium	Light	Medium	Medium
Walls	Light	Medium	Light	Dark	Medium	Dark
[1] Prismatic, clear	60	53	......	48	48	45
[1] Prismatic, V.F.	53	50	......	45	45	42
[1] Holophane-realite	51	47	......	44	45	38
[1] Steel, porcelain, aluminum.	48	46	......	44	45	44
[1] Sudan	50	45	......	42	42	40
[1] Druid	48	43	......	39	38	34
[1] Druid, semi-indirect	40	37	......	33	25	20
[1] Sudan, semi-indirect	35	33	......	30	20	17
[1] Ivanhoe, indirect	31	28	......	25	18	15
Opal	50	45	44	42	42	40
White glass, light density.	48	44	43	40	40	36
Indirect and semi-indirect.	31	28	21	25	19	17
Bare lamps	41	35	34	30	30	25

NOTE that the above are average, and ordinarily safe, working cons *The actual constant to use in any case will be determined to some exte the size of the room to be illuminated.* For rooms of floor areas of les *200 sq. ft., the constants used may be smaller than those above given b 10 to 40 per cent.* For rooms of areas larger than 1,000 sq. ft., co *reater than the above—by not more than 15%—may be used, par here the walls are of medium or dark colors.* [1] Holophane Work

85. Example, "Flux of Light" Method of Calculating Illumination.—Suppose we have a notions store to light, the dimensions of which are length, 80 ft.; width, 25 ft.; height, 12 ft. 6 in. The ceiling and walls are light. Tungsten lamps with prismatic velvet-finish reflectors are to be used.

Referring to the table in paragraph 17 we find that stores of this character should have an illumination of 3.0 ft-c. The area of the store is 80 × 25 or 2,000 sq. ft. The illumination constant for prismatic velvet-finish reflectors with tungsten lamps in rooms with light ceilings and light walls is 0.53 (paragraph **84**). Substitute in the formula of **82** thus:

$$F = \frac{S \times I}{C} = \frac{2{,}000 \times 3.0}{0.53} = 11{,}300 \text{ lumens.}$$

Now determine the number and size of lamps necessary to supply this quantity of light. In **79** we find that a 25-watt tungsten lamp gives 234 lumens; a 60-watt lamp, 588 lumens; a 100-watt lamp, 1,032 lumens; and a 150-watt lamp, 1,634 lumens. (All of the data just given apply to vacuum lamps.)

The number of 25-watt lamps required would be, therefore, 11,300 ÷ 234 = 48; the number of 60-watt lamps, 11,300 ÷ 588 = 19; the number of 100-watt lamps, 11,300 ÷ 1,032 = 11; and the number of 150-watt lamps, 11,300 ÷ 1,634 = 7.

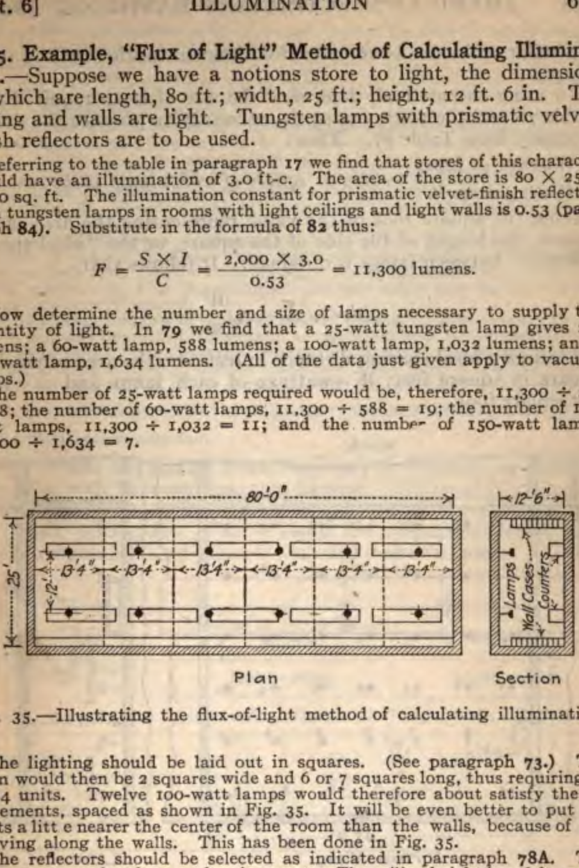


FIG. 35.—Illustrating the flux-of-light method of calculating illumination.

