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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

AUTOMATIC TELEPHONE SYSTEMS
HOUSE TELEPHONES
TESTING OF TELEPHONE CIRCUITS
TELEPHONE-LINE CONSTRUCTION
TELEPHONE CABLES
POWER EQUIPMENT

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear, is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives, have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one select the proper formula, method, or process and in teaching him how and when it should be used.

As automatic telephone systems are now successfully used in many exchanges, their circuits, construction, operation, and care have been very fully considered in this volume. The use of intercommunicating or house telephones in large factories, public institutions, and hotels is constantly increasing, and the many circuits employed for such purposes are fully described and illustrated. The testing of telephone apparatus, circuits, and lines, the splicing of cable conductors, the wiping of lead-sheath cable joints, and overhead and underground distribution and construction work have been very fully treated. The practical man is given enough of the theory to enable him to handle intelligently any difficulty that he is apt to encounter in his line of work. A subject that is increasing in importance, but is usually neglected in publications relating to telephony, namely, the power equipment required in a telephone exchange, is fully covered. The entire field has been thoroughly covered, the information being supplied by men engaged in practical work.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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CONTENTS

AUTOMATIC TELEPHONE SYSTEMS

(PART 1)

STROWGER AUTOMATIC TELEPHONE SYSTEM

INTRODUCTION

1. **An automatic telephone system** is one designed to supplant the telephone-exchange operator by automatic appliances. Switches, located at a central office, automatically connect two lines for a conversation and also disconnect them, this result being produced as a result of certain operations performed by the subscribers themselves. An automatic system usually consists of a telephone and selecting device at the subscribers' stations, the selecting device being used by the subscriber to select, by sending a certain number of impulses over one or both line wires, the line desired, and at the exchange a switch that automatically connects the calling line to the line selected by the subscriber. To establish connections between any two lines running to the same automatic exchange, no operators are, therefore, required. Thus a large item of expense—operators' salaries—is saved in the cost of operation. Those favoring manually operated systems claim that more expert trouble men and switchboard men are required, which more or less offsets the saving in operators' salaries. For toll service and trunking between different exchanges, even if both exchanges are automatic, operators are generally employed. The use and popularity of automatic systems is increasing and a large number of exchanges, both large and small, are now equipped with such systems. The Strowger automatic telephone system, made by the Automatic Electric Company, is quite extensively used and is proving very successful. It has taken at least 16 years to develop this system into its present satisfactory condition. Even now, every new installation is liable to contain improvements and new features.

INSTRUMENTS AND SWITCHES

SUBSCRIBER'S INSTRUMENT

2. The automatic telephone instrument located at the subscriber's station, consists of the usual transmitter, receiver, bell, transmitter battery, and induction coil, with the addition of the **selector calling device,** which occupies a space about $5\frac{1}{2}$ inches by $4\frac{3}{8}$ inches on the front of the telephone and a depth of about $3\frac{1}{4}$ inches. A front view of the selector calling device, which may form part of a wall or a desk telephone, is shown in Fig. 1. The metal calling dial is about $4\frac{3}{8}$ inches in diameter and has along the edge ten finger holes, numbered consecutively from 1 to 0.

FIG. 1

3. To call a number, say subscriber 761, the calling subscriber first takes the receiver from the hook, then, placing his finger in hole 7, turns the dial around until the finger comes against the stop *s*; when released, the dial is restored to its original position by a clock spring immediately behind the dial. In the same manner he then calls *6* and *1* in this group.

Having turned the numbers desired, he presses the button *J*, which causes the bell of the station called to ring. The connection is now completed. If the desired subscriber is busy, a buzzing sound in the receiver notifies the calling subscriber of this fact, no connection is made with the busy line, and all circuits are restored to their normal condition.

SUBSCRIBER'S SELECTOR CALLING DEVICE

4. Fig. 2 shows the mechanism of the subscriber's calling device, as made in 1906, omitting the hook switch. It is built on two base plates held apart by studs; one of the

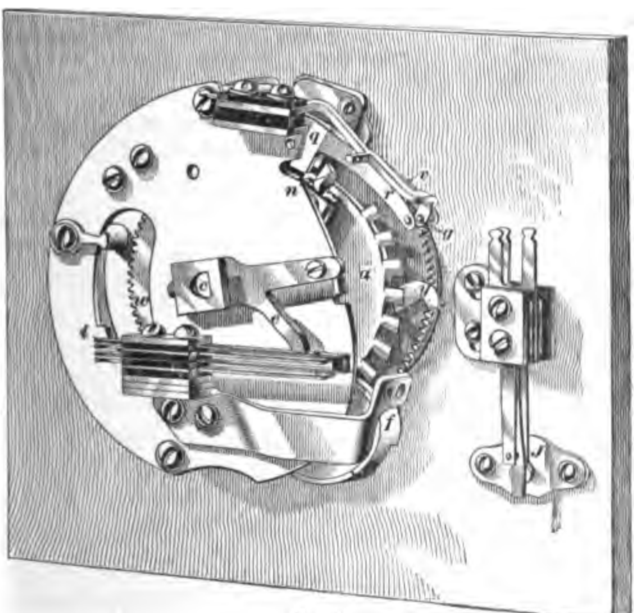


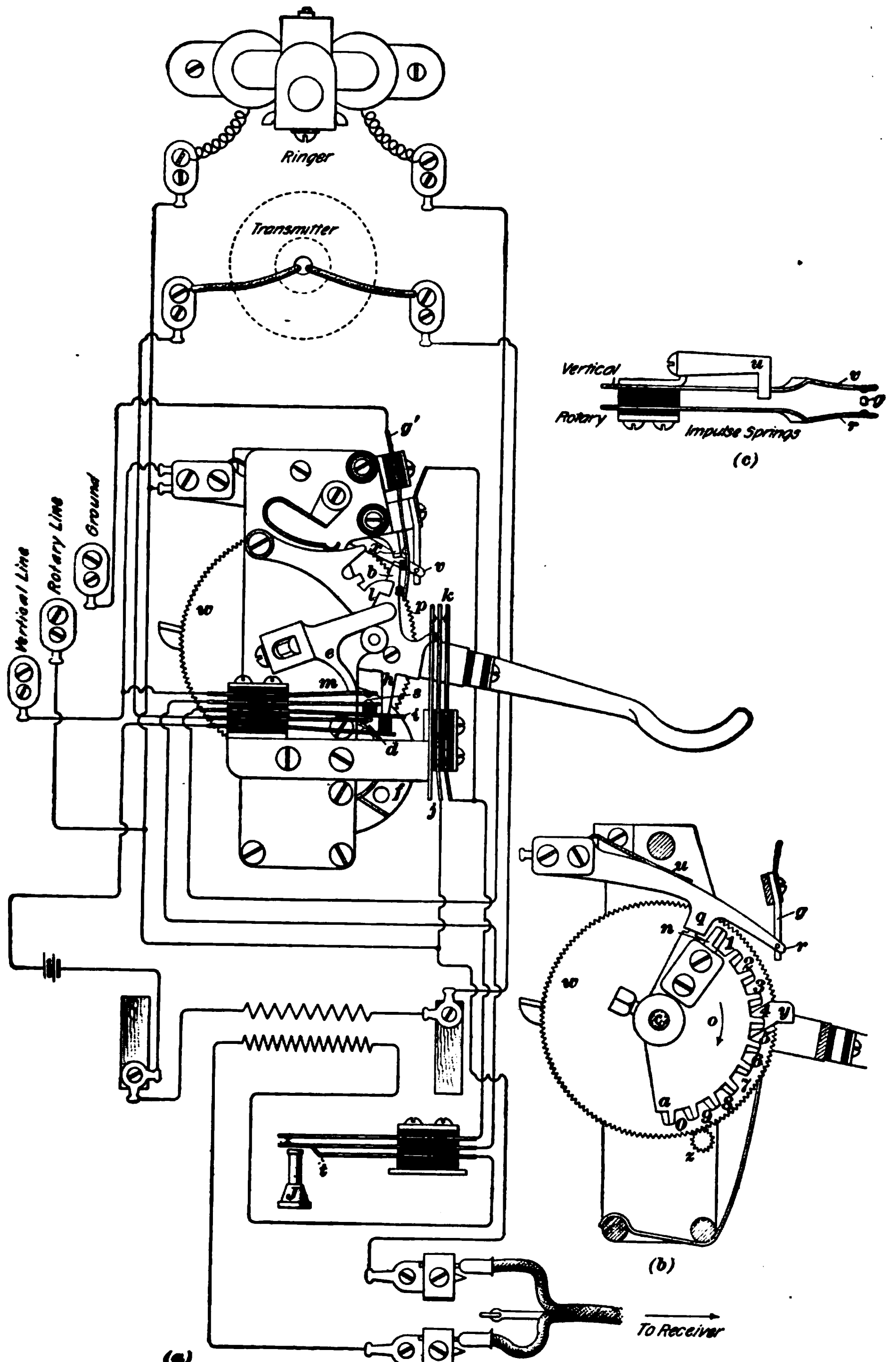
FIG. 2

plates is fastened to the door of the telephone box. A shaft *c* extends through the base plates, projecting on both sides. On the front end is mounted a strong clock spring and the dial shown in Fig. 1. Between the base plates there is mounted on the shaft a wheel *a*, called a *comb*, with eleven special-shaped teeth. The ten teeth along the edge *a* move in one plane and the eleventh tooth *n*, which is insulated from but fastened to the same wheel, moves in a plane about ⅛ inch distant.

The so-called vertical-impulse spring *v* projects into the path of the ten teeth *a* in such a manner that the contact between the spring and the ground is not made as the dial is rotated by the finger, but this ground contact is momentarily made, as the spring rotates the toothed wheel back to its original position each time that a tooth passes the spring. The so-called rotary-impulse spring *r* is operated in a similar manner by the eleventh tooth *n* as it returns and passes by the projection *q*. On account of the location of this tooth *n*, the rotary-impulse spring *r* makes contact with the contact *g* once after the last of the ten teeth *a* has caused the vertical spring *v* to touch the contact *g*.

5. Fig. 3 shows the device, including also the hook switch and circuits as applied to a wall telephone. It is all mounted on the inside of the door of the telephone instrument. When the receiver rests on the hook, the finger *h* presses down the spring *i* and thus keeps the transmitter open at *d* and the rear end of the hook holds the finger *e* up just enough to keep the receiver circuit open at *s*, while the bell circuit is closed through spring *i*–finger *h*–metal parts of the device–finger *e*–spring *m*. In some instruments, a wire soldered to *h* connects the latter to the vertical line binding posts, thus eliminating the contacts between *h* and the frame and between *e* and *m*.

Fig. 3 (*b*) shows a separate view of the comb wheel with its teeth, rotary spring *r*, and the projection *q* by means of which *r* is pushed against the grounded contact *g* by the tooth *n* as the latter moves in the direction of the arrow *o*. The vertical spring is behind the rotary spring *r*. The arrangement of the vertical spring *v*, rotary spring *r*, and ground contact *g* is shown in the plan view (*c*). The flat



Ringer
Transmitter
Vertical Line
Rotary Line
Ground
Vertical
Rotary
Impulse Springs
(c)
(b)
To Receiver
(a)

FIG. 2

spring *u* merely rests lightly on *v* to prevent the latter from vibrating unduly as the teeth *a*, Fig. 3 (*b*), pass rapidly by and press it against the ground contact *g*. The grounded spring *g′* does not normally touch the piece *x* to which the contact *g*, Fig. 3 (*c*), is attached; because an insulated piece rests against the upwardly projecting arm *b* attached to the hook switch. When the hook is raised, the spring *g′* cannot touch *x* because the lower piece of insulating material on the spring *g′* rests against the end *l* of a dog. As soon, however, as a movement of the dial is made, the piece *e* raises the dog *l* and thus allows the grounded spring *g′* to rest against *x*. Hence, the hook must rise—that is, the receiver must be removed from the hook and a movement of the dial must be made—before any connection with the ground can be made in the subscriber's instrument. Furthermore, the dog *l* is so designed that no movement of the front dial can be made until the receiver is removed from the hook.

On the rear of the center shaft that carries the front dial is keyed a finger *e*. When a number on the dial is pulled down, the finger *e*, Fig. 3 (*a*), opens the receiver circuit at *s* as long as the comb *a*, Fig. 3 (*b*), is out of its normal position while making a call. This secures the disconnection of the two line wires from the telephone apparatus proper during the transmission of the current impulses while calling a number and is necessary to prevent impulses being sent over both line wires when either spring *v*, *r* touches the ground contact. The transmitter circuit is closed at *d* and the bell circuit is open between spring *i* and finger *h* as long as the receiver is off the hook.

The spring *p* is connected to the piece *x*, Fig. 3 (*a*), and *g*, Fig. 3 (*c*). The springs *p*, *k* are so arranged that all three come together momentarily only when the hook moves down, not when the hook rises. Consequently, the two springs *k* are grounded through *p*–*x*–*g′* when the hook moves down, provided that the dial has been operated so that the end *c* does not prevent the spring *g′* from touching *x*. In either the up or down position of the hook, the springs *k* are out of contact with the spring *p*; thus both line wires are momentarily grounded by the two springs *k* coming in contact with the spring *p* as the hook moves down, provided that the dial is moved while the hook is up.

To the comb wheel *a* is fastened the pawl *y* that drags with it the brass gear-wheel *w*. *J* is a push button that is used to operate the ringing relay at the central office. When the connection has been established by operating the dial with the receiver off the hook as described, the button *J* is pushed, thereby opening at *t* the receiver loop and throwing a ground on the vertical line to operate the ringing relay.

6. Governor.—Between the base plates at *f*, Fig. 2, is a small flywheel governor connected with the wheel *w* by means of a pinion. A separate view of this governor is shown in Fig. 4. The object of the governor is to regulate the speed of the main shaft. When the dial is rotated by the finger, the pawl *y*, Fig. 3 (*b*), moves with it. When the dial is released by the finger, this pawl *y*, to which the clock spring is attached, engages the large brass gear-wheel *w* and forcibly rotates it. This wheel engages a small pinion *z* on the shaft of which is mounted the governor shown in Fig. 4. The large gear-wheel *w*, Fig. 3 (*b*), has about twenty times as many teeth as the pinion *z*, which, therefore, rotates much faster than the wheel. The governor, Fig. 4, consists of a wheel rim *x* mounted loosely on the shaft *z* and two rather heavy brass segments *l*, *t*, each pivoted near its circumference and at opposite ends of the same diameter on the ends of the piece *b* that is fastened to and rotates with the shaft.

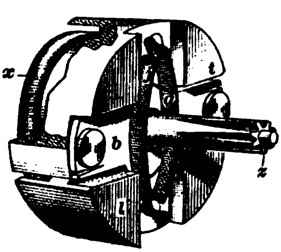


Fig. 4

As the speed of the shaft increases, the free ends of the brass segments, which are normally drawn toward the center of the hub by light spiral springs *a*, *j*, are moved outwards by centrifugal force until the inner surfaces rub against the inside edge of the iron rim *x*. The friction and centrifugal force are so related to each other that the large brass wheel *w*,

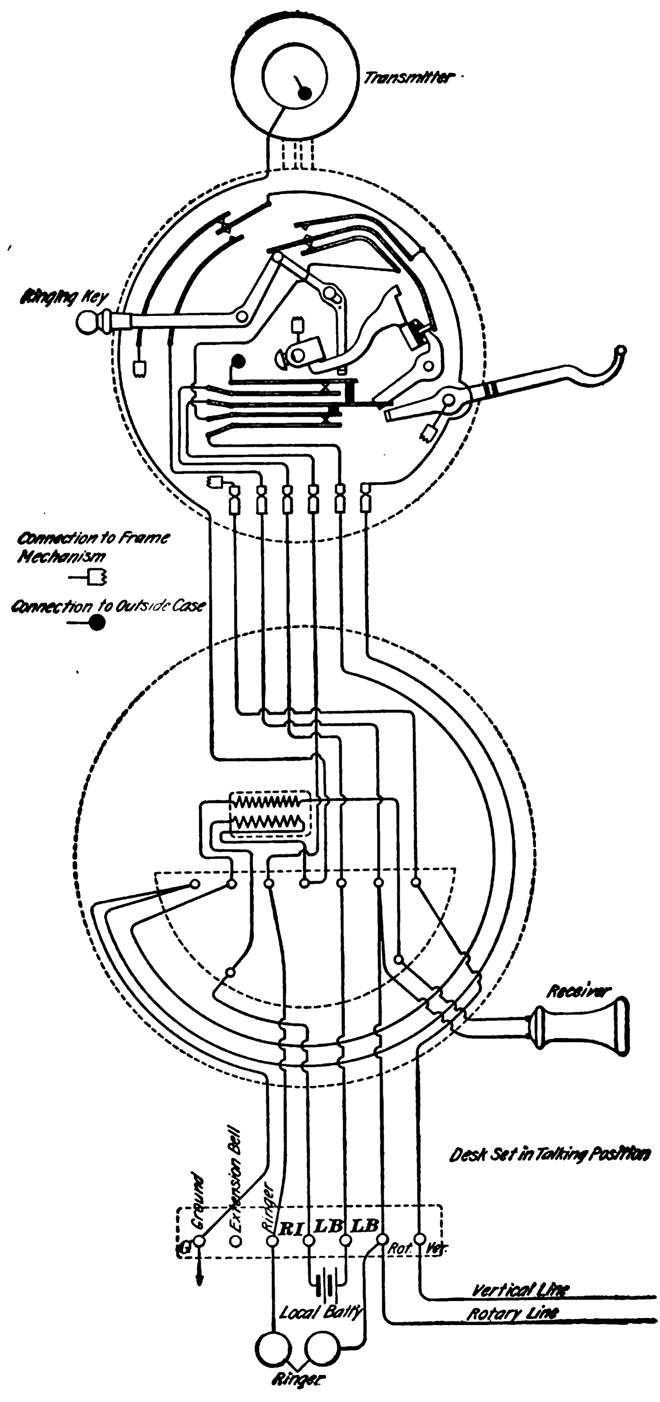

Transmitter
Ringing Key
Connection to Frame Mechanism
Connection to Outside Case
Receiver
Desk Set in Talking Position
Ground
Extension Bell
Ringer
RI
LB
LB
G
Rot.
Ver.
Vertical Line
Rotary Line
Local Batty
Ringer

FIG. 5

Fig. 3 (*b*), rotates sufficiently uniform and slow to allow the central-office switches the proper time to operate, which is about 1 second.

7. Fig. 5 shows the arrangement of the parts and the wiring inside of one form of a desk telephone. The mechanism and connections are the same as in a wall telephone, but somewhat differently arranged.

AUTOMATIC SWITCHES

8. For a system not exceeding 100 lines, the automatic switch located in the exchange is called a **connector.** For a system between 100 and 1,000 lines, an additional switch, called a **first selector** is required, while an additional intermediate switch, called a **second selector,** is required for systems between 1,000 and 10,000 lines. These three switches are very similar in general construction, but differ somewhat in details.

9. The automatic switches are set up in banks to form the central-exchange switchboard. Two side views of a connector switch are shown in Fig. 6. The over-all dimensions of this connector switch are about 13½ inches in height, 7¼ inches in depth, and 6 inches in breadth or width. Selector switches, which are similar in shape, are about 1¼ inches less in depth because they do not require a ringing relay. In other dimensions, they are about the same size as a connector. The frame of the switch is made of a non-magnetic metal. All other parts are fastened to this frame, so that a switch is a complete machine in one piece. Mounted on this frame are six electromagnets—two main-line relays and four local magnets that operate the movable parts and contacts.

10. Contact Banks.—Mounted on the lower part of the frame are three banks of contacts. The upper bank, called the **busy,** or **private,** bank has one hundred contacts arranged in ten rows of ten contacts each. The other two banks, called the **line banks,** have fifty pair of contacts each. The banks are held in position on the two side rods. In the

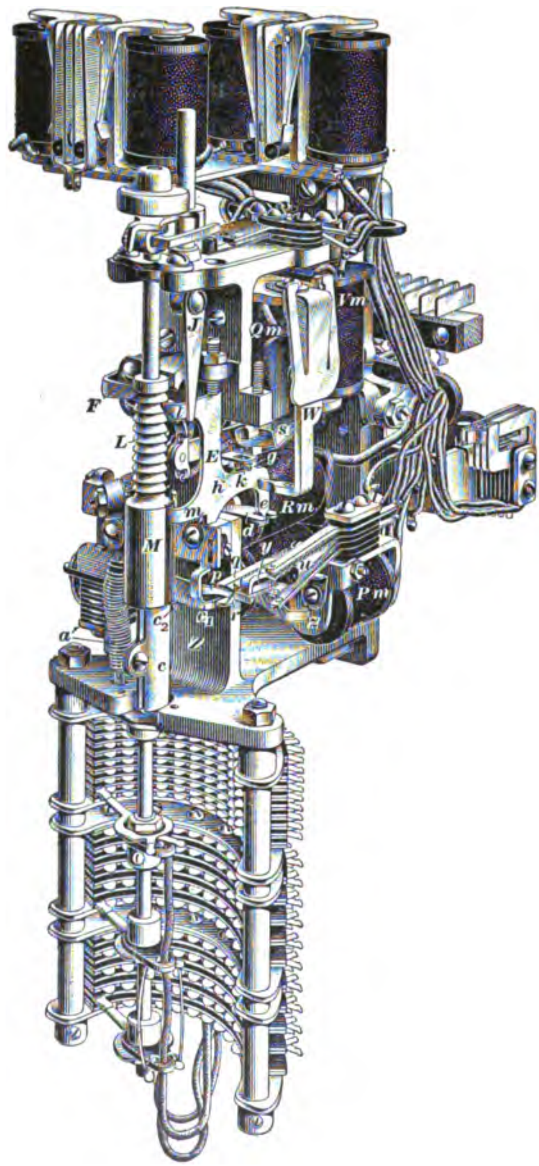


Fig. 6 (*a*)

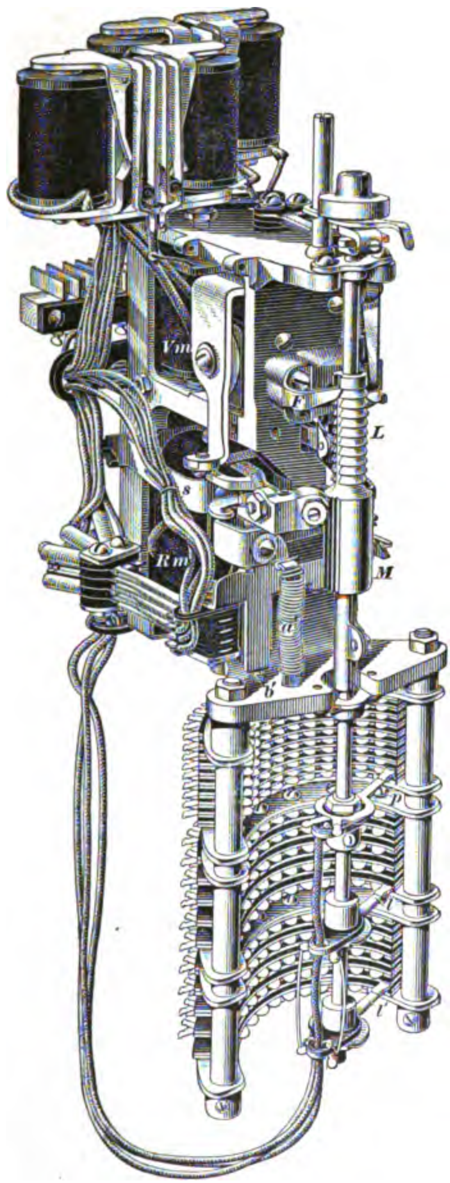


FIG. 6 (b)

later systems, the lower two banks are wired with conductors twisted in pairs to avoid cross-talk and induction troubles. The lower two banks each consist of five rows of contacts; in each row, there are ten pair of contacts; the two contacts constituting a pair are carefully insulated from each other. The insulation is said to consist of empire bond paper, treated with linseed oil. All banks are wired with No. 24 tinned copper wire covered with one layer of cotton and two layers of beeswaxed silk.

11. Wipers.—All the contacts are mounted on a semicircular structure, the axis of which is a vertical rod, or shaft, about the size of a lead pencil, on which are fixed three contact arms, *p*, *l*, *l'* about $1\frac{1}{8}$ inches in length; they are called **wipers.** Each wiper consists of two spring blades forming the jaws of a rotating knife switch. The two springs constituting the upper, or **private, wipers** *p* are not insulated from each other and form one conductor. The two lower pair of wipers, *l*, *l'*, called **line wipers,** each consist of two springs insulated from each other by a thin piece of insulating material. The bottom spring of the bottom pair is connected by a bare wire with the bottom spring of the middle pair, and the top spring of the bottom pair is similarly connected to the top spring of the middle pair. The two lower pair of wipers are thus connected in parallel; however, only one pair is in use at any one time. When a connection is made, the upper spring of a line wiper rests on the upper contact of a pair of contacts and the lower spring rests on the lower contact of the same pair.

12. Shaft.—Important movable parts are the shaft in the center of the front of the switch and the wipers. The shaft and wipers have both a vertical and a rotary motion, each controlled by a magnet. When the subscriber calls 76, for instance, the first movement of the subscriber's dial allows the flow of current impulses that raise the shaft and wipers step by step to the seventh row of contacts. The second movement of the subscriber's dial allows the flow of current impulses that rotates the shaft and turns the wipers to the sixth contact in the seventh row, thus securing the connection with 76.

13. To the middle part of the shaft is riveted a hub, the upper part *L* of which has ten horizontal, circular teeth and the lower part *M* has ten vertical teeth. The circular teeth may be engaged by a pawl that is behind the hub *L* and is moved by the armature of the so-called vertical magnet *Vm*. An impulse through the vertical magnet causes the pawl to lift the shaft one tooth, the armature and pawl being drawn back after the impulse by the flat spring *s*, Fig. 6 (*a*). The pawl slips back over the next tooth and falls into the next groove. The shaft is held in position by the upper arm *l* of the double dog *E*. A second impulse through the vertical magnet will lift the shaft another tooth. As the shaft has ten teeth, each $\frac{1}{8}$ inch in height, it may be raised a total of $1\frac{1}{4}$ inches and retained at any one of ten heights.

The longitudinal teeth of the hub *M* are engaged by another pawl attached to the end of the so-called rotary magnet *Rm*. An impulse through the rotary magnet causes the pawl to rotate the shaft through the space of one tooth. When the rotary armature is released, the spring *s*, Fig. 6 (*b*), pulls it back, but the shaft is held from rotating backwards by the lower arm *m* of the double dog *E* and is supported in any horizontal position while rotating by the finger *F*. A second impulse will rotate the shaft another tooth. Thus the shaft may be moved to and held in any one of one hundred positions.

14. Movement of Wipers.—If the shaft moves up one step, the lower pair of wipers *l'* is in line with the lowest row of contacts of the lowest bank and the top or private wiper *p*, which represents a single conductor and not a pair, is in line with the lowest row of single contacts in the private bank. When the switch moves up two steps, the next to lowest, or middle, pair of wipers *l* is in line with the lowest row of contacts of the middle bank, and the private wiper is in line with the second row of contacts in the private bank. Thus the first row of line contacts is the bottom row of the lowest bank; the second row of line contacts is the bottom row in the middle bank; the third row is the second row in the bottom bank; the fourth row is the second row in the middle bank; and so on. Therefore, the space between the rows of the two lowest, or line-wire, banks is twice that between the rows of the private bank. Thus one pair of line wipers makes contact while the other pair is idle and moves between two rows of contacts. The line banks are made in two banks in this manner, so that the vertical movement of the wipers need not be increased beyond an efficient working distance and to prevent such an overcrowding of the wires as to render difficult the ready location of troubles. Both line wires being switched, there are necessarily double the number of line contacts as private contacts, only one of the latter being necessary for one pair of lines.

15. System of Numbering.—In a 10,000-line system, there are ten hundreds to each thousand. For example, between 2,000 and 3,000, including 2,000, there are ten hundred as follows: 21, 22, 23, 24, 25, 26, 27, 28, 29, 20; each of whose first, or thousand, digit is of the same denomination, while the second, or hundreds, varies from 1 to 0, and so on for each of the other nine thousands. 20 is placed last for the reason that in the value of electrical impulses 20 represents 2 tens and ten units, whereas 21 represents 2 tens and one unit. Zero (0) has the value of ten impulses.

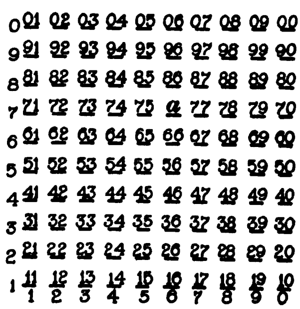


FIG. 7

Referring to the private bank shown in Fig. 7, the contact *a* is reached in steps by going up seven tens and horizontally six units. Its position in the square will represent the number, 76, which is equivalent to 10 + 6; that is to say, ten vertical and six horizontal movements of the switch. All line members have two digits. To obtain line *04*, the pulling down of the dial to *0* raises the shaft ten steps, and *4* rotates it four steps, giving *04* in the top row.

In a system up to 100 lines, all numbers below 10 must be written 01, 02, etc., and the subscriber must pull the 0 on the dial, otherwise he will get no connection. To avoid this difficulty, the numbers 0 to 9 may be omitted, in which case the switch is not used to its full capacity. For similar reasons, in a 1,000-line system, the numbers from 1 to 9, inclusive, must be written 001, 002, etc., and the numbers from 10 to 99 must be written 010, 011, etc. Similarly, in a 10,000-line system, the numbers must be written 0001 to 0009, 0010 to 0099, 0100 to 0999, that is, all digits, preceding numbers below 1,000 must be filled with zeros and these zeros must be used by the subscribers in calling such numbers, or else such numbers must not be used. In a large system, such numbers could be reserved for special purposes—for instance, for the use of toll operators.

OPERATION AND CONSTRUCTION OF SWITCHES

SIDE SWITCH

16. Having given a general idea of the Strowger automatic system, the mechanical and electrical features of the system will be taken up in detail, beginning with a connector switch. As far as practical, the same reference letters will be used for similar parts in all figures showing different views or parts of the same switch. Two side views of a 1906 type of connector switch have been given in Fig. 6 and views of the most important parts will now be shown. Fig. 8 shows a side view of what is known as the *side switch*, and Fig. 9 a plan view across the whole switch a little above the side switch. This side switch

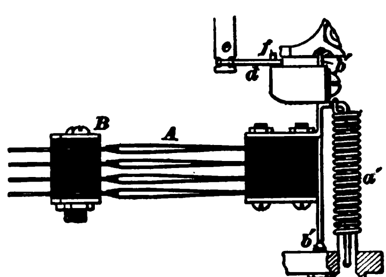


Fig. 8

consists of four pair of wiping spring contacts *A*, Fig. 8, which may occupy one of the three positions *a*, *b*, *c*, Fig. 9, on the block of contacts *B*. The first position *a* is the normal position on which the arms rest when the switch is released; *b* is the position held while selecting a line; *c* is the final position. This side switch is under the tension of a spiral spring *a'*, shown in Figs. 6, 8, and 9, that tends to make it rotate about the axis *b' b'*. It is restored to its normal position on the row of contacts *a*, Fig. 9, by the action of the armature *W* of the release magnet *Qm*, Fig. 6, and held there normally because the lever *p* that is rigidly fastened to the side switch moves backwards, as the side switch is restored, between the pieces *q*, *r* and is held by

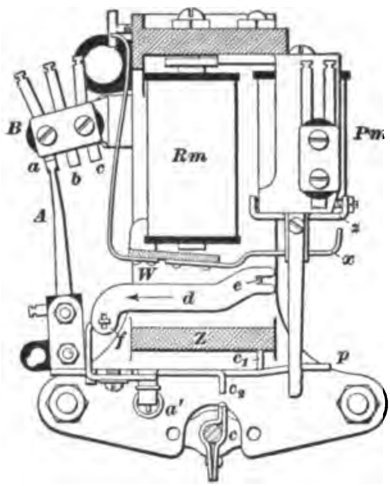


Fig. 9

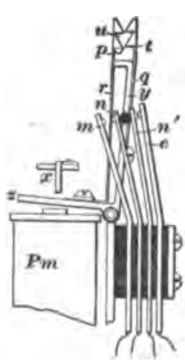


Fig. 10

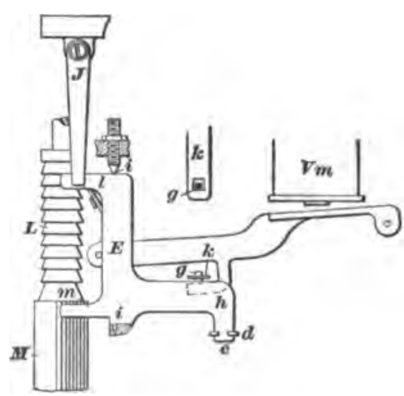


Fig. 11

the rear notch in *r*, as shown in Fig. 10. The pressure of the end *e*, Figs. 9 and 11, on the link *d*, in the direction of the arrow, Fig. 9, restores the side switch to its normal position with the stop c_1, Figs. 6 (*a*) and 9, resting against the frame *Z* of the switch and the wiper springs *A*, Fig. 9, on contacts *a*. In Fig. 11, a separate horizontal view of the spring *k* and pin *g* is shown above the position it actually occupies in this figure. This pressure of the armature *W*, Fig. 6 (*a*), of the release magnet must be greater than the combined tensions of the spiral spring *a'* and the flat spring *J*, as well as the friction of the wiper of the side switch and the other moving parts, in order that the pin *g*, Figs. 6 (*a*) and 11, may be pushed in far enough to allow the thin spring *k* to slip over and hold the dog *E* away from the shaft while the latter returns to its normal position.

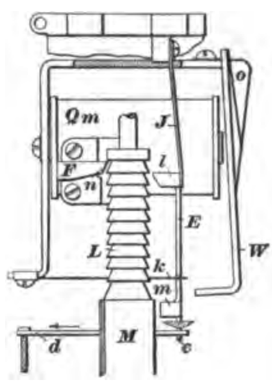


FIG. 12

17. Figs. 6 (*a*), 11, and 12 show also the double dog *E* that engages the two toothed hubs *L*, *M* of the shaft, which it holds in its successive steps of advancement, either vertically or rotary. *E* is pivoted on axial points *i*, *i*, Fig. 11, and is under the tension of the flat spring *J*, which tends to throw the ends *l*, *m* of the piece *E*, Figs. 6 (*a*) and 11, into engagement with the toothed hubs *L*, *M*. The piece *E* is normally held disengaged by the thin spring *k*, a slot in which slips over a pin-like projection *g* when the release armature *W*, Fig. 12, is attracted by its armature. The hook *h*, Fig. 11, forming part of the armature of the vertical or lifting magnet *Vm*, disengages *k* from *g*, when this armature is attracted, thus setting *E* free on the first movement of the armature of *Vm*. One end of the piece *F*, Figs. 6 (*b*) and 12, which is fastened to the frame, rests in a vertical slot in the hub *L* when the latter is in its normal position. It therefore allows the hub *L* to move up and down only when in its normal position, and allows *L* to rotate only when *F* is exactly opposite one of the depressions between the teeth. It then supports the shaft during rotation. The release magnet *Qm*, Fig. 12, returns the side switch *A* to its normal position and releases the double ratchet *E*.

Fig. 10 shows the private magnet *Pm* with its accompanying parts. The side switch is restored to its normal position by the action of the armature *W* of the release magnet *Qm*, Fig. 6 (*a*), when the switch is released, but it is not held in that normal position by this armature. To the armature *z* of the private magnet *Pm*, Fig. 10, is fastened an arm *y* and two thin springs *r*, *q*. These two springs *r*, *q* have small teeth, as shown, that retain [see also Fig. 6 (*a*)] the long lever arm *p* of the side switch in its normal position after *k*, Fig. 11, has been disengaged from *g* and *e* set free in the slot in the end of *d*.

CONNECTOR SWITCH

18. The movements of the connector switch shown in Fig. 6, taken as a whole, will now be considered. The shaft carrying the three wipers (the "busy" and the two pair of line wipers, which in manual phraseology correspond to the calling plug of the operator's cord circuit) has two distinct motions—vertical and rotary. The first is effected by electrical impulses, sent in from the subscriber's station over the vertical line, operating directly the line relay in that line. The vertical line relay controls the vertical magnet that actually produces the vertical movement of the switch. Each digit of a number is represented by as many electrical impulses as there are units in that digit plus one, and the dial of the telephone instrument, each time that it is pulled down and let go, sends over the vertical line as many impulses as there are units in the digit selected by the subscriber, followed by one impulse over the rotary line. This extra, or last, impulse over the rotary line performs about the following operation for each digit of the number called: For a first-selector switch, it is a trunk selector; for a second-selector switch, it is a trunk selector; for the tens' move of the connector, it passes the side switch to the *b* contacts, thereby reversing the lines; for the units, it completes the connection if the desired line is not busy, or releases the connector if the line is busy.

19. The first impulse or impulses pass through the vertical line and operate the vertical relay, shown at the top of Fig. 6, and in turn the vertical magnet *Vm*, Fig. 11. When its armature is drawn up, it first causes the hook *h* to push *k* off *g*, thus allowing the ends *l*, *m* of the double dog *E* to engage the shaft. The further movement of the armature of *Vm* causes a pawl to engage and lift the shaft *L* one step, while the end *l* slips over the first tooth and then moves under it, thus holding the shaft in that vertical position. At the same time, the side switch lever *d* is set free by *e*, but is still retained in normal position by the notched springs *r*, *q*, Figs. 6 (*a*) and 10, that engage the latch *p*. For the succeeding vertical impulses of that digit, there is no change in any of the parts except in the position of the shaft, which rises one step for each impulse.

The last impulse to each digit, being rotary, operates the rotary relay, shown at the top of Fig. 6, and causes the private magnet *Pm*, Fig. 10, to attract its armature *z*, and *p* then moves into the notch on the side *t*. On the release of this armature, the springs *r*, *q* are moved just enough to allow *p* to move from notch *t* to notch *u* under the tension of the spiral spring *a'*, Figs. 8 and 9. It is held in this position until the shaft rotates one step, by a projecting finger c_1, Figs. 6 (*a*) and 9, that comes against the cam *c* mounted on the shaft. In this position, the side switch is held on the second row of contacts *b* and the rotary magnet is substituted for the vertical magnet, so that when the units' impulses flow through the vertical line, the shaft will be rotated by the rotary magnet *Rm* one step for each impulse. Then follows a single impulse over the rotary line, which again causes the private magnet to attract its armature, on the release of which the springs *r*, *q* move so as to release the projecting finger *p* and allow the side switch to move into the third position *c*, thereby completing the connection if the desired line is not busy. If it is busy, this last impulse over the rotary line causes the release magnet to release the whole switch.

20. The operation of a **selector switch** is very similar to that of a connector, but the rotary motion is governed in a somewhat different manner. After the shaft has been raised, the proper number of steps and the side switch, when one is provided, is placed in the *b* position, the current through the rotary magnet is interrupted, thereby causing the shaft to rotate, as will be explained in connection with the circuit diagrams. The first impulse of the rotary magnet brings the private wiper in engagement with the first contact point of the particular horizontal row designated by the number of vertical impulses previously sent in. Formerly, selectors were provided with side switches about the same as connectors; but in the later type of selectors the rotary magnet itself interrupts the current passing through it from a battery, and no side switch is required.