The lighting should be laid out in squares. (See paragraph **73**.) The room would then be 2 squares wide and 6 or 7 squares long, thus requiring 12 or 14 units. Twelve 100-watt lamps would therefore about satisfy the requirements, spaced as shown in Fig. 35. It will be even better to put the lights a litt e nearer the center of the room than the walls, because of the shelving along the walls. This has been done in Fig. 35.

The reflectors should be selected as indicated in paragraph **78A**. The lamps are spaced 12 ft. to 13 ft. 4 in. apart. The ceiling height is 12½ ft., making the lamps about 10 ft. above the tops of tables and counters. The ratio of lamp spacing to height of lamps is $\frac{13}{10}$ = 1.3. By suspending the lamps at the ceiling the ratio would be $\frac{13}{10}$ = 1.25 (approx.), the correct ratio for average intensive reflectors.

86. Watts per sq. ft. Method of Designing Illumination Installations.—Where only one type of lighting unit, the tungsten lamp, for instance, is used and the mounting height of the units falls within the limits specified in **78**, this method can be used. However, the *Flux of Light* is now usually considered the preferable method. The "*Watts Per Square Foot*," of Table **87**, is *based on the fact that with a given type of lamp and given conditions, one foot-candle intensity will be produced on the working plane by* a certain expenditure (in watts per sq. ft.) of energy

Similar tables can be compiled for illuminants other than tungsten lamps.

In using the method, determine the size of lamp required from Table 78 and the watts per sq. ft. necessary to produce the desired intensity from Table 87. Then:

$$\frac{\textit{Wattage of lamp}}{\textit{Watts per sq. ft.}} = \textit{area of square of which lamp is the center.}$$

Taking the square root of the value representing the area of this square, the length of the side of the square, or the "ideal spacing distance" between lamps is obtained. It follows that

$$d = \sqrt{A} = \sqrt{\frac{W}{w}}$$

Wherein d = ideal spacing distance in feet; A = the area of the ideal square in square feet; W = wattage of each lamp and w = watts per square foot.

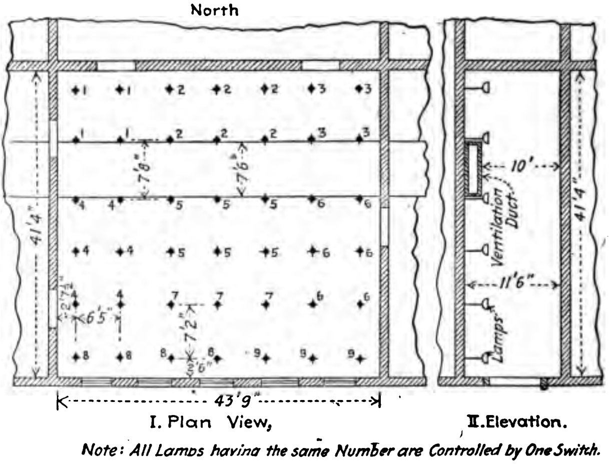


FIG. 36.—Example in laying out the illumination for an office room.

The spacing distance d having been ascertained, the designer should so lay out his area into squares or rectangles (Fig. 33) that the distance between lamps will be as nearly equal to the distance d as possible.

Where there are different ceiling heights in the same room, the size of lamp is finally decided by the relation of spacing distances to the dimensions of the room. For the sake of standardization, the number of sizes of lamps used may be reduced to four as shown in the right-hand half of Table 78.

le of Application of the Watts per Square Foot Method.—A draughting a ceiling 11 ft. 6 in. high and both it and the walls are light colored. is 41 ft. 4 in. by 43 ft. 9 in., equalling 1,810 sq. ft. A ventilating ses an obstruction, as shown in Fig. 36, the bottom being 18 in. below ıg. An illumination of 7 ft-c. is desired. Tungsten lamps in prislectors are to be used.

fect will be best if all the lamps are mounted with the top of the level with the bottom of the air duct. This gives a mounting which is always measured to the socket) of 10 ft. It is decided, erring to Table **78**, to use 60-watt lamps, the watts per square foot om Table **87**) 0.19 *watts per sq. ft. per foot-candle* × 7 *ft-c.* = 1.3 *sq. ft.* The ideal spacing distance, calculated out as explained, is 6

out the lamps it is found that in a direction east to west, a spacing of 6 ft. 5 in. places them free from obstructions and leaves 2 ft. each wall. In the other direction the width of air duct is 7 ft. 6 in., akes 7 ft. 8 in. the minimum distance apart that the two rows of n here be spaced.

lacing one row of lamps as near as possible to each side of the duct ıg out the rest of the system, a convenient spacing distance is found o be 7 ft. 2 in., and this figure is adopted, the row of lamps nearest being 2 ft. 6 in. distant therefrom. The general spacing distance in. by 6 ft. 5 in. = 46 sq. ft. (Fig. 36), giving $\frac{60}{46}$ = 1.3 watts per each lamp and for the whole area the figure is found to be $\frac{42 \times 60}{1,810}$ atts per square foot.