21. Mounting of Switches.—The automatic switches are mounted on shelves, 25 switches to the shelf, each section, or switchboard containing six shelves, or a total of 150 switches. The makers state that the actual floor space occupied by such a switchboard is 11 feet 6 inches by 6 inches, and the floor space required is 3 feet by 12½ feet; while the space allowed in making calculations for room is 39 square feet. The automatic switchboard can be increased to any capacity by adding new sections with the desired number of switches mounted thereon. About 90 per cent. of the electrical contacts and connections on the automatic switchboard are made at the factory. The automatic switchboard is said to require no more room than the manual board, and no space or accommodation for the operators is needed.

The meter system can be introduced, by means of which all service can be measured. In appearance, these meters resemble a cyclometer, and one is attached to each individual switch. Its operation is automatic, and it records every connection secured by the telephone having the same number as the switch to which it is attached.

Having considered the mechanical construction and operation of the switch and the general plan of numbering, it should now be easy to understand the electrical circuits and their functions in switching.

100-SUBSCRIBER EXCHANGE

22. It will be best to first consider an exchange for not more than 100 subscribers; the operation of larger exchanges will then be easier to understand. Each subscriber's station is connected to the exchange by two wires, and a ground circuit is also used when making a call, but is disconnected at other times. The calling device works by grounding the one or the other line a certain number of times. Each subscriber's line ends in a separate switch at the exhange, so that there are as many switches as there are pairs of line wires.

The subscriber calls the party desired by working his dial in the manner already described and the switch at the exchange makes the connection in the time the subscriber is occupied by his calling.

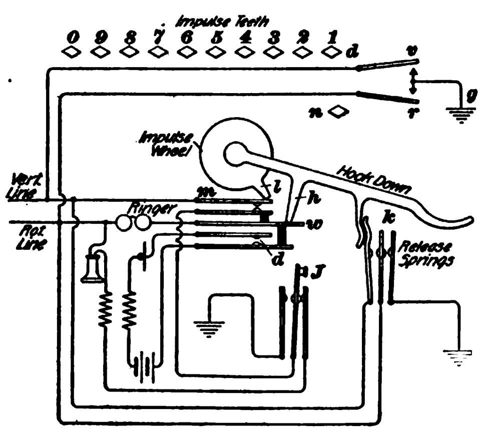


Fig. 13

23. Fig. 13 shows in a simplified manner the circuits of the subscriber's instrument for any size system in normal position; that is, ready to receive a call. Suppose that the subscriber desires to call 76. He takes down the receiver and puts his finger in hole 7 and pulls the dial around until his finger is stopped by the finger stop. This first opens both line wires between the spring *m* and the projection *l* on the impulse wheel and then the rotary tooth *n* and seven of the vertical teeth *d* pass by the impulse springs *v*, *r* in such a way that they make no contact. When the subscriber releases the dial, the seven vertical teeth cause the vertical-impulse spring *v* to touch the ground contact seven times, after which the rotary tooth *n* causes the rotary-impulse spring *r* to touch the ground contact once. As the impulse springs are connected to their respective lines, these lines receive impulses from the central-exchange battery through the ground. The subscriber then pulls *6*. By this operation, six impulses pass through the vertical line followed by one through the rotary line.

Finally the subscriber pushes the ringing button *J*, which grounds the vertical line and, at the same time, breaks the connection between the two lines as long as he presses the button. When through talking, the subscriber hangs his receiver on the hook, which in moving down causes the release springs *k* to simultaneously and momentarily connect the two line wires to the ground. This allows an impulse to pass through each line simultaneously, using the ground as a common return circuit. The springs *k* are so arranged that they are not even temporarily grounded when the hook moves up.

24. In the exchange, the lines of a system not exceeding 100 lines end at a switch called a connector, one of which has been shown in Fig. 6. Fig. 14 shows the connections and some mechanical parts in a manner to more clearly indicate their operation. Some details are omitted but, in general, it is the circuit used in some large exchanges. The side switch S_1, S_2, S_3, S_4 in this case is a four-pole switch, the arms of which are adapted to be thrown into any one of three positions, *a*, *b*, *c*. This switch is controlled by the private magnet *Pm*. The method of control indicated is not, however, the actual construction employed for this purpose; the actual construction was shown and explained in connection with Figs. 6 and 10. One of the line wires from the subscriber's station, called the **vertical line,** passes through the 30-ohm vertical relay *Vr*, the other, called the **rotary line,** passes through a similar 30-ohm rotary relay *Rr*. These series-relays stay in the circuit all the time and are connected through high-resistance impedance coils *I*, *I'* and a 50-volt storage battery to ground.

The vertical relay, when energized, pushes a spring *o* against a grounded contact, and the rotary relay does the same with spring *q*. An impulse through the vertical relay *Vr* closes a local circuit through the ground–spring *o*–*s*–back

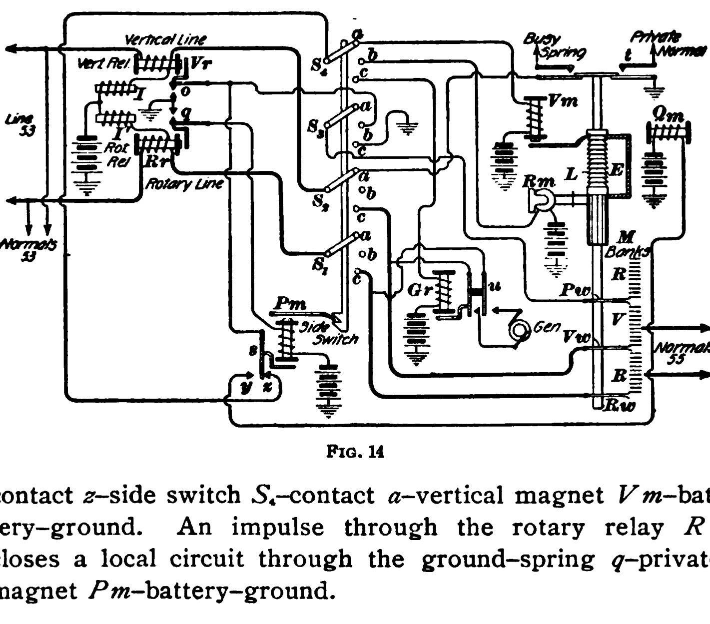


FIG. 14

contact *z*–side switch S_4–contact *a*–vertical magnet *Vm*–battery–ground. An impulse through the rotary relay *Rr* closes a local circuit through the ground–spring *q*–private magnet *Pm*–battery–ground.

25. Suppose that subscriber 53 wants to call subscriber 56. After taking down the receiver, subscriber 53 pulls *5*, which grounds the vertical line five times and the rotary line once, thereby sending five impulses through the vertical relay, which closes the circuit of the vertical magnet, thus lifting the shaft five steps or teeth, then one impulse flows through the rotary relay, thus closing the circuit containing the private magnet *Pm*, the movement of whose armature allows the side switch to pass from *a* to *b*. The spring *s* is also momentarily pressed against the front contact *y*, but all circuits connected to *s* are open somewhere, hence no effect is produced.

Now subscriber 53 pulls *6*; that is, the units of 56. Six impulses flow through the vertical relay *Vr*, but as the arm S_4 of the side switch rests on contact *b*, the rotary magnet *Rm* is energized by current that flows through the ground–*o*–*s*–contact *z*–switch arm *4*–*b*–*Rm*–battery. After this, the impulse through the rotary line and relay *Rr*, will allow current to flow through ground–*q*–private magnet *Pm*–battery which will allow the side switch to move to position *c*. Although *s* touches the front stop *y*, no effect is produced, because all circuits coming to *s* are still open. The line wires are now connected to the wipers *Vw*, *Rw* and the private wiper *Pw*, and one pair of line wipers rest on contact *6* in the fifth vertical row of contacts, that is, on 56. The two lines 53 and 56 are thus connected together.

Subscriber 53 now pushes his ringing button, which grounds the vertical line. As long and as often as he pushes the button, the vertical relay is energized, thereby closing the local circuit through the ground–*o*–*s*–*z*–side-switch arm S_4–contact *c*–generator relay *Gr*–battery; the relay *Gr* connects the ringing generator terminals across the two line wipers *Vw*, *Rw*, which are now connected through the contacts in the banks with line 56, thereby ringing the bell of subscriber 56. Most of the ringing current flows through the desired line 56, because the only resistances in that circuit are the desired subscriber's line and bell, while there is a relay in each side of the calling subscriber's line.

26. Conversation Completed.—When the conversation is finished, both subscribers hang up their receivers. The momentary and simultaneous grounding of both line wires as subscriber 53 hangs up his receiver, energizes the vertical and rotary relays *Vr*, *Rr* simultaneously; allowing current to flow through *Pm*–*q*–ground–battery, thereby energizing *Pm*, and allowing current to flow through the ground–*o*–*s*–*y*–*Qm*–battery. The release magnet *Qm* pushes the double dog *E* out of the teeth of the hubs *M*, *L*, thereby allowing a spring at the top of the shaft to rotate the shaft, so that the wipers move back over the contacts in the sixth row and then the shaft and wipers fall down by their own weight to their normal position. The action of pushing back

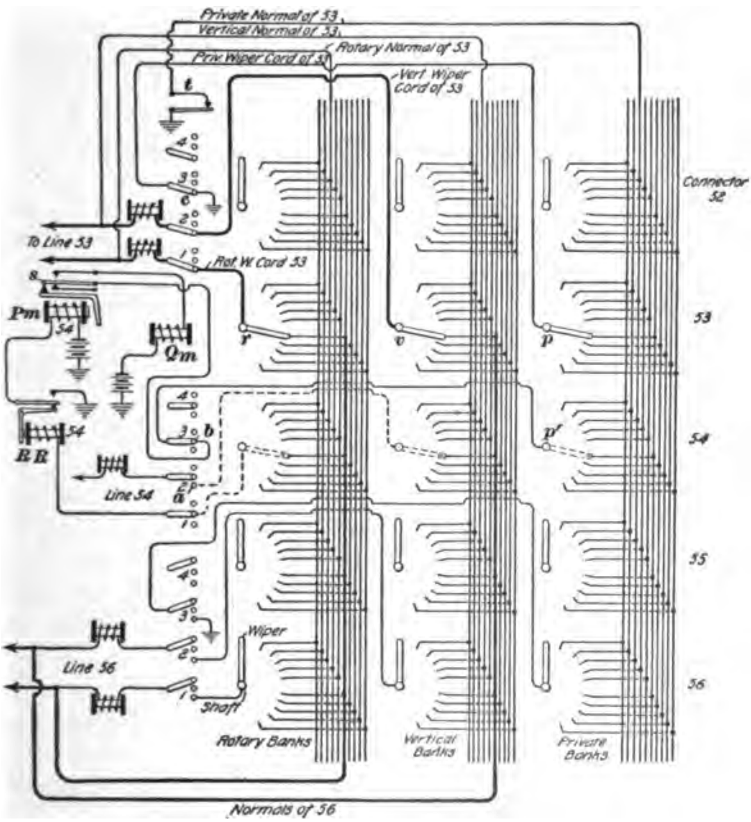


FIG. 15

the double dog *E* also restores the side switch to position *a* by a mechanical link that could not be shown in this figure, but has been shown at *d* in Figs. 6 (*a*), 8, 9, and 11. The complete restoring motion is finished before the receiver has completely pulled down the hook.

27. In a 100-line exchange, there are 100 switches, and all similarly numbered contacts in the three banks of the entire 100 switches are connected in multiple. Each subscriber's line wires are connected not only to two arms S_1, S_2 of the side switch, but also, through the so-called normals of that line, to the vertical and rotary contacts of the same number in the line banks of all switches. In other words, each subscriber is represented in each other subscriber's switch by a pair of contacts. The spring *t* at the top of the shaft is connected to the private normal that runs to all private-bank contacts in all the other switches having the number of this switch, that is, *53*.

28. A part of the multiple wiring through five switches is shown in Fig. 15. The fifth level of the three banks of switches *52*, *53*, *54*, *55*, *56* is represented. The wipers are represented by the arms *r*, *v*, *p*. The wipers of line *53* rest on contacts *56*. The heavy lines show the connections between the two lines *53* and *56*. The side-switch arm *3* of connector *53* rests on contact *c* and hence connects the private wiper of *53* to the ground. The private wiper *53* engages the private contact *56*, consequently the whole private multiple of *56* is grounded through the private wiper and contact *c* of side switch *3* of connector *53* and the private multiple of *53* is grounded through the spring *t*, Fig. 14, controlled by the top of the shaft of connector *53*.

29. Busy Test.—Suppose that subscriber 54 calls 56 while 53 is talking to 56. The connector *54* will step up five notches and the side switch will be thrown into position *b*, Fig. 15, as a result of pulling down *5* on the dial. Then six impulses pass through the vertical line and the two wipers of line 54 engage contacts *56*, but the lines are not yet connected because this only occurs when side switch of *54* is in position *c*. The side switch of connector *54* is shown in the position it assumes, that is, on the *b* contacts, the moment before the last rotary impulse. As the whole private multiple of *56* is grounded, the contact *b* on side switch *3* of connector *54* is also grounded. Hence, a circuit is complete from ground through contact *c* and arm *3* of side switch *53*–private wiper *p* of connector *55*–private multiple of *56*–private wiper *p'* of connector *54*–arm *3* and contact *b* of side switch *54* to spring *s* of private magnet *Pm* of connector *54*; at this point the circuit is now open. The rotary impulse that finally flows through the rotary line and rotary relay energizes the latter, thereby closing the circuit through the private magnet *Pm*, which, in turn, connects the spring *s* through the release magnet *Qm* and battery to ground, thereby energizing the release magnet *Qm* of connector *54*. The armature of this relay presses against the rear end of the double dog of connector *54* [see Fig. 6 (*a*)] and an arm *e* of this double dog presses against a link *d* that returns the side switch to its normal position. At the same time the shaft is released by the dog and returns to its normal position and the dog is locked in this normal or released position by the thin spring *k* that slips over a projection *g* on the piece *E*. Thus connector *54*, Fig. 15, instead of being connected to line 56, is returned to its normal position.

30. However, subscriber 54 is not yet aware that he did not get line 56 and so pushes his ringing button, which connects the vertical line to ground and energizes the vertical relay; this in turn energizes the vertical magnet, which lifts the shaft of connector *54* one step. This allows an alternating or interrupted current to flow through the busy spring (see Fig. 14), which is closed by the rising of the top of the shaft–contact *a*, Fig. 15, and arm *2* of the side switch *54*–vertical line–subscriber's ringing button–ground. When the ringing button at instrument *54* is released, this current flows, instead of to ground, through the receiver–rotary line–rotary relay–impedance coil–battery–ground. This current will not operate the relays. The subscriber recognizes, by the hum produced in his receiver, that the line desired is busy and hangs up his receiver. As the hook switch moves down, it momentarily grounds both line wires and restores switch *54* to its normal position.

If subscriber 54 calls subscriber 53 while 53 is talking to 56, the private wiper *p'* is connected through contact *53* in the private bank of connector *54*–private normal *53*–spring *t* at the top of connector *53* to ground; hence, connector *54* is released and the busy-tone test is produced in the same manner as when subscriber 56 was called.

LARGE EXCHANGES

31. Trunks.—In a system of 100 to 1,000 subscribers, the trunking feature is introduced. Ten trunk lines have been found sufficient to do the business of each 100 subscribers, but any number of trunks may be provided for every 100 subscribers. A board equipped for 1,000 subscribers would, therefore, have 1,000 switches called *selector switches* and may have 100 connector switches, or, in manual phraseology, 100 pair of cords, unless a greater percentage of connectors should be required. The connector switches are arranged in ten groups of 10 switches each, and each group is capable of connecting to 100 subscribers; the first group connecting subscribers whose numbers are between 100 and 200, the second group connecting those between 200 and 300, and so on. In calling, the first movement of the dial would pick out one of the ten trunk lines leading to the hundreds group desired. The next two movements would connect with the desired number in that group. To illustrate, it may be said that number 761 is wanted. Number 7 on the dial being pulled down, the subscriber is automatically connected with one of the ten trunk lines leading into the seventh group of hundreds. The next two movements, numbers 6 and 1, select the number 61 in that group, and he is then connected with the desired number. The apparatus automatically selects the trunk lines that are not busy. If the first trunk line is engaged, the connecting arm passes over it and selects the second; that being engaged also, it selects the third, and so on, until a disengaged trunk line is found. The use of first selectors and connectors allows any number with three digits, that is 000 to 999, inclusive, to be called.

32. In a 10,000-line system, each subscriber's number will have four digits, namely, thousands, hundreds, tens, and units and the operation of such a system requires an intermediate switch called a second-selector switch. Thus, in an exchange having between 1,000 and 10,000 lines, there is one first selector for each pair of line wires; these select the thousands' trunks that run to the second-selector switches, which, in turn, select the hundreds' trunk that run to the connector switches. The connector switches, by being moved in two directions—so many tens up and so many units around in a horizontal plane—locate, by their position in the banks, the subscriber's number and thus complete the connection. Three switches will therefore be required to effect a connection. The second selectors are practically the same in construction and operation as a first selector; about the only difference is that no normals are attached to a second selector.

33. In a 10,000-line exchange, there will be 10,000 first selectors, while there may be 2,660 second selectors, and 1,500 connectors. The subscriber desiring subscriber 7,654 will, by the first movement of his dial, automatically select one of the trunk lines of the 7,000 group; the second movement will select one of the trunk lines of the 600 group; the last two movements will select the tens and units, that is the line desired and complete the connection. The use of first and second selectors and connectors allows any number with four digits, that is, from 0,000 to 9,999, inclusive, to be called. As a 1,000-line system may be considered as a special case of a 10,000-line system, in the former case, no second selectors being required, an explanation of the more general case, that is, a 10,000-line system, should readily enable one to understand the operation and general connections of the simpler 1,000-line system. For this reason, 10,000-line systems will now be considered.

10,000-LINE SYSTEMS

34. The method of operating an exchange of from 1 to 10,000 lines is simply an extension of the trunking system. In Fig. 16, *A* represents one switch in a group of 100, known as first-selector switches, which are the subscribers' individual switches. B_1, B_2, B_3, etc. each represents the first switch, B_1' the second, B_1'' the third, etc., in each group of ten, known as the second-selector switches. These *B* switches are common to all the switches in a certain

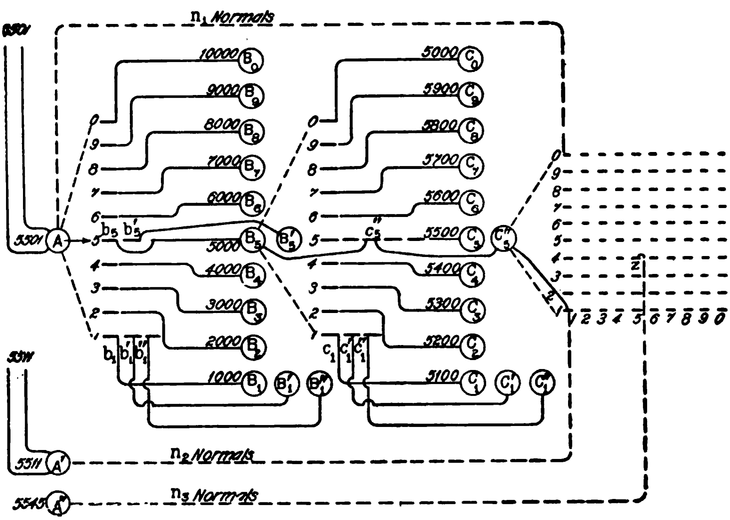


FIG. 16

group of *A* switches only. C_1, C_2, C_3, etc. each represents the first, C_1' the second, C_1'' the third, etc., connector switch in each group of ten; each group of ten second-selector switches represents, therefore, 100 trunk lines ranging between 5,100 and 5,000, including the latter. b_1 represents the first, b_1' the second, b_1'' the third, etc., vertical row of bank contacts in the switch *A*. For the sake of simplicity, one line represents both vertical and rotary contacts. c_1, c_1', c_1'', etc. represent the same for switch B_5. At the right is shown the full 100 contacts for connector switch C_5''; n_1, n_2, n_3 are only three of the 100 so-called normals leading back to subscribers' switches.

It will be seen from this that the first selectors or subscribers' switches appear in groups of 100 each; each group having its own group B_1, B_2, etc., of second-selector switches and C_1, C_2, etc. of connectors. All similarly numbered line and private bank contacts of all connectors in one group are connected in multiple and all similarly numbered second-selector trunks in the whole exchange are connected in multiple.

35. Suppose that A, whose number is 5,501, desires connection with A', whose number is 5,511. In calling the first 5, or thousands, digit, he places his switch in position of arrow at A and it will take the first contact of the fifth horizontal row of contacts, provided that it is not busy. This will connect him with B_5, which is the first switch of a group of ten in the 5,000 group A, and is known as second-selector switch. With this switch, he will be able to connect, as will be seen by studying the diagram, with the ten hundreds between 5,100 and 5,000, including the latter (note that 5,000 follows because 0 has the value of 10 in calling and ten vertical impulses carry the switch to the top vertical row). In this particular case, he wishes the 5,500 group. By calling 5 in the second, or hundreds, digit he places the switch on the fifth level or row of contacts, taking the first contact that is not busy, for instance c_5''. He is now connected with the connector switch C_5'' of the 5,500 group, with which switch he is able to make one hundred possible connections, that is, to any number between 5,500 and 5,600. In this particular case, he wants 11, which is represented by one step up and one step in. Although 5,511 has the lowest number of electrical impulses that can be called in the 55 group, nevertheless 5,500 to 5,510 can be called and their positions can be readily found by remembering that each 0 corresponds to ten impulses. From contact 11, a pair of normals n_2 leads back to the subscriber's switch 5,511 or A', thence to that telephone. This represents the completed connection in a simple diagram for a 10,000-line system.

The first selectors, as said before, are in groups of one hundred mounted on one board or frame and have all similar bank contacts of the three banks wired in multiple, as shown in Fig. 17, where, for simplicity, is shown a horizontal section through the first row of contacts of a first-selector switch, of the three banks containing the private, vertical, and rotary contacts. The line banks have trunks leading to the second-selector switches, only the first three trunks being represented.

The number of second selectors on each board may be varied from ten to twenty as desired; if over ten switches

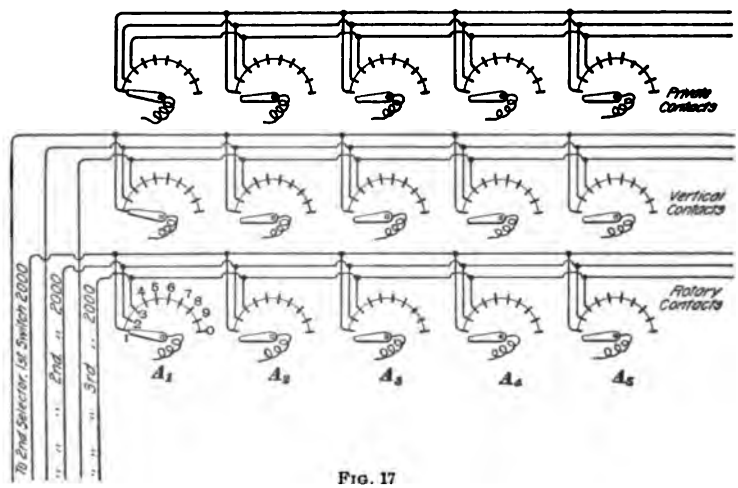
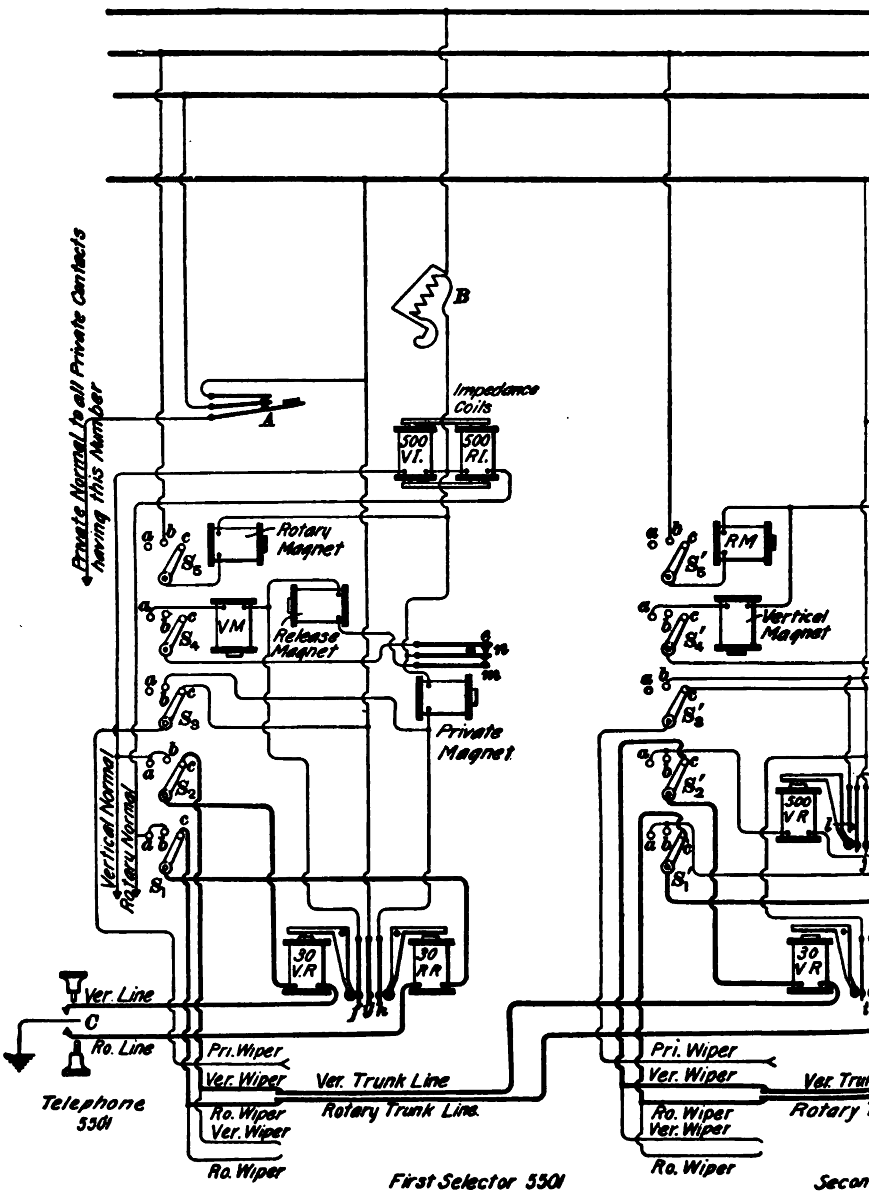


FIG. 17

are used, the scheme of trunking divides the work among them.

It is apparent that for a 100,000 system another selector or multiplier ten would have to be added.

36. That there may be no interference in selecting a connector, all the private banks of the second selectors (no matter to what group of first selectors they belong) must be in multiple thousand for thousand. That is, for example: The 5,000 group of second selectors of A have their private banks in multiple with the 5,000 group of second selectors for group A' and every other group of 5,000 second selectors.



B
Impedance Coils
500 VI.
500 RI.
A
Private Normal to all Private Contacts having this Number
Rotary Magnet
VM
Release Magnet
Private Magnet
RM
Vertical Magnet
Vertical Normal
Rotary Normal
500 VR
30 V.R
30 RR
30 VR
f g h
Ver. Line
C
Ro. Line
Telephone 5501
Pri. Wiper
Ver. Wiper
Ro. Wiper
Ver. Wiper
Ro. Wiper
Ver. Trunk Line
Rotary Trunk Line
Pri. Wiper
Ver. Wiper
Ro. Wiper
Ver. Wiper
Ro. Wiper
First Selector 5501

Similarly, every thousand group of second-selector switches must have their private-bank contacts in multiple. These multipled groups of second selectors, in selecting a connector, act identically the same as a group of first selectors; that is, if the first connector of the hundreds group desired is busy, the next one not in use will be selected.

SERIES-RELAY CIRCUIT

37. Fig. 18 is a diagram of the circuits through the various switches of the central-office apparatus, showing the completed circuit between two subscribers' lines, as well as the local circuits and operating magnets. With this diagram and with what has been given before of the mechanical operation of the switch and the trunking scheme, there should be no difficulty in following the various steps in connecting, automatically, the telephone of one subscriber to any other in the system.

For simplicity, the telephone mechanism at *C* and *D* is represented in this diagram by two push buttons corresponding to the two impulse fingers of the selector calling device. The two line wipers and the two banks of line contacts are in pairs. When a connection is made, only one of the two pair of line wipers and the private wiper are engaged at a time. The side switches S_1, S_2, S_3, S_4, S_5 are represented in the third, or trunked, position for the operated switches. Private, vertical, and rotary normal wires lead from the normal position of the first selector switch (see right-hand switch) to the bank contacts of the connector switch, where, by their position in that particular hundred's bank, they represent the number of the first selector switch on the right and the number of the station connected to it. The three springs at *A* are normally separated; but as soon as the switch is stepped up one point in calling, the three springs are brought together, thereby connecting the grounded-battery bus to the motor-starter bus and to the private normal, rendering that contact, or switch number, busy in all banks of one group of connectors. *B* is a cut-out or heat coil so arranged that an excess of current through it opens the circuit to the main-battery bus.

38. In the normal condition of a switch, all side-switch arms rest on contacts *a*. When subscriber *C* turns and releases the dial in making a call, the first time the vertical spring is pressed against the ground contact current will flow from the 50-volt storage battery at the exchange through the ground to *C*, then through the vertical line–30-ohm vertical relay–S_2–contact *a*–500-ohm vertical-impedance coil *VI*–main-battery bus to battery. The vertical relay *VR* will be operated, thereby bringing together springs *f*, *g*, which closes a circuit through the grounded-battery bus–*g*–*f*–vertical magnet *VM*–*a*–S_4–springs *e*, *n* controlled by the private magnet–main-battery bus to battery. This circuit will remain unchanged for all the following vertical impulses of the thousand's digit. The last vertical impulse of that digit will be followed by an impulse over the rotary line, which will flow from ground at telephone *C* through rotary line–30-ohm rotary relay–S_1–*a*–500-ohm rotary retardation coil *RI*–main-battery bus to battery. This brings together contacts *g*, *h*, thereby closing the circuit from battery through the private magnet, which brings the side switch to its second position *b*. Referring to Fig. 10 and the explanation of its operation, it will be seen that the side-switch lever *p* is released from one notch and allowed to pass to the next notch while the magnet is energized and then deenergized, thereby holding the side switch in its second position *b*; *r*, *q*, *y*, and *z* move together, *r*, *q*, and *y* being attached to the armature *z*. The long lever arm *p* of the side switch [see also Fig. 6 (*a*)], does not move in the same plane with *r* and *q*, but at right angles to them. When the armature *z* is drawn toward the core of the private magnet, the pieces *r*, *q* move toward the left, and *p*, instead of resting in its present position under the lower tooth of *r*, rests under the lower tooth of *q* at *t*. When the armature is released, the spring *n* forces the pieces *y*, *q*, *r* back to their normal positions; during this movement, the point of the lower tooth of *r* strikes the slanting edge of *p*, and the latter, pressed by the spiral spring *a′*, Figs. 6 (*a*) and 8, passes into the next notch at *u*, Fig. 10, under the upper tooth of *r*. This allows the side switch to move to its second position *b*. There it remains, because the lever *p* is held in notch *u* by the projection c_2, Figs. 6 (*a*) and 9, which rests against the cam *c*, until the first rotary impulses pass through the rotary magnet and cause the shaft to rotate.

With *p*, Fig. 10, resting in the notch *u* and the side switch, Fig. 18, in the second position *b*, current flows through the main-battery bus–rotary magnet of the first selector 5,501–S_6–*b*–interrupter bus–interrupter *d* to the grounded terminal of the battery, thereby causing the shaft (by the first impulse received by the rotary magnet) to be rotated one step, which brings the wipers into engagement with the first contact in the first row of contact points in the private and line banks.

39. Busy Trunk.—At this juncture, and while S_3 is in its second position *b*, suppose that another switch has already taken the first private and line contacts of the same number. In this case, the private wiper of the switch shown in this figure is connected to ground through the first contact on which it now rests, because this contact is connected through the multiple wiring of this group of private banks to the first contact in the private bank of the other selector, through its private wiper and a path similar to S_3–*c* to the grounded-battery bus. But the arm S_3 of the first selector 5,501 is now connected for a moment through *b* and the private magnet to the main-battery bus. In this case, the private magnet will be energized by the battery current and continue to hold *p*, Fig. 10, in the second notch while a second interrupted-current impulse flows from the positive terminal of the battery, Fig. 18, through the interrupter *d*–interrupter bus–*b*–S_6–rotary magnet–main-battery bus to battery, thereby rotating the wipers to the second contact. If this trunk is also busy, this action will be repeated until there is found in the private bank a contact that is not busy. Then the private magnet is deenergized and *p*, Fig. 10, is permitted to pass out of the second notch and the side switch into the third, or trunked, position. The private magnet will be deenergized the moment the private wiper touches a bank contact not engaged by some other switch of that group. In the third position of the side switch, Fig. 18, both the vertical and rotary magnets are on open circuit and inert to any further operation of the relays.

40. The second selector is slightly different from the first, using 500-ohm relays for controlling the vertical and rotary magnets. These relays are on open circuit in the trunked, or third, position of the side switch, only the 30-ohm line relays remaining in circuit. The operation of selecting a hundreds' trunk by the second selector will be similar to that of selecting a thousands' trunk by the first selector. The private magnet has an armature and the parts *r*, *y*, *q*, Fig. 10, the same as the first selector, but does not have the springs *m*, *n*, *e*.

The lamp above the second selector, Fig. 18, is a so-called **off-normal signal** used to assist the attendant, when locating trouble, in tracing back a connection to the group of first selectors from which the call has come. The subscriber transmits the number in the hundreds' place by sending as many impulses as there are units in the hundreds' place, over the vertical line, followed by another impulse over the rotary line. The impulses pass through the connections of the first selector switch, as already established and explained.

41. The first vertical impulse passes through the ground–vertical line–30-ohm vertical relay–S_1–*c*–vertical wiper–contact–vertical trunk line–30-ohm vertical relay–S_1'–*a*–500-ohm vertical relay to battery, and operates the 500-ohm vertical relay. It is now immaterial whether the 30-ohm vertical relay in the second selector operates, because both the 30-ohm vertical and the 30-ohm rotary relays must operate simultaneously to close contacts *t*. The operation of the 500-ohm vertical relay causes impulses to flow through grounded-battery bus–*j*–*k*–S_1'–*a*–vertical magnet–main-battery bus, thereby operating this vertical magnet the requisite number of times to raise the wipers to the proper level. The last impulse of the hundred's digit passes through the rotary line–30-ohm rotary relay–S_1–*c*–rotary wiper and contact–rotary-trunk line–30-ohm rotary relay–S_1'–*a*–500-ohm rotary relay to battery, and operates the 500-ohm rotary relay, which allows one impulse to flow through main-battery bus–heat coil–private magnet–*l*–*j*–grounded-battery bus. As a result, the private magnet puts the side switch of the second selector in the second position, cuts out the vertical magnet by opening the circuit between S_4' and *a*, and cuts in rotary magnet by closing the circuit between S_2' and *b*. The interrupted-current impulses can now flow through the interrupter bus–*b*–S_2'–rotary magnet to battery and operate the rotary magnet until the private magnet is deenergized due to the private wiper coming to and resting on a non-grounded private-bank contact. As soon as the impulse through the 500-ohm rotary relay ceases, the private-magnet circuit opens between *l* and *j*, unless the private wiper touches the contacts of a switch already in use in a similar location at another second-selector switch. In the latter case, the private-magnet circuit is closed through main-battery bus–private magnet–*b*–S_2'–private wiper–busy contact on the switch here shown–busy contact, private wiper and side switch S_3'–*c* of the second-selector switch not shown in this figure to battery and, the armature of the private magnet being held in its attracted position, the side switch cannot move to the third position, but remains where it is. When the private wiper no longer touches a busy contact, the private magnet is deenergized and the side switch is moved to the third position *c* and the rotary magnet and 500-ohm relays are cut out, so that the connections through the second-selector switch are now established. The two 30-ohm relays at each selector switch are now in circuit, but they have no effect that need be considered at present; for neither vertical nor rotary relays of the first- or second-selector switches, acting independently, after the side switch has passed into its third position will produce any effect on the switch, because the vertical, rotary, and release magnets will be open somewhere. It is only when the vertical and rotary relays act jointly, or together, as when the receiver is placed on the hook, that a circuit in the local switch is produced, and in that case it is through the release magnet.

42. The connector switch involves some new features in conjunction with those already set forth. In this switch, the connection with the normals of the subscribers' lines is made, the busy signal is produced, provision is made to prevent interference with busy lines, and the ringer relay appears.

Referring to S_4'' of the connector switch, it is seen that the vertical magnet has one terminal at *a*, the normal position of the side switch S_4'', and the rotary magnet has one terminal at *b* of the same side switch. It follows, then, that in sending in the tens' impulses of the number, the 500-ohm vertical relay, when closed, will close the circuit through main-battery bus–heat coil–*z*–*y*–*i*–S_4''–*a*–vertical magnet–*x*–*j'* grounded-battery bus, and thus operate the vertical magnet of this switch, thereby stepping up the shaft as many steps as there are units in the digit; then follows the one impulse over the rotary line through the first and second selectors–30-ohm rotary relay of the connector–500-ohm rotary relay–S_4''–*a*–busy bus–winding *l* to battery, thereby operating the 500-ohm rotary relay and closing the circuit from the main-battery bus through *z*–private magnet–*x'*–center contact spring (located between *x'* and *x*)–grounded-battery bus. The operation of the private magnet at this time has no other effect than to trip the side switch to second position.

Finally, the unit's digit is pulled down, thereby sending impulses over the vertical line, followed by the one over the rotary line; the former cause the shaft to rotate as many steps as there are units in the digit. To effect this rotation, it is necessary that the rotary magnet be operated, which it will be, although the impulses are sent in over the vertical and rotary lines in the usual manner, the transfer to rotary magnet having been produced by the side switch S_4'', which has moved to the second position. Current from the battery now passes through the ground to the subscriber's station –vertical line–first and second selectors–vertical trunk line –30-ohm vertical relay–500-ohm vertical relay to battery, thereby closing the 500-ohm vertical relay and allowing current to flow through grounded-battery bus–center contact spring (located between *x* and *x*′)–spring–*x*–rotary magnet –*b*–S_4''–*i*–*u*–*z*–main-battery bus. The last impulse of this digit (units) passes through the rotary line–first and second selectors–rotary trunk line–30-ohm rotary relay–500-ohm rotary relay–S_4''–*b*–busy bus–winding *I* to battery, thereby closing the circuit through the main-battery bus–*z*–private magnet–*x*′–center contact spring–grounded-battery bus, and determining whether the side switch shall be put in the third position or not.

43. Busy Line.—If the private contact of the desired line is not busy, there is nothing to prevent the side switch from being tripped into the third position and connection with the subscriber completed.

If, however, this contact is busy, it is already grounded through the private wiper and the third position of the side switch at the selector switch where it is already in use; the following circuit is then established the instant the last unit's impulse is sent over the vertical line: grounded-battery bus–*c*–S_3'' and private wiper at the connector switch where the line is in use–private wiper of the connector switch shown here–S_3''–middle contact–*w*–*y* (private magnet is closed) –release magnet to main-battery bus. The operation of the release magnet will release or disconnect the connector switch from the bank contacts and return it to its normal position. When the release magnet attracts its armature, it causes the thin spring *k* [see Figs. 6 (*a*) and 11] to slip over the pin *g*, thereby causing the dogs *l*, *m* to release the shaft; the spring at the top of the shaft rotates the latter back so that the wipers are free of all the bank contacts, and the shaft then falls by its own weight to its normal position. Furthermore, the side switch, under the same restoring force, is also forced to its first or normal position.