Watts per Square Foot Necessary to Produce an Intensity :. with Vacuum Tungsten Lamps. (*National Electric Light ion*).—Table is compiled on the assumption of an efficiency tt per candle. This is about the average efficiency for all ommonly used sizes of vacuum tungsten lamps.

ting unit	Area 30 ft. × 30 ft. or larger		Small areas	
	Light ceiling		Light ceiling	
	Light walls	Dark walls	Light walls	Dark walls
:............	0.19	0.21	0.27	0.30
ivy density...	0.40	0.21	0.26	0.29
ht density....	0.24	0.27	0.34	0.37
irect.........	0.29	0.35	0.43	0.53
ndirect.......	0.32	0.37	0.50	0.62

e the efficiency of the lighting unit to be used is other than watt per candle, the watts per square foot required will roportionately with the efficiency. The watts required ft. varies directly as intensity in foot-candles.

Procedure in Designing a General Illumination Installa- the Watts per Square Foot Method (Alex. J. Airston, *Journal*).—1. Measure the location, making a rough of plan and elevation showing ceiling or roof trusses, posi- f windows, obstacles which may affect the installation, outlets and switching if any, and giving full dimensions. ke a note of color and condition of walls, ceiling, furniture, machinery and equipment as well as the class of work carried on and the closeness of application required.

3. a. Draw plans to scale.

b. Decide on the lamp size and mounting height.

c. Assume the watts per square foot to be used.

d. Deduce the ideal spacing distance—$d = \sqrt{\frac{\text{Wattage of lamp}}{\text{Watts per sq. ft.}}}$

e. Lay out positions of lamps on the plan, to give regular spacing distances, installing a row within 2 ft. 9 in. of each wall if an office, and approximating, as near as possible, to the ideal spacing distance in both directions.

f. Make a tracing, from the plans, showing boundaries of the area and positions of lamps and old outlets, if any, also switching.

g. Specify size of lamps and reflectors, mounting height and any other information deemed necessary for the assistance of the wiremen.

h. Show control of lamps by numbering all lamps on one switch with the same number.

4. Check up the design at the actual location to see that each lamp is effective and free from all possible obstacles.

89. Efficiencies of Utilization for Indirect Lighting
(*National X-ray Reflector Company*)

Minimum dimension of room divided by ceiling height	Efficiency of utilization	
	Dark walls	Light walls
1.0	0.20	0.24
1.5	0.22	0.26
2.0	0.24	0.28
2.5	0.28	0.30
3.0	0.30	0.32
3.5	0.32	0.34

NOTE.—The above values are 20 per cent. low, to provide for depreciation due to dust and aging of lamps. With lamps new and reflectors clean, the efficiencies of utilization will be correspondingly higher than given in the table.

INTERIOR ILLUMINATION

90. House Lighting.—The intensity generally required in each room of a residence is given in the table of paragraph **16**. Ceiling fixtures in which the lamps hang at an angle should be avoided. As shown in Fig. 37, such fixtures tend to throw a strong light around the walls, and into the eyes of persons in the room, although the angle shown in Fig. 37 is the correct one when an incandescent lamp is completely enclosed in a ground glass or opal globe—an inefficient arrangement, but considered by some to be artistic. Lamps hanging pendant as in Fig. 38 distribute the light in useful directions. Diffusing globes or shades should be used on all lamps which hang low enough to fall in the line of vision. Bowl-frosted lamps should be used unless the lamp itself is completely shaded.

91. Lighting the Kitchen and the Bedroom.—These are the two rooms in a house in which the arrangement of the lights is ordinarily most unsatisfactory. A single light or group of lights in the center of the kitchen usually compels the cook to work entirely in her own shadow, whether at the range, the sink or the kitchen cabinet or table. A couple of small bracket lights at the side of the room can usually be arranged to satisfactorily light all

FIG. 37.—Effect of hanging residence lamps at an angle.

FIG. 38.—Effect of hanging residence lamps vertically.

three of these locations, and a third small light in the center of the room will give general illumination. The three need consume no more current than a single larger unit, and will give much more satisfactory service. Similarly in a bedroom, one or two bracket lights should be provided at the dressing table, with a small unit in the center of the room for general illumination. The ordinary arrangements are usually satisfactory for other rooms, except that a single ceiling or table light in a library requires that all readers shall sit with their backs toward one another to secure satisfactory reading light. This can be obviated by using scattered ceiling lights, four or more, depending on the size of the room, or by side brackets with reflectors of a type which will shade the light from the eyes of those sitting across the room.