Thus the parts of the connector switch are restored to their normal position, but the first and second selectors are not yet restored or affected. The busy-signal current now flows through the winding *I*–busy bus–*a*–S_2''–500-ohm rotary relay –30-ohm rotary relay–rotary trunk and line–telephone–vertical line and trunk–30-ohm vertical relay and 500-ohm vertical relay of the connector–main-battery bus back to *I*. This current flows through the calling subscriber's receiver, in which it produces a buzzing sound that is recognized by the subscriber as a busy signal.

The last impulse releases the connector switch only when the line is busy, in which case the side switch of the connector is in the first, or normal, position when the subscriber places the receiver to his ear to determine if the line is busy or not before pressing the ringing button. Hence, the busy circuit must be considered when the side switch is in the first, or normal, position. A current is induced in *I* by *K*, which is connected across the main battery, one side, however, being opened and closed by the interrupting device at *q*.

44. Line Not Busy.—If the contact had not been busy, the release magnet would not have been energized, because if the private-bank contact of this particular number is not occupied somewhere else in the multiple, it will be open, or dead; that is, it will not be in a closed circuit including a battery, as is the case when busy. If the number called is not busy, *p* [see Figs. 6 (*a*) and 10], under the tension of its own spring *a'*, will then move out of the notch *u*, and the side switch will move to its third position.

If the contact is not busy and the side switch passes to its third position, the vertical trunk line will be connected through the 30-ohm vertical relay of the connector–S_2''–*c*–*o*–*p* to the vertical wiper, and the rotary trunk will be connected through the 30-ohm rotary relay–S''–*c*–*r*–*s* to the rotary wiper, and hence both lines are connected to the normals of the first selector 5,511 and through the 30-ohm relays of that first selector to the line wires of the subscriber called. A circuit is now complete from the main-battery bus through *z*–*u*–*i*–

S_4''–c–ringer relay to center spring t' of the two main-line relays. The calling subscriber next presses his ringing button, which operates the 30-ohm vertical relay, of this connector, thereby completing the ringer-relay circuit from t' through v to the grounded-battery bus. The operation of the ringer relay connects the springs p, s, and therefore the called subscriber's lines, to the ringing generator.

The ringing current in large exchanges is supplied by some form of motor generator, while for small exchanges a pole changer is used. The interrupting device produces about 1,000 interruptions per minute, that being a safe working speed for the armature of the rotary magnet in selecting trunks. The 1,000-ohm relay Z, having one side connected to the negative terminal of the battery and the other to the motor-starter bus, is brought into action when any first selector switch rises one or more steps, thereby connecting to ground through A both the motor-starter bus and the private normal of that switch. Thus, power is only supplied to the ringing transformer T and the interrupting devices d, q when some first-selector switch is out of its normal position. This provides an economical use of power, supplying it only when needed.

45. Disconnection.—When the conversation is completed, the receivers are hung on their hooks at the two stations. Hanging the receiver on the hook at either telephone grounds momentarily and simultaneously both the vertical and rotary lines. If the receiver at the calling telephone is hung up first, both 30-ohm relays of each of the three switches in the circuit will be operated at one time, the effect of which will be to close the circuits through each release magnet of the several switches, restoring all parts to their normal positions. Grounding the rotary line energizes the private magnet of the first selector, thereby closing the contacts m, n, which connect the main-battery bus through n–m–release magnet to spring f, which is at the same time connected through spring g to the grounded-battery bus by the operation of the 30-ohm vertical relay, which is energized by the grounding of the vertical line at the operated telephone. No successive second call can be made until this release operation is performed. The simultaneous operation of both the 30-ohm relays of the second selector closes the circuit from the main-battery bus through the release magnet–springs *t* to the grounded-battery bus, thereby operating this release magnet and restoring the second

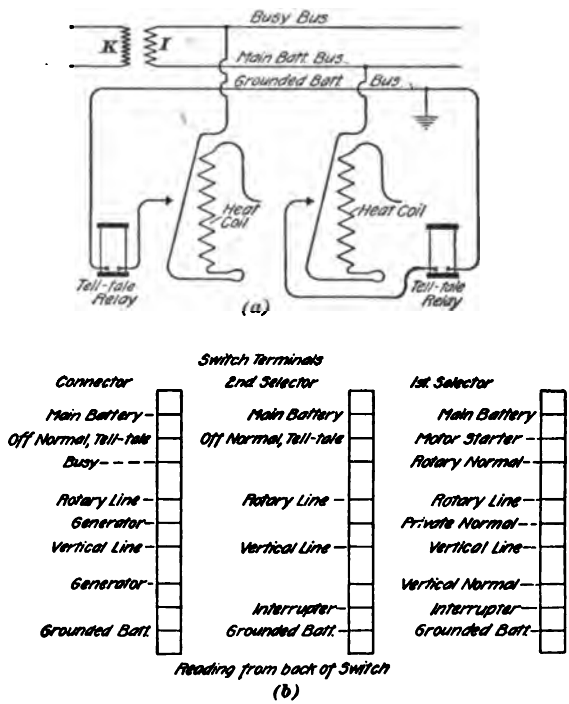


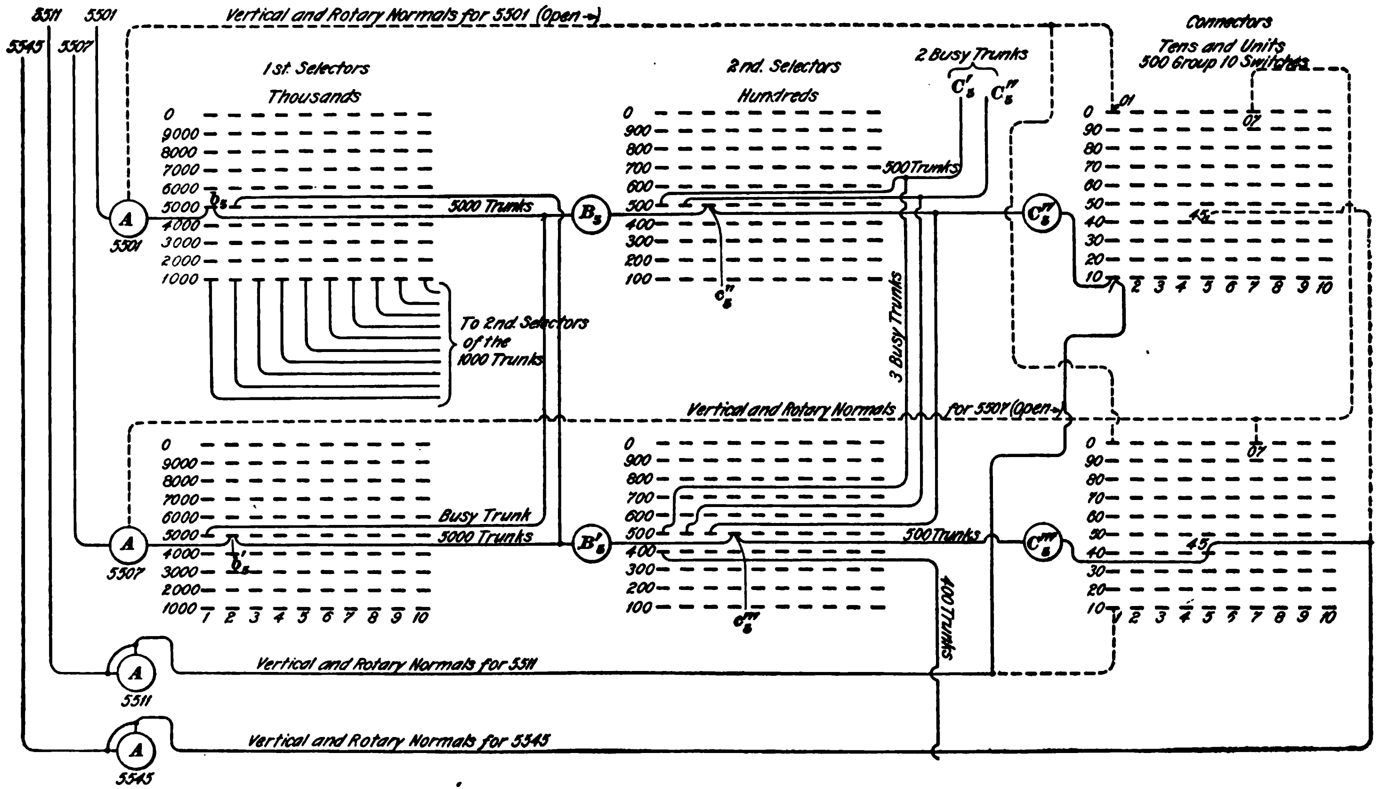
FIG. 19

selector to its normal position. The release magnet of the connector is connected from the main-battery bus through springs *t′*, *v* to the grounded-battery bus, thereby restoring the connector to its normal position. If the receiver at the called telephone is hung up first, the switches are not released.

46. It will be well to consider an interesting feature of this system. Suppose that subscriber 5,501 wants information from subscriber 5,511 about which the latter has to make some inquiries himself before answering, say from subscriber 3,111. Subscriber 5,511 replies "Wait a minute" and calls subscriber 3,111 with the same telephone. When his first selector responds to the call, it disconnects line 5,511 from the normals between the connector used by 5,501 and the first selector 5,511, by moving the side switch of the latter into the third position, but the connector between line 5,501 and the side switch of the first selector 5,511 remains unmolested. After receiving this information from subscriber 3,111, subscriber 5,511 releases his connection with subscriber 3,111, thereby reestablishing the old talking circuit between subscribers 5,501 and 5,511, due to the fact that as the first selector 5,511 falls back to its normal position the side switch also moves back to the first position, to which 5,501 is still connected.

47. Fig. 19 (*a*) shows merely the arrangement of heat coils and telltale relays that are associated with the busy-test circuit of Fig. 18. Fig. 19 (*b*) shows the proper connections for the terminal springs that project in a horizontal row from the rear of each type of switch used in Fig. 18.

48. Fig. 20 represents the switches and connections, except for the private-bank connections, which are not shown, when 5,501 has called and is connected to 5,511 and when the next call, which is from 5,507 for 5,545, is also completed. It has been assumed that the call for 5,511 is the first call for a number from 5,000 to 6,000 in this group of selector switches and hence the selector switch 5,501 (A) selects the first contact b_5 in the 5,000 row of trunks, which is connected through the first 5,000 trunk to the second-selector switch B_5, which, in turn, selects the first trunk not busy in the 500 row. The first two are assumed to be busy and hence the third 500 trunk c_5'' running to C_5'' is selected. The connector switch C_5'' makes connection with the first contact in the first row, whose number is 11, thereby completing the connection from 5,501 to 5,511, assuming that it is not busy. If this line were busy, the switches would have



5511
5501
5545
5507
Vertical and Rotary Normals for 5501 (Open→)
1st. Selectors
Thousands
2nd. Selectors
Hundreds
2 Busy Trunks
Connectors
Tens and Units
500 Group 10 Switches
5000 Trunks
500 Trunks
To 2nd. Selectors of the 1000 Trunks
3 Busy Trunks
Vertical and Rotary Normals
for 5507 (Open→)
Busy Trunk
5000 Trunks
500 Trunks
400 Trunks
Vertical and Rotary Normals for 5511
Vertical and Rotary Normals for 5545
5501
5507
5511
5545

Fig. 20

been released. Now comes the call from 5,507 for 5,545. The 5,507 first-selector switch, being in the same thousands' group as 5,501, finds the first 5,000 trunk busy, hence selects the second 5,000 trunk leading to B_s'. This second-selector switch finds the first three 500 trunks busy, hence selects the fourth contact c_s''' leading to the connector switch C_s'''. This switch connects to 45, if it is not already engaged, and thus completes the connections from 5,507 to 5,545. Dotted lines represent wires that are open at same point and hence not used in the connections here shown. In order to make the diagram as clear as possible, each line represents, not a single wire, but a pair of wires, each subscriber having a complete metallic circuit.

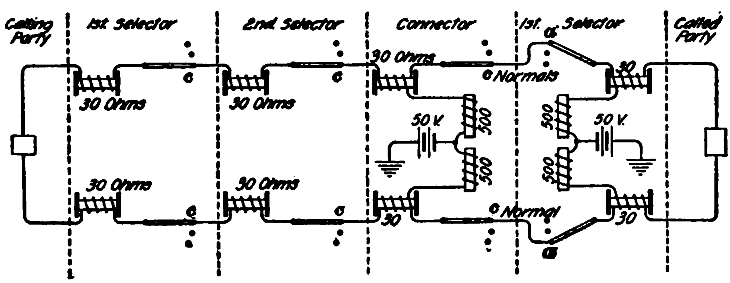


FIG. 21

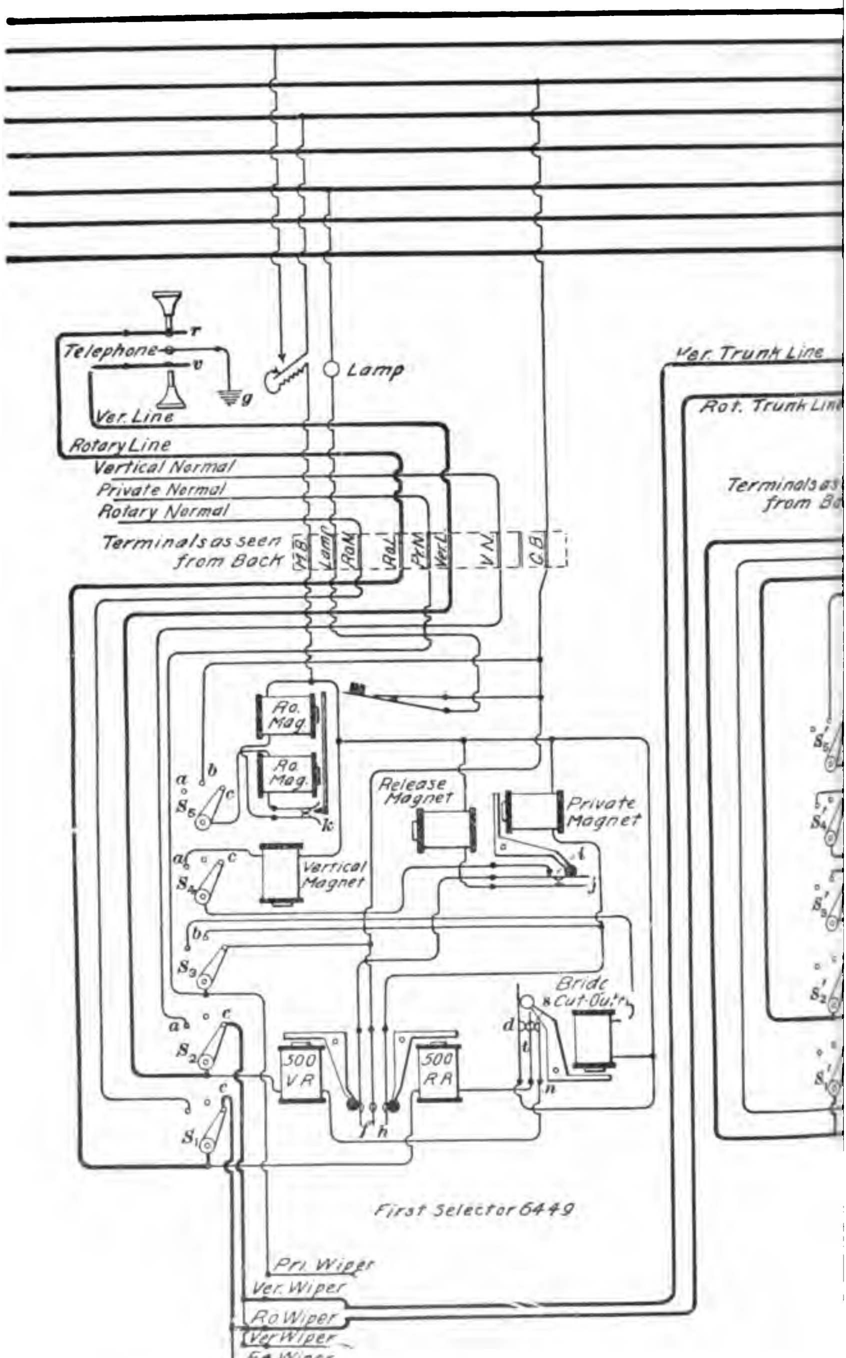
49. Circuit During Conversation.—The circuit of a 10,000-line series-relay system during conversation and stripped of all unnecessary details is shown in Fig. 21. There are four 30- to 35-ohm relays in each side of the circuit including the first selector of the called line; and in the connector there are 500-ohm impedance coils bridged across the circuit with their centers connected through the same storage battery of 50 volts to the ground. In the talking circuit, there are, therefore, four coils of about 30 ohms resistance each in each side of the circuit and two bridges of 1,000 ohms each. The cores of the 30-ohm relays, which are in series in the circuit, are surrounded by a copper tube, which is claimed to prevent any great increase in their impedance when the high-frequency voice currents flow through the relay coils. The vertical, rotary, private, and release magnets are usually wound to a resistance of 35 ohms.

In 1904, there was completed at Lincoln, Nebraska, a Strowger automatic system, accommodating 3,000 subscribers, but having an ultimate capacity of 7,000 subscribers. The switches used in this exchange have the line relays connected across the circuit instead of in series with the circuit, as in many previous systems made by this company. The impedance of these magnets is thus removed from the talking circuit. All later systems are constructed with the line relays bridged across the line wires.

10,000-LINE, LOCAL-INTERRUPTER, TWO-WIRE, BRIDGING CIRCUIT

50. Fig. 22 shows the connections through a first selector, second selector, and connecter and first selector of the called line in a so-called **10,000-line, local-interrupter, bridging system** put out by the Automatic Electric Company, about 1904. In this system, the various line relays are bridged across the circuit instead of being connected in series in the line, as in the systems already described. As this circuit closely resembles that used in the series-system, it will only be necessary to give an outline of its operation. It is called a local-interrupter system because the rotary magnet of each selecter interrupts the current that is used to rotate the shaft and select an unoccupied trunk line. Thus, no interrupting wheel device common to all selectors is required. It is here called a two-wire circuit to distinguish it from another circuit, in which a third wire, associated with the private banks, assists in releasing the switches.

51. Operation.—Let us suppose that subscriber 6,449 desires to call subscriber 6,437. The subscriber performs exactly the same operations as in the series-system and exactly the same results are produced in the telephone instrument and line wires. Pulling down number *6* on the dial



Telephone
r
v
g
Ver. Line
Rotary Line
Vertical Normal
Private Normal
Rotary Normal
Terminals as seen from Back
V.R.B.
Lamp
Ro.N.
Ro.L.
Pr.N.
Ver.L.
V.N.
C.B.
Lamp
Ver. Trunk Line
Rot. Trunk Line
Ro. Mag.
Ro. Mag.
Release Magnet
Private Magnet
Vertical Magnet
Bridge Cut-Out
500 V.R.
500 R.R.
First Selector 6449
Pri. Wiper
Ver. Wiper
Ro. Wiper
Ver. Wiper
Ro. Wiper

grounds the vertical line at the telephone six times, allowing impulses to flow through ground-*g*-*v*-vertical line-500-ohm vertical relay-*n*-*d*-main battery-ground. This causes the 500-ohm vertical relay to close the circuit from the ground-battery wire through *f*-*i*-S_4-*a*-vertical magnet-battery; which raises the shaft six steps. The last impulse produced by grounding the rotary line at the telephone flows through *g*-rotary line-500-ohm rotary relay-*t*-*d*-battery, thereby closing the circuit through ground-*h*-private magnet-battery. This causes the private magnet to operate and put the side switch of the first selector in the second position, thereby closing the circuit from the main battery through one coil of the rotary magnet-contacts *k*-other coil of rotary magnet-side switch S_2-*b*-ground. This rotates the wipers to the first contact in the sixth level and also opens the circuit at *k*. If this first trunk is in use, the private wiper is grounded through the private bank; hence, the circuit through ground-private wiper-S_2-*b*-private magnet-battery, is held closed in order that the side switch may not move to the third position. In the meantime, the release of the armature of the rotary magnet closes its own circuit again at *k*, so that it is again energized and steps the wipers around to the second contact in the sixth row. If this contact is not occupied at any other first selector of this group of first selectors, the private wiper will not be grounded; hence, the private magnet will release its armature, thereby allowing the side switch to move to its third position. This first selector is now connected to the second 6,000 trunk.

52. The **individual rotary device** operated by the armature of the rotary magnet that opens the springs *k* when attracted is used on each selector switch and renders unnecessary the interrupting machine used in many exchanges built by the Automatic Electric Company, and described in connection with the series-system. The actual arrangement of this interrupting device is illustrated in Fig. 23, which shows two side views of a type of selector switch made in 1906. It is not in all respects exactly like the selector switch

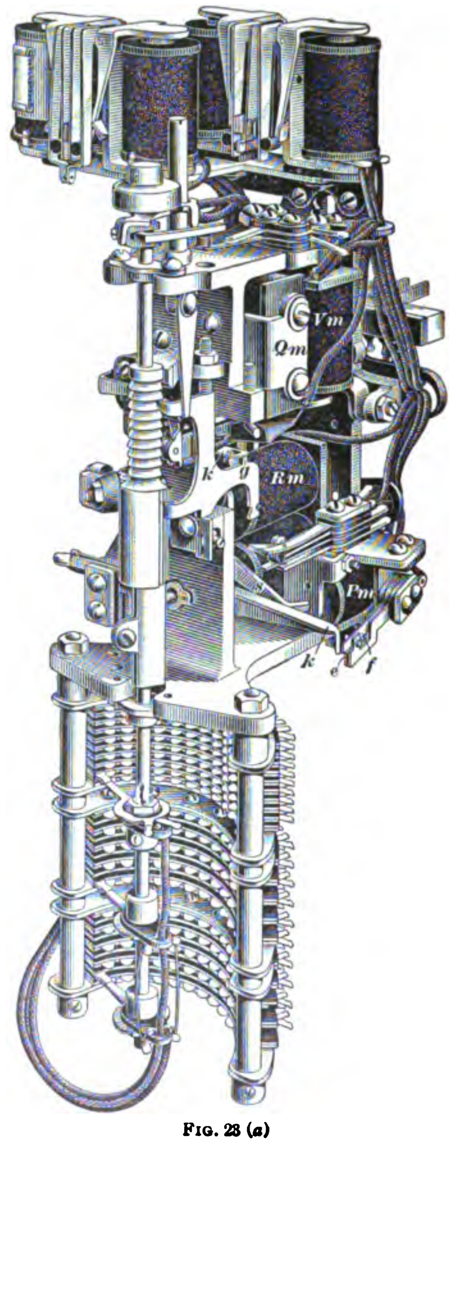


FIG. 23 (a)

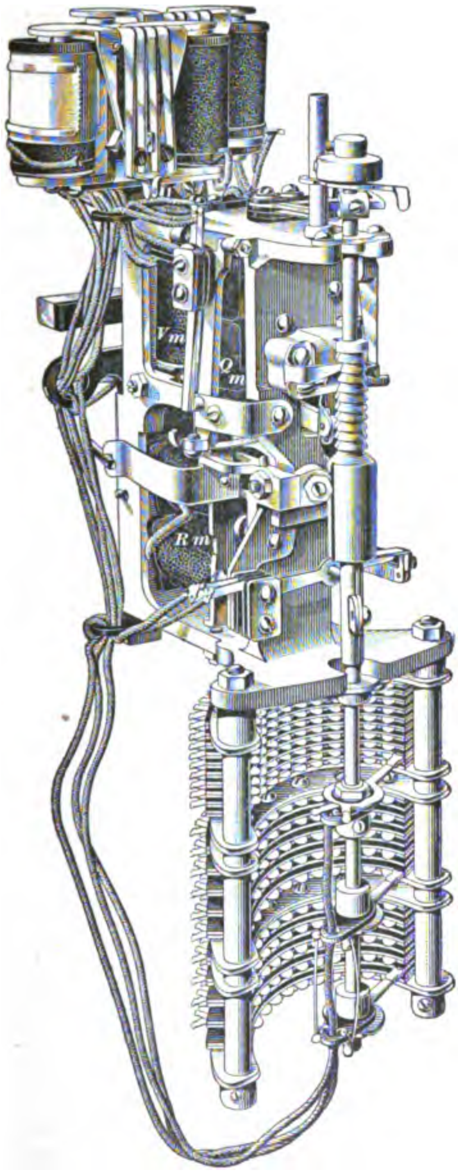


Fig. 28 (b)

represented in Fig. 22. When the rotary magnet *R m*, Fig. 23 (*a*), moves its armature, to which *k* and *s* are attached, the end of *k* passes between springs *e*, *f*, momentarily separates them and opens the circuit of *R m*.

53. When the subscriber pulls down the number *4*, the four impulses produced in the vertical line, Fig. 22, cause the second selector to raise the shaft four steps and the following impulse through the rotary line puts the side switch in the second position, thereby causing the second selector to rotate the wipers to an idle hundreds' trunk and then puts the side switch in the third position. The second selector is now connected through the vertical and rotary trunk lines to one of the connectors in the 400 group. The action of the second selector is so much like that of the first selector that a further explanation of its operation does not seem necessary.

The subscriber now pulls down the number *3*, thereby sending three impulses through the ground–*g*–*v*–vertical line–S_2–*c* and vertical wiper of the first selector–vertical trunk line–S_2'–*c* and the vertical wiper of the second selector–vertical trunk line–500-ohm vertical trunk-line relay of connector–battery. This operates the vertical trunk-line relay of the connector, thereby allowing current to flow through the battery–vertical magnet–*a*–S_4''–*o*–*l*–ground, thereby raising the shaft three steps. The following impulse through the ground–rotary line–S_1–*c* and rotary wiper of first selector –S_1'–*c* and rotary wiper of second selector–rotary trunk line–500-ohm rotary trunk-line relay, energizes the 500-ohm rotary trunk-line relay of the connector to battery. This allows current to flow through the battery–private magnet–*p*–ground, which energizes the private magnet and puts the side switch in the second position, thereby substituting through *b*–S_4'' a rotary magnet in the same circuit that previously contained the vertical magnet.

Now, when the subscriber pulls down the last digit *7*, current flows through ground–vertical line–first and second selectors–vertical trunk line–500-ohm vertical trunk-line relay–battery, thereby energizing the vertical trunk-line relay and allowing seven impulses to flow from the battery through the rotary magnet–*b*–S_4''–*o*–*l*–ground; this rotates the wipers to the seventh contact in the third level. The following impulse flowing over the rotary line energizes the 500-ohm rotary trunk-line relay, which energizes the private magnet, puts the side switch in the third position and completes the connection, provided the desired line is not busy.

54. Busy Line.—If line 6,437 is busy, the private wiper of the connector shown here will rest on a grounded contact and current will flow through the ground–private wiper of connector–S_2''–*b*–*m*–release magnet–battery, thereby restoring the connector to its normal position. When the subscriber presses the ringing button, the vertical line is grounded, thereby causing the connector to rise one step and close the contacts *v* at the top of the shaft. This allows a variable current from the busy bus to flow through the springs *V*–*a*–S_2''–*u*–condenser *C*–vertical trunk line–second selector–first selector–vertical line–subscriber's telephone receiver–rotary line–first selector–second selector–rotary trunk line–$\left\{\begin{array}{c}\text{500-ohm rotary trunk-line relay–}t\\ \text{condenser }Q\text{–500-ohm back-signal relay–}z\end{array}\right\}$–battery, thus producing a busy hum in the subscriber's receiver but no other effect.

55. Line Not Busy.—If line 6,437 is not busy, the private magnet of the connector will be grounded, the side switch will be moved to its third position, the connector will not be released, and current will flow, when the ringing key is closed, through ground–vertical line–first selector–second selector–vertical trunk line to the connector–vertical trunk-line relay–battery. This allows current to flow from the battery through a ringing relay common to the whole exchange or to one or more sections of connectors–ringing-relay bus–ringer relay on this particular connector–*c*–S_4''–*o*–*l*–ground, thus closing both the main ringing relay that connects the ringing generator of the exchange across the generator leads and the ringer relay on this connector, which allows current from one generator lead to flow through *u*–S_2''–*c*–rotary wiper–rotary normal–*a* and S_1''' of the first selector 6,437–rotary line–telephone 6,437–vertical line–S_2'''–*a*–vertical normal–vertical wiper of the connector–*c*–S_1''–*n* and other generator lead, thus ringing the bell of subscriber 6,437.

56. Use of Bridge Cut-Out Relay.—While the private wiper of any connector rests on the private contact of 6,437, the latter contact is grounded through the private wiper of that connector. Consequently, the private normal coming to the first selector 6,437 is grounded, and, the side switch being in its normal or first position, a circuit is closed through the ground–*c*–S_3''–private wiper–private normal–S_3'''–*a*–bridge cut-off relay of selector 6,437–battery. This energizes the bridge cut-off relay, and it cuts out of the line circuit at *q*, *e*, the 500-ohm vertical and rotary relays of selector 6,437, as long as line 6,449 is in connection with line 6,437.

57. Disconnection.—When the conversation is finished the momentary and simultaneous grounding of both line wires at the calling telephone causes both the vertical and rotary trunk-line relays of the connector to attract their armatures, thereby allowing current to flow through the battery–private magnet–*p*–ground. This causes the private magnet to attract its armature, thereby allowing current to flow through the battery–release magnet–*m*–*w*–*l*–ground, which operates the release magnet and restores the connector and its side switch to their normal positions. The simultaneous closing of both the vertical and rotary relays of the second selector closes its private magnet and then its release magnet, thereby restoring the switch to its normal position. The first selector is restored in a similar manner.

If, however, the answering subscriber is the first to hang up his receiver, the temporary and simultaneous grounding of his vertical and rotary lines allows current to flow through ground–vertical line–S_2''' and *a* of the first selector 6,437–vertical normal–*c*–and S_1'' of the connector–*n*–back-signal relay–*z*–battery; also, through the ground–rotary line–S_1''' and *a* of the first selector 6,437–rotary normal–*c* and S_2''

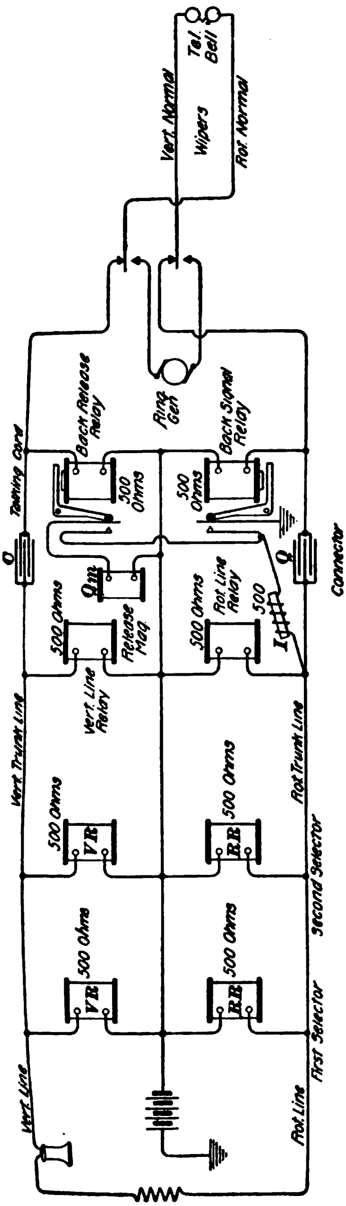


FIG. 24

of the connector–u–back-release relay–z–battery. This energizes both the back-signal and back-release relays, thereby allowing current to flow through the battery–release magnet–x–y–ground, which releases the connector but does not release either the first or second selector. This leaves the called party's line free, and the first and second selectors are not restored until the calling party hangs up his receiver. I is merely a resistance.

CIRCUIT DURING CONVERSATION

58. Fig. 24 shows the circuit while two subscribers in a 10,000-line system are connected together, but just before the called subscriber has taken down his receiver. The circuit is the same when the receiver is removed from the hook, except that the receiver and secondary winding of the induction coil are substituted for the bell. There are four sets of two 500-ohm relays each bridged across the circuit. In each line wire in the connector circuit are condensers Q, C through which only the voice currents pass. The 500-ohm resistance *I* and the release magnet *Qm* are on open circuit during the conversation, and the 500-ohm vertical and rotary relays of the first selector of the desired subscriber's line are cut out by the action of the bridge cut-off relay, which has already been explained but is not shown in this figure.

BRIDGING POLE CHANGER

59. In Fig. 25 are shown the connections for a pole changer that is used for the small exchanges that do not require a regular ringing generator. The main bus-wires may be considered as a continuation of the main bus-wires in Fig. 22 and would replace the transformers, batteries, and all other power apparatus. As pole changers have been fully explained, it will be only necessary to explain the special features of this particular one. The pole changer is normally at rest—that is, not in operation. As soon as the shaft of a switch rises one or more steps, the motor-starter circuit is closed by being grounded and the motor-starter relay *MS* attracts its armature, thereby closing the circuit through the

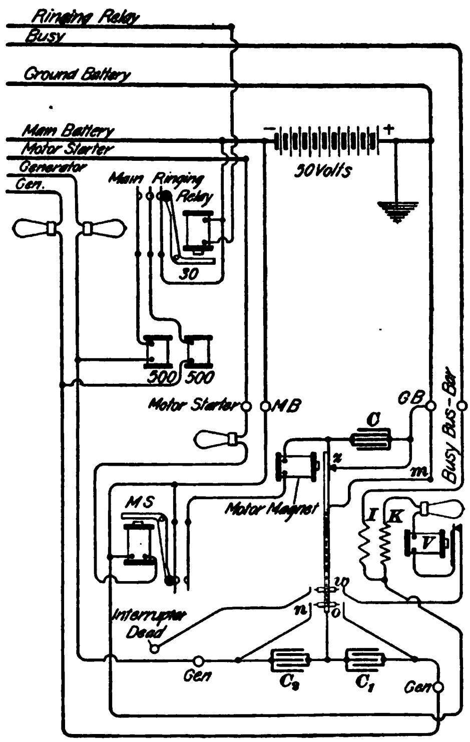


Fig. 25

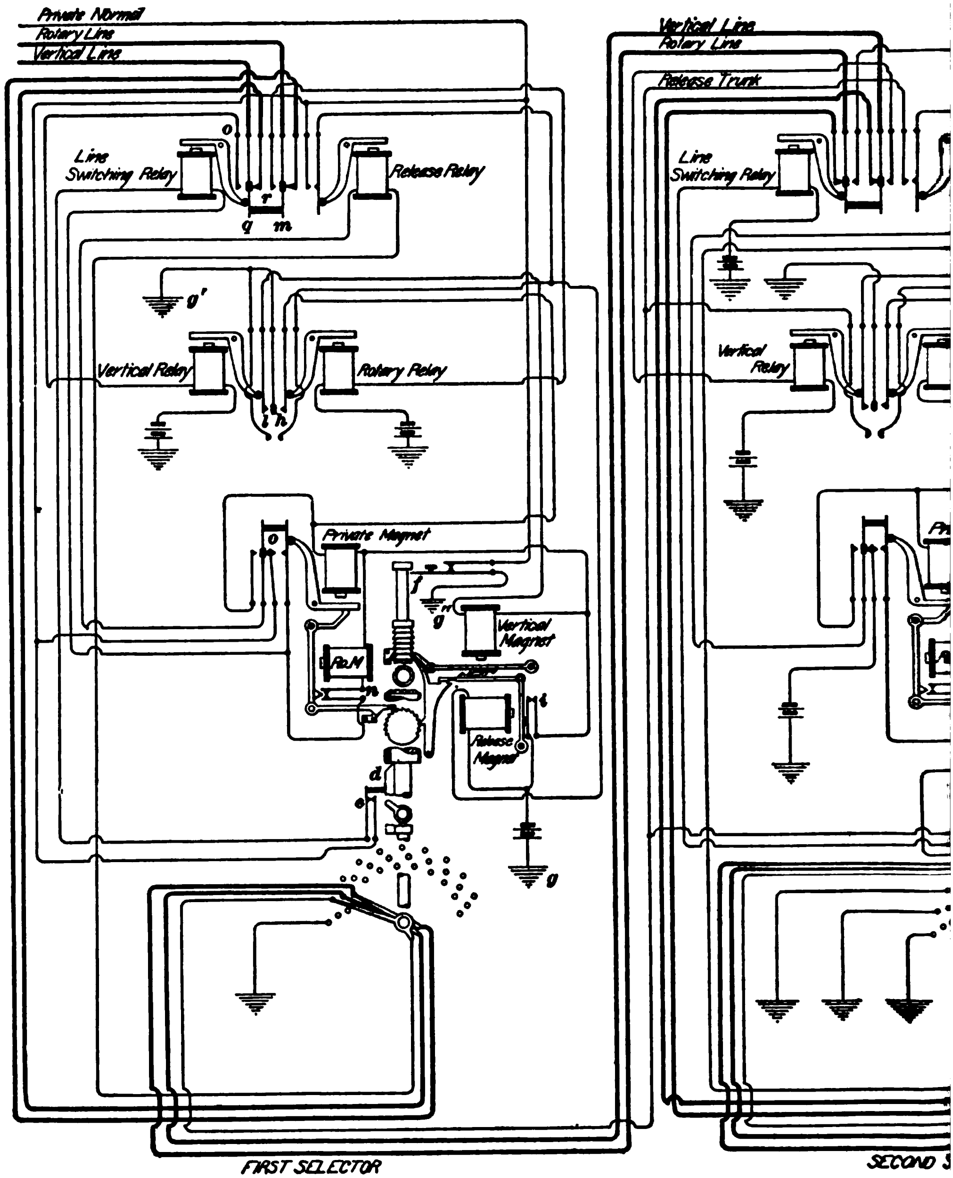
motor magnet of the pole changer. The pole changer is now put in operation and continues in operation as long as the shaft of any connector switch is out of its normal position. Current for ringing flows from the battery through *m*, alternately through contact *o* or *n* to one or the other of the two generator binding posts and leads. The condenser *C* is used to reduce the sparking at the contact *z*, while the condensers C_1 and C_2 reduce the sparking at the other contacts of the pole changer lever and give a smoother current curve. The main ringing relay, which has a resistance of 30 ohms, connects the negative terminal of the battery to the center of two 500-ohm impedance coils that are bridged across the generator—that is, the pole changer circuit—when the main-ringing relay is energized. Thus an impulse flowing through *o* or *n* and out either line can return through the other line and one 500-ohm coil to the negative terminal of the battery. Current from the battery flows through *m*–*w*–buzzer *V*–lamp–winding *K* to battery. This current, interrupted by contact *w* of the pole changer and again much more rapidly by the buzzer, flows through the winding *K* of a transformer and superimposes on the battery current in the other winding *I* a rapidly varying current. Consequently, the winding *I* supplies the busy bus with a current suitable for producing a hum in the subscriber's receiver in case the subscriber calls a line already engaged. The terminal marked *interrupter dead*, is not in use with the circuit shown in Fig. 22 because each rotary magnet interrupts its own circuit. This post would be used with the circuits shown in Fig. 18. By considering the connections of the pole changer in connection with the switches shown in the 10,000-line bridging- or series-relay system, the operation and necessity of the connections shown in this figure will be apparent.

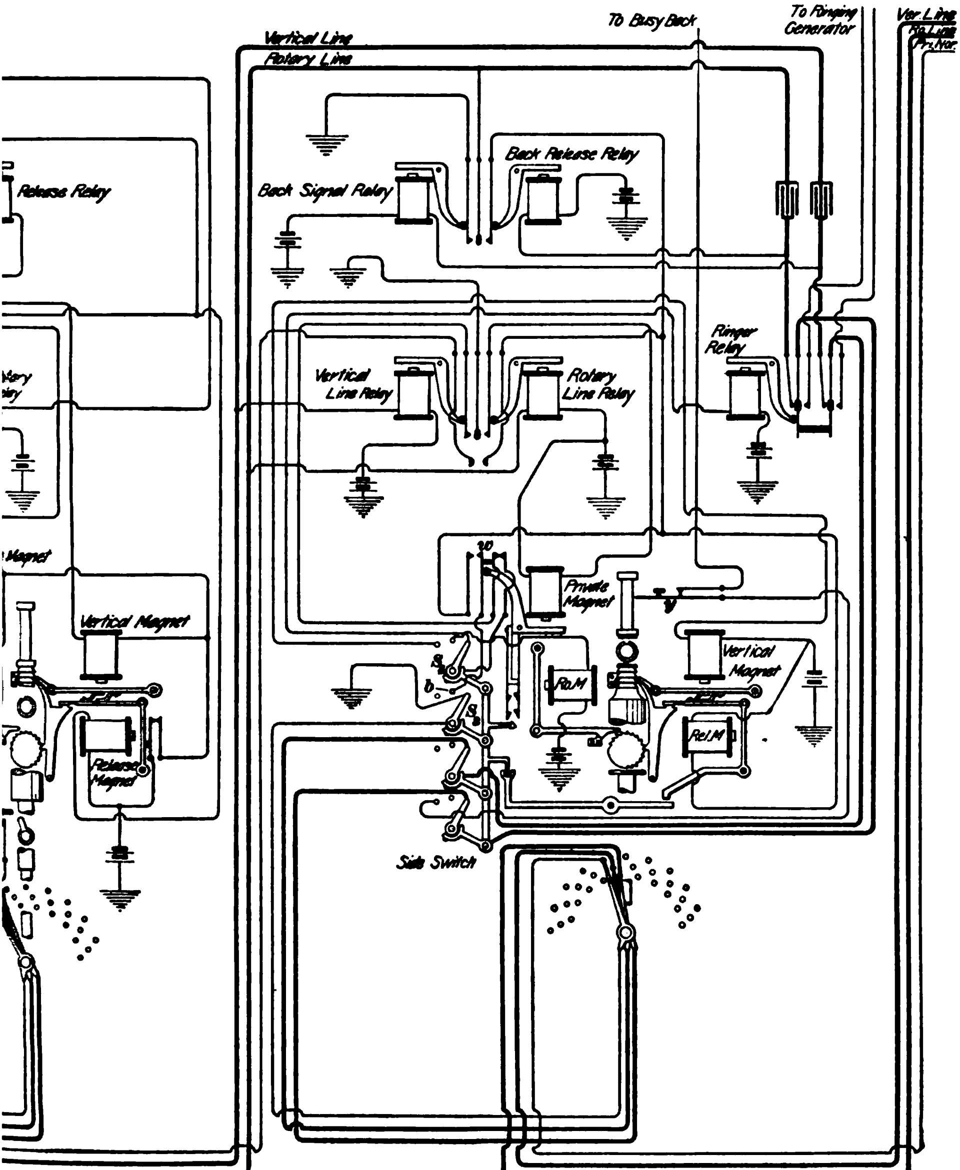
10,000-LINE, LOCAL-INTERRUPTER, THREE-WIRE, BRIDGING CIRCUIT

60. Fig. 26 shows a somewhat different bridging circuit of the Automatic Electric Company. In this system, a third wire, called the **release trunk**, is used for releasing purposes, similar to the third wire in a three-wire cord circuit. The shape and relation of some of the mechanical parts of the switches are shown in this figure, the aim being to represent the various movements depending on one another. The first and second selectors are not provided with side switches; only the connector has a side switch. However, the first and second selectors are provided with cams immediately below the shaft. The cam *d* of the first selector is so arranged as to cause the contacts *e* to remain closed while the shaft remains in its normal position. After the first vertical step, the circuit is opened, and it is closed again by the first rotary step.

To draw the double dog away from the ratchet requires that the circuit be first closed through the release magnet, which causes a thin link to catch on a pin on the double dog. When the current through the release magnet ceases, a spring draws the release-magnet armature and with it the double dog to its normal position, thus releasing the shaft, which also returns to its normal position.

61. Operation.—The first vertical impulse, passing through *q*–*o*–vertical relay and battery, operates the vertical relay, which allows current to flow through *g*–battery–*i*–vertical magnet–*l*–*g'* and causes the vertical magnet to raise the shaft one step and allow *f* to rise so that the private normal and also the private wiper–release relay–contacts *o* are connected to ground *g''*. The circuit of the line switching relay is also opened at *e*. Each succeeding vertical impulse raises the shaft one step. The rotary impulse through *m*–*r*–rotary relay–battery–ground, following the last vertical impulse operates the rotary relay, which, in turn, closes a circuit through the ground–*g'*–*h*–private magnet–contacts *i*–battery, thereby allowing current to flow through *g*–battery–*i*–rotary magnet *Ro. M*–*n*–*o*–*f*–ground. The private magnet is released after the rotary impulse ceases to flow through the rotary relay, but the circuit of the rotary magnet is now closed through *g*–battery–*i*–rotary magnet–*n*–line switching relay–*e*–*f*–ground. The shaft is rotated by the rotary magnet until the wipers rest on an unoccupied trunk, and the vertical


Private Normal
Rotary Line
Vertical Line
Line Switching Relay
Release Relay
Vertical Relay
Rotary Relay
Private Magnet
Vertical Magnet
Ro.M
Release Magnet
FIRST SELECTOR
Vertical Line
Rotary Line
Release Trunk
Line Switching Relay
Vertical Relay



ECTOR CONNECTOR

. 26 30

line is shifted by the line switching relay from the vertical relay of this first selector to the vertical wiper and vertical trunk line running to the second selector.

The action of the second selector is very similar to that of the first, the shaft being stepped up the necessary number of steps indicated by the second digit of the number called. The cam immediately below the rotary shaft of the second selector differs from that of the first selector in that it is not cut away at the top, so that the contact *x* assumes the open position shown only after the first rotary step has been taken. The second selector is here shown in its condition after all movements of the shaft have ceased. The line switching relay, however, remains closed during all vertical steps, but takes its present normal position on the first rotary step. The rotation of the second selector continues until connections are made to a connector that is not busy in the same manner in which the first selector found an unused second selector. It hardly seems necessary to explain the operation of the connector, as it is similar to connectors already explained. Closing the ringing button after a connection has been completed with a desired and unoccupied line, energizes the vertical-line relay on the connector and in turn the ringer relay, which connects the ringing generator across the line wipers and line wires leading to the desired telephone.

62. Busy Line.—If the line selected is busy, the private magnet is energized, while the rotary-line relay is receiving the last impulse over the rotary line and the side switch is in its second position, thus closing the circuit from the private wiper (which is grounded through the private bank and wiper of a switch already occupying a similarly numbered private contact), through S_3–*b*–*w*–release magnet–battery–ground. Thus, the connector is released. On pressing the ringing button, the shaft is raised one step, thereby closing the busy-back spring *y*, which allows the busy-tone current to flow through the vertical line and the subscriber's receiver. In hanging up the receiver, the first and second selectors are in turn released.

63. Disconnection.—When the calling party is the first to hang up his receiver the first selector is released by the operation of the release magnet, the circuit of which is closed, by the simultaneous operation of the vertical and rotary relays. If, however, the called subscriber hangs up his receiver first, the back-release and back-signal relays operate simultaneously, closing the circuit through the release magnet of the connector, but not releasing either the first or second selectors, which leaves the called party's line free, but the switches remain in connection with the calling party until his receiver is hung up, when the release of the first and second selectors takes place as already explained.

GENERAL CONSIDERATIONS

64. It can now be readily seen that there are as many first-selector switches as there are lines. The first-selector switches may be divided into any number of groups. Suppose that there are $66\frac{2}{3}$ groups of 150 switches each. The trunks would be in multiple for all switches in one group, but the groups would be entirely separate. Hence, each first-selector switch can select one of ten trunks in each thousand in its own group, giving 100 second-selector switches for each group. But there are $66\frac{2}{3}$ groups of first-selector switches, hence there would be $66\frac{2}{3} \times 100 = 6{,}667$ second-selector switches. These 6,667 second-selector switches are in multiple, thousand for thousand, and each thousand may have 100 connector switches. There being 10 thousands, there will be $10 \times 100 = 1{,}000$ connectors.

10,000 first-selector switches
6,667 second-selector switches
1,000 connector switches
17,667 total number of switches for a system of 10,000 subscribers' lines.

The manufacturers of this system do not seem to think that full groups of ten would always be required. The number required for good service would settle this question.

65. A feature introduced about 1904 is a rotary device, which may be devoted, say, to the 3,200 section of the switchboard, and fifty connectors and selectors, which are reserved for those firms whose business justifies the installation of more than one telephone in their establishment. Any subscriber having two or three telephones at the same place of business, advertised under one number, may be connected with this device, which enables any calling party to get the idle telephone should the other one or two be in use. The automatic calling device passes on from the first to the second and on to the third, and should that one be busy also, the calling party receives the busy signal in the usual manner.

The arrangement of the switches is such that should any particular section be used more than another, connectors from less active sections can be transferred to the more busy section, thus giving about the same flexibility to the automatic system that the intermediate frame provides for in the manual system. The wire chief's desk is usually provided with numerous switches and testing keys, also one second selector and one connector. A Weston voltmeter and a Wheatstone bridge are also located at his desk, thus affording him all the necessary appliances for his duties.

A four-party-line system has been developed. It was first exhibited in 1905. Four telephones on one line are connected to a first selector, which is but slightly different from the ordinary first selector, the only alteration being the addition of a small spring and an extra relay. Any of the four telephones on one line may be used to call any other telephone in the exchange system, either an individual or a party-line telephone. By the use of the harmonic system of ringing any one of four bells bridged across the same line, such as the Dean system, which has been adapted, only the bell of the party wanted is rung and the other three parties on the same line are locked out.

66. Telltale Board.—The cross-connecting frame is usually equipped on the switchboard side with heat coils and lightning arresters, and terminal boxes are provided for the incoming line wires. The terminal boxes have about 50 per cent. more terminals than there are heat coils and arresters on the cross-connecting frame. The protectors are furnished with telltale circuits, so that in case a heat coil blows, an alarm is instantly given, calling the attention of the switchboard attendant. The heat coils on the automatic switchboards, and the main fuses on the power board, are also equipped with the telltale alarms. The telltale board shows at a glance when a heat coil blows on any of the switches. When this takes place, a lamp is lighted on the telltale board and a bell rings, drawing the attention of the wire chief or switchboard attendant to the fact that something is wrong. One such lamp is provided for each one hundred selectors. There is also a lamp provided for each twenty-five first selectors in each group, so that the location of trouble is easy. The same care is taken for the generator circuits, in that the current for each group of one hundred is taken through two lamps on the telltale board, and if a line is grounded or short-circuited in any group the lamp provided will light, when the test is made by sending generator current over the line.

67. Fire-Alarm Feature.—A special feature installed in some exchanges is the *fire-alarm system.* The fire-alarm stations and other points interested in fire-calls use the regular telephones, and ordinarily call and receive messages in the regular manner. In case of a fire, however, any party, by pulling the figure 5 on his dial and pushing his button, can ring and talk to all of these interested parties simultaneously and give the location of the fire. The fire-chief can immediately give his orders to all his assistants without making any calls, because they are all connected to his telephone at this time. After a subscriber has thus sent in a fire-alarm call, it is impossible for him to again use.his telephone until the switchboard attendant at the central office has made a record of the number of the party who made the call, and has again thrown the subscriber's apparatus into service. This method of interlocking reduces the malicious ringing of false alarms.

68. Power Required.—In large exchanges, two storage batteries of twenty-six cells each are provided with the necessary charging machines. For 10,000 subscribers, a capacity of about 360 ampere-hours per battery is sufficient when a local-battery talking circuit is used. The amount of power required to operate any Strowger exchange may be estimated from the following example. The maximum traffic, which occurred in one Strowger exchange a short time after the exchange was cut over from the manual to an automatic board, was about 1,500 calls established and released in each 5 minutes. This required an average current of from 40 to 50 amperes. Normally, in a busy exchange for 6,000 subscribers, the current is about 20 amperes at the busiest hour. The line apparatus in each line is said to require from .05 to .1 ampere and the local apparatus about .5 ampere.

The ringing machines are usually in duplicate, one running in the daytime from the commercial power and the other running at night from the battery. In small exchanges, a battery is used, but no ringing and no charging machines are required. The charging is done from a direct-current circuit, and the ringing is done by means of a pole changer. The pole changer is started from the off normal springs of the switches and no current whatever is used as long as no switching operation is going on. The pole changer also operates the busy signal. This is very desirable for small exchanges where a constant waste of current would make itself noticeable. Small exchanges may be run from batteries having a capacity of 16 ampere-hours and less.

69. Troubles.—The troubles of the automatic system are the same as those of any other telephone system involving the same apparatus, with the addition of a few more, owing to the additional mechanism employed, such as the keyboard of the telephone and the automatic switch at central. The time of contact of the impulse spring is an important consideration. While considerable range is permitted, it is desirable that the time of contact be as uniform as possible, for the smooth working of the switches. A very long make with a short break is liable to cause the line and local relays to stick, particularly if the speed of the dial is high and the line has a high resistance ground or cross. In general practice, the only uniformity in the operation of apparatus desired is, speed of dial and duration of impulse.

Instrument and line faults are readily picked up by the attendant at the exchange by the manner in which the switch operates. This is worthy of consideration, for almost all troubles may be detected by those familiar with the system at once by sound and sight. An open line, a grounded line, a crossed line, in fact, almost any line disorder that will interfere with fairly good transmission, may generally be detected and remedied before the subscriber has knowledge of such disorder; so also with the calling apparatus. When calling with an open line, only one relay is operated, while a crossed line releases the switch with each impulse. A grounded line will show itself by opening the cut-out within a few seconds if the ground is heavy. The eye and ear of the attendant soon become adapted to the proper working of the switch and read the trouble almost without an error, whether detecting a new trouble or testing with the inspectors. Carrying the same polarity of battery on both lines makes outside testing for open circuits, crosses, etc. very easy for trouble men and inspectors.

Any second-selector, or connector, switch in trouble can be made "busy" by the attendant in a few seconds' time, without interfering with the service of any subscriber, and the trouble can be fixed at his leisure. A second-selector switch is made busy by placing some first selector of that group on the trunk leading to the second selector in trouble: the same may be done for a connector switch in trouble. Like all machinery, delicate or otherwise, the automatic switch must be kept clean and properly cared for. A conservative estimate would place the operating force required for 100 subscribers in a Strowger automatic system at one switchboard man, two inspectors, and one line-trouble man.

TOLL CONNECTIONS

70. Small Toll Traffic.—There are two methods for handling toll lines in connection with the Strowger automatic systems—one for light toll traffic and one for heavy toll traffic. In each case, a regular lamp-signal manual toll board with one or more positions is used. For a small toll business, the toll operator has a regular telephone number, say No. 600. A subscriber wishing a toll connection, calls 600 in the regular way. The toll operator answers, gets the order, and requests the subscriber to hang up his receiver until called. After the toll operator has completed the toll connection, she inserts the mate of the plug used on the toll side into one of the trunk jacks to the automatic switchboard and calls the subscriber automatically. The toll conversation goes over the automatic board. For outgoing and incoming toll calls, the toll board is equipped in the usual way. For connections between the toll lines and the automatic subscribers, the toll board is equipped with an automatic calling device that can be connected to any calling cord by throwing a key belonging to the cord. Some trunk lines lead from jacks at the toll board to the automatic switchboard and end there like subscribers' lines on first selectors. Any number of trunks may be provided, and it is easy to increase the number if the toll traffic becomes larger. The cord circuits are provided with two lamps for supervising the connections on each side of the cord.

71. Large Toll Traffic.—For large toll traffic, one of several similar arrangements is as follows: From the main distributing frame, the lines run in the regular way to the first selectors. At the same time, a separate pair of wires for each line is brought from the main distributing frame to a so-called switching section, that is, a manual board with as many 2-spring-and-sleeve jacks as there are subscribers, each pair of wires ending at the jack of its number. One or two so-called switching operators are employed on this board. The recording operator has no number in this arrangement, but the words "long distance" are placed on the subscriber's dials opposite either an eleventh hole or the tenth hole, which is marked *0*.

A subscriber calling *0* or using the eleventh hole raises his first selector to the tenth level in either arrangement, which is directly connected to the recording operator. On pushing the ringing button, a signal is displayed on the recording operator's desk. This operator having connected herself to the line, gets the order, and requests the subscriber to hang up his receiver until called. The recording operator passes the order to the proper toll operator who secures the desired party. She then communicates over an order wire with one of the switching operators, who designates a trunk between the toll board and switching section. The toll operator inserts the mate of the used toll-calling plug into the trunk jacks, and the switching operator connects her end of this trunk directly with the subscriber's line by inserting the trunk plug in a jack associated with the calling subscriber's line. In this way, a purely manual connection is established, and all signals are arranged to conform with manual practice. When such a toll connection is made, the first selector of the called line is made busy, so that it cannot be called over the automatic exchange.

72. Example of a Toll Circuit.—In the automatic exchanges at Grand Rapids, Michigan, and Lincoln, Nebraska, each line, on entering the exchange, as shown in Fig. 27 and according to a writer in the American Telephone Journal, passes through the main distributing frame, then through a cut-off jack located in a so-called switching section in the toll room and finally to the first selector. The dial on the telephone set of each subscriber to the automatic exchange has, in addition to the ten holes ordinarily furnished, and marked consecutively from *1* to *0*, one marked *toll*. Whenever a subscriber desires a toll connection, he places his finger in this extra hole and turns the dial. By so doing he operates the first selector in the same manner as though he had pulled the *0* hole, that is, the first selector will step up ten steps, then rotate on the tenth level until an unbusy trunk to the recording toll operator is secured, thus establishing a connection between the subscriber's instrument and the first of a number of recording trunk lines that is not in use.

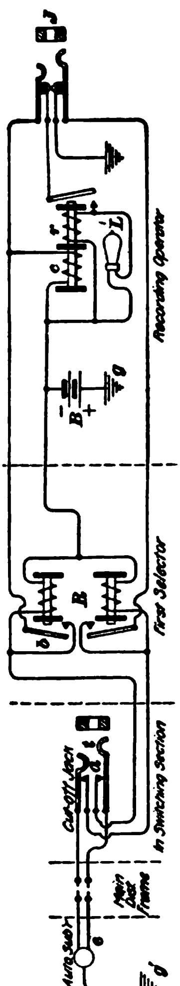


FIG. 27

Each recording trunk line ends in a lamp *L* and a jack *J* at a position of the toll board termed the **recording operator's position.** When the automatic subscriber turns his dial, a circuit is established from his telephone, by the operation of the first selector *R*, to the recording operator's position. If the subscriber were calling a second automatic subscriber, he would, after making the proper movement of his dial, press the ringing button, thus grounding one side of the line and operating a relay, which would cause current from a generator to pass out over the line of the called subscriber and ring the bell of that subscriber. In the case of a call for a toll line, the subscriber will press the ringing button in the same manner after operating the dial once only, and the result of his act will not be the same. Instead of closing a circuit for generator current, the relay at the recording operator's position will be operated by current flowing through *B–g–*ground*–g′–e–t–a–b–c–B*, and the lamp *L* will be lighted, thus attracting the attention of the recording operator.

In front of this operator are located a certain number of plugs adapted for use with the recording-trunk lines. In response to the lighting of the trunk lamp, the recording operator will insert one of these plugs into the trunk jack, and after throwing a listening key obtain from the subscriber the order. She will then write the

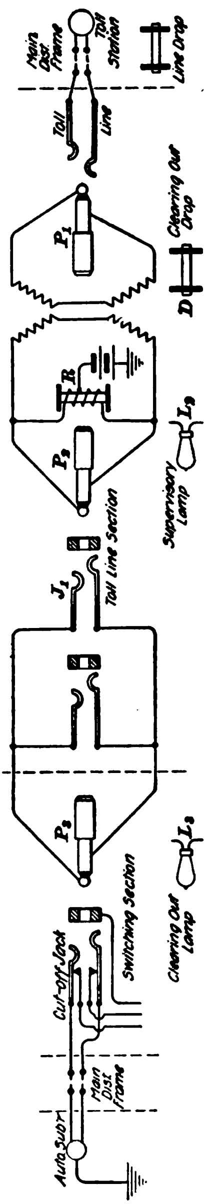


FIG. 28

information on a ticket, pass it to a toll-line operator, and tell the subscriber to hang up his receiver until called. Replacing the receiver restores his line to normal condition.

73. Each toll operator's position, is provided, as shown in Fig. 28, with cords, one plug P_1 of each being adapted for use with a multiple, or answering, jack of a toll line and the other P_2 in connection with a multiple jack J_1 of a trunk line leading to the switching section. This trunk terminates in a plug that may be connected with any local line by inserting it into the cut-off jack of the line. As soon as the toll operator receives the ticket from the recording operator, she will insert one of the plugs adapted to toll service into a jack of the desired toll line and call the person wanted. When the toll operator succeeds in obtaining the party desired, she will, over an order wire to the operator at the switching section, give the number of the automatic subscriber who called toll and receive in return the number of the trunk line that is to be used. The toll-line operator will then insert the plug P_2, corresponding to the toll plug already in the toll-line jack, into a multiple jack J_1 of the designated trunk, and the switching operator will, if on testing the cut-off jack of the automatic line, she finds it free, insert the toll-trunk plug P_3 into it.

The toll-line operator will immediately assume charge of the connection and ring the automatic subscriber. When he answers, she will tell him to make a movement of his dial, after which she will allow the conversation to begin. This request is made so that at the end of the conversation the apparatus at the exchange will be restored to its normal position when the calling subscriber hangs up his receiver by temporarily grounding both sides of the line simultaneously. As the called subscriber may not have an automatic telephone, and if he has he makes no movement of his dial before conversation, hence the called instrument is not able to ground the line when the receiver is hung up. In the case of a toll connection, the calling automatic subscriber is called from the toll board, and as his instrument must perform the clearing-out function, it is necessary to first place it in condition to do this by a preliminary movement of the dial.

Connected across the automatic end of each cord circuit are the two windings of a relay R; the inside terminals of which are connected to the ungrounded side of the battery. When current flows through either or both windings of this relay, it will be energized and a lamp L_2 will light. This lamp serves as a disconnect signal and enables the subscriber to signal the operator by pressing the ringing key, thus placing a ground on one side of the line, or he may hang up his receiver.

74. There are two disconnect signals—the falling of the shutter of a clearing-out drop D in the toll side of the cord circuit and the lighting of a lamp L_2 in the automatic side. The act on the part of the toll operator of removing the plug P_2 from the toll-trunk jack J_1 will light a lamp L_1 associated with the toll trunk plug P_1 at the switching section, and the operator will remove the connection. Except that the toll-line operator makes out the ticket, the step that it is necessary to take in establishing and removing the connection when a person at a toll station calls for an automatic subscriber is the same as described above, after the toll-line operator receives the ticket from the recording operator. In establishing such a connection, the recording operator plays no part.

During a conversation between a toll and an automatic subscriber, the connection normally existing between the automatic subscriber's station and the automatic exchange is broken at the switching section, and therefore the multitude of contacts in the talking circuit and the bridging magnets present across the circuit are removed. There is, therefore, no reason why excellent toll service should not be furnished.

75. While the Dayton, Ohio, toll board is similar to the one at Grand Rapids, there are some radical differences. At Dayton, the dials are not provided with special holes for calling toll, but a certain number is used. With this exception, subscribers notice no difference in the steps to obtain a toll connection. At Dayton, there is no switching section. An automatic subscriber desiring a toll connection is first placed in communication with a recording operator, who, after obtaining the necessary information for making out a ticket, requests him to hang up his receiver; conversation then takes place through the automatic-exchange apparatus, the toll operator calling the automatic subscriber by means of a dial similar to the ones furnished the subscriber. One dial is furnished for each operator's position, and a key in each cord circuit enables the dial to be used in connection with any one. The disconnect signal is received at the toll board in the same manner as at Grand Rapids. If, however, the automatic subscriber does not move his dial when requested to do so by the operator, there is an arrangement by which a ground may be momentarily placed on the trunk line to operate the disconnect signal.

SUGGESTIONS FOR SWITCHMEN

76. It is impracticable to give a complete list of troubles on a Strowger automatic system and their remedies that will be general enough to apply to all such systems. However, the suggestions, almost exactly as prepared by Roy Owens, switchboard manager for The Columbus Citizens Telephone Company, for the switchmen under his charge, will be given.

These directions will be clear and of use only to those actually engaged in caring for similar systems. To fully explain all these directions would make them too long, longer than necessary for the switchmen for whose benefit they are given.

77. Use the following abbreviations when reporting troubles: C C, can't call; C C A O, can't call any one; T C D A, tests clear, don't answer; B D R, bell doesn't ring; grd, grounded; O O O, out of order; O O Adj, out of adjustment; Xed, crossed; B R C A, bell rings, can't answer; C H, can't hear; O N, off normal; N I, not in at time party called them; W N, gets wrong numbers; sw grd, swinging ground; P T, poor transmission; O K, all right; X, cross.

78. The switchmen who start work at 7 o'clock will immediately go over the off normals of the whole exchange, firsts, seconds, and connectors; this is very important.

If you find that a first selector is on a contact, trace the call and see whether it is complete, and then release it with pliers. If it releases O K, call up party for test; there may be line or telephone trouble. Second selectors and connectors found off normal should be traced back; if a first selector is found on the trunk and releases all right, call up party for test.

79. If a switch is on a contact and will not release with pliers, something is wrong and should be fixed. Either there is paper on the contact or the V (vertical circuit), R (rotary circuit), or P (private circuit) is open, battery off or hang-up on the same contact. In such a case, do not release the switch and call it O N or O K on test. If not able to locate the trouble, notify the repairman. If at night, and repairman is absent, call up switchboard chief.

If the switch is found in on a contact and releases O K, and the line is not Xed, open, or grounded, make report on red slip, O N, and the number of the contact it is on. If up and not in on a contact, and there is no apparent reason for same, simply report O N.

If a switch is found off normal, whether in on a contact or not, and on test the line is found to be open, Xed, or grounded, or if paper is found on the contact, don't report it

O N, but make the report according to what the trouble was. In fact, the only times to report off normals as O N are when no apparent reasons can be found for them.

80. If you see a switch stepping up or calling Xed or getting rotary impulses, make test at switch *at once* to see if line is open or Xed with another line.

If you hear the line relays of a switch rattling as if generator is on the line, make tests at once for X with another line, open private normal, or open line-switching relay coil, or possibly dust on cam-spring contacts or under line-switching relay armature. Always, when you see a switch acting wrong, make these tests; they only require a moment's time, and help the wire chief a great deal.

81. To test for an open circuit, step the switch up and in, and with your pliers connect the private wiper with the vertical. (It is always best to step it up on the level of its own thousand.) This will release the switch if line is short-circuited, or normal, unless condensers are in the circuit, in which case call up the party. There are some exceptions to this rule, as some of the extension circuits will not act this way. In this case, connect the rotary wiper with the private. If it still tests open, try the same test from the back of the switch by connecting ground to either line in turn. This will test the back contacts of the line-switching relay, while testing from the front of switch tests only the make contacts. Condenser lines will be marked with blue paper on vertical relay coil.

To test for open line-switching relay coil, try first if stepping switch in on a contact or if grounding middle jack-contact, pulls down armature. If it does not, either the relay coil is open or there is an open circuit in the switch. For an open private normal, test that number from every connector in the group. One of the connectors may have paper on the private contact, it may not make the circuit busy, or private circuit may be open in banks or at terminal.

82. If a first selector switch will rotate over all contacts on all levels, whether busy or not, it shows that the line-switching relay coil is either shunted or short-circuited. If it makes a big spark on the interrupter spring, or if it sticks on the interrupter, the trouble will generally be a line-switching coil grounded on the core. If rotating a switch blows or explodes the heat coil or blows the fuse, there is a direct main battery on the frame of the switch.

To test for X with another line, hold line-switching relay armature down with one hand and with pliers touch ground to each line in turn. If there is a spark, the line is Xed with another. This will not show up, however, if the line with which it is Xed is plugged at switch.

To test for short circuit in first-selector banks, step switch on to the contact in doubt and press the cam-springs apart. This opens the line-switching relay contacts so that, if the switch releases by touching the private to the vertical wiper, it shows that the bank is short-circuited or another switch is on that contact, not making it busy. Try the same test with another switch near to verify.

83. If putting a switch off normal grounds the lines, it shows that the private normal is Xed with one of the lines. Look at jacks at back of switch for the trouble, and if not there make tests to locate it in the switching section.

In testing out a reported trouble, make all tests possible at switch. For instance, if A can't call B, test A for X, open, grd, etc. Examine line relay adjustment, line-switching relay, normal- and cam-spring adjustment, wipers, vertical and rotary motion. In fact, give the switch a general inspection. Then try B switch the same way. When you call B, watch the generator lamp to see whether line is Xed, grd, or short-circuited, or whether receiver is off the hook. When he answers, tell him you are testing the line, and ask him if his bell rings O K; also, if he was in at such a time (the time the trouble was reported). Then have A call B, and watch the call carefully. Listen in to make sure he gets the party. If there is no answer, press down the vertical relay armature on the connector, and feel for generator on the wipers. This is to make sure the ringing is all right. By all means watch the call until it is completed. When having any one call any number, it is no test to wait until the call is complete or to watch for the connector to step up on to the called number. Watch the first selector step up, and then watch the second selector, and then the connector. You will have to hurry in order to do this, but it is absolutely necessary.

If A says he doesn't want B any more or that the party who did want him has gone out, have him call you to see if he calls O K.

84. Do not take up any more of the subscriber's time than is absolutely necessary. If there is anything wrong inside, tell him you will have it taken care of soon and will let him know when O K. Always be pleasant and courteous to subscribers and thank them for their trouble. They will endure considerable trouble if they see it is being taken care of and if they are treated right.

Don't make any definite promise to subscribers as to when the trouble will be cleared. Tell them that you don't know when, but that it will be attended to and cleared as soon as possible. If, when testing with a subscriber, you get an unsatisfactory test or if he is too busy, make report on trouble ticket, "Unsatisfactory test, send man." When calling up subscribers for test, always begin the conversation by saying: "This is central testing your line; what is your number, please?" This explains everything to the subscriber at the start and all he has to do is to say his number.

85. All first-selector troubles should be fixed at once and second selectors and connectors in trouble should be made busy by connecting grd. to trunk release at their jacks and the repairman notified so that he can make repairs at once.

By being constantly on the lookout for trouble, you prevent troubles being reported to the desk.

If a line tests short-circuited, look at the wipers before reporting it to rackman. If a first selector releases on second move of dial, either the wipers are short-circuited or the bank contacts are short-circuited or have a switch on them not making busy. This contact, if found short-circuited, should be made busy at once at back of its second selector and repairman notified at once.

Never change the line-relay contacts in any way on a second selector or connector without testing immediately or notifying repairman to do so. If you change the spring adjustment on any first-selector switch, it is well to have the party call for test.

86. If you hear a second selector or connector calling crossed, try to release it by pressing down both line relays, and if that does not release the switch operating it, look up the two switches immediately that are hung up on it. Do not release either until you know both and make out a pink trouble slip. For instance,

$$\left.\begin{matrix}80\text{—}4\\81\text{—}3\end{matrix}\right\}\begin{matrix}14\\13\end{matrix}$$

means that the fourth second selector in the 8,000 board is 1 up 4 in and the third second selector in the 8,100 board is 1 up 3 in (both on same contact).

$$\left.\begin{matrix}6{,}042\\4{,}030\end{matrix}\right\}\begin{matrix}22\\24\end{matrix}$$

means that 6,042 is 2 up 2 in and 4,030 is 2 up 4 in (both on same contact).

6,132 O N

means that 6,132 is off normal, but not in on a contact.

6,132 O N 31

means that it is 3 up 1 in and releases O K—no apparent reason being found for its being off normal. In this case, if 6,132 was found off normal on 31 and either the line was open or paper on the contact, it should not be reported as O N.

60—10C

means the tenth connector in the 6,000 board.

$$\text{Tel. No. 6,021—O N 42—}\left.\begin{matrix}40\text{—}7\\41\text{—}3\end{matrix}\right\}\begin{matrix}82\\81\end{matrix}$$

means that 6,021 was off normal 42 and on tracing the call its second selector 40—7 and another 41—3 were hung up. Use these symbols always in reporting trouble.

87. If a subscriber complains continually that he does not get his calls, short-circuit his lines at the switch and ring from every connector on the shelf. If open at any switch the generator lamp will not burn.

If he complains that his line goes dead at times and that others get the busy in calling him when he is not busy, test to see if the private normal is Xed with some other private normal. To do this, open the heat coil and put ground on the private. If there is a spark, it is Xed. Probably the cam or normal springs are out of adjustment. Considerable trouble has been caused by the normal springs not opening when the switch is normal.

Because a party can call *one* number is no reason why he can call *all* numbers. There may be a certain connector or second selector that his switch takes in calling, which might be in trouble, so that all reported troubles should be tested and looked after for all possible causes of trouble.

88. Make out a red trouble ticket for every trouble detected whether fixed at once or not. Make out a red trouble ticket for everything you notice wrong whether it is fixed at once or not.

If you cannot raise a party and his line seems to test all right, report T. C. D. A., which means "Tests clear, don't answer." That will show the rackman that you have made an effort to find out what is the matter.

If the lines of a second selector or connector become grounded, look up the trouble at once. Never plug the heat-coil springs, as some other switch will call in on that switch and become hung up. Never reverse the wires at the back of any switch. Reverse them at the back of the rack on cable side of terminal.

89. When writing a trouble ticket after testing, to say that the switch "was stuck" or "out of order," or that there was "switch trouble," is not sufficient information. Always, in reporting the result of a test or in repairing switches, state exactly what part was repaired or adjusted so that the trouble may be classified properly on the weekly trouble report. On all trouble tickets fill out everything necessary for the information of the assistant wire chief, so that on his test it will not be necessary for him to ask the subscribers the same questions over again.

Whenever you replace any broken, worn-out, or burned-out part of anything with a new part, write it on a red trouble ticket. This is the only way a record of new parts that are needed for replacements can be obtained.

90. When you hear a first-selector switch buzzing on the tenth contact of the first level, call up the party and ask what number he is *calling*. (Don't ask him what number he is *trying* to call.) By paying strict attention to this you will detect all reverses, those calling old numbers and those that get 1 in calling 2.

If it is buzzing on the tenth contact of any other level, release it and then look immediately to see whether all the second selectors in the board it is calling into are really busy, hung up, or out of service. Use your own judgment in calling up the party in this case. Sometimes, it is best to let the party call again without calling him up.

If a second selector is buzzing on the tenth contact of any level, release it by pressing double dog and then put switch up on to another level, so that when subscriber pushes the button again it will step up a connector and give him the busy. Never place any first or second selector on any contact in any way other than with rotary relay. In this way you cannot put it on a busy contact.

91. The early night men, after the rush trouble tickets have been attended to, will go over all the grounded reports. If still grounded, make report on the ticket and also state the time. If clear, write on ticket, "Call for test," if it is too late to do so then. The day man will call up party the next morning.

92. Whenever it is necessary to hold a trouble ticket for a day or so on account of some switch adjustment to be made later or on account of a chronic case to be watched, do not hold the yellow ticket. Write on it the nature of the trouble and O K it, writing, "See red slip." Then make a copy on the red ticket and keep that and mark it duplicate.

The large gong rings when any main-battery fuse blows on a fuse panel. Drop everything and put in new fuse at once. Then try every switch in that hundred for hang up. During the time the fuse is out, any party calling into that board or anybody in that board calling out will be hung up.

When heat-coil bell rings, look immediately to see whether it is in *your* thousand. If so, fix it at once. If line is grounded, listen in and say, "Hello," and if talking make report to that effect on trouble ticket. If not grounded, test for open, X, or short circuit, and if clear call for test. This is the only way chronic ground troubles can be remedied.

93. If a switch calls Xed and on test with subscriber it still calls Xed, be sure to tell him there is trouble on his line and that it will be attended to. If urgent, have the party he wants call him.

In all cases of testing from trouble tickets be sure to notify the party who made the complaint whether everything is all right or not. Subscribers sometimes report that the switchman call them up and ask them to call a certain number and that is the last they hear of it. It is very important that when a party makes a complaint he is afterwards given some information regarding it. It is not necessary to go into details with subscribers in describing troubles, but it is necessary to follow up every complaint and let them know the conditions.

94. Avoid all unnecessary conversation with subscribers, and above all use the test telephones for *testing only*. They must not be used for social purposes. There are sixteen trouble men and many mere installers, interior wiremen, linemen and subscribers who must use these telephones for testing.

Do not talk to subscribers through your receiver except to say "Hello" when going over off-normals. A lot of time is wasted repeating, and it gives the subscriber a wrong impression, namely, that someone is listening on the line. If you want to talk to a busy line, call the first three figures of that number and push the button the number of times of the last figure, then let out the side switch on the connector and you can then talk to the subscriber in the ordinary way. When you hang up, the connection is not disturbed.

95. Between the hours of 11 and 1 every day (lunch hours) it will be necessary for each man to look after two thousand, his own and the one adjacent.

Do not take any switch parts or material away from the building. All experimenting can be done in the exchange room.

96. If, when making a "call for test" according to a white ticket, the subscriber makes any complaint, tell him you will have an inspector look after his trouble. These tickets are a check on any of five troubles and consequently any further complaint made must be attended to.

Ordinary *reported* troubles are written on yellow tickets—*special*, *rush*, or troubles reported by manager or superintendent, on white tickets; and *detected*, *cross-cut*, *adjust switch for cutting in*, on red tickets.

When given a ticket marked *call for test*, examine switch first and then have party call the test telephone. When given a ticket marked *adjust switch for cutting in*, adjust the switch, trying the switch from back and front, so that when the installer is ready to run in the telephone the switch will be in good order and hence the installer will not have to wait while the switchman puts in a new switch, coil, or spring. Then mark the ticket "adjusted," and sign your name after the O K.

97. In connecting numbers to traffic trunks, observe the following: Plug the line-switching relay springs with fiber and hang a tag on switch, stating what it is connected to and why. Then connect traffic trunk to this number at connector-bank terminal—lines and private. Then unsolder jumpers at rack and tag them the same way. Call the number to see whether the information clerk answers. Tags are in back of rack.

98. Following is a list of adjustments on switches:

*Try relay bracket and heel pieces for looseness.

*Try relay coils for looseness.

*Test set adjustments.

*Try relay springs for looseness.

*See that core strikes well in center of armature.

*Try relay armatures for play and bind.

*Try tension in relay springs, adjust length of contacts.

*Try release armature for play or bind and springs.

*Try rotary armature for play or bind and springs.

*Try vertical armature for play or bind.

*Try double dog for play or bind.

*Tighten normal pin and post.

*Put tension in cup spring.

*Adjust vert. pawl.