92. Living-rooms.—The lighting of the living-rooms should in general be done with a view toward producing a comfortable and cheerful appearance rather than a high efficiency. The more highly efficient types of reflectors are generally out of place, as they do not allow sufficient general illumination to properly show the pictures and decorations, and therefore produce a gloomy effect.

93. Store Lighting.—The object of the illumination in a store is two-fold. Primarily, sufficient illumination must be provided to enable articles for sale to be seen plainly. But of almost equal importance is the advertising value. The lighting units must be so selected as to give a pleasing and cheerful appearance to the store *as a whole*, without glare. Stores may be divided into three classes: *The small store*, in which efficiency is of first importance; *large store*, such as a department store, in which efficiency is n sary on account of the large areas to be lighted, but must be balanced by artistic appearance, the result being a compromise between the two; and shops, large or small, in which the articles for sale are of a special type and the profits large enough that they can afford to have even the most inefficient system if it be sufficiently attractive or unique to attract customers. The general requirements which must be met are outlined in the following paragraphs:

94. General Features of Store Lighting.—The intensity of illumination must be varied with the articles which are to be sold. Furniture requires well-diffused lighting of relatively low intensity. Colored dress goods, men's clothing, rugs and carpets, etc., require

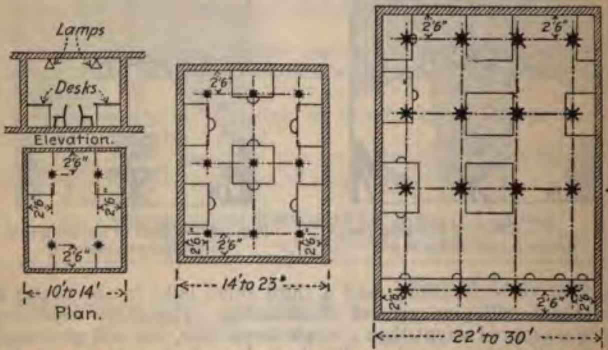


FIG. 39.—Good spacings of ceiling lights for offices (adapted from C. E. Clewell in *Electric Journal*).

a high intensity. In many installations side-light is very necessary and should be given especial attention in selecting types of units, and reflectors. Cut glass and jewelry should be so lighted as to sparkle and glitter. This requires bare lamps and mirrored reflectors. Glare is to a certain extent, in this case, unavoidable, but the light units can usually be so located as to be out of the customer's range of vision, when he is inspecting the ware. Pictures require a high intensity, with the light units at such an angle that light will not be reflected from the surface of the painting, or from the glass, directly into the observer's eyes. Individual units or mirrored trough reflectors, with linolite or tubular tungsten lamps are ordinarily used.

95. Office Lighting.—In general it is found more economical and more satisfactory to provide general rather than specific illumination in offices containing a number of desks. The lighting required can be found by the method given in a preceding paragraph. In locating the lights, the outer row should not be placed more than $2\frac{1}{2}$ ft. from the wall, to avoid shadows on desks placed about the walls. Fig. 39 shows good spacing of lamps in offices of various sizes and of ordinary height. Fig. 40 gives, in the form of a chart, spacing distances which have been found by experience to be satisfactory with different ceiling heights. As in industrial lighting, the cost of illumination is usually so small a percentage of the salaries of the men in an office that a very small increase in their efficiency, due to less eyestrain, fewer headaches, etc., will more than pay for even an extravagant lighting system (C. E. Clewell, *Electric Journal*).

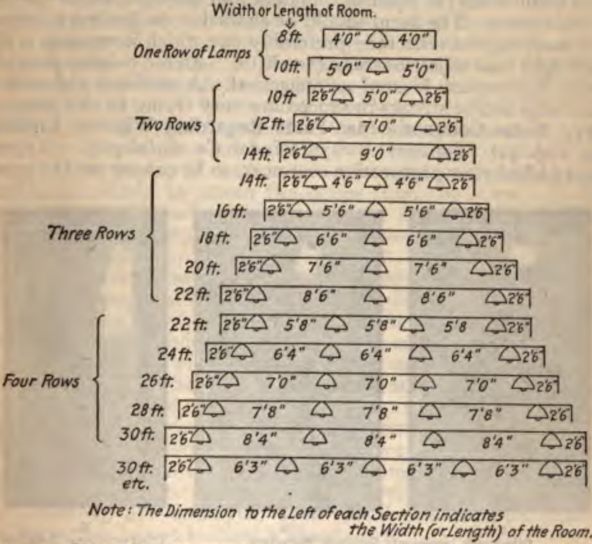


FIG. 40.—Chart showing spacing distances of lamps for offices of various sizes. (C. E. Clewell, *Electric Journal*.)

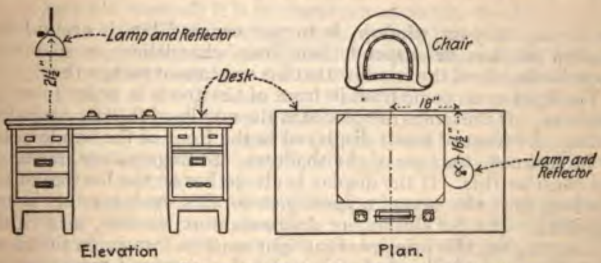


FIG. 41.—Proper method of hanging a desk lamp.

96. Specific desk lighting (Fig. 41) should as a general proposition be avoided. This is particularly true in large offices where a number of desks are located. A much better plan is to provide as outlined under "Office Lighting," a general illumination suff ciently bright to render individual desk lighting unnecessary. Specific desk lighting should generally be restricted to cases where one or two desks are located in an office chiefly used for other purposes which permit of a comparatively low degree of illumination.

Do not locate the desk light too close to the work. The light unit for a desk should be hung 21 to 24 in. above the desk, about 16 to 18 in. from the front of the desk and about 18 in. to the left of the center. The lamp should be shaded from the line of vision by a bowl type of reflector—preferably one which is opaque. Too much light is as objectionable as too little. An 8-c-p. lamp provides ample light when located as suggested. A polished reflector is intolerable as the streaks produced are very trying to the eyes.

97. **Some Common-sense Facts Regarding Window Lighting** (see Fig. 42) (*National X-ray Reflector Co. Catalogue*).—A good way to blind your prospective customer, so he cannot see the goods

I. II. Effect with Improperly Selected Reflectors. III. Effect with Proper Reflectors.

FIG. 42.—Illustrating good and bad window lighting.

on display in your window, is to put exposed lamps around the window borders or suspend them from chandeliers or so install them in the top of the window that his eye cannot escape them.

The light must come from in front of the goods in order to avoid shadows. If the lamps are placed in the middle of the show-window ceiling, the front of goods displayed in the front of the window will be in darkness, because of the shadows. Strange to say, many do not consider this. If the display is altogether on the bottom of the window, as in the case of a jewelry store, this shadow effect is unimportant. In the clothing or drygoods store window, it is vital.

Carrying out this principle that light must be thrown on the goods from the front of the window in order that passers-by may see no shadows on the goods, practically means that the lamps must be placed high up in the window next to the window pane, because there is no other place where they can be put to throw the light in the proper direction and keep the lamps out of the ordinary range of vision.

98. Show-window Lighting (*I. P. Frink Catalogue*).—In the average sized window, linolite lamps will give excellent results when used with properly designed reflectors on account of their high efficiency and adaptability to limited space conditions. Reflectors with standard base lamps should be used in unusually high windows, and in windows unusually deep, such as found in furniture stores, as well as in some cases where the windows in question are situated next to a store front on which there is installed a mass of exposed lamps, the glare of which makes it necessary to use an excessive amount of illumination to make the adjoining window appear properly lighted. With correctly designed reflectors there are few windows that require more light than that given by 40-watt lamps spaced 8 in. apart. With this equipment, 8 to 12 ft-c. on the floor of the windows from 8 to 12 ft. high can be developed. If the window is not boxed in, the reflector should be provided with a shield to screen the lamps from the store. If the upper part of the window back is glass, or the window is backed with mirror, the reflector should also be designed with a shield to prevent back reflection.

99. Watts and Number of Lamps Required per Front Foot for Window Lighting (National X-ray Reflector Company).—The number of lamps per front foot of window or the watts per front foot required for good window illumination, depend very much on the location of the show window, whether it is on a brilliantly lighted street and in a city where a great deal of light is commonly used in show windows, or whether it is in a town where only a limited amount of show-window lighting is common. For example, in a small country town a single reflector may give a better illumination of a window with an 8-ft. frontage than is common among the other windows in the town. In large cities where dark dry-goods and men's clothing are displayed, some merchants consider that a window cannot be too brilliantly illuminated.

On account of the efficiency of properly designed reflectors (because of the fact that they confine and direct nearly all of the light where it is wanted) it is of course not necessary to use as many lamps where the reflectors are properly designed as where they are not. Where reflectors are designed for large lamps of 105 and 60 horizontal candle-power (100 and 60 watts) respectively, the lamps can be spaced some distance apart and still give good results. Some splendidly lighted show windows in large cities have 100-watt lamps spaced 18 and 24 in. apart. In the small towns where lower standards of illumination prevail, this spacing can be safely increased to 36 in. or more.