Adjust rot. pawl.

Tension in pawl springs.

Straighten escapement springs, adjust same (the first teeth of escapements springs should meet).

Adjust side wipers.

Adjust spider arm to move freely in bearings.

Adjust spider arm with regard to first and second teeth on bottom escapement spring.

*Adjust private bracket to spider arm in second position, private armature down.

Adjust cam and cam-springs.

Adjust private springs.

Spider arm should pull in at normal.

*Adjust release link.

*Line up side switch block.

Adjust release arm. stop.

With rotary pawl stop loose, set rotary magnets to allow rotary dog to drop in.

Set rotary pawl stop.

Set interrupter springs with regard to interrupter arm at normal and drawn in.

Adjust rotary armature finger.

Set vertical magnets, and vertical dog.

Adjust stationary and double dogs.

Tension in double-dog spring.

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*Test set adjustments.

Adjust vertical armature spring to vary with adjusting screw up.

Line up and adjust normal springs.

Adjust tension of back-release relay and line-switching relay.

*Tighten all screws and nuts.

Note all connections and see that they are well soldered.

See that wiring is not exposed or in positions likely to cause short circuits.

99. Distinguish between *cut-outs* and *cut-offs*. **Cut-out** means that the conversation is broken and disconnected, but that the party is not disconnected from the party he calls.

Following is a list of possible causes for **cut-offs:**

1. *Calling Telephone.*—Release springs too close, desk cord trouble, insulation skinned on wiring in the telephone and in contact with case or frame, swinging ground or leak in interior wiring, dirty carbons in protectors.

2. *Line.*—Swinging ground or swinging cross with another line, slight ground or cross with another line, leaky line, cable, or spider wires.

3. *Rack.*—Carelessness of rackman getting two lines together with soldering irons both in back and front of rack, heat-coil springs touching at protectors, dirty carbons, heat coil falling down, line Xed with telltale.

4. *Switch.*—Poor adjustment of switch or of some other switch, either first or second selector, so that it will stop on a busy contact, or will not make a contact busy. Cross in either first selector, second selector, or banks. (In the groups affected by the particular call in question.)

Wipers of the first selector, second selector, or connector out of adjustment so that they touch either the contact above, below, or either side, or the wipers of any first selector or second selector in the same groups as those in the particular call in question, may be out of adjustment so that in rotating they may strike the busy contact.

In short, a cut-off is caused by either line becoming grounded from some source during the conversation whether

*Test set adjustments.

from an extension telephone on its own line or from its own telephone or any of the other possible cases mentioned.

100. During the day, there will be one man stationed in each thousand group. As the 2,000 and 3,000 groups are so much busier than any of the others, the 4,000 and 5,000 men will be expected to help them when necessary.

The men who work Sundays will be off duty on the afternoon of the day before (Saturday). They must stay until 12:30 o'clock, however, regardless of what their regular hours are.

Do not leave your boards to do repairing at the bench. The repairmen will attend to all repairing. It is necessary for each man to keep within hearing of his switches as much as possible. When you leave the switch room for a short time, let the man in the nearest group know. Where two men are necessary, call on the man in the nearest group if the repairman is too busy to help. Do your receiver repairing either when off duty or when your work is slack.

Mistakes may be overlooked if it is seen that you are working for the best interests of the company.

There are no objections to bringing visitors into the switch room, but all except switch-room employes must stay outside of the railing.

AUTOMATIC TELEPHONE SYSTEMS

(PART 2)

CLARK AUTOMATIC TELEPHONE SYSTEM

1. The **Clark automatic telephone system** is intended for exchanges requiring from twenty to seventy-five stations and located in small towns, factories, mills, warehouses, and hotels. The system consists of a switchboard made up of the required number of automatic step-by-step switches, one for each line, two line wires between the central office and each substation, a common-return wire, or a ground return, and a telephone instrument with a selecting dial at each substation.

SUBSCRIBER'S DIAL

2. Fig. 1 shows a **subscriber's dial**; this forms the base of the desk stand, but is mounted on the front or alongside of the wall telephone. It contains a clockwork mechanism consisting of two brass wheels having seventy-five teeth, each mounted on a central axle with a smaller wheel, which engages a retarding mechanism that regulates the speed of rotation of the lower of the two main wheels. This mechanism is mounted on a cast-iron base, and covered by a nickel case. On the side of the case is a small plunger *b* that engages a locking lever. The top wheel on the spindle acts as a dummy, and is used to store power in a spiral spring for operating the lower wheel, the two being connected only by this spring. The lower wheel is mounted loosely on the central spindle, and a small contact spring is arranged so that when this wheel revolves, the spring touches the teeth of the wheel successively and closes the circuit each time.

FIG. 1

3. The operation of the dial is as follows: The locking lever is held normally by means of a small spring, so that it engages the dummy wheel, which is prevented by a pawl from moving backwards. On pushing in the plunger *b*, the dummy wheel is released from the locking lever and the lower wheel is locked. It is then possible to turn the dummy forwards by means of the knob *c* on the axle, thereby storing up power in the clock spring and setting the dial to whatever number it is desired to call. The numbers 1 to 75 appear on a disk, which is mounted on the central axle and turns with the dummy wheel and knob *c*, the pointer *d* being stationary and fastened on the nickel case. On releasing the plunger, the dummy wheel is again locked and the spiral spring revolves the lower wheel forwards until a pin on its rim engages a pin on the rim of the dummy wheel—this being the normal relation between the two wheels. For example, if the dummy be turned forwards seven teeth, the lower wheel will be revolved forwards seven teeth by the coil spring. Mounted on a red-fiber block in the base is a small contact spring, which is set so that its point normally rests between two teeth on the lower wheel, touching the teeth on this wheel only as the wheel is revolved by the spring. The making of the contact closes an electric circuit through a magnet mounted on the automatic switch at the central exchange. On the face of the dial are the words "turn to black space when through talking."

AUTOMATIC SWITCH

4. **The automatic switch,** shown in Fig. 2, consists of a red-fiber base *a* having seventy-five contact buttons mounted on it in a circle, each being the terminal of a subscriber's line. Four upright posts support a top frame, on which is mounted a magnet, whose armature *b* is mounted on a lever, the lower end *c* of which engages the teeth of a wheel *d*; a spring *e* attached to this wheel makes a sliding connection with each of the contact buttons, in turn, as it passes over them. Each impulse sent through the magnet by means of the dial at the subscriber's station causes the switch wheel to turn $\frac{1}{75}$ of a revolution—that is, one tooth. As the teeth on the switch wheel correspond in number to the teeth on the dial wheel and to the number of contact buttons on the base of the switch, the contact spring of the switch wheel may evidently be brought into contact with any subscriber's number. The automatic switches are mounted in cabinets and wired to binding posts, so that the installation work is very simple.

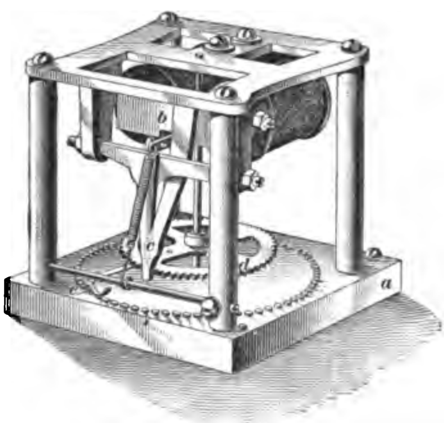


FIG. 2

BRIDGING SYSTEM WITH OPERATING MAGNET IN LINE CIRCUIT

5. Fig. 3 shows a diagram of connections for three stations, using ordinary bridging telephones and a third wire as a common return for all the telephone switches. The ground may be used in place of this common-return wire. This system operates as follows: The subscriber at any station, as 1, pushes in the plunger on his dial and sets the pointer for the station desired, for example, 2. When the plunger is released, the teeth of a wheel in the dial pass under a spring, with which they make contact in passing, and close twice a circuit through the magnet *m* of switch *1* at the exchange–battery *B*–and common-return wire or ground back to the dial at station *1*, thereby sending two electrical impulses through the magnet *m* and moving the contact arm *e* on switch *1* forwards two steps (had number 6 been called, six

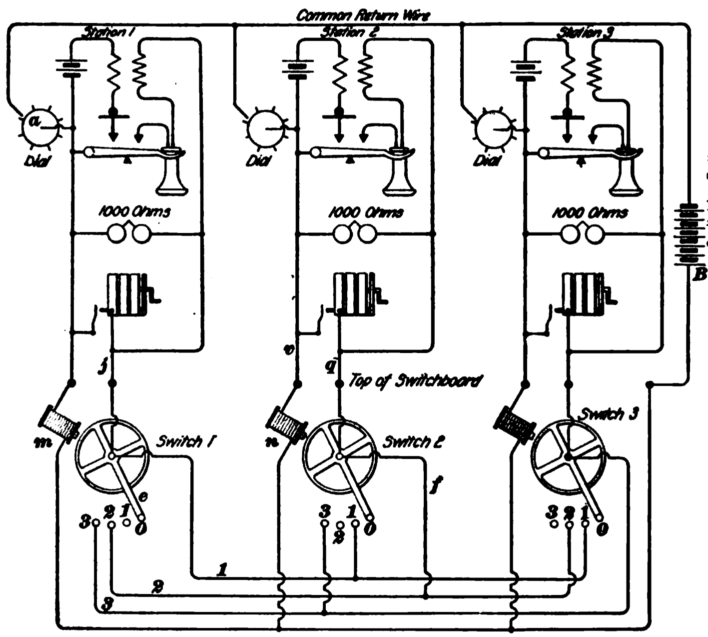


FIG. 3

impulses would have been sent through the magnets, and the arm would have moved forwards six steps), thus establishing a circuit from telephone *1* through line wire *j*–arm *e*–contact button 2–wires 2–*f*–line wire *q*–telephone 2–line wire *v*–magnets *n*, *m*–telephone *1*. Thus, the voice currents must pass not only through the telephone instruments, but also through the two magnet coils *n*, *m*. They are not strong enough to operate the magnets.

The bell at station 2 may be rung in the usual manner, for which purpose magneto-generators and polarized bells are shown in Fig. 3. Batteries and vibrating bells may be used for house systems having short lines. Similarly, subscriber 2 might set his dial at *3* to call station 3; in fact, any number of independent conversations, up to 38, may be held at the same time. When the conversation is completed, the

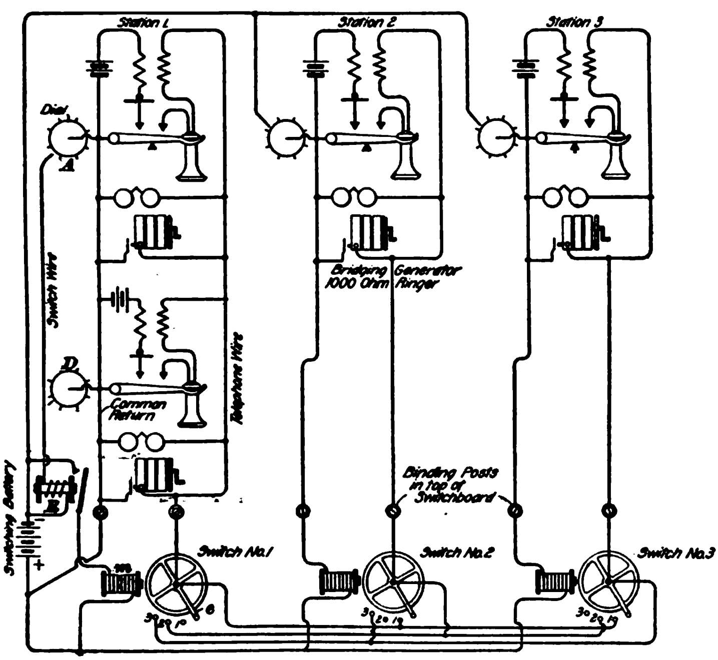


FIG. 4

calling subscriber should turn his dial to the black space, that is, back to its normal position; otherwise, the two stations left connected together would both be rung up the next time a third party called either station. There seems to be no provision in this system to prevent a subscriber from securing connection with a line that is busy.

BRIDGING SYSTEM WITH RELAY IN COMMON RETURN

6. For long rural lines, a relay inserted in the common return from the rural stations controls the magnet that operates the automatic switch. This arrangement is shown in Fig. 4, in which *A*, *D* are two rural stations on the same bridging party line. The dials at all rural stations in the same line are connected in parallel and the relay *R* that controls the operating magnet *m* is connected in the common-return wire from these stations. By this method, no increase in the voltage of the central switching battery is required for long rural lines.

TOLL CONNECTIONS

7. Subscribers connected to such an exchange may call any long-distance point from their telephones as follows: The local toll operator is also a subscriber to the automatic system. When a subscriber desires a long-distance connection, he first calls the toll operator, on the automatic telephone, and gives her the name of the party desired. When the toll operator obtains the long-distance connection, she simply trunks it through a jack-panel to the local subscriber by means of a pair of cords, at the same time ringing the bell of the local party. On an incoming call, the toll operator, on receiving the number wanted, trunks the long-distance call through the jack-panel, at the same time ringing the local subscriber. The jack-panel referred to has two uses: first, in testing the lines, and second, in making it possible to connect the automatic subscribers to the toll lines direct, thereby cutting them off the automatic system entirely and insuring an all-metallic connection independent of the local system.

8. For a Clark automatic telephone system installed at Hope Valley, Rhode Island, in 1903, No. 12, B. W. G., galvanized-iron wire of B. B. grade was used for the talking circuit and the same wire with weather-proof insulation for the common-return conductor. The object in insulating the common return is to prevent any likelihood of a cross with one of the talking wires that is also used for switching purposes, as this would short-circuit the central switching battery and throw the system out of service. The common-return wire is used only for switching and might be replaced by a ground connection. Ordinary bridging telephones are used. The system is operated by means of a central switching battery consisting of eleven storage cells charged by means of thirty-three gravity cells. This method of charging the storage battery is employed because the town has no light or power facilities from which charging current can be obtained.

From the lightning arresters, the lines pass through a small panel of jacks, mounted near a toll operator's telephone, to the automatic switchboard. A rural line 4 miles long is connected with the automatic switchboard. The total number of subscribers in November, 1903, was fifty-four. The rentals obtained were $20 per year for residences and $24 per year for business houses.

WESTERN ELECTRIC AUTOMATIC TELEPHONE SYSTEM

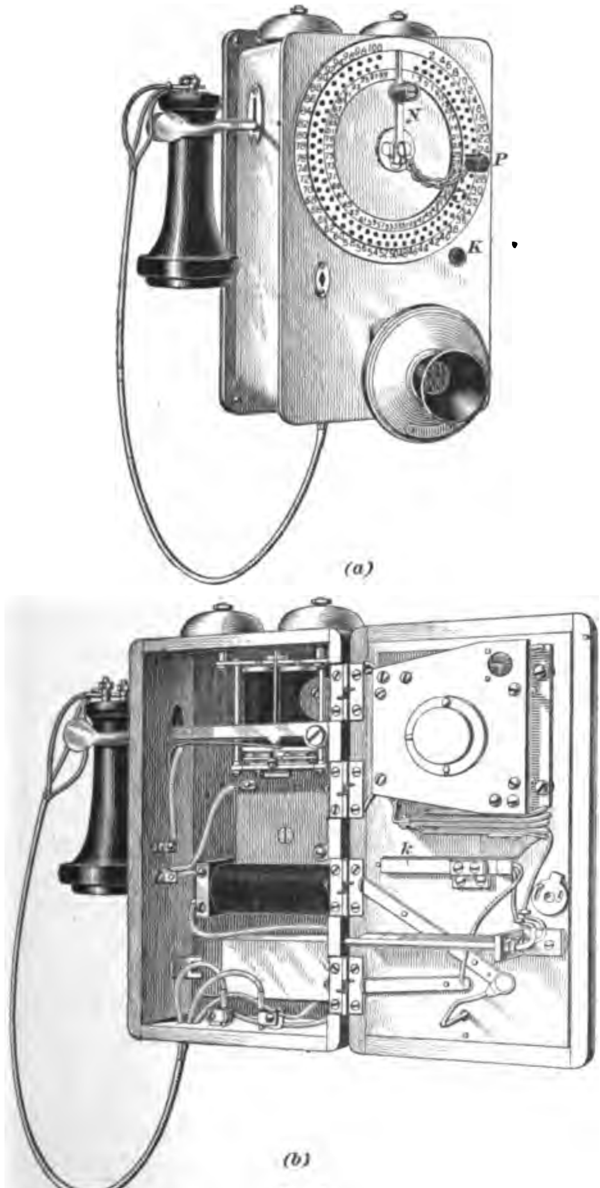
APPARATUS AND CIRCUITS

9. The Western Electric Company makes for the use of the licensees of the American Bell Telephone Company, a 100-line automatic exchange and a 20-line automatic exchange. These automatic exchanges are used as private-branch exchanges, and also in localities where not exceeding twenty or one hundred pair of line wires are required. Across each pair of line wires, one or more subscribers' stations may be connected. Where two or more subscribers are connected across the same pair of wires, the ringing is not selective; for instance, the first subscriber on line 45 may be denoted simply by the number 45, the second subscriber on the same line by the number and letter 45 A, the third by 45 B, etc. To call subscriber 45, the calling subscriber, after selecting line 45, presses his ringing button once; to call 45 A, he presses his ringing button twice; to call 45 B, three times, etc.

SUBSCRIBER'S TELEPHONE SET

10. The substation apparatus consists of a subscriber's telephone, to which is added an interrupting device, with a numbered dial, a rotatable arm, and a push button for ringing. The talking apparatus is connected in exactly the same manner as in practically all the central-energy subscribers' instruments used by the licensees of the American Bell Telephone Company. In Fig. 5 is shown two views of the subscriber's set, in the closed- and open-door positions, respectively. The dial-like board on the front of the door has a rotatable arm *N* that operates the selective devices. A plug *P* may be placed opposite any number desired; the arm *N* is rotated until stopped by the plug and then released. The ringing button is shown at *K*. On the back of the door in a metal frame is the interrupting mechanism, which is controlled by the rotating arm and operates the selective apparatus at the exchange.

11. The **interrupter mechanism** consists of a dial, a pointer and clockwork for restoring the pointer to its normal position, and contact springs for interrupting the line current. The dial is shown, in Fig. 5 (*a*), mounted on the outside of the lid of the subscriber's instrument and contains one hundred peg holes numbered from 1 to 100. The pointer is mounted on a shaft extending through the lid at the center of the dial and carrying a pawl, which engages the first of a series of clockwork wheels. The last wheel in the chain of gears is a small pinion, which engages the actuating spring of the line contact breaker. The mechanism is operated by an ordinary clockwork spring, which is wound by the action of the subscriber in moving the pointer around the dial. The speed is governed by a solid non-adjustable verge, or



(a)

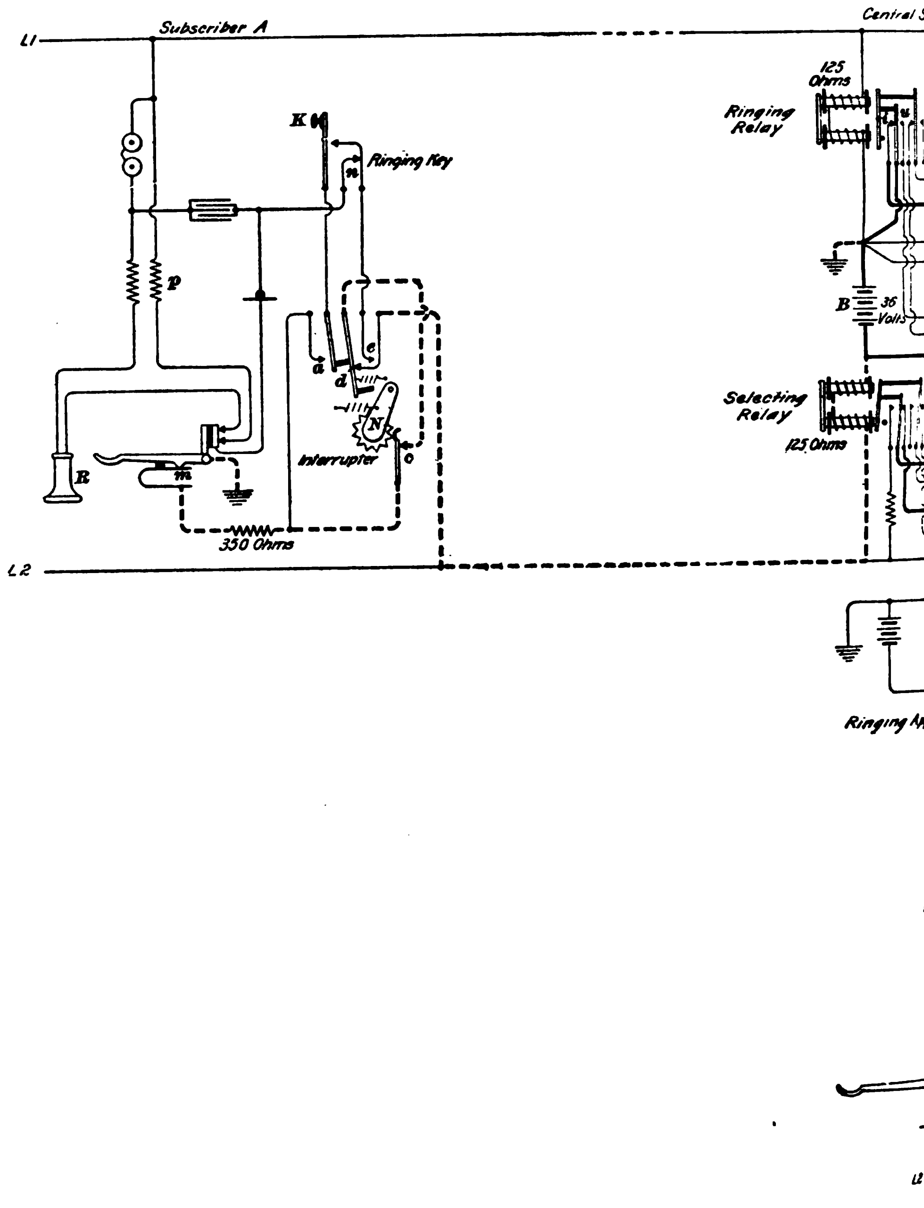
(b)

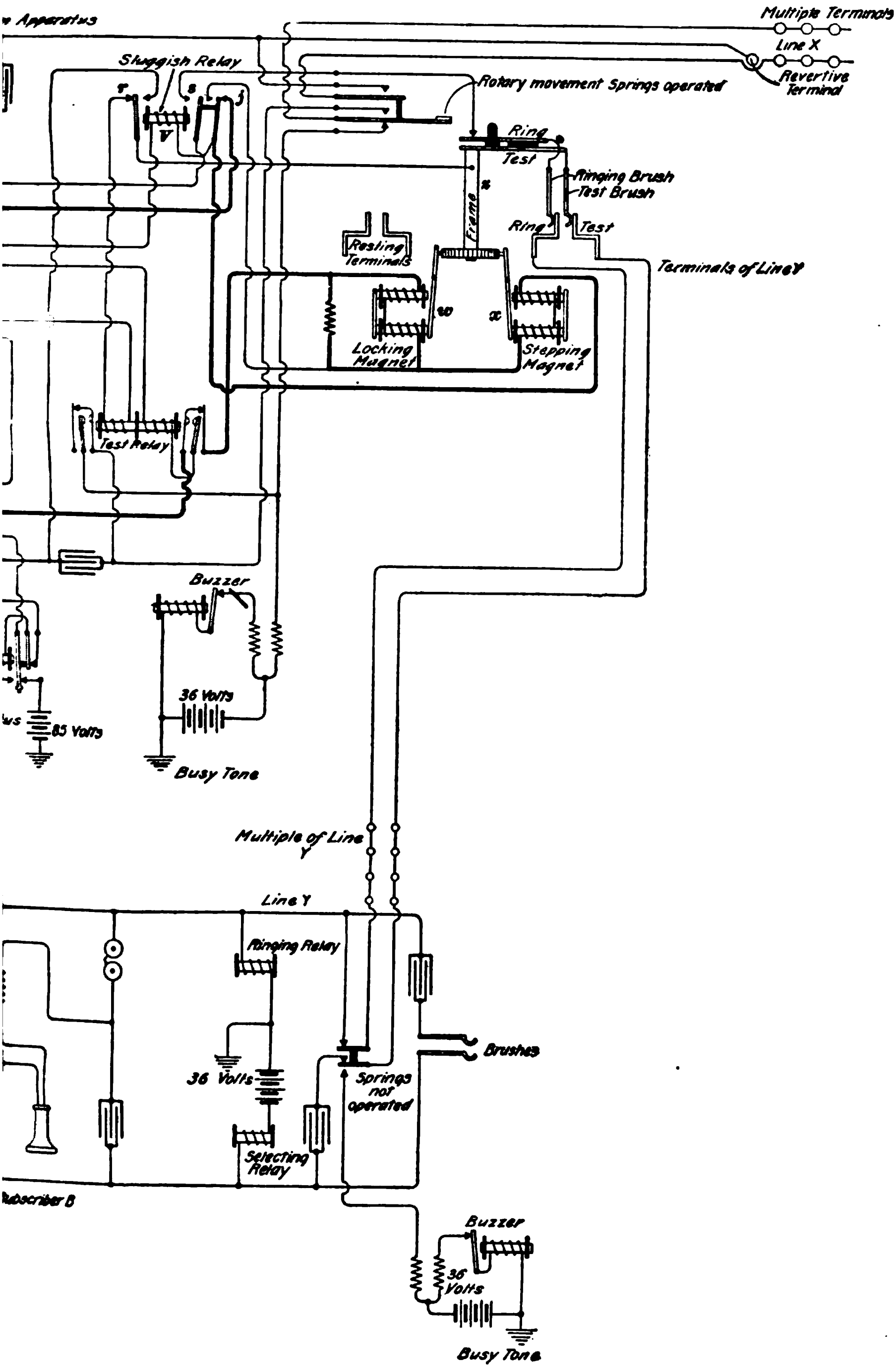
FIG. 5

escapement, which is used to secure a uniform rotation, and is such that the pointer should return from the *100* point on the dial to its normal position in from 8 to 10 seconds. Any variation of speed outside these limits causes incorrect selection. The line contact springs are simply a pair of flat platinum pointed springs carried by a heavy formed spring engaged by the small pinion. In their normal open position, the platinum points should be separated by .015 to .02 inch, gauges being furnished for accurately measuring this distance. Also operated by a pawl on the pointer shaft is a group of springs called the *substation rotary movement springs*, whose purpose is to change the local circuits as described in connection with the circuit drawings. It is essential that this group of springs be completely operated by the time the pawl has advanced a distance equal to one-half of one tooth in the first wheel in the chain of gears, otherwise incorrect selection will result. The pointer must be so fixed, with respect to the mechanism, that four current impulses will be sent to line when it returns to its normal position after having been turned to the peg placed in the first hole in the dial, this being necessary to operate the rotary movement springs of the central-office selector. Hence, three more current impulses are transmitted than is represented by the number in which the peg is inserted.

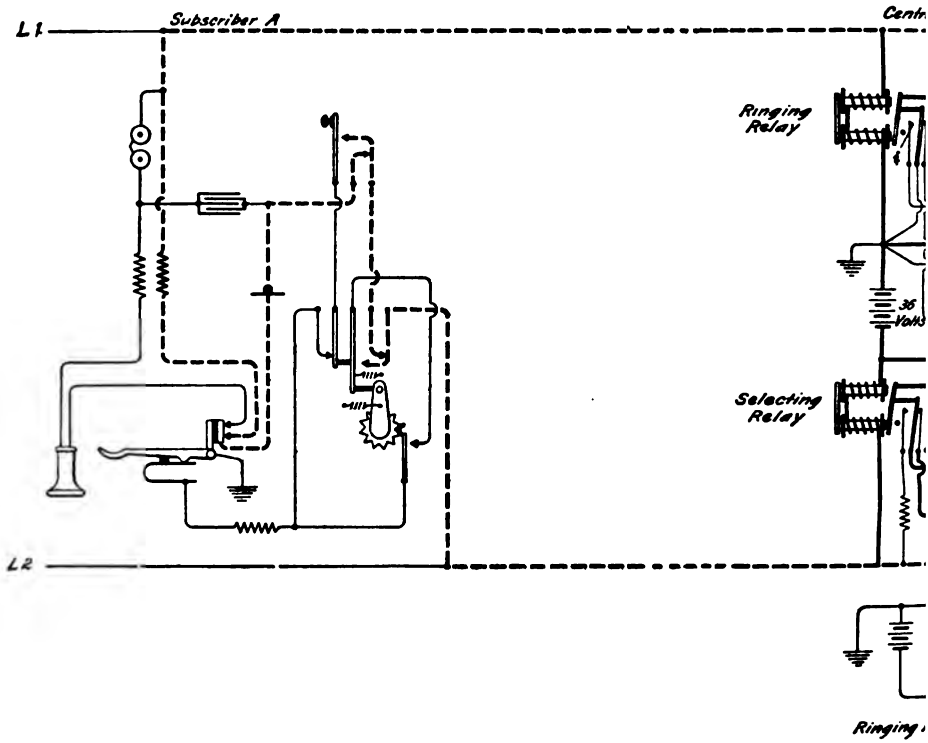
12. The **substation ringing key** K controls three contact springs k so arranged that in pressing the push button one contact is made and one is broken. The springs are adjusted so that the back contact is made before the front contact breaks. This avoids the possibility of opening the line circuit and permitting the selector arm in the central-office switch to return to its normal position. This is one of the small but very important points to be kept in mind in the adjustment of the apparatus.

13. Instruction Card.—The following instruction card, which explains briefly the operations required on the part of the subscriber, is fastened to each subscriber's telephone:


L1
Subscriber A
125 Ohms
Ringing Relay
K
Ringing Key
n
p
a
d
e
N
Interrupter
o
R
m
350 Ohms
L2
B
36 Volts
Selecting Relay
125 Ohms

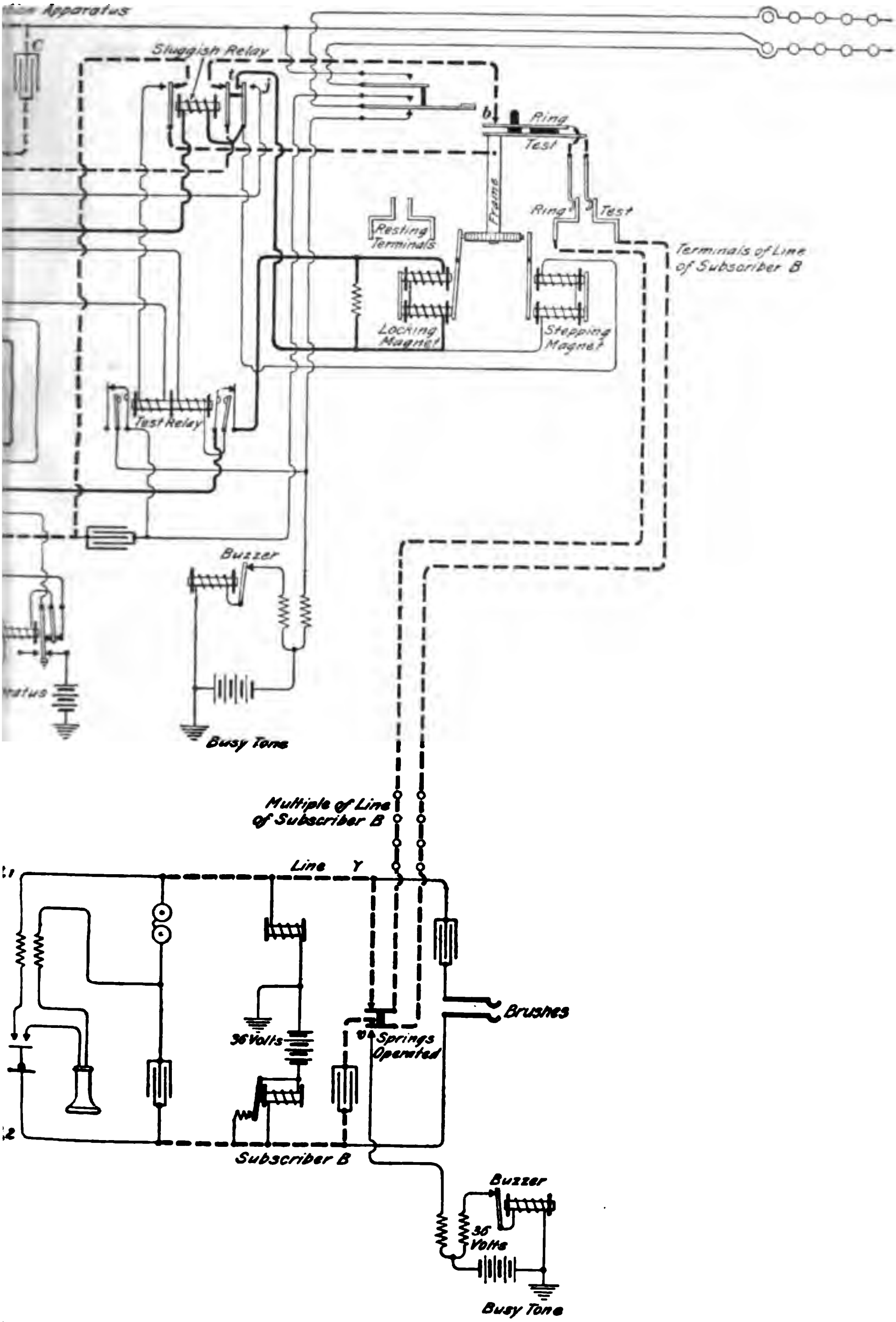


Apparatus
Multiple Terminals
Line X
Revertive Terminal
Sluggish Relay
Rotary movement Springs operated
Ring
Test
Frame
Ringing Brush
Test Brush
Ring
Test
Resting Terminals
Terminals of Line Y
Locking Magnet
Stepping Magnet
Test Relay
Buzzer
36 Volts
Busy Tone
85 Volts
Multiple of Line Y
Line Y
Ringing Relay
36 Volts
Brushes
Springs not operated
Selecting Relay
Subscriber B
Buzzer
36 Volts
Busy Tone



L1
Subscriber A
Centr
Ringing Relay
36 Volts
Selecting Relay
L2
Ringing

F



...tion Apparatus
C
Sluggish Relay
t
j
b
Ring
Test
Frame
Ring
Test
Resting Terminals
Terminals of Line of Subscriber B
Locking Magnet
Stepping Magnet
Test Relay
Buzzer
...ratus
Busy Tone
Multiple of Line of Subscriber B
Line
Y
Brushes
36 Volts
Springs Operated
Subscriber B
Buzzer
36 Volts
Busy Tone

Telephone Number . . To call any (Scranton) subscriber: (1) remove receiver from hook and (if this telephone is on a party line) listen; (2) if no one is talking, place the peg in the hole bearing the number of the desired line; (3) revolve the arm until it strikes the peg and let go; (4) after the arm stops, a throbbing hum will be heard in the receiver if the called line is in use. (5) If the called line is not in use, press the ringing button in accordance with the following code:

CODE.—When number wanted has no letter, give 1 ring; on a party line, give 2 rings for *A*, 3 rings for *B*, etc.

To call a subscriber in another exchange, call for the connecting exchange in the same manner as for a (Scranton) subscriber; if one toll line is busy, try the others.

While making a call, don't hang up receiver or move hook until through; always hang up the receiver between calls.

14. The central station to which all lines are connected consists of a so-called centralized battery for operating the automatic apparatus and for transmission during conversations; also, apparatus for producing positive pulsating ringing current and a busy-tone current, both of which may be supplied from batteries of dry cells. With each pair of line wires, there is associated a stepping device, a stepping magnet and locking magnet for controlling the same, a polarized selecting relay, a polarized ringing relay, a test relay, and a slow-acting, so-called *sluggish relay*. These are all shown in the diagrams and a general view of the central-station apparatus, which will be later described. The circuits and the operation of the system will first be considered.