100. In lighting counter and display cases the same rule is followed as with show-window lighting, viz: Throw the light on the goods displayed and not into the eyes of the observer. If the glare from the lamps reaches the observer's eyes he is partially blinded and the result desired is not accomplished. Tube tungsten lamps are to be preferred and they should be equipped with proper —*continuous if possible*—reflectors. Ordinary pear-bulb lamps *can be used with* suitably designed reflectors but the tube lamps *give more effective* results and constitute a neater installation, and

ʰe wattage required to properly illuminate display and ...es varies with conditions. Experience provides the ... this work as conditions, such as reflection from the ...d mirrors, render calculation useless. As a general ... illumination in cases should be double that in the ...ns-Manville Co.). In an 8- to 12-ft. show-case, ...ry show-case reflectors and tungsten lamps) will ...ults with an average illumination of 7 to 8 ft.-c. ...-lined reflectors, the same intensity may be maintained, ...e same wattage, in a 12-ft. case.

EXTERIOR ILLUMINATION

103. General Requirements for Street Lighting.—In all four lasses of street lighting (see par. 104) it is desirable to have uniform ntensity, good diffusion to prevent sharp shadows, and low inrinsic brilliancy to reduce glare. It is not usually feasible to ttain all of these desirable conditions. It is their high intrinsic rilliancy, particularly when clear outer globes are used, that makes he older types of arc lamps objectionable as street illuminants.

104. Classification of Street Intensities.—City streets are genrally grouped in four classes as to illumination requirements. *Class* 1, public squares, principal business streets, streets leading o railway stations, and sections of streets where crime is prevalent, hould have an illumination intensity of 0.4 to 0.6 ft.-c. *Class* 2, omprising streets where night traffic is moderate, such as business treets having little traffic at night, and the outlying parts of main horoughfares, require about 0.2 ft.-c. *Class* 3, comprising outying residence streets, do not require more than 0.1 to 0.15 ft.-c. *Class* 4, comprising sections of the city not built up, or country oads, are sufficiently illuminated (beacon lighting) with 0.05 ft.-c. n addition to these there may be a "white way" where 1 or even 1.5 ft.-c., in addition to the illumination produced by the window nd sign lights, is permissible. (From paper by C. E. Stephens.)

105. Electric Light Sources Available for Street Lighting.—Arc lamps and gas-filled tungsten incandescent lamps provide the most economical illumination for streets. Of the arc lamps, the open and enclosed carbon arcs have become practically obsolete as street illuminants. The metallic flame arc has largely replaced the older forms of lamp. The color of the light is white and the distribution curve shows a maximum candle-power from 15 to 25 degrees below the horizontal. Its maintenance cost is comparatively low. The efficiency of light production varies from 0.4 to 0.5 watt per m. l. h. c-p. The light from tungsten lamps can be refracted in any desirable angle.

The flame carbon lamp is the most recent arc-lighting development. The efficiency of light production varies from 0.25 to 0.35 watt per mean lower hemispherical candle-power. The light distribution curve shows a maximum candle-power from 20 to 30 degrees below the horizontal. The maximum candle-power varies from 1,600 to 2,500 c-p., depending upon the carbons used. (C. E. Stephens.)

Tungsten series incandescent lamps are available in sizes ranging from 60 to 1,000 c-p. The efficiency of light production varies approximately from 0.8 to 0.45 watt per candle. When properly equipped with a suitable reflector, they are well suited for street illumination.

106. Number and Size of Units for Street Lighting.—Using a small number of units of very high candle-power, mounted at considerable height and placed at great distances, requires a larger total light flux to secure the minimum allowable illumination midway between units than is required with closer spacing. There is some waste of energy where the sources are spaced at great distances from one another. On the other hand, increasing the number of units increases the installation and maintenance cost of the system. In general, if energy cost is low, large units at great distances apart are better; if energy cost is high, small units placed at frequent intervals are more economical.

On streets having trees, arc lamps cannot be used because the height at which they should be mounted will cause the trees to throw dense shadows on the streets. In such cases tungsten lighting is always most suitable.

In making calculations, the point-by-point method should be used, making calculations quarter and halfway between units, under each unit, and about 25 ft. from each unit. In making these calculations it is necessary to consider only the illumination caused by the two nearest units. (C. E. Stephens.)