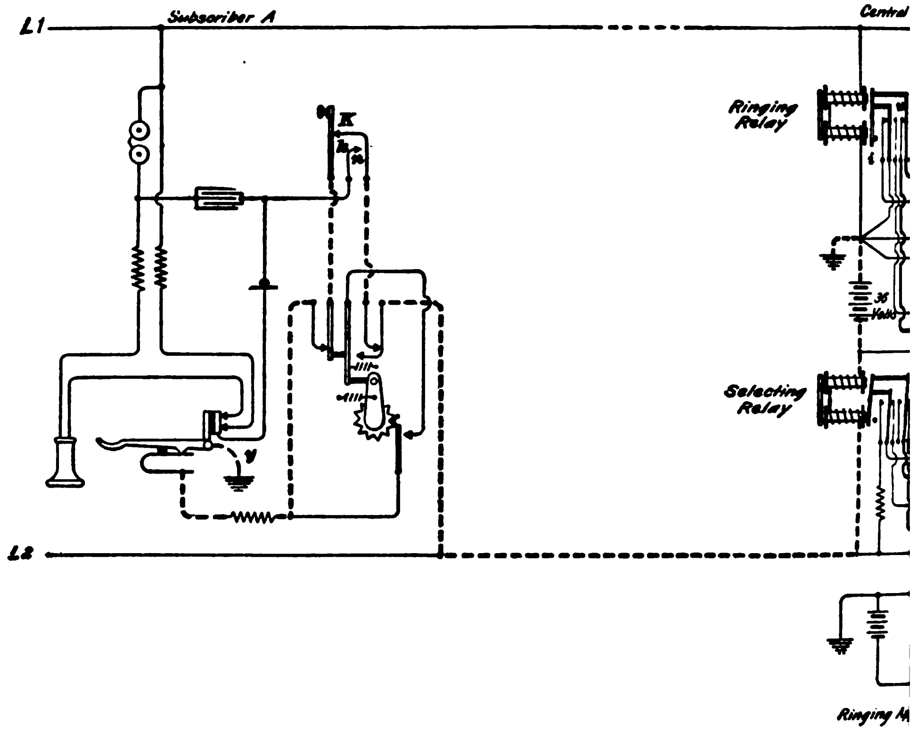
SYSTEM EQUIPPED WITH BUSY-TONE AND LOCK-OUT FEATURES

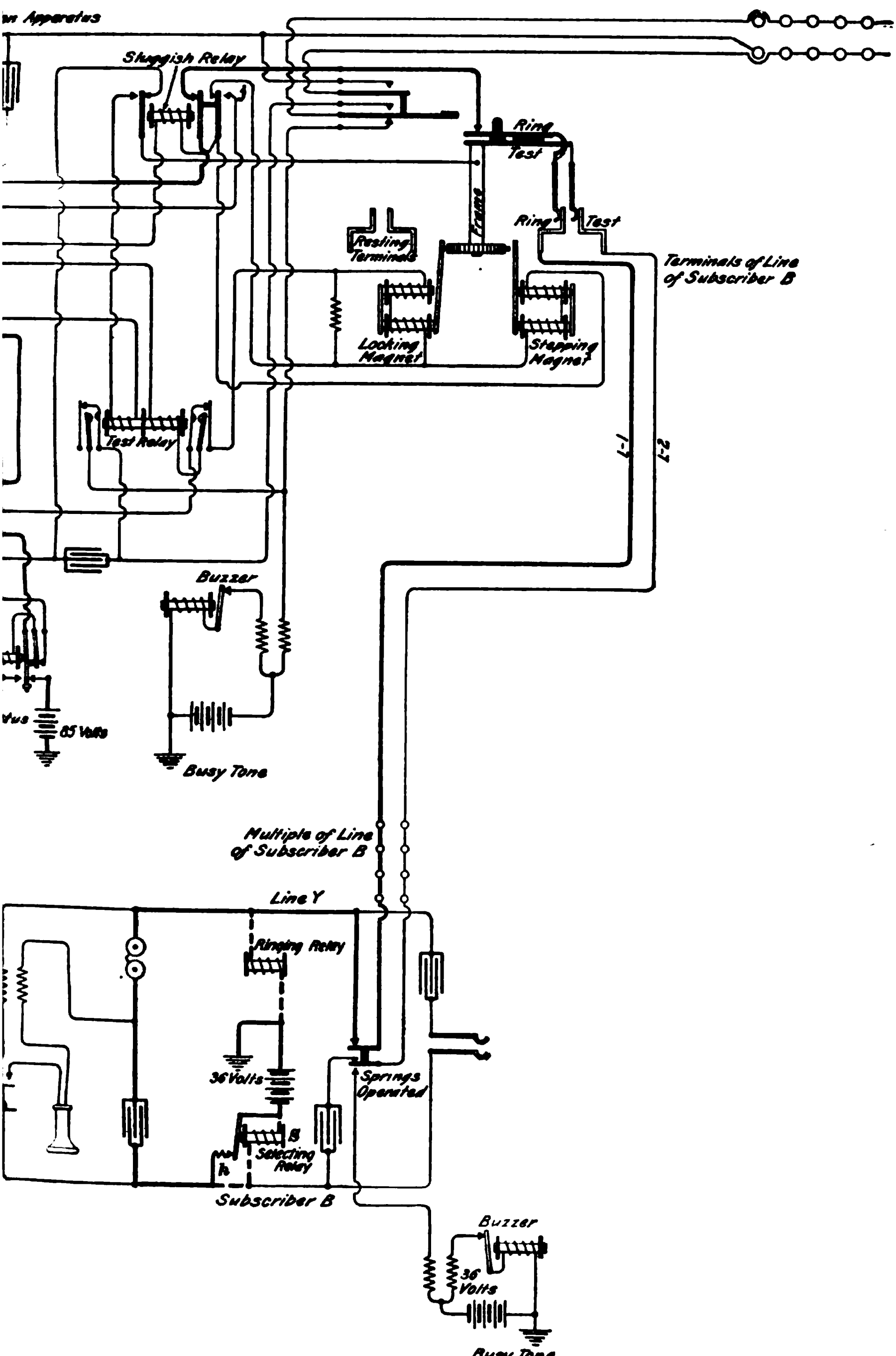
OPERATION OF CALLING A DISENGAGED LINE

15. Selection.—Subscriber *A*, whose telephone is associated with line *X*, will call for subscriber *B*, whose telephone is associated with line *Y*. Subscriber *A* first removes his receiver from the hook and then proceeds to select the desired line *Y*. The circuits are shown in Fig. 6. When the receiver *R* is taken down, a circuit is closed through *B*–

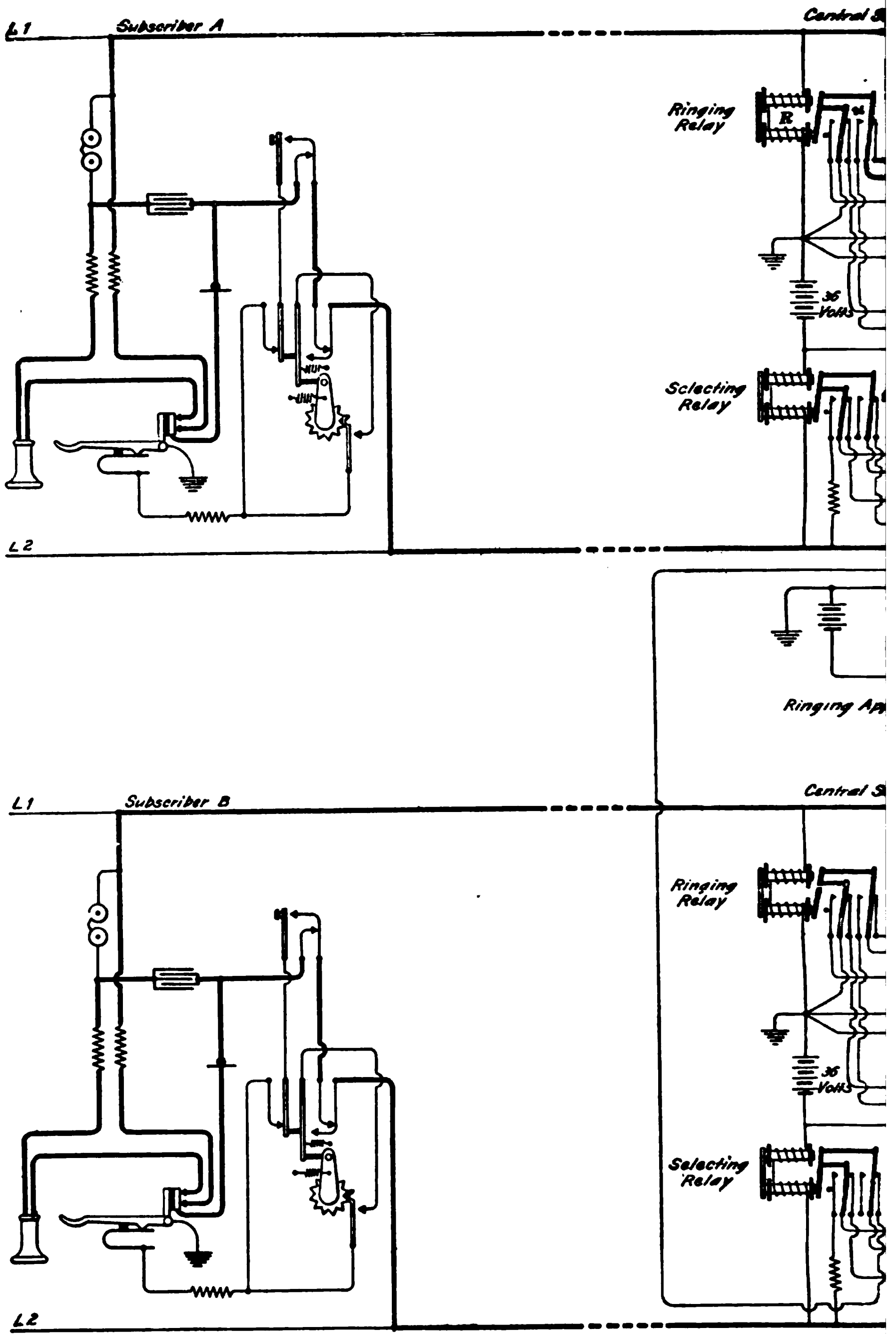
selecting relay–line *L 2*–contact *e*–contact *n*–transmitter–contact on hook switch–winding *p* of induction coil–line *L 1*–ringing relay. The armature movement of the polarized relays causes a selector arm *z* to advance one step, which is an incidental operation that affects no change in the talking circuits. The subscriber then inserts the peg *P*, Fig. 5, in the hole bearing the number of the desired line and moves the arm *N* against the peg, thereby operating the rotary movement springs in the subscriber's instrument, which opens at *e*, Fig. 6, the circuit between the two line wires *L 1*, *L 2* and connects the ground through *m*–350-ohm resistance–contact *c*–contact *d* to line *L 2*. When the arm *N* is released, it begins its return to its normal resting position and by alternately closing and opening the interrupter spring contact *c* causes a pulsating current from *B* to flow through the selecting relay whose armature, by means of a local circuit shown in Fig. 6 by heavy lines, causes the armature *x* of the quick-acting stepping magnet to imitate its movements and advance the selector arm step by step until its trailing brushes, termed the *ringing brush* and the *test brush*, reach the terminals of the desired line. Each step is retained by a stop-pawl controlled by the sluggish locking magnet whose armature *w* is unresponsive to pulsating current.

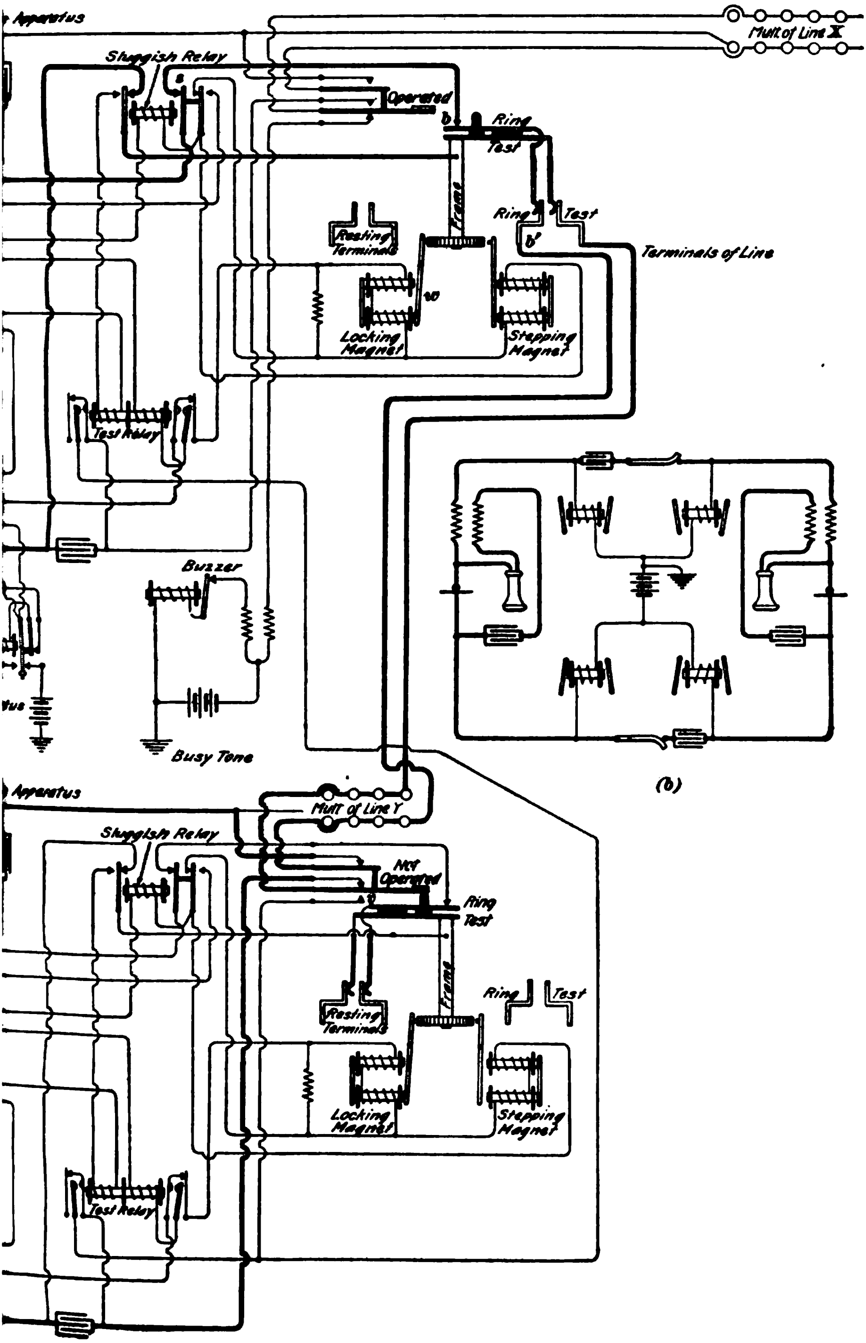
During the period of selection, the ringing relay is not operated and, by means of a back contact *i*, it short-circuits and thus excludes the sluggish relay *V* from the local selecting circuit. The closing at *e* of a circuit across the two line wires at the substation by the action of the interrupter springs operates the ringing relay and removes this short circuit from around the sluggish relay, which, in attracting its armature, accomplishes four results that are indicated in Fig. 7. First, line *L 2* is connected to the test brush of the selector; second, line *L 1* is connected through condenser *C* and contacts *q*, *t*, *b* to the ringing brush of the selector; third, contact *i* in the short-circuit around the sluggish relay is opened for a purpose to be presently explained in connection with the ringing operation; fourth, the stepping magnet is short-circuited by contact *t* and the selector arm is thereafter


L1
Subscriber A
Central
K
Ringing Relay
36 Volts
Selecting Relay
L2
Ringing M



...n Apparatus
Sluggish Relay
Ring
Test
Frame
Resting Terminals
Ring
Test
Terminals of Line of Subscriber B
Locking Magnet
Stepping Magnet
Test Relay
1-1
1-2
Buzzer
85 Volts
Busy Tone
Multiple of Line of Subscriber B
Line Y
Ringing Relay
36 Volts
Springs Operated
B
Selecting Relay
h
Subscriber B
Buzzer
36 Volts
Busy Tone


L1
Subscriber A
Ringing Relay
R
36 Volts
Selecting Relay
L2
L1
Subscriber B
Ringing Relay
36 Volts
Selecting Relay
L2



Apparatus
Mult of Line X
Sluggish Relay
Operated
Ring
Test
Frame
Ring
Test
Resting Terminals
Terminals of Line
Locking Magnet
Stepping Magnet
Test Relay
Buzzer
Busy Tone
Apparatus
Mult of Line Y
Sluggish Relay
Not Operated
Ring
Test
Frame
Resting Terminals
Ring
Test
Locking Magnet
Stepping Magnet
Test Relay

(b)

. 9

held in its advanced position by the sluggish locking magnet, which will not respond to the slight disturbances of the selecting relay that sometimes occur during revertive ringing. The selector brushes are now in contact with the terminals of the desired line and the circuit, as shown in Fig. 7, is ready for signaling.

16. Signaling.—To ring the bell of the subscriber selected, the subscriber presses the ringing key *K*, Fig. 8, which first grounds through contact *k* and ground connection *y*, the line *L 2*, and then opens the circuit at *n* between the two line wires. This relative operation of springs *k*, *n* not only maintains the excitation of the selecting relay, because it merely substitutes the ground return for line *L 1*, but also causes the ringing relay to release its armature, because *L 1* is now open. The ringing brush of the selector is now connected through its back contact to the ringing apparatus, from which positive pulsating current passes to the *L 1* side of the called line, through the bells and condensers connected to that line and back partly through the selecting relay *S* of the called line and battery to ground, but mainly through the non-inductive resistance *h* bridged across that relay, its back contact, and battery to ground, as shown by the heavy black lines. The back contact *i* of the ringing relay cannot now short-circuit the sluggish relay because of the break in the short-circuiting path introduced at *j* by the latter relay. *I* is an electromagnet connected in a local circuit and used to interrupt the current from the 85-volt battery. The ringing apparatus is a simple interrupting device.

17. Transmission Circuit During Conversation. When the called subscriber answers, there is established a compound talking circuit comprising bridged impedances and interconnecting condensers arranged in a familiar manner. These circuits are fully shown by the heavy lines in Fig. 9 and with many details omitted in Fig. 9 (*b*). The ringing and selecting relays now act as impedance coils through which battery current is supplied to both line circuits.

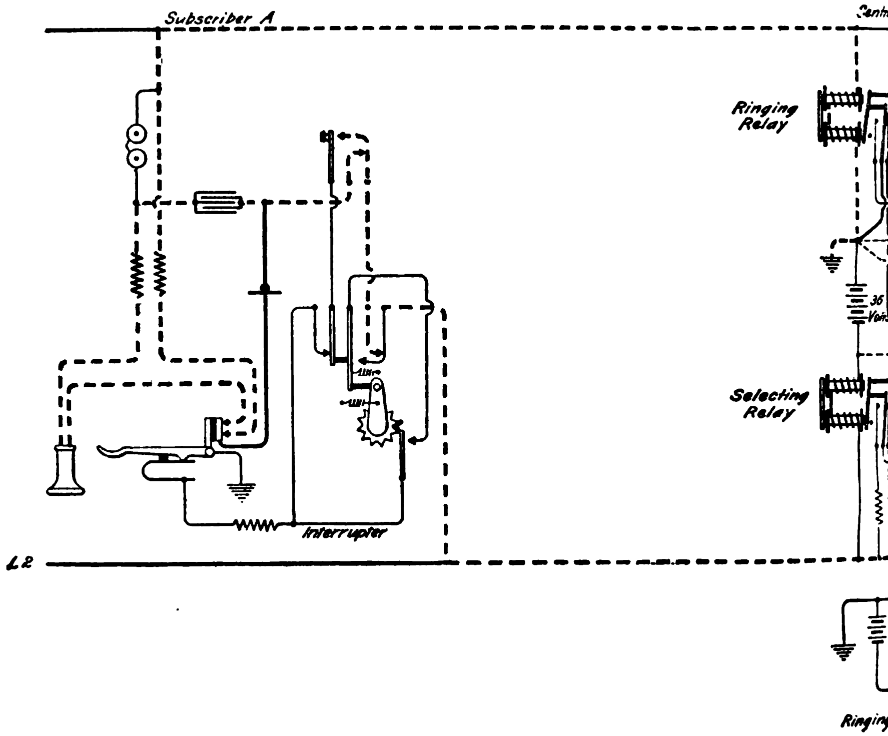
OPERATION OF CALLING A BUSY LINE

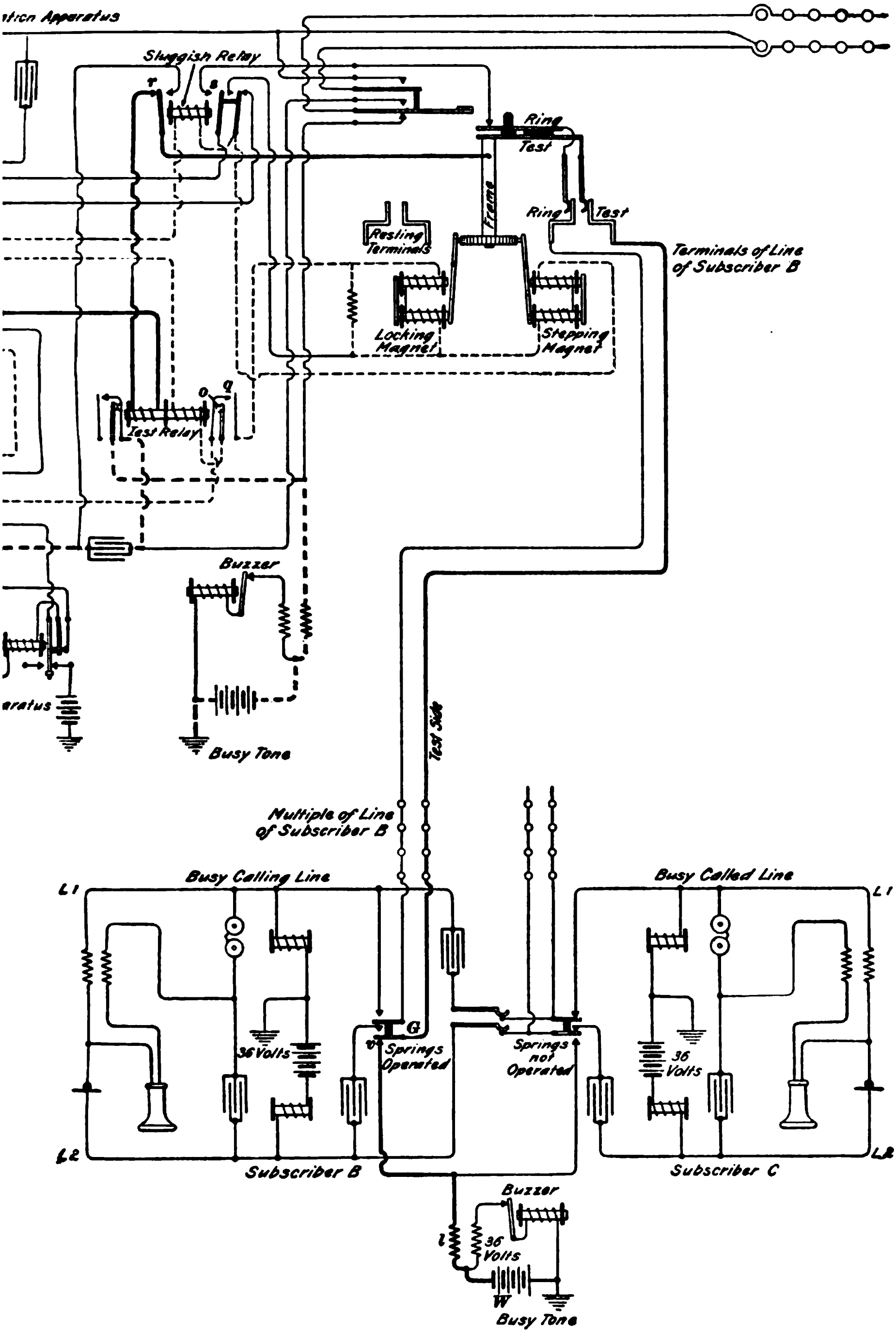
18. Selection.—Suppose that subscriber *A* calls subscriber *B*, who has already called subscriber *C* and that *B* and *C* are in communication. Subscriber *A* is then said to be calling a busy-calling subscriber *B*. Subscriber *A* proceeds as before and the selector brushes are stepped forwards until they reach the terminals of the desired but engaged line *Y*. The connections are about the same as shown in Fig. 7, except that contact *v* is now closed, as shown in Fig. 10, which causes the left-hand winding of the test relay to be in a closed circuit with the busy-tone test battery *W*.

19. Testing.—The test side of the multiple terminals of the engaged line of subscriber *B* is connected with the ungrounded side of the busy-tone battery *W*, while that of a disengaged line would be open at *v*.

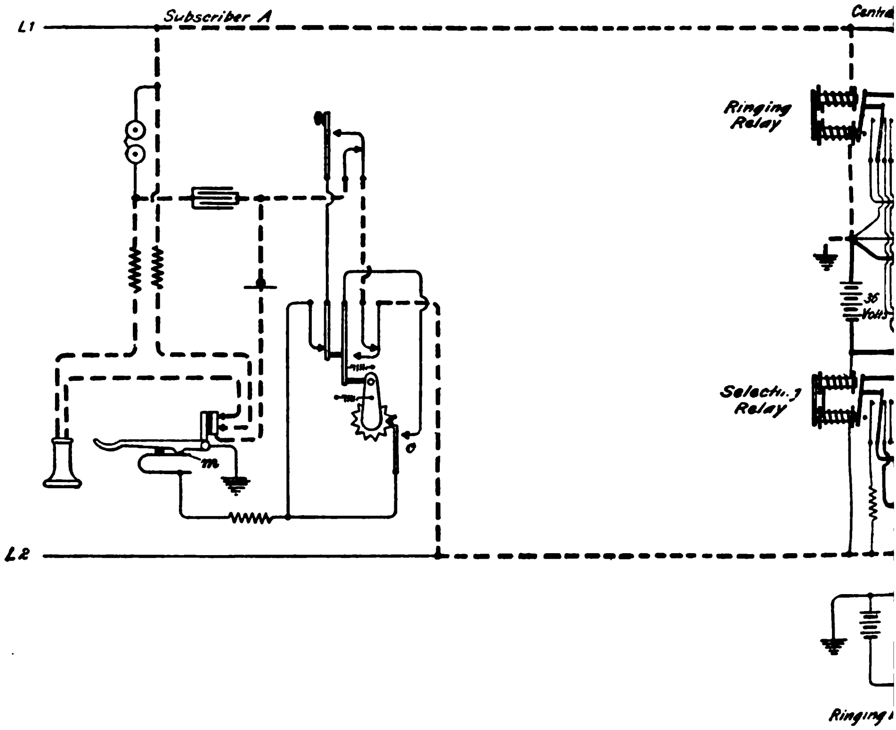
The **lockout feature** is affected by the operation of the quick-acting test relay caused by current flowing through it to ground from the tone-test battery *W* through the test-selector brush when the latter reaches the test terminal of the desired busy line. This circuit is shown by heavy lines in Fig. 10. It should be noted that, during their advance, the circuits of the ring-selector brush is open at contact *s* of the sluggish relay and the test-selector brush at front contact *f* of the ringing relay. This is necessary to avoid premature lockouts from busy but undesired lines touched by the brushes as they rotate. When the brushes arrive at the terminals of the desired busy line, the ringing relay and the sluggish relay are simultaneously excited, but the former attracts its armature first and in so doing completes a path from the test-selector brush through the back contact *r* of the sluggish relay,–one of the two windings of the test relay–the front contact *f* of the ringing relay to the grounded side of the battery.

20. Lockout.—The test relay is immediately operated and the closed circuits are shown by heavy lines in Fig. 11.

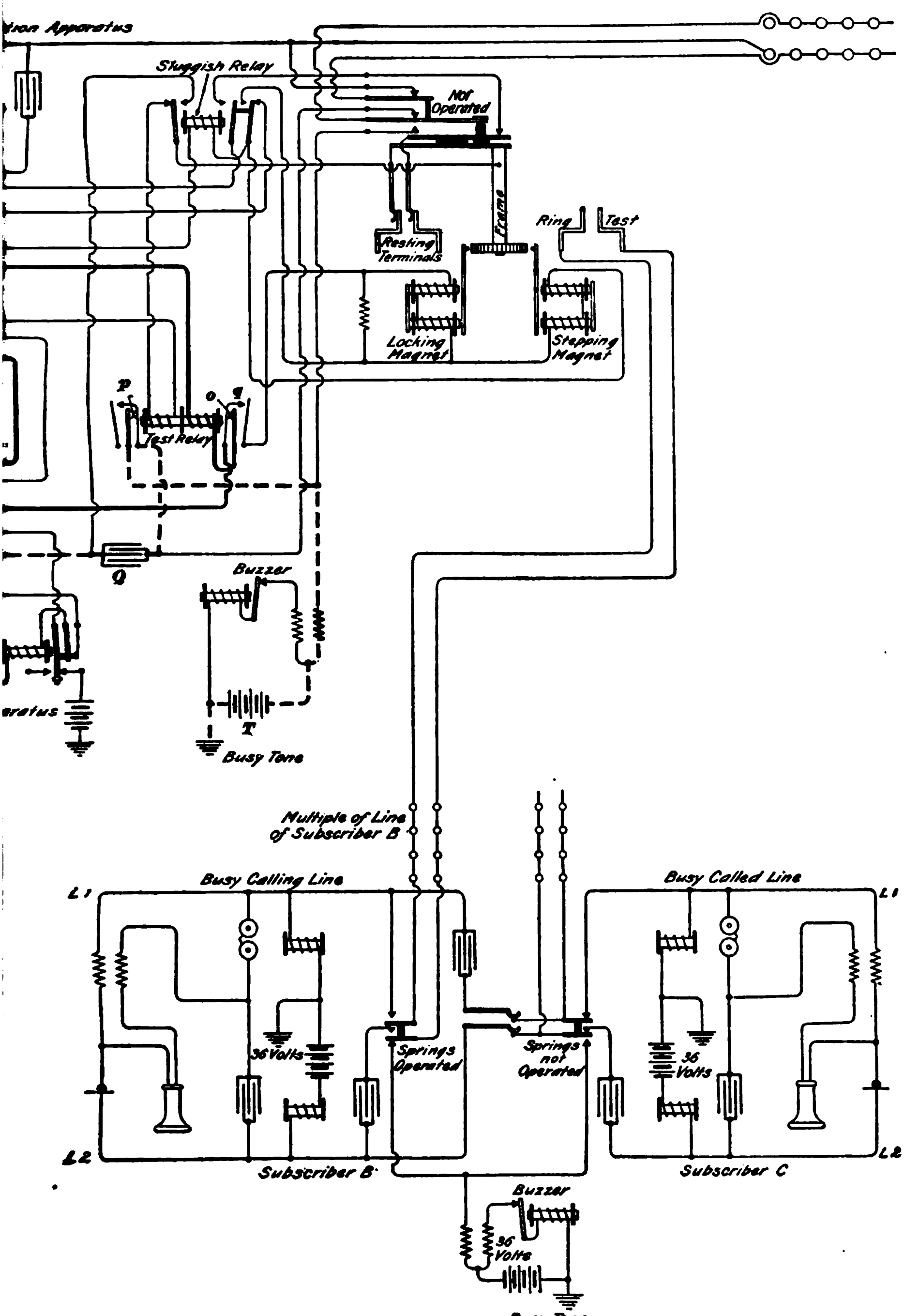

Subscriber A
Ringing Relay
36 Volts
Selecting Relay
Interrupter
L2


Sluggish Relay
Ring
Test
Frame
Ring
Test
Resting Terminals
Terminals of Line of Subscriber B
Locking Magnet
Stepping Magnet
Test Relay
Buzzer
Busy Tone
Test Side
Multiple of Line of Subscriber B
Busy Calling Line
Busy Called Line
L1
L1
36 Volts
36 Volts
Springs Operated
Springs not Operated
G
L2
L2
Subscriber B
Subscriber C
Buzzer
36 Volts
W
Busy Tone

G. 10 131



L1
Subscriber A
Centr
Ringing Relay
36 Volts
Selecting Relay
m
o
L2
Ringing



tion Apparatus
Sluggish Relay
Not Operated
Frame
Resting Terminals
Ring
Test
Locking Magnet
Stepping Magnet
P
O
q
Test Relay
Q
Buzzer
T
Busy Tone
aratus
Multiple of Line of Subscriber B
Busy Calling Line
Busy Called Line
L1
L2
36 Volts
Springs Operated
Springs not Operated
Subscriber B
Subscriber C
Buzzer
36 Volts
Busy Tone

The test-relay armature, by opening the circuit at *q* deprives the locking and stepping magnets of current and by closing, at *o*, a circuit through its second winding, the test relay remains locked in its closed position. The stepping and locking magnets, being deprived of current, allow the ring and test arms to return to their normal resting positions. The calling subscriber is now locked out and receives notification that the called line is busy by a busy tone transmitted over his line from battery *T* through the front contact *p* of the test relay and condenser *Q*. When he hangs up his receiver, the circuit is opened at *m*; or, if he selects again, the circuit is opened at *c*, either of which operations causes the deenergization of the selecting relay, which unlocks the test relay.

Referring to the selection of a disengaged line, it will now be clearly understood that the test relay is not energized at the end of selection, Fig. 7, and that it is removed from the talking circuit by the operation of the sluggish relay, Fig. 9.

21. The operations of the three relays involved in the test and lockout operations may be briefly summarized as follows: At the moment when the selector brushes reach the terminals of the desired busy line, the quick-acting ringing relay closes a testing circuit through the quick-acting test relay, which attracts its armature before the sluggish relay has time to act. The test relay, in operating, deprives the sluggish relay of current; and a locking winding on the test relay keeps the circuits unchanged until the subscriber hangs up his receiver or reselects.

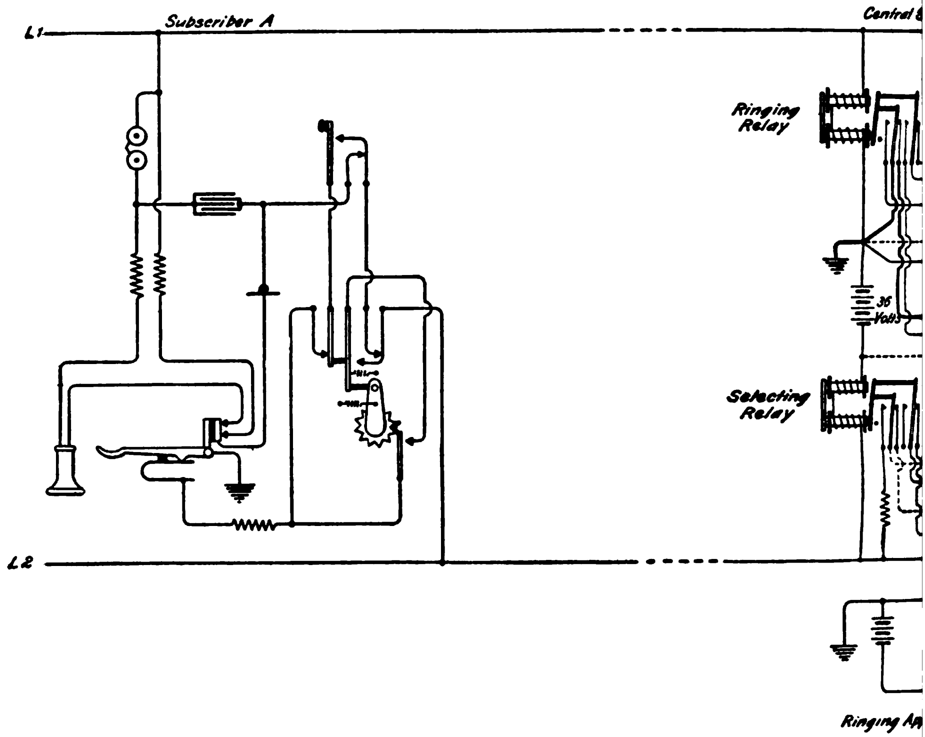
Obviously, a line may be "busy" for two reasons—because calling and because called. As already explained, a calling line *B* is protected from intrusion by a group of rotary-movement springs *G*, Fig. 10, operated by the rotary movement of its selector arm, which opens the paths leading from its relays and line wires to its multiple terminals and connect at *v* the test side to the ungrounded side of the battery through the secondary winding *l* of the busy-tone transformer.

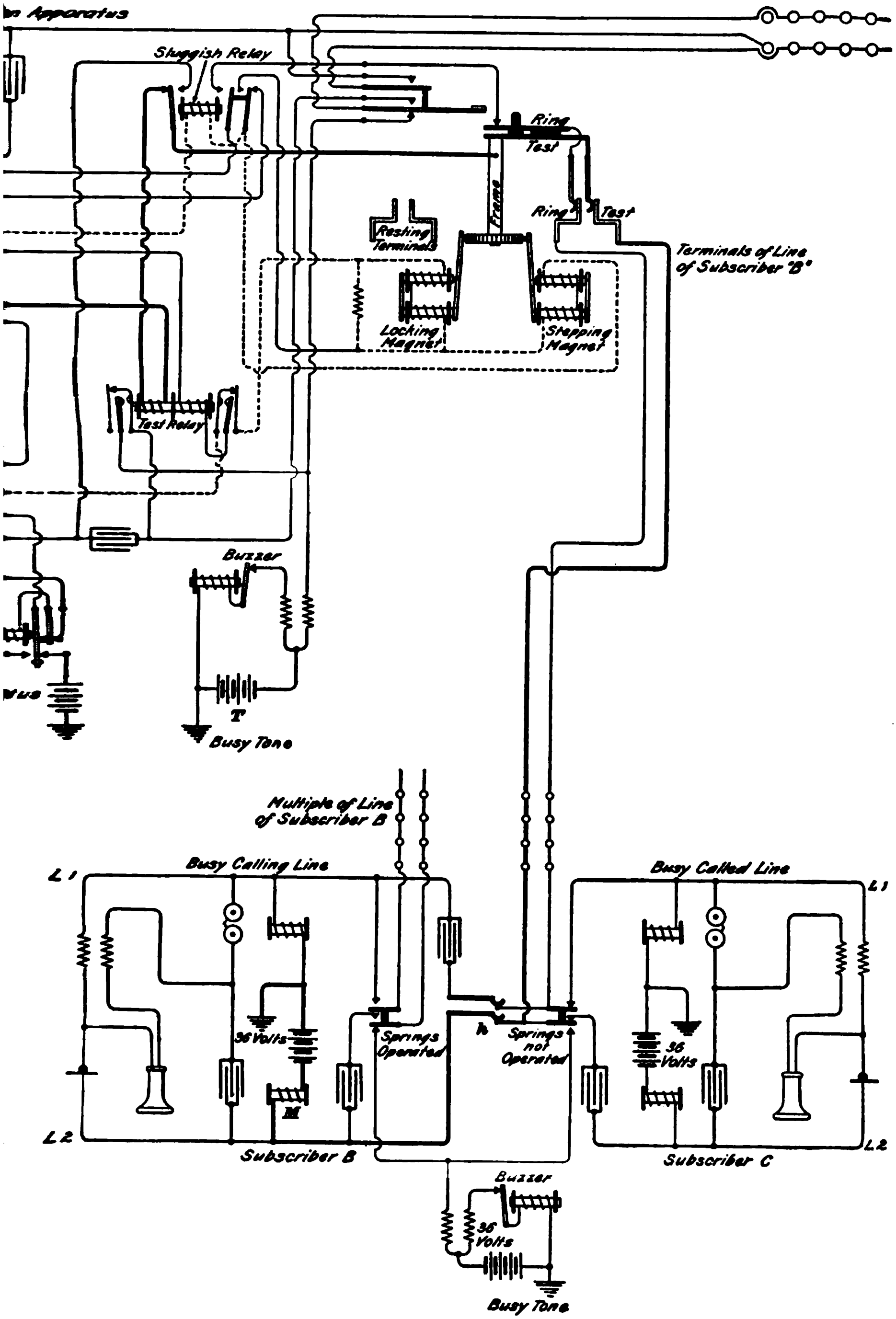
22. Testing a Called Subscriber's Line.—Suppose that subscriber *A* calls subscriber *C*, who has already been called by and is in communication with subscriber *B*. The busy called line of subscriber *C*, Fig. 12, is protected by the fact that its test multiple terminal *h* is connected, through the test-selector brush resting on *h* and the selecting relay *M* in the line of subscriber *B*, who has called it first, to the ungrounded side of the battery. Fig. 12 shows the circuit conditions the moment the brushes rest on the contacts of the busy line. The test relay then becomes energized and a busy hum flows from battery *T* over the circuit, as shown by the heavy dash lines in Fig. 11; in fact, all circuits then return to the condition shown in that figure. A subscriber, under all circumstances, is free to operate his selector, that is, if subscriber *A* on one line calls subscriber *B* on another line, *B* can at will disconnect from *A* and make any desired selection, the condensers introduced between the individual circuits making *B*'s line relays independent.

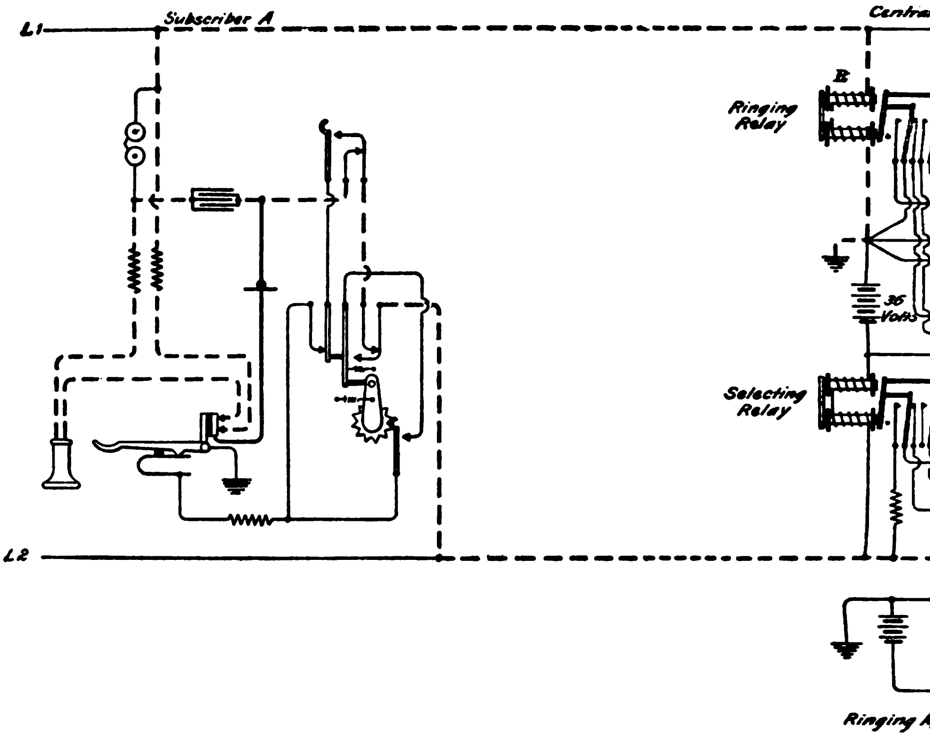
If subscriber *B*, Fig. 13, should select another line instead of answering the call from subscriber *A*, the latter would receive the busy signal in the following manner: The rotary movement springs *G* of the selector of subscriber *B* would operate and the test side of the multiple of the line of subscriber *B* would be thereby connected to the busy-tone apparatus. As the selector brushes of subscriber *A* would still be in contact with the multiple of subscriber *B*'s line, a busy tone would be transmitted from battery *E* to subscriber *A* and the ringing relay *R* to ground, as indicated by the heavy dash lines in this figure.