107. In residence street lighting the use of relatively small units is usually preferable because with the smaller units the illumination is more uniform. Another feature that should be considered in this connection is that although large units are for a given installation preferable from the standpoint of installation and maintenance costs because a minimum number of units is necessary, considerable of the light from these large units will be wasted in lighting the yards facing the street. With small units spaced closer together, most of the light falls on the street and walks and little is wasted (Fig. 43). (C. E. Stephens.)

108. Spacing and Height of Units.—The uniformity of illumination with a given unit varies with the distance between units and their height. The very nature of the street area determines that the light units must be in a single or double row along the street. The number and size of units and their height are determined by the intensity requirements and cost of operation. In making a selection of units for a given condition it is necessary, therefore, to carefully consider the curve of light distribution of the available units. Increasing the height of the lamp decreases the intensity of illumination directly under the lamp quite rapidly and does not materially change the intensity at greater distances from the lamp. The height of a lamp is usually limited on account of the extremely high cost of installation, maintenance, tree obstruction, etc. (C. E. Stephens.)

109. The actual amount of illumination to be tolerated as a minimum on the street (Bell, *Standard Handbook*) is common based in the United States on getting something like the effect of average moonlight say in the neighborhood of 0.02 ft-c.

110. Distribution of Street Illumination.—In the illumination of a sidewalk, for example, the required minimum being 0.04 ft-c., the specification could be better fitted by common candles placed 6 ft. high and 6 ft. apart along the curb than by powerful sources of light spaced 200 ft. apart, although the latter would give more than fifty times the total light of the former. (See Fig. 43.)

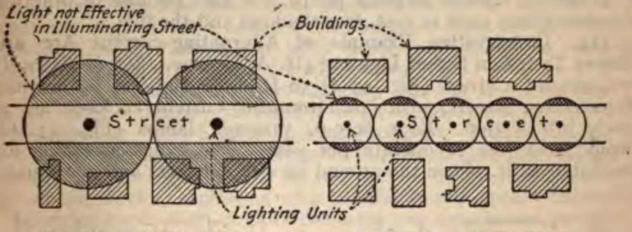


FIG. 43.—Illustrating how a considerable portion of light is ineffective in illuminating a street where high-power lighting units are used.

Some point between these extremes should evidently be chosen in the joint interest of economy and good average illumination, and a few trial computations will bring out the facts. In general, radiants of moderate power placed at moderate distances give the best illuminating effects, whether on the street or indoors.

111. In locating arc lamps for outside illumination one should be placed where possible at each street intersection so that the

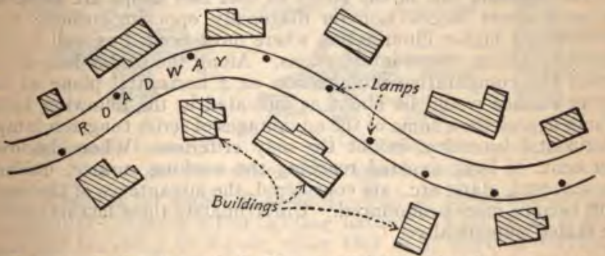


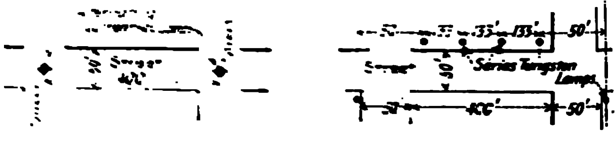
FIG. 44.—Preferable method of locating lighting units along a curved roadway.

light will be useful in all four directions. Spacing distances between street intersection lamps is a thing that must be determined by local conditions. Where blocks are long, or strong illumination is required for display purposes, one, two or even more lamps can be equidistantly located between the street intersection lamps.

112. In locating **lamps along curved roadways** it is often considered preferable to place them as suggested in Fig. 44 rather than all on the same side of the road. When arranged as shown more lamps can be seen at one time and it is claimed that distant moving objects in the road are more effectively revealed in that they will always lie between the observer and the lights.

113. **Height of Arc Lamps for Outdoor Illumination.**—Generally speaking the lamps should be hung as high as feasible. As a rule arc lamps are hung too low for best results. From 35 to 45 ft. from the ground is probably about right for average conditions, but it is seldom feasible to place lamps this high because of practical considerations such as cost, tree shadows and the like.

114. **Comparative Example of Alternating-current Arc and Series Tungsten Street Lighting** (H. A. Hussey, *Electric Journal*). Consider a street (Fig. 45 I) 50 ft. wide and 400 ft. between intersecting streets, with one alternating-current enclosed arc at each intersection. Four [illegible] tungsten lamps (Fig. 45 II) [illegible] per year. The tungsten lamps are [illegible] above the ground on 4-ft. brackets and are equally



I. Alternating Current Arc Lamps. II. Series Tungsten Lamps.

Fig. 45. [illegible] enclosed arc and tungsten lamps.