OPERATION OF MAKING A REVERTING CALL

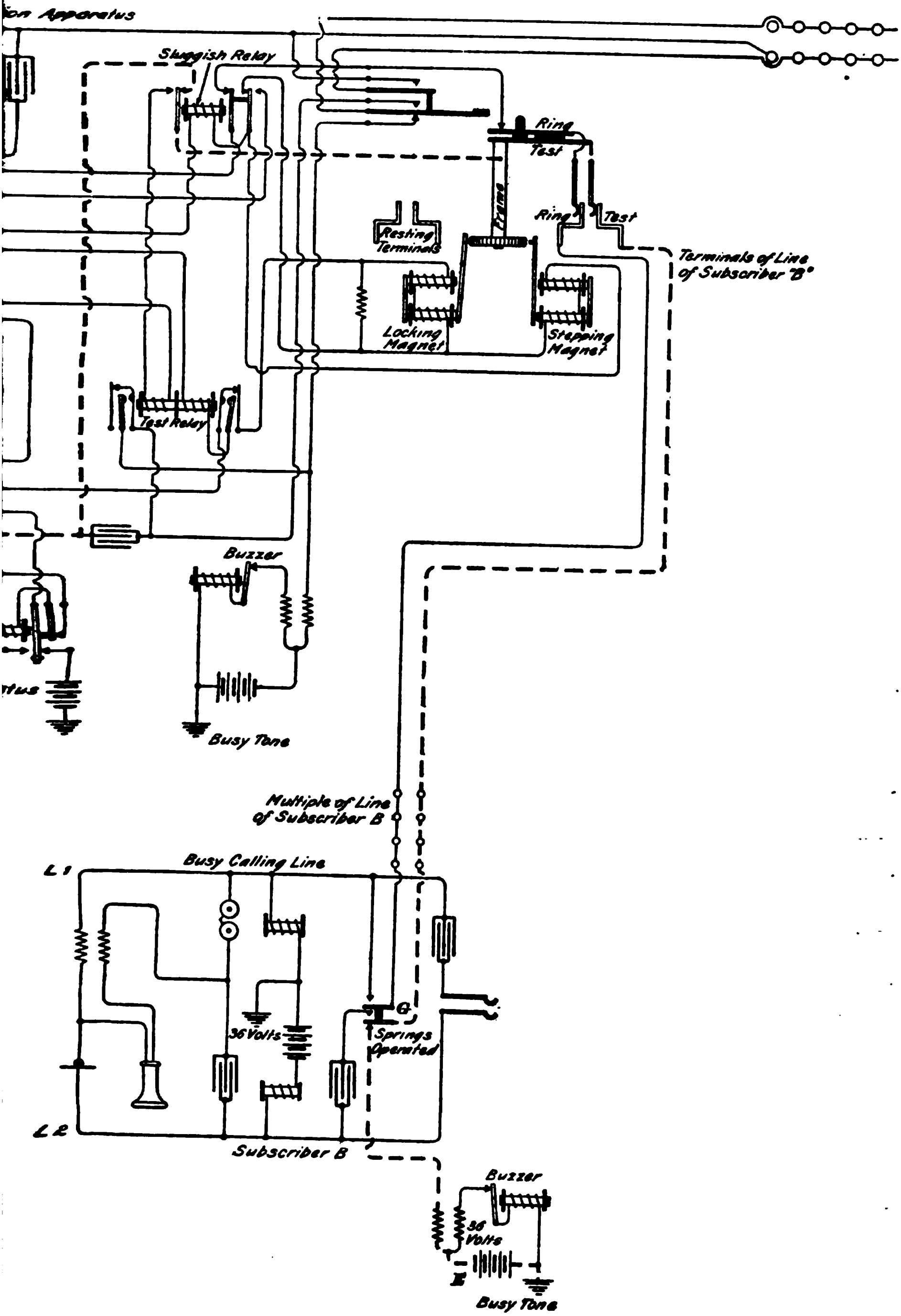
23. Selection.—When one subscriber calls another subscriber on the same party line, it is termed a **reverting,** or **revertive, call.** With this system, reverting calls can be made; that is, one subscriber can signal and converse with another subscriber on the same party line. Furthermore, the operation of selecting and ringing is exactly the same as


Subscriber A
L1
L2
Ringing Relay
Selecting Relay
36 Volts


...n Apparatus
Sluggish Relay
Ring
Test
Frame
Ring
Test
Resting Terminals
Terminals of Line of Subscriber "B"
Locking Magnet
Stepping Magnet
Test Relay
Buzzer
T
Busy Tone
...tus
Multiple of Line of Subscriber B
Busy Calling Line
Busy Called Line
L 1
L 1
36 Volts
36 Volts
M
Springs Operated
h
Springs not Operated
L 2
L 2
Subscriber B
Subscriber C
Buzzer
36 Volts
Busy Tone


L1
Subscriber A
Central
B
Ringing Relay
36 Volts
Selecting Relay
L2

F



ion Apparatus
Sluggish Relay
Ring
Test
Frame
Resting Terminals
Ring
Test
Terminals of Line of Subscriber "B"
Locking Magnet
Stepping Magnet
Test Relay
Buzzer
Busy Tone
Multiple of Line of Subscriber B
L1
Busy Calling Line
36 Volts
Springs Operated
G
L2
Subscriber B
Buzzer
36 Volts
Busy Tone

though the desired subscriber were on another line. The selector brushes *J*, Fig. 14, are caused to advance to a pair of *revertive terminals* bearing the number of the calling line, of which only the ringing terminal is connected to the ringing side of its own line. The ring selector brush is brought into contact with the said revertive line terminal, which is permanently connected with the *L 1* side of the circuit, instead of being carried through the rotary movement springs *S* of the selector.

24. Signaling.—When the ringing key *K* is pressed, contact *n* is opened and the ringing relay armature falls back and closes a circuit from the ringing apparatus through contacts *g*–*f*–*s*–ring selector brush–revertive line terminal–line *L 1*–bells *V* and condensers *W* of the other subscribers on the same line–contacts *n'*, *e'*–line *L 2*–contacts *e*, *k*, *a*, *m* at the calling station to ground.

There is a shunt to this ringing circuit from the revertive line terminal to ground through the ringing relay; but as the latter is polarized and biased in such a manner as to be insensitive to current flowing in that direction, it does not attract its armature and therefore this ringing current does not interfere with the operation of the ringing relay, nor is the impedance of the ringing relay low enough to prevent the ringing of the subscriber's bell.

A negligible amount of ringing current returns over the *L 2* side of the line through the selecting relay and battery to ground.

25. Protection From Intrusion.—While two subscribers on the same line are engaged in conversation, it is busy to calling subscribers on other lines because of the operation of the rotary movement springs *S* caused by the advance of the calling subscriber's selector arm from its normal resting place. When both subscribers have hung up their receivers, the selector arm returns to zero and the busy test is removed by the opening of the circuit at *q'*.

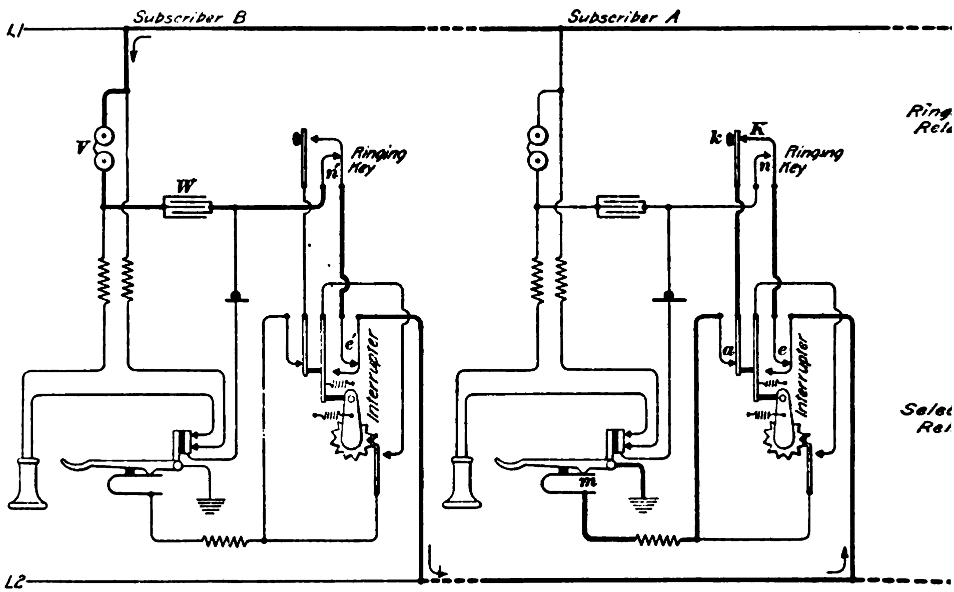
26. General.—The non-inductive shunt *F* around the selecting relay, when it is closed, keeps its armature from chattering when a line is being signaled. The shunt is of such resistance as to take most of the ringing current from the relay but without affecting its operation by direct current.

Contact *g*, Fig. 9, of the selecting relay is in series with the ringing lead and is used to prevent an undesired short ring or click of the bells connected across a called line just as the calling subscriber hangs up his receiver. The ringing relay *R* of the calling line releases its armature more quickly than the locking magnet *W* can release the selector arm. Thus the ringing selector brush *b* would be left in contact with the *L 1* side of the called line while still connected to the ringing apparatus through the back contact *u* of the calling subscriber's ringing relay but for the said front contact *g* of his selecting relay which, being quick-acting, opens the ringing lead at *g* at the same instant that the ringing relay closes it at *u*. Therefore, no ringing current reaches the called line *Y* during disconnection. In the springs of the substation interrupter, the two springs *a*, *e*, Fig. 6, that disconnect the ringing key from the ground during selection, are to prevent an impatient subscriber from interfering with the circuit, while the selecting mechanism is rotating, by pressing the ringing key. When the switch hook is down, the ground circuit is opened at *m*, Fig. 6, so that purposeless manipulation of the interrupter arm or of the ringing key will not operate the central-station apparatus.

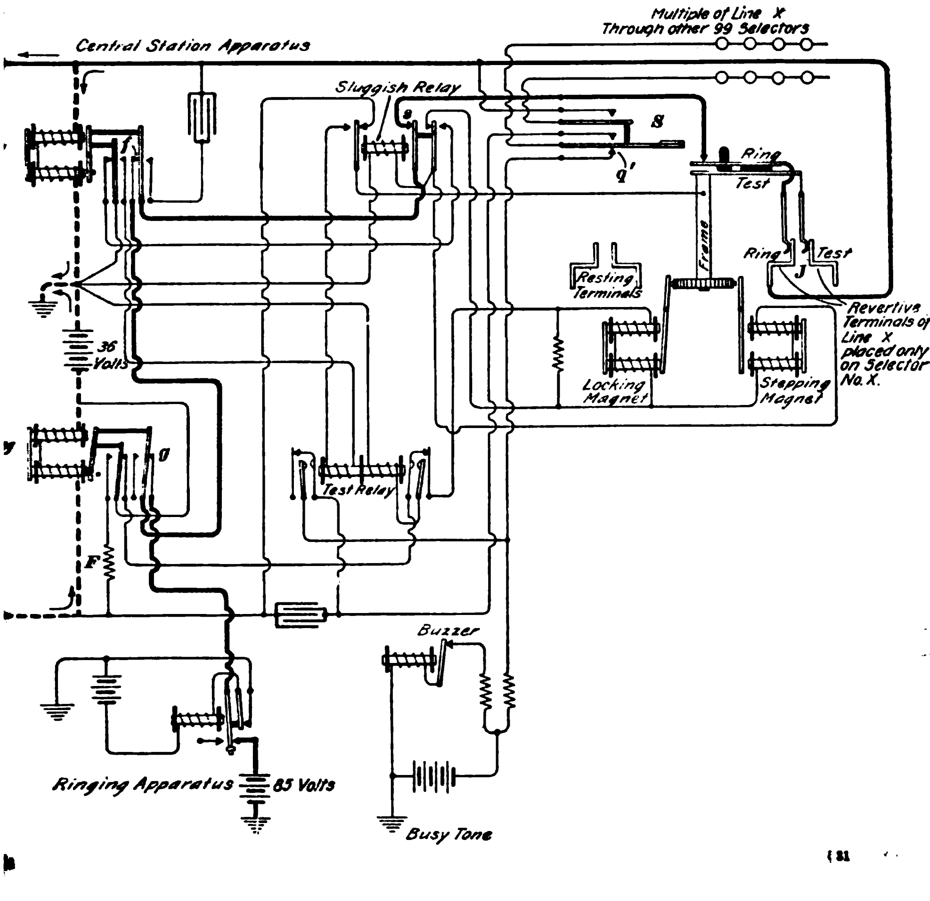
SYSTEM NOT EQUIPPED WITH BUSY-TONE AND LOCKOUT FEATURES

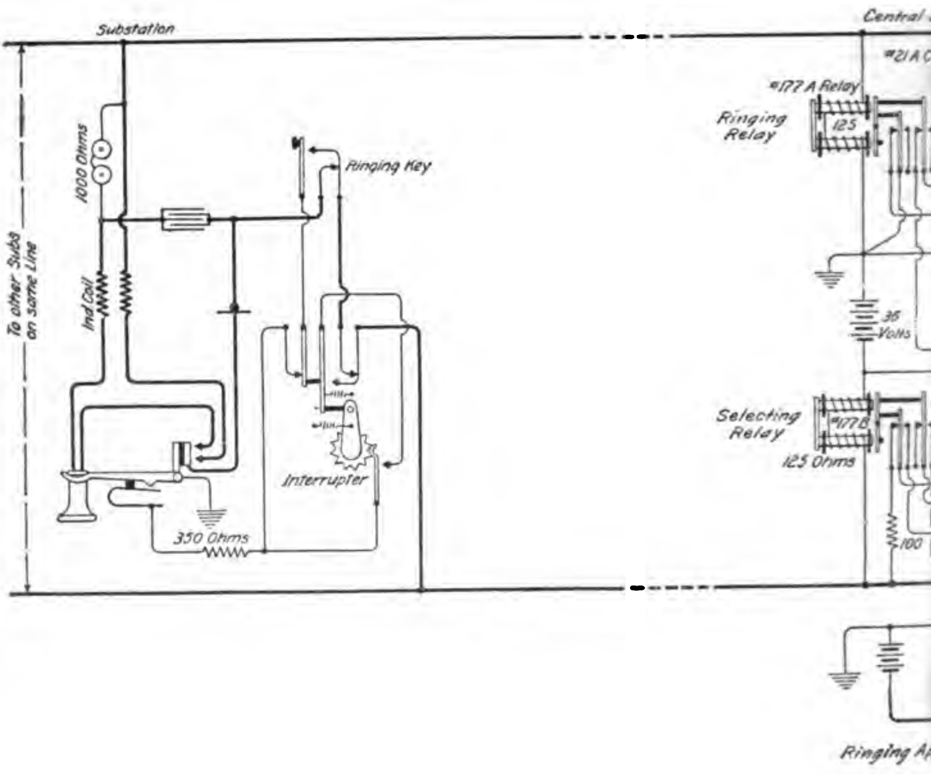
27. The central-station apparatus for each line, when not equipped with busy-tone and lockout devices, is shown in Fig. 15, and is the same as in the lockout system except that the test relay is omitted. From the central-station apparatus common to all lines, the busy-tone outfit is omitted. The subscriber's set is identical with that used in the lockout system.

The system operates in the same manner as when equipped with the busy tone and lockout feature, except that the omission of the test relay enables the subscriber to connect himself with any line in the exhange whether busy or not.

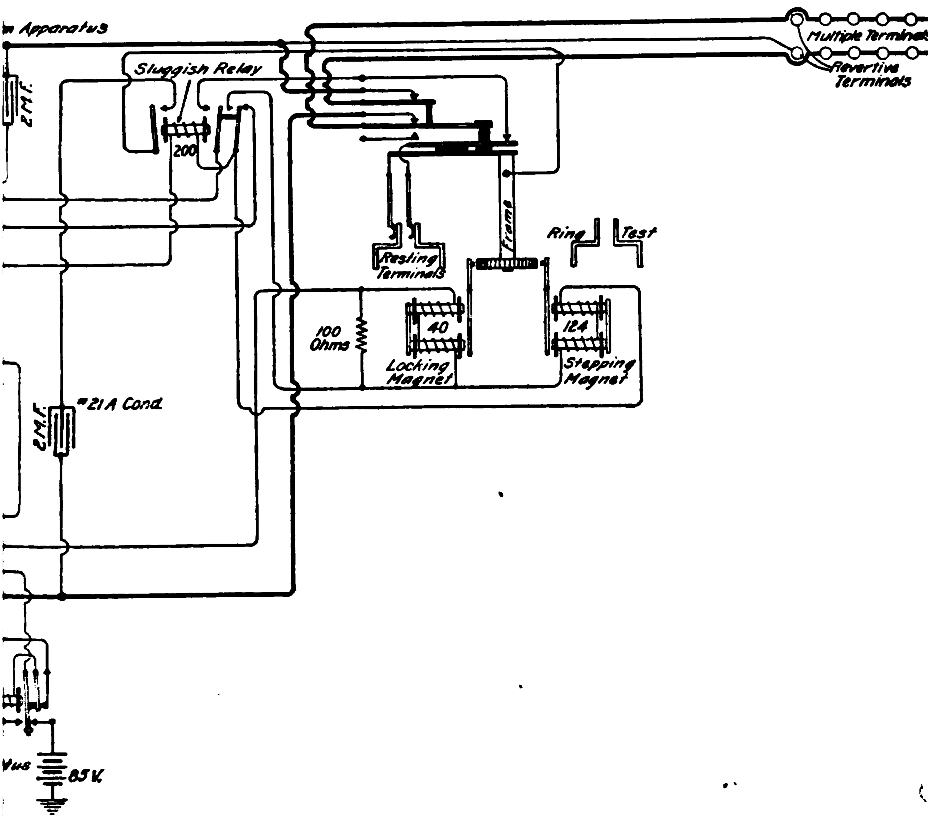


Subscriber B
Subscriber A
L1
L2
V
W
Ringing Key
n'
e'
Interrupter
k
K
n
a
e
m
Ring
Rel
Selec
Rel


Multiple of Line X
Through other 99 Selectors
Central Station Apparatus
Sluggish Relay
S
q'
Ring
Test
Frame
Ring
Test
J
Resting Terminals
Revertive Terminals of Line X placed only on Selector No. X.
Locking Magnet
Stepping Magnet
36 Volts
f
g
F
Test Relay
Buzzer
Ringing Apparatus
85 Volts
Busy Tone



Substation
Central S
#21 A Co
#177 A Relay
Ringing Relay
125
1000 Ohms
Ringing Key
To other Subs on same Line
Ind Coil
36 Volts
Selecting Relay
#177 B
125 Ohms
Interrupter
350 Ohms
100
Ringing Ap


Apparatus
Sluggish Relay
200
2 M.F.
Multiple Terminals
Revertive Terminals
Frame
Ring
Test
Resting Terminals
100 Ohms
40
Locking Magnet
124
Stepping Magnet
#21 A Cond.
2 M.F.
85 V.

CENTRAL-EXCHANGE APPARATUS

28. A general view of the apparatus required for each pair of line wires is shown in Fig. 16. In the center is shown the stepping device and around the edges are mounted the various relays and condensers. The various devices will be separately described.

29. Polarized Selecting Relay.—In Figs. 16 and 17 is shown the polarized selecting relay, which is also, in a general way, similar to the polarized ringing relay with the exception of the magnet windings. These relays are composed of the parts of a standard series ringer made by the Western Electric Company except that the ringer ball and clapper rod are omitted and the supporting yoke for the armature is so formed that a group of contact springs can be mounted on it in such a position that insulated studs on the armature engage the middle or operating springs *3* of each group, causing them to move with the movements of the armature. Each upward movement of the yoke piece *2* causes the lower contacts, which are invisible in this view, to be broken and contact made with the upper springs *1*, *1*. The springs *3* are so adjusted that sufficient tension is brought to bear on the insulated yoke *2* to hold the armature *4* in its lower and normal position.

30. Selector.—The **central-office selector** is shown in the center of Fig. 16 and consists of a punched-steel disk about 6 inches in diameter with a hole in the center through which a shaft carrying the rotating arm *a* projects. At the circumference of this disk, and completely surrounding it, is a hard-rubber circle *h* in which are fixed the multiple line contact terminals. These terminals are so made that they project above the surface of the hard rubber and form contact points for the contact brushes *m*, *n* mounted on the rotating arm *a*. There is a total of 104 pair of terminals. The large ratchet wheel *i* controls the movement of the shaft supporting the arm *a* and is, in turn, controlled by the stepping magnet *b*, whose armature *c* carries the pawl *d*, and

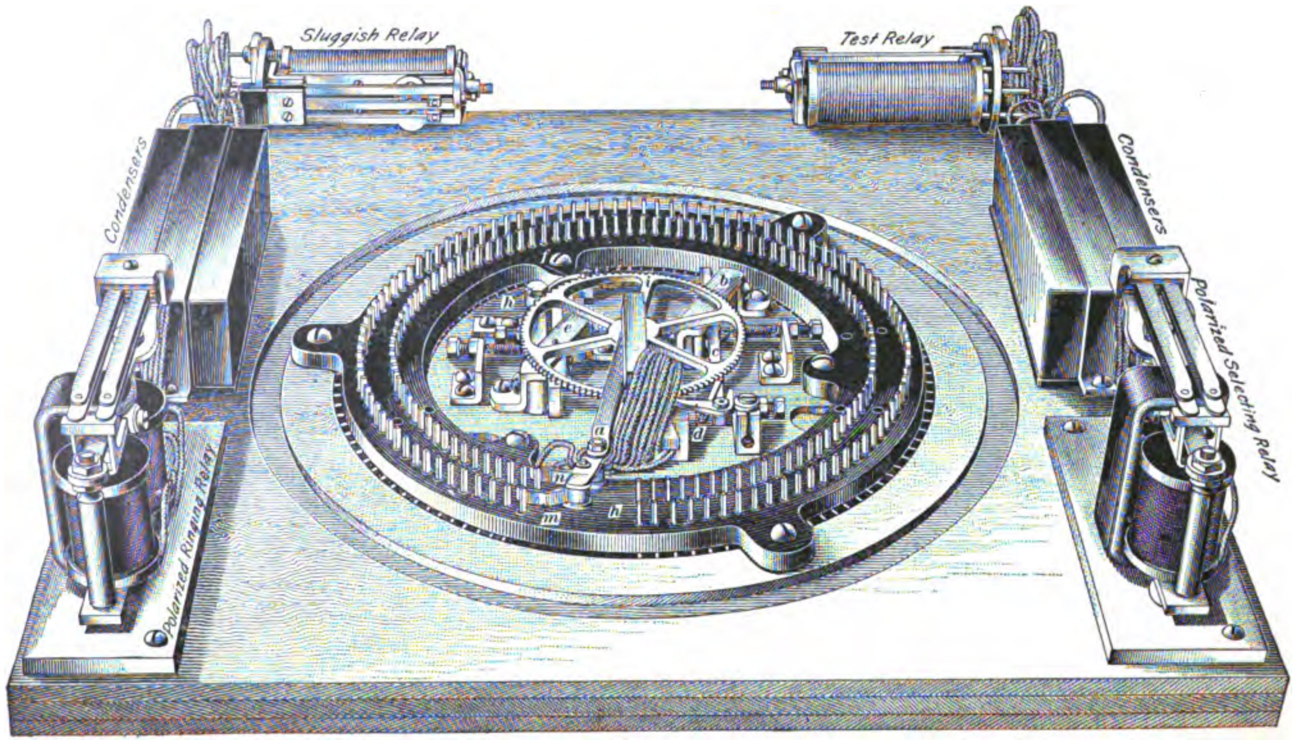

Sluggish Relay
Test Relay
Condensers
Condensers
Polarized Selecting Relay
Polarized Ringing Relay

Fig. 16

by the locking magnet *e* with its pawl *f*. These magnets are of the common double-coil type, their armatures being soft-iron levers, on the ends of which are mounted the pawls engaging the ratchet-wheel teeth. The leverage of the selecting-magnet armature is such as to make it quick-acting, while that of the locking magnet makes its action more sluggish. The action of the locking magnet is made still slower by being shunted by a non-inductive resistance of 150 ohms, which shuts out rapid changes in the current.

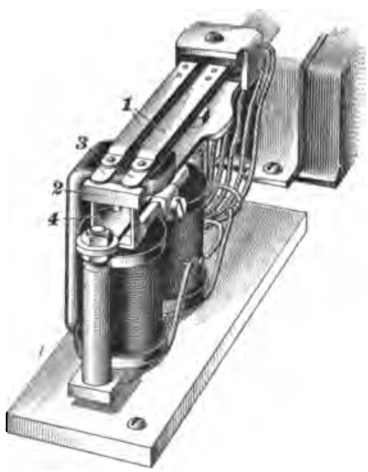


Fig. 17

31. The rotating arm *a* consists of two aluminum bars insulated from each other and rigidly connected at one end to the ratchet-wheel shaft, their other ends supporting the contact springs *m*, *n*, which engage the multiple line terminals. A spiral spring behind the contact springs produces constant tension at the contact points. Above the rotating arm *a* and operated by it, but not well shown in this figure, is mounted a group of springs known as the rotary-movement group. These springs are fully operated when the arm has moved forwards three steps and their function is to cut off the calling subscriber's line from its multiple terminal on other selectors and to throw a busy tone on such terminals. The fifth pair of terminals on the selector forms the first subscriber's terminals.

DIRECTIONS FOR ADJUSTMENT OF APPARATUS

CENTRAL-STATION APPARATUS

32. Relays.—The following directions are given only for those who have to install and care for this automatic system. The No. 177 type of polarized relay, shown in Fig. 17, should be so adjusted that the under side of its armature in the non-operated position is .025 inch from the extreme outer edge of the magnet core, as measured with a gauge furnished with the equipment. It is essential to successful operation that in these relays the contact with the lower springs (on the side nearest the magnet-spool terminals) should be firmer and more prolonged than that with the upper springs. The upper, or outer, springs should be lifted from the limiting stop as far as the movement of the armature will permit. The distance between the platinum contacts of the middle and outer springs should be about equal to the thickness of foolscap paper.

If the ringing relay has its back contact, which is included in the ringing circuit, imperfectly closed, weak ringing will result during a reverting call; if the back contact that short-circuits the sluggish relay during selection is imperfect, the selective operation may be inaccurate.

33. Selector, Sluggish Relay, and Test Relay.—The **selector, sluggish relay,** and **test relay** will rarely need readjustment after shipment.

34. Stepping Magnet.—When energized by interrupted current, whose makes and breaks are properly proportioned, the **stepping magnet** causes its armature to reciprocate so that, during selection, the hexagon head of the screw that supports the driving ratchet can be seen with equal clearness in its extreme forward and backward positions.

If the reciprocating screw head in the backward position is clearer than in the forward position, either the breaks in the interrupter current are too long or the pull of the spring recovering the stepping armature is too strong. The breaks in the current traversing the selecting local circuit may be too long from two causes: first, the outer spring of the selecting relay may not be near enough to the middle spring; second, the substation interrupter springs may be too far apart. If, on the other hand, the head of the hexagon screw shows more plainly in the forward than in the backward position and displays a tendency to stick in the former position, either the retractile spring of the stepping armature needs tightening or the contact springs of the selecting relay or of the substation interrupter are too near together.

The travel of the stepping armature should be very carefully regulated. A point at the center of the screw on which the stepping pawl turns should move $\frac{1}{8}$ inch from the backward to the forward position; the movement at this point should never exceed $\frac{9}{64}$ inch.

35. Locking Magnet.—The **locking magnet** is made sluggish by a non-inductive shunt bridged permanently across its windings. The force exerted on the armature by the recovery springs should be only just enough to draw the stop-pawl from the wheel when the selector arm has been stepped forwards to line number 100 and released. If the breaks in the local selecting circuit are too long, this magnet will show a tendency to release its armature during selection. The method of correcting this fault is described in Art. **32.** The retaining armature should have the least possible motion necessary to raise the stop-pawl from the wheel with a safe clearance between the two and to allow the stop-pawl to drop to the bottom of the tooth. The locking magnet on the selector is made slower acting than the stepping magnet by changing the length of the armature lever and by using a lighter spring.

36. Rotary-Movement Springs.—The **rotary movement springs** *S*, Fig. 14, should be adjusted so that the necessary contacts are made with the least possible expenditure of force in order that the power required to restore the arm to its resting position may be reduced to a minimum.

The springs should be operated when the selector arm has been advanced three steps.

37. Spiral Shaft Spring.—The spiral spring wrapped about the shaft should, without an unnecessary amount of force, restore the selector arm and brushes positively to normal resting position when the latter are placed in the space between the first and the second pair of dead line terminals and then released. All parts of the selector, except the selector brushes, should be freely lubricated with clock oil, including the point where the stepping pawl and the back eccentric stop come in contact.

38. Ringing Interrupter.—The No. 64–D and No. 64–F interrupters used for pulsating current should be so adjusted that with the ringing battery at 85 volts there should be an electromotive force of not less than 60 volts between the binding posts marked "positive pulsating" and the ground side of the ringing battery, as measured with an alternating-current voltmeter when the interrupter makes 1,250 cycles per minute. The contact spring struck by the lever in its movement toward the magnet is placed there for purely mechanical reasons. It is designed to act as a buffer on the front stroke and in conjunction with the back spring to maintain the lever at the proper rate of vibration.

39. Tone Interrupter.—The No. 64–E and No. 64–G interrupters, which are used to interrupt the busy tone, should be adjusted to make 200 cycles per minute. The adjustment of the back contact spring included in the circuit through the magnet spools has much to do with the rate of vibration.

40. Busy-Tone Buzzer.—The **busy-tone buzzer** is capable of giving a smooth tone of medium pitch when properly adjusted. Only one set of springs is used, the other set being a spare, but both sets should be adjusted alike; that is, the normally closed contact between the outer and inner springs should break just as the armature strikes the pole piece. By means of the back stop-screw, the armature is brought considerably nearer the pole piece than usual. If the buzzer starts with a hoarse or double tone, the difficulty may be corrected by bending the outer spring so as to vary the length of the break between the inner and outer springs.

41. Transfer Relay.—To avoid a failure of the ringing apparatus on account of a burn-out or a breakdown of the regular interrupter magnet *I*, Fig. 8, a duplicate ringing apparatus is provided and connected as shown in Fig. 18. As long as current can flow from the local battery *L B* through the transfer relay and the magnet *I*, the **transfer relay**, known also as the *178 relay*, will hold up its armature and

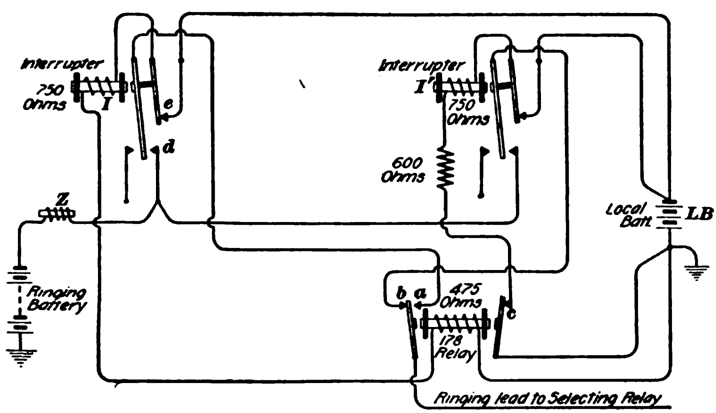


FIG. 18

keep the contact *a* closed and contacts *b*, *c* open. Should the magnet *I* burn out or its circuit open in any way, the 178 relay will release its armature, thus opening at *a* the circuit that is opened and closed at *d* by the action of the magnet *I* and connecting a similar interrupter *I'* whose circuit it closes at *c*, *b* in its place. *Z* is an impedance coil whose resistance limits the strength of the current and whose inductance tends to reduce the very sharp points in the curve of the interrupted ringing currents. There is such a transfer relay in both the tone-test and ringing apparatus. The 178 relay is sufficiently sluggish not to release its armatures when the interrupter *I* is working properly and interrupting at *e* the current that passes through the winding of the 178 relay.

If the 178 transfer relay fails to attract its armature, the active interrupter *I* should be short-circuited for a moment.

42. Centralized Operating Battery.—The **centralized operating battery** should have an electromotive force of not less than 35 volts nor more than 42 volts with one-tenth of the working lines in use.

SUBSTATION APPARATUS

43. Subscriber's Interrupter.—Enough has already been stated in regard to the subscriber's interrupter springs to indicate that proper spacing is essential to correct selection. As delivered from the factory the space between the springs is correct for average line conditions. An unusual amount of line resistance necessitates setting the springs closer together; an unusual amount of capacity necessitates setting them farther apart.

The subscriber's interrupter arm should return from peg hole No. 100 in not less than 8 seconds nor more than 10 seconds. The substation rotary movement springs should be restored to normal condition during the last half step of selection. The two springs included in the talking circuit should press together as firmly as the movement of the rotary springs will allow.

44. Ringing Key.—It is equally important that the ringing key springs, which are normally in contact, should press together as firmly as the operating movement will permit.

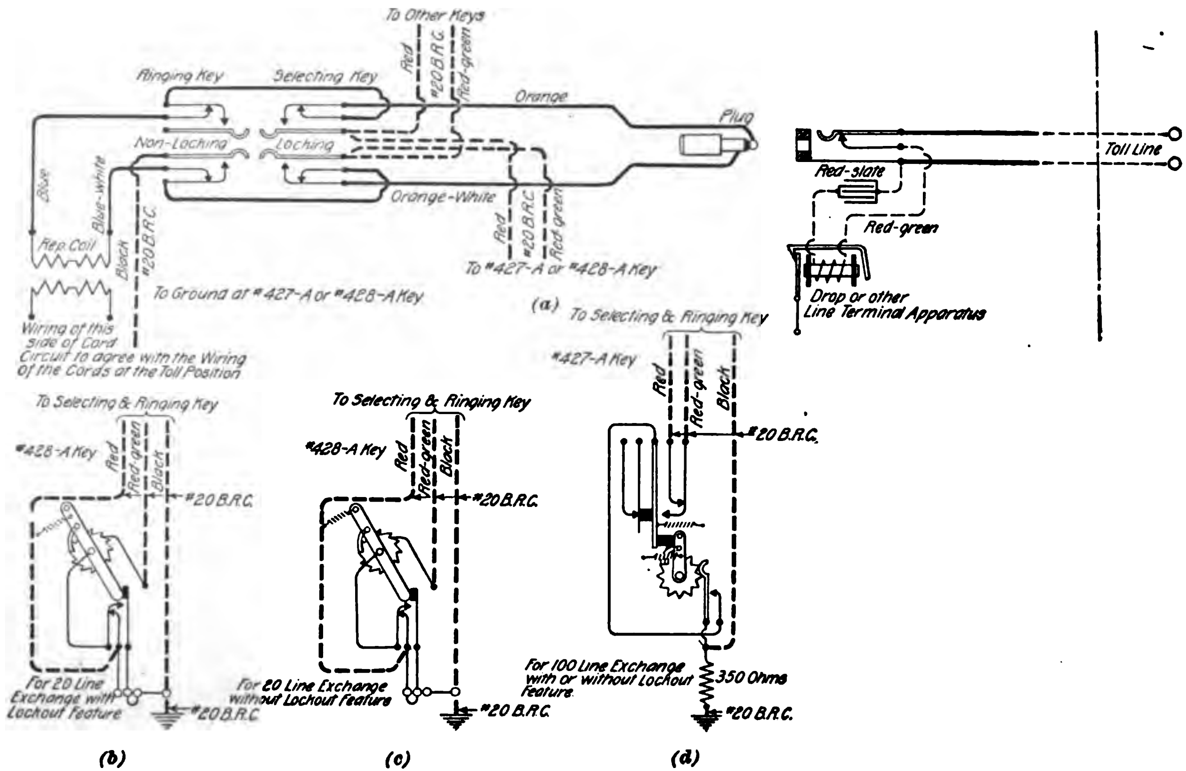
45. Grounds.—The substation and central-station grounds should be of low resistance. If water or gas pipes are not available, the ground rod or plate should be buried in permanently moist soil, which if not found near the surface may usually be reached at a greater depth or in damp cellars.

TOLL LINE AND CORD CIRCUIT

46. Fig. 19 (*a*) shows the **toll line and cord circuit** that may be used in connection with 100-line and 20-line automatic exchanges. In Fig. 19 (*b*) is shown the 428–A key that is used for a 20-line exchange with lockout feature; in Fig. 19 (*c*) is the 428–A key that is used for a 20-line exchange without the lockout feature; and in Fig. 19 (*d*), the 427–A key that is used for a 100-line exchange with or without the lockout feature. *B R C* stands for braided and rubber-covered wire. The red wire leading from view (*a*) is connected to the red wire leading to the key in view (*b*), (*c*), or (*d*), depending on which key is used; similarly, the red-green and black wires are, respectively, connected together.

The combination ringing and selecting key used in the cord circuit at the toll board is a standard keyboard listening and ringing key; the ringing end being non-locking, that is, the plunger when thrown to its operating position has to be held in place by hand. If thrown to the selecting position, corresponding to the listening position of an ordinary telephone key, it remains in position until manually removed.

The circuits at the toll board are self-explanatory if it is borne in mind that the keys shown in Fig. 19 (*b*), (*c*), and (*d*), together with operator's telephone set, perform exactly the same functions as the selecting and ringing mechanism together with transmitter and receiver at any subscriber's station.