[illegible] Alternate blocks have the lamps [illegible] so that two lamps are provided [illegible] diagonally opposite corners, thus [illegible] where most needed as well as dis- [illegible] along the center line of the [illegible] on a horizontal plane at the [illegible] as indicated in the following table. [illegible] series tungsten lamps. [illegible] When shadows, [illegible] working surface, uniform [illegible] advantages of the small [illegible] these factors cannot [illegible]

[illegible] Comparative Values, A.C. Arcs and Series Tungstens

		[illegible]	Tungsten
[illegible]	[illegible]	[illegible]	0.160
[illegible]	[illegible]	[illegible]	0.035
[illegible]	[illegible]	[illegible]	0.082
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible] efficiencies.

116. **Series Tungsten Street Lighting.**—The adjuster socket stem operates only on constant-potential circuits. It consists a simple series of lamps connected across high-tension constant-tential alternating-current mains, or across the secondary ter-nals of a constant-potential transformer or auto-transformer. reactance coil is connected in shunt across the terminals of each np. When the lamp is burning the reactance coil takes only 4 5 per cent. of the current. If the lamp filament is broken or e lamp removed the voltage forces the total current of the cir-it through the reactance coil, magnetizing it to saturation, ereupon it produces a counter-electromotive force equal to the tential difference across the lamp when burning. This main-ns the continuity of the circuit at all times.

117. **Series Tungsten Street Lighting.**—In the regulator sys-n the series of lamps is supplied from a constant-current regulat-transformer. (See Section on Transformers.) This automatic-y controls the current and voltage of the circuit, and maintains a nstant current regardless of the number of lamps burning. A n cut-out device, consisting of a receptacle and socket located the street hood, short-circuits the lamp and thus maintains the ntinuity of the circuit when a lamp burns out. The lamp cut-t, used in the regulator system for maintaining the continuity of e circuit, consists of a thin copper, aluminum or lead disc coated th an insulating enamel, placed between clips provided in the cket. If the lamp burns out, the increase of potential across the ps punctures the film between the socket clips and short-circuits e lamp.

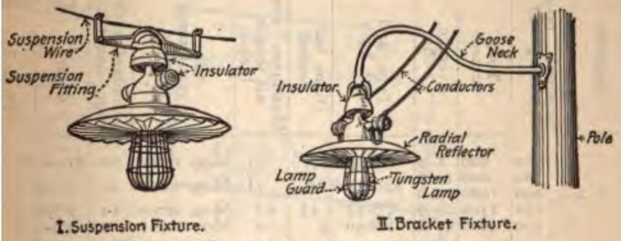


FIG. 46.—Street fixtures for tungsten lamps.

118. **Fixtures for Street Tungstens.**—Fig. 46 shows two of the ost popular tungsten street-lighting fixtures. That of II is ar-nged for fastening to a pole, while that of I, when in service, ngs from a cable or span wire supported by two poles.

119. **In locating single light series tungsten units, along the rb** (see Fig. 46), the best results are obtained by allowing the nps to hang from 1 to $1\frac{1}{2}$ ft. outside of the curb line. In the case single line lighting, a distance of from 3 to 5 ft. outside of the rb line is usually desirable. Lighting units may also be placed *er the center of the street*, either by suspension similar to that *nmonly employed* for arc lamps, or on ornamental standards *ced on "Islands of Safety."*

for lamps of 250 c-p. and higher should specifically state if they are ned in other than pendent position. **The light center length of the o ampere MAZDA C lamps shown above is 9½ inches for burning in position and 8½ inches where ordered for burning tip up.**
um Screw Skirted Base also supplied at same price, except the 400, 1000 c-p. lamps, which are supplied only with Mogul Screw Base ted.

A lamps for street series service selected for use on multiple com- or for any other purpose where a single voltage or a range of closer than stated are required will take a special price which may be from the manufacturer upon application.

When any lamp is hung so low that it lies within the f **vision** of a nearby observer the glare from the unit should nated by the application of a proper reflector or shade.

A reflector should always be used with any incandescent ghting lamp. Where no reflector is used a large portion ight generated is projected above the lamp into the air vholly ineffective in lighting the street.

Where lamps are installed on streets bordered with trees ps should always be hung a trifle lower than the lower s of the trees. If they are not, heavy shadows will be cast branches and the effectiveness of the illumination will be impaired.

[illegible]

[illegible]

[illegible]

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