To Other Keys
Ringing Key
Selecting Key
Red
#20 B.R.C.
Red-green
Orange
Plug
Non-Locking
Locking
Blue
Blue-white
Rep. Coil
Black
#20 B.R.C.
Orange-White
Red
#20 B.R.C.
Red-green
To #427-A or #428-A Key
To Ground at #427-A or #428-A Key
Wiring of this side of Cord Circuit to agree with the Wiring of the Cords at the Toll Position
(a)
Toll Line
Red-slate
Red-green
Drop or other Line Terminal Apparatus
To Selecting & Ringing Key
#427-A Key
Red
Red-green
Black
#20 B.R.C.
For 100 Line Exchange with or without Lockout Feature
350 Ohms
#20 B.R.C.
To Selecting & Ringing Key
#428-A Key
Red
Red-green
Black
#20 B.R.C.
For 20 Line Exchange with Lockout Feature
#20 B.R.C.
To Selecting & Ringing Key
#428-A Key
Red
Red-green
Black
#20 B.R.C.
For 20 Line Exchange without Lockout Feature
#20 B.R.C.
(b)
(c)
(d)

Fig. 19

OTHER AUTOMATIC SYSTEMS

GLOBE AUTOMATIC TELEPHONE SYSTEM

47. The automatic telephone system, invented by J. J. Brownrigg and J. K. Norstrom, is manufactured by the Globe Automatic Telephone Company. In this system, each telephone is provided with a keyboard as shown in Fig. 20, each key being mounted in a keyway so that it can be moved downwards and set opposite any one of the numerals, *0* to *9* inclusive, which appear along the side of each keyway. The key at the right-hand side is used for units, the next for tens, and the third for hundreds. If 625 is wanted, the left-hand key is placed opposite 6, the middle key opposite 2, and the right-hand key opposite 5; the receiver is then taken from the hook and the bells of the calling and desired telephones are rung; this completes a metallic circuit from the party calling to the party called. When a call is made and the bell fails to ring, it is an indication that the line is busy and connection with a busy line cannot be made. When the receiver is hung up, the mechanism is restored, ready for other calls.

Fig. 20

Any number of conversations may be carried on simultaneously, and a conversation cannot ordinarily be interrupted. Electric currents are employed merely for the purpose of controlling the movements of the switching mechanism, and not to make the movements themselves. The movable contact in the exchange switch is restored to its initial position by a common source of power, each switch being supplied with electric, air, gas, hydraulic, or other sources of power for operating it. By employing the external power in this manner, the inventors claim to avoid intricate and complex mechanical mechanism and produce a more simple and inexpensive central-station equipment. Relays associated with the line circuit control the external power that operates the switches. The Globe Automatic Telephone Company has installed a number of systems in small towns that seem to be giving satisfaction.

48. There are other automatic telephone systems, but at the present time those previously mentioned are the only ones that have commercial exchanges in actual operation. In the Faller automatic system, invented by E. A. Faller (patent number 686,892), the functions of the operator are performed by a mechanism, which, in effect, moves the equivalents of the plugs and cords of an ordinary transfer switchboard. The switching apparatus uses external power, which is supplied by an electric or other motor. The method of calling is to move a dial, contained in a small cast-iron box attached to, or near, the telephone, until the proper numbers show on the dial; moving a key then permits the call to go in and operate the central-office mechanism. As this system is not, at present, in practical operation in any commercial system, and as it would probably be modified, more or less, before it were installed, it is not practical to give here a description of it.

Other automatic systems recently devised are those made by the Lorimer Automatic Telephone Company and the American Automatic Telephone Company. The manufacturers of these systems, which were not in practical operation in any exchange, to our knowledge, in 1906, claim much for them.

HOUSE TELEPHONES

INTERCOMMUNICATING TELEPHONE SYSTEMS

1. Two general plans may be followed in installing telephone systems in buildings, factories, and institutions when communication between any two telephones is desired: One is to run a separate circuit from every station to a switchboard placed at the central office; any of the switchboard systems adapted for small exchanges may be used for this purpose. The other is to run at least one more wire than there are stations through all the stations, and to provide a switch at each station whereby the instrument at that station may be connected with any other station; this system, which is known as the **intercommunicating system,** or **house system,** has the distinct advantage, for a compact system, not exceeding about twenty telephones, over the use of a central switchboard, that it does not require the service of an operator to make the connections between the various stations. Beyond about twenty stations, the amount of line wire required becomes excessive.

2. Complete Metallic-Circuit System.—A **complete metallic-circuit, intercommunicating, telephone system** is here intended to mean one that has a pair of wires for each station and, if necessary, one or more wires that may be used for signaling purposes in common by all the stations. All these wires run through all the stations. The object of using two wires, usually twisted to form a pair, for each station is to eliminate cross-talk. Where cross-talk to a moderate degree is not objectionable, systems using only one wire for each station, in addition to one or more common wires, are cheaper to install, simpler, and give good satisfaction. However, where the wires are run in cables, as is usually the case in first-class installations, and all cross-talk must be eliminated, it is almost necessary to use a complete metallic-circuit system—as here defined—of some kind. In systems having only one wire for each station, there is liable to be more or less cross-talk, due either to induction between line wires running parallel and close together or to the use of one common wire as a common return by all stations as a part of their talking circuits.

Cross-talk can be avoided by holding each conversation over two independent wires and corresponds to what would be called a complete metallic circuit in a telephone-exchange system. If the wires are run in cables, each pair must be twisted together as in ordinary telephone cables used in complete metallic-exchange systems. If not run in cables the different pairs of wires should be fairly well separated. Cross-talk may also be caused by poor insulation, such as a damp cable.

MAGNETO-BELL SYSTEMS

COMMON-RETURN CIRCUIT

3. A simple intercommunicating system using ordinary magneto-generators and polarized bells, and the necessary talking apparatus and switches is shown in Fig. 1. Only three subscribers' stations *1*, *2*, and *3* are shown, but more can be added. Below each telephone is an intercommunicating switch and an ordinary push button. Both of these are usually mounted on the backboard of the telephone set. The lever of the intercommunicating switch is adapted to slide over and make contacts with any of the buttons, *1*, *2*, and *3*. In addition to one so-called common-return wire, there are as many line wires running through each station as there are stations. Each line bears a number corresponding to the number of the station to which it particularly belongs and is permanently connected with the buttons bearing the same number at each station. On each switch, the button bearing the same number as the station to which that switch belongs, is placed at the left-hand end of the row, and is called the *home button*. Thus, at station *3*, the button marked *3* is placed at the left-hand end of the row of buttons, instead of occupying its regular place in the sequence

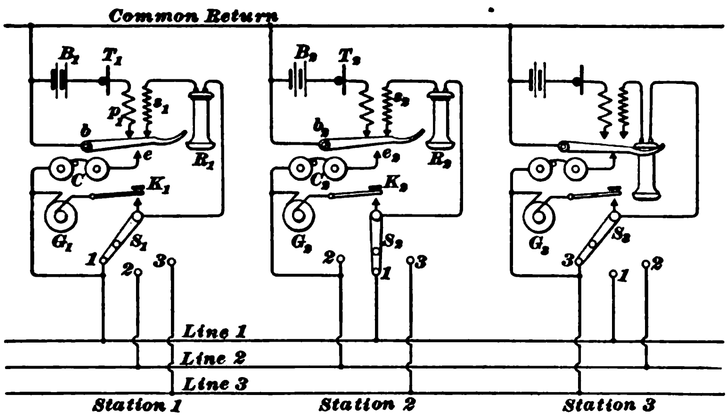


FIG. 1

of numbers. The system of electrical connections is in no wise affected by this, the button being merely shifted from the position it would ordinarily occupy to the first position because it is more convenient to have it there. The common-return wire runs through all of the stations with the other line wires.

4. Operation.—The operation of intercommunicating systems is very simple. All the levers normally rest on the left-hand or home button. When, however, one station desires to call another, the party at the calling station moves the lever on his telephone to the button bearing the number of the station he desires to call. This act connects his telephone to the line belonging to that station. He then presses the push button and turns his generator handle, and after the called subscriber has taken down the receiver, the two converse over the line wire bearing the number of the called station and the common-return wire. As shown in Fig. 1, the lever at station *2* has been moved to button *1*, in order to call station *1*, and by tracing the circuit it will be found that these two stations are now connected in a metallic circuit formed by the line wire *1* and the common return.

With intercommunicating systems, it frequently happens that the user will forget to return the switch to the home position, which should always be done. However, in this system the wiring is such that the bell at any station can be rung from any other station, no matter on what button the switch lever has been left, but before a conversation can be carried on, the switch at the station called must be returned to the home contact if not already there. This is usually the most desirable arrangement and the parties using such systems soon learn to do this.

5. Suppose that station *2* has called up station *1*, whose switch lever has been carelessly left on button *3*. The bells at stations *2* and *1* will ring; the ringing current flows from generator G_2 through K_2–S_2–*1*–line *1*–bell C–e–b–common return–b_2–e_2–bell C_2–G_2. It cannot flow through any other circuit, hence no other bell will ring. But, when the receiver R_1 is removed from the hook, while S_1 rests on *3*, no current can pass from line *1* through any apparatus at station *1*, because the circuit is open at *1*, e, and K_1. As soon, however, as the switch S_1 is placed on button *1*, the talking current flows through s_2–R_2–S_2–line *1*–S_1–R_1–s_1–b–common return–b_2–s_2. The transmitter T_1, transmitter battery B_1, and primary winding p_1 of the induction coil are connected in a local circuit when the receiver is off the hook.

If a bell rings and nothing can be heard when the receiver is taken down, the party answering the call will naturally look at the switch and, finding it off the home button, will return it to that button, after which the conversation may be held. This compels the return of the switch to the home button each time a station is called, if it is not already there, and tends to cultivate the habit of returning the switch to its home position. By this arrangement, the desired bell can always be rung, and neither the ringing nor talking currents are subdivided through idle stations where the switches may not have been returned to their home positions.

6. If station *2* should want to hold a consultation with both stations *1* and *3* simultaneously, station *2* would first call up station *3*, request that the switch there be turned to button *1* and left there; station *2* would then call up station *1* and the three stations would be connected in parallel between line *1* and the common return. The talking current originating at one station would then subdivide between the other two stations. This would reduce the loudness, but usually not enough to seriously interfere with the conversation. At the end of the consultation, all switches should be returned to the home position.

This system requires one more line wire than there are stations, and a regular series magneto-generator telephone, intercommunicating switch, and push button at each station. The generator need not have an automatic shunt device, however. If it is provided with an automatic cut-in device that normally leaves the generator on open circuit, the push button will not be required; one generator lead would be connected directly to the lever of the intercommunicating switch.

COMPLETE METALLIC-CIRCUIT SYSTEM

7. To eliminate all trouble from cross-talk and interference from ringing currents, the wiring shown in Fig. 2 may be used. Two radial switch arms *c*, *d* are mechanically connected by an insulating piece to which one handle h_1 for controlling both arms is fastened. Of course any other form of switch that will accomplish the same result may be used, for instance, jacks and plugs or double-contact push buttons. The switch is drawn in this manner in certain figures in this Section in order that the connections may be clearly shown.

To call a station, turn the switch to the number of the station desired and hold the double-contact push button P_1 closed while the handle of the magneto-generator G_1 is turned. The piece *e* is insulated from the hook switch so that the ringing currents cannot interfere with other telephones in use should the switch arm be left off its home position. The bell can be rung no matter in what position the switch is left, but it must be returned to the home position at the station called before a conversation can be carried on. A series-bell and generator are required with the wiring

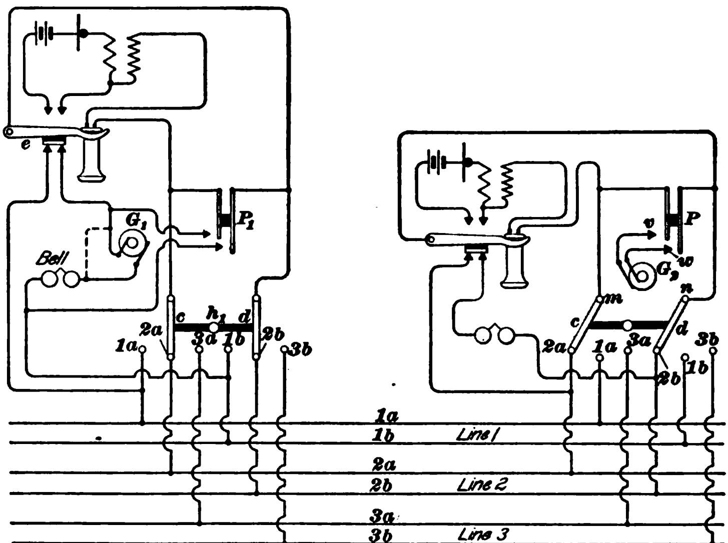


FIG. 2

shown at station *1* and the usual automatic shunt used in series-telephones is necessary, as indicated by the dotted line around the generator G_1. However, the generator may be connected as shown at station *2*, that is, across the contacts *v*, *w*; in this arrangement, any suitable generator may be used and no automatic shunt or cut-in device is necessary; indeed, one terminal of the generator could then be permanently connected to *m* and a single-point push button used to connect the other generator terminal to *n* when using the generator. A generator having an automatic cut-in device could be connected across *m*, *n*, no push button being then required. Either series or bridging bells may be used with the wiring shown at station *2*. As many pairs of wires, twisted together, are required as there are stations.

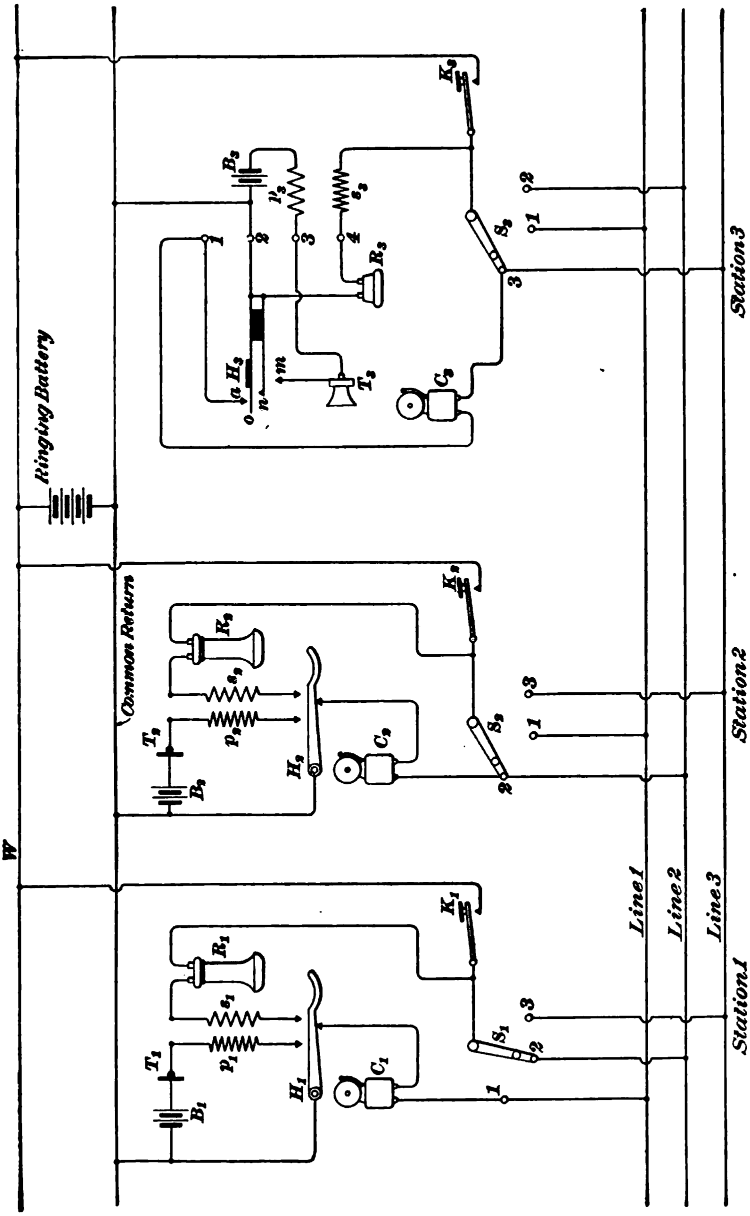

W
Ringing Battery
Common Return
Line 1
Line 2
Line 3
Station 1
Station 2
Station 3

FIG. 8

COMMON RINGING-BATTERY SYSTEMS

COMMON-RETURN CIRCUIT

8. The **common ringing-battery system** is one in which one battery is used in common by all stations in the system for signaling purposes only. Fig. 3 shows about the best way to wire the system, using a common-return conductor; with this wiring, the ringing and talking currents flow only through the stations properly connected, neither are subdivided through any other stations no matter where the switches at the other stations may be left. There is the usual transmitter battery, talking apparatus, and intercommunicating switch at each station. The means for signaling consists of an ordinary vibrating, or battery, bell and a push button at each station and one ringing battery conveniently located for ringing the bells.

With S_1 resting on *2* and K_1 closed, current from the ringing battery flows through K_1–S_1–button *2*–line *2*–button *2* at station *2*–bell C_2–hook switch H_2 and common return back to the ringing battery. The voice currents flow through s_1–R_1–S_1–button *2*–line *2*–button *2* at station *2*–S_2–R_2–s_2–H_2–common return–H_1–s_1. The bell at the station making the call does not ring. It is necessary to arrange the bells so that only one bell will ring, because two vibrating bells do not work well in series, unless the vibrating contact of one is removed, which would not be applicable to a system having more than two stations. This system requires two more line wires than there are stations.

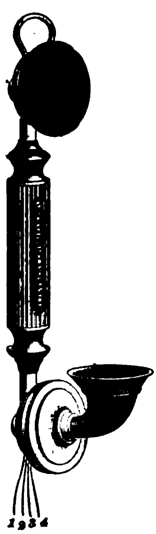


FIG. 4

9. Microtelephone.—At station *3* is shown the connections for a so-called **hand microtelephone**, which consists of transmitter and watch-case receiver, both a little smaller and lighter in weight than the ordinary transmitter and receiver, and a switch, all mounted, as shown in Fig. 4, in one handle that can be conveniently held by one hand with the receiver to the ear and the transmitter mouthpiece in front of the mouth. The switch in the handle can easily be held closed by the same hand that holds the microtelephone. When the switch H_3, Fig. 3, is pressed, *o* parts from *a* and *o*, *n*, and *m* are all connected together. Normally *o* rests against *a*. Hence, this switch replaces the ordinary hook switch. The induction coil p_3, s_3, the bell or buzzer C_3, the push button K_3, and the intercommunicating switch S_3 may all be mounted in a little box and located in a convenient place, while the microtelephone may be hung where most convenient, or placed in the pigeonhole of a desk. The numbers *1*, *2*, *3*, *4* in Fig. 4, and in the upper part of station *3*, Fig. 3, represent the four wires running out of the microtelephone handle and are here numbered exactly as on the tags fastened to the microtelephone, which is now made by several companies.

COMPLETE METALLIC CIRCUIT

10. A good way to wire common ringing-battery telephone instruments for a system having two wires for each station is shown in Fig. 5. The wiring is shown more clearly at station *1*, but the practical arrangement of the hook-switch contacts is more accurately shown at station *2*. A centrally located battery *R B* is used for ringing ordinary battery bells V_1, V_2. At station *1*, a contact piece *e* is fastened to, but insulated from, the hook switch in such a manner as to close the bell circuit only when the receiver rests on the hook, for neither lower contact should ever touch the hook switch to which wire *q* is attached. At station *2*, the hook switch forms no part of any circuit and is at all times insulated from the contact springs. At each station, there is required a switch, with two arms controlled by one handle, and a double-contact push button. A battery-signaling system, as shown in this figure, requires two more line wires, through which the battery current is supplied to each station for signaling purposes, than the magneto-signaling system shown in Fig. 2. The polarized bell and generator would cost more than the battery bell, but the former would, perhaps, give less trouble.

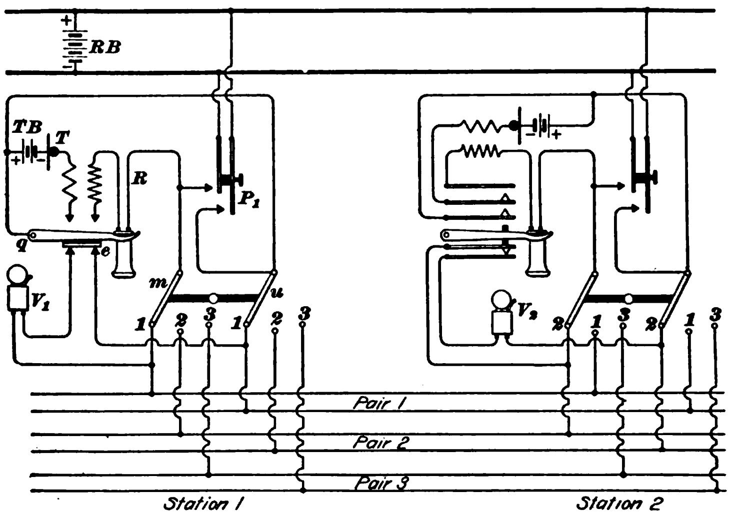


FIG. 5

11. Operation.—To call up a station the switch is turned until it rests on the buttons corresponding with the number of the station desired and the push button is then pressed. The fact that the switch at the station desired may not rest on the home position does not prevent that station being called from any other station. However, the switch at the station called must rest on, or be returned to, the home position before any conversation can be carried on. This is usually a desirable feature, however. During both conversation and signaling, the currents flow between the two stations through the pair of wires having the same number as the station called. No further detailed description of the operation of this system seems necessary.

12. Plug Switch for House Systems.—Some manufacturers, instead of using the rotary switch shown with the foregoing systems, use a flexible cord and plug in place of the switch lever, and jacks in which the plug may be inserted, instead of the contact buttons. This arrangement has some advantage over the switch-arm-and-buttons principle, due to the fact that a well-made plug and jack insures better contact than that usually obtained by the mere contact of a switch arm on a button. The rotary switch, however, is adapted to give good service if properly made, and there is little choice between them.

SECRET INTERCOMMUNICATING SYSTEMS

COMMON RINGING-BATTERY SYSTEM

13. Messrs. Parsons and Sloper have designed an ingenious intercommunicating system in which the secrecy of communication is absolutely assured; a diagram of connections for this system is shown in Fig. 6. In addition to the usual apparatus, there is a relay M_1 connected as shown at each station. Normally, the intercommunicating switches S_1, S_2, S_3, rest on the open home contact, as shown at station *2*.

The operation of this system is as follows: Suppose that station *1* desires to call station *3*. The switch S_1 is turned to contact button *3*, as shown, and the push button K_1 is pressed. Current then flows from the common ringing battery RB through n–a–K_1–S_1–contact *3*–line *3*–h_3–V_3–battery RB. The party at station *1* then takes down his receiver and listens, although his transmitter is not yet in the circuit, as the branch containing the transmitter T_1 is open, because the armature of the relay M_1 rests against the open contact e. The party at station *3* hearing the bell ring, takes down his receiver, but as yet he can hear nothing, because his switch S_3 rests on button *3* and hence the circuit is open at contact *3* and at e. He then moves the switch arm S_3 slowly over the contacts until it touches one that causes a click in his receiver, a similar click being produced also in the receiver at the original calling station, in this case at station *1*. This indicates that a complete circuit has been established through M_1–*d*–*i*–contact button *1* at station *3*–S_3–K_3–B_3–M_3–*u*–h_3–line *3*–contact button *3* at station *1*–S_1–K_1–B_1. Thus, B_1 and B_3 are connected in series, and current flowing through the relays M_1 and M_3 causes them to close the

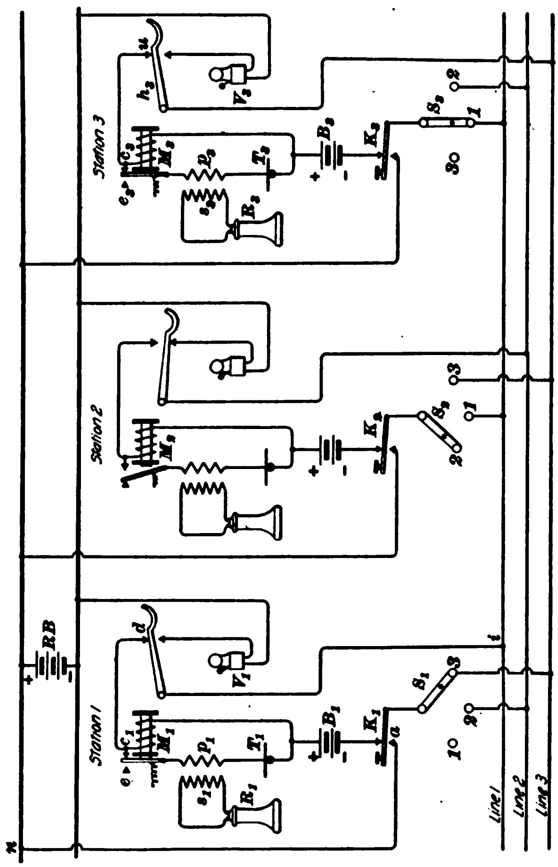


FIG. 6

transmitter circuits at c_1 and c_3, thereby inducing in the secondary windings s_1, s_3 of the induction coils a current that produces the click in the receivers R_1, R_3. No third party can cut in because the hook switch at each station is connected only to the line belonging to that station, and it will be seen that this line circuit is open at the switch contacts at all the other stations, and hence no circuit with stations *1* and *3* can now be established, even if the switch arm S_2 is turned over contacts *1* and *3*. A party at station *2* cannot even ring the bells at stations *1* and *3*, because their bells are cut out of the circuit while they are conversing. This cooperation at both stations in establishing the connections, simplifies the circuits, while all the usual objects seem to be obtained in addition to secrecy. The bell at any station where the receiver is on its hook can be rung from any other station, no matter where the intercommunicating switch arm may have been left. This system requires two battery wires in addition to one line wire for each station, and a relay in each telephone.

The same parties have devised a similar system using magneto-generators and polarized bells.

COMPLETE METALLIC-CIRCUIT SYSTEM

14. Messrs. Parsons and Sloper have also devised a **complete metallic-circuit system** in which secrecy of communication is also assured. In this system, which is shown in Fig. 7, two line wires are required for each station, one battery at each station being used for both signaling and talking purposes. In addition to the usual apparatus, there is a buzzer M_1, M_2 at each station, and each station has one pair of wires extending throughout all the stations. At each station either the receiver or bell is connected through the hook switch across the pair of wires belonging to that station, while the transmitter, buzzer, battery, and the push button are connected in the plug-cord circuit, which may be connected by means of jacks to any other line circuit.

If station *1* desires to call up station *2*, the plug P_1 is inserted in the jack J_2 that is connected to the pair of wires constituting line *2* and to which the receiver R_2 or bell V_2 at station *2* is connected. On pressing the push button K_1, current flows through B_1–K_1–M_1–t–line wire $2a$–h_2–V_2 line wire $2\,b$–s–B_1, thus ringing the bell at station *2*. The party at station *2* then removes the receiver R_2 from the hook, thereby connecting it in series with the transmitter T_1 at station *1*, which allows the party at station *1* to announce his own number. The party at station *1* knows when the receiver at station *2* has been taken down by the stopping of his buzzer M_1. The party at station *2*, on hearing the

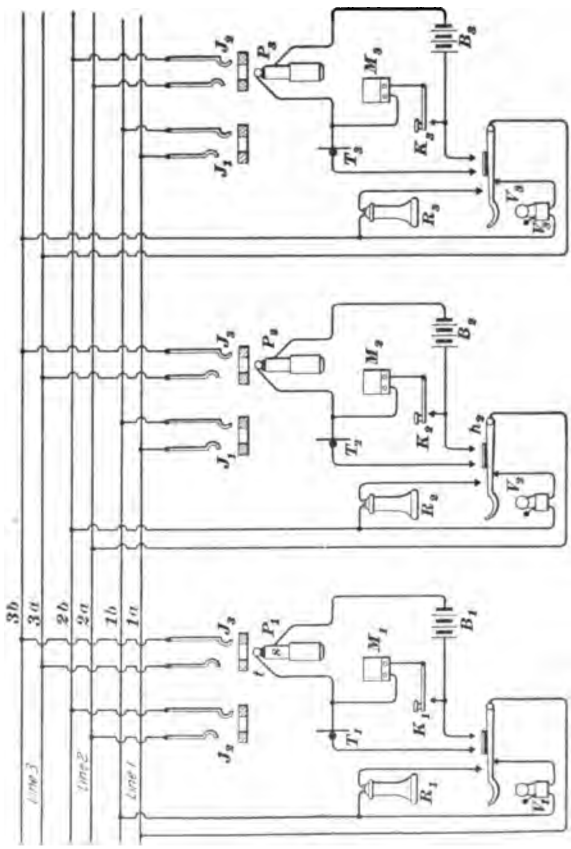


FIG. 7

number announced by the calling party, inserts his plug in the jack J_1 associated with the line belonging to station *1*, thereby connecting his transmitter T_2 and battery B_2 in series with the receiver R_1 at station *1*. Thus the receiver at each station is in series only with the transmitter and battery at the other station. Evidently, no third party can listen in, for he cannot connect his receiver to the pair of line wires in use, his receiver being permanently connected only to his own pair of line wires. The bell at any station where the receiver is on its hook can be rung from any other station no matter in what jack the plug at the other station may have been left.

The same parties have arranged this system for use with magneto-generators and polarized bells.

CENTRAL-ENERGY INTERCOMMUNICATING SYSTEMS

COMMON-RETURN CIRCUIT

15. One Wire for Each Station and Three Common Wires.—A **central-energy intercommunicating system** is one in which all batteries for both talking and ringing purposes are located at any one convenient place, the more nearly central this place is with respect to all the telephones, the more nearly uniform will the various telephones work. However, the lengths and resistances of line wires are usually so small compared with the resistances of the various devices in the system that the location of the batteries is generally immaterial.

Where it is desirable to have no batteries at the subscriber's stations, the central-energy system is the one to use. The objection to many central-energy intercommunicating systems is the liability to cross-talk when several pairs of telephones are in use simultaneously. The fact that all the wires are usually run in one cable tends to increase the cross-talk if the wires are not run and twisted in pairs. In the arrangement shown in Fig. 8, two centrally located batteries are used, one set of cells *a b* supplies the various transmitters with current when the receivers are removed from the hook switches, and the cells *d c* are used for ringing the bells. It is usually preferable to use separate batteries for ringing and talking purposes. However, on a small system and where the same number of cells will answer for both ringing and talking purposes, one wire less will suffice. In this case, the various transmitters may be connected to the ringing wire and the transmitter wire and battery *TB* may be omitted. In the latter arrangement, two, and in the one shown in the figure, three more line

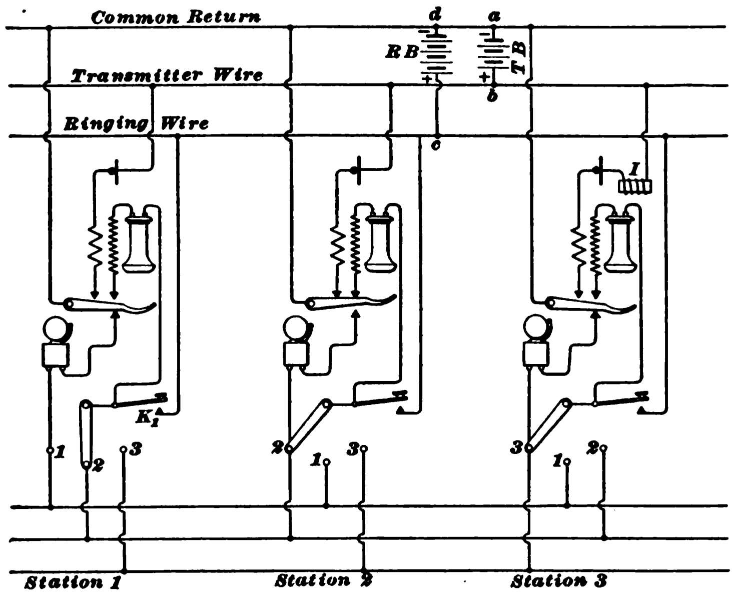


FIG. 8

wires are required than there are stations. The necessary number of cells may be connected between *b* and *c* in series with *TB* and all the cells between *a* and *c* used as a ringing battery.

16. Cross-talk may be reduced by connecting a 25- to 50-ohm impedance coil *I* in the transmitter circuit at each station, as shown only at station *3* in this figure. This makes the transmitter circuits much higher in resistance than the circuit formed by the battery *TB* and the transmitter wire, therefore the variations in the line voltage are a smaller percentage of the total voltage. The greater the impedance of these coils the less the cross-talk. While these impedance coils cut down the efficiency of transmission, the prevention of cross-talk may more than compensate for their use. Making the common-return and transmitter wires of very low resistance will also tend to cut down the cross-talk. In a system of any size or importance, impedance coils should at least be used to reduce the cross-talk. To entirely eliminate cross-talk requires not only impedance coils, but also a twisted pair of line wires for each station in addition to the one or two wires used in common by all stations for signaling purposes. For systems having less than six telephones or where the line wires do not run along in one cable for more than about 100 feet, the common-return systems already shown should be sufficiently free from cross-talk. A little cross-talk may often be endured considering the fact that systems not entirely free from it usually cost less to install.

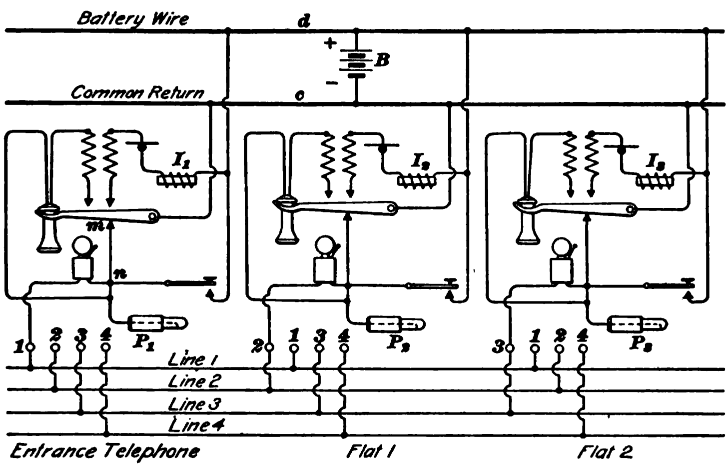


FIG. 9

17. Apartment-House System.—In Fig. 9 is shown a similar arrangement that is more suitable for communication between the vestibule and the various flats in a modern apartment house because it is unnecessary to return the plug to its home jack or to remove it from any jack in order for the parties to converse. Any station may be rung, regardless of the position of its plug. Two more wires are required than there are stations. At each station there is a telephone having, in addition to the usual telephone apparatus, impedance coils I_1, I_2, I_3 to reduce the cross-talk and plugs P_1, P_2, P_3 to make connections through one of the jacks *1, 2, 3, 4* with the desired telephone. This arrangement may be used to provide communication between the tenants, between the tenants and callers, and between the tenants and the janitor in whose quarters a telephone set may be located. The common battery B may also be placed in the janitor's quarters.

An objection to this system is that, if any two stations are connected, and a third station calls either one of the first two, the bells at the first two stations will both ring if the receivers are on their hooks. By using coils I_1, I_2, I_3, of sufficient impedance, the reduction in cross-talk may be made to more than compensate for the loss in efficiency due to their presence in the transmitter circuits. In many cases, no bell would be required in the entrance telephone and the circuit *m–n–1* would be omitted.

18. Simple Plug-Switch System.—In Fig. 10 is shown a very simple central-energy intercommunicating system, described in the Telephone Magazine by James V. Crecelius, who says that he has installed about twenty such systems and has found them more satisfactory, where the longest line does not exceed 1,000 feet, than many other more complicated systems. Provided that the receivers are hung up when not in use, no bell except the one desired will ring, even though the plugs are accidentally left in any jack.

To call station *2* from station *1*, insert the plug P_1 in jack *2* at station *1*, and press the push button K_1. Current then flows through B–w–W_2–H_2–line *2*–jack *2* at station *1*–P_1–K_1–e–B, thus ringing bell W_2. Very little current passes through the transmitter T_2, because the bell W_2 has very much less resistance than T_2, which it shunts. If considered desirable, although it has not been found necessary with

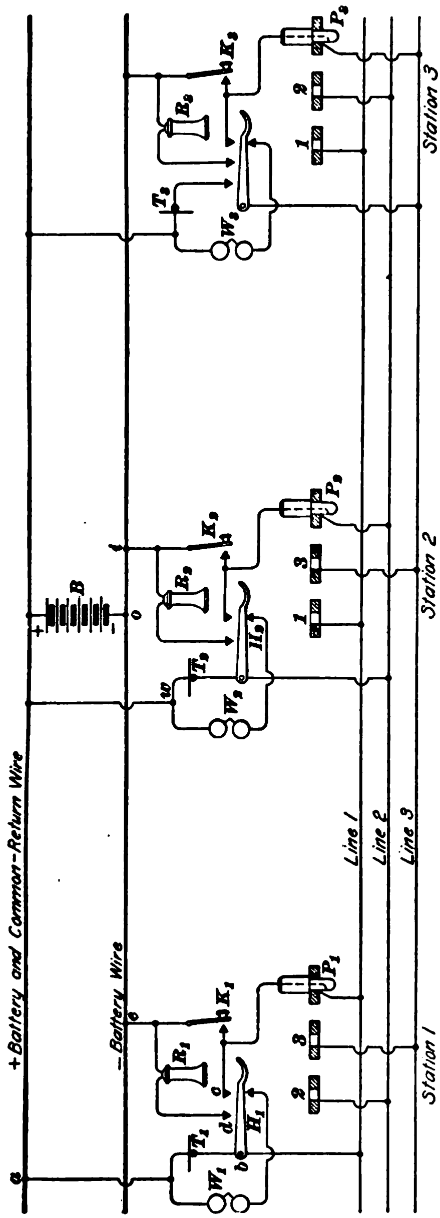


FIG. 10

165—10

transmitters of sufficient resistance, the arrangement shown only at station *3*, in which the transmitter circuit is normally open and therefore not in parallel with the bell, could be used at all stations.

19. When the two parties are conversing, current from the battery flows through $a-T_1-H_1-d-R_1-e-o$ and through $T_2-H_2-R_2-i-o$, which are in parallel and the variation in the potential between the points *a*, *b* when speaking into the transmitter T_1 produces fluctuating voice currents in the circuits H_1-c-P_1-jack *2*–line $2-H_2-R_2-i$ and H_1-d-R_1-e, which unite at *o* and return through *B* to *a*. Mr. Crecelius says this talking circuit is very effective for distances to be met with in intercommunicating systems. The receiver must be connected in the proper direction in the circuit and the plugs should always be withdrawn at the end of a conversation, because otherwise there is a chance for cross-talk should four or more people be talking at the same time. The same-sized wire, preferably No. 18 B. & S., should be used for all line wires to reduce the cross-talk and to have a balanced talking circuit. For the battery *B*, he recommends enough good (low internal resistance) dry cells to give from 6 to 9 volts.

COMPLETE METALLIC CIRCUIT

20. Two Wires for Each Station and Two Common Wires.—A more desirable central-energy intercommunicating system than the one just described and one that is suitable for a larger system, because it is freer from cross-talk, is shown in Fig. 11. There is one battery *RB* for signaling purposes and another *TB* for supplying current to all the transmitters. From *RB*, two wires *W*, *X* run through all the stations. There are in addition to *X*, *W* as many twisted pairs of line wires running through all the stations as there are stations. Each wire of each of the latter pairs is connected through a coil of high impedance to the talking battery *TB*. The two batteries and all the impedance coils are located at some one convenient place. A two-arm strap switch, or its equivalent, is necessary at each station. The switch shown in the figure consists of two metallic arms c_1, d_1 insulated from each other, but mechanically connected by a bar and handle so that one handle moves both arms. Ordinary vibrating bells are used. The transmitter is connected in series with the primary of an induction coil and the receiver in series with the secondary and in a permanently closed local circuit. At station *3*, the bell V_3 is disconnected from the circuit at the hook switch while conversing; this prevents the possibility of interference while talking, due to charging and discharging currents and to leakage through the bell and the wire. However, it is very doubtful if this would usually be serious enough to warrant the use of the extra contacts *n*, *o*, *e* thereby required.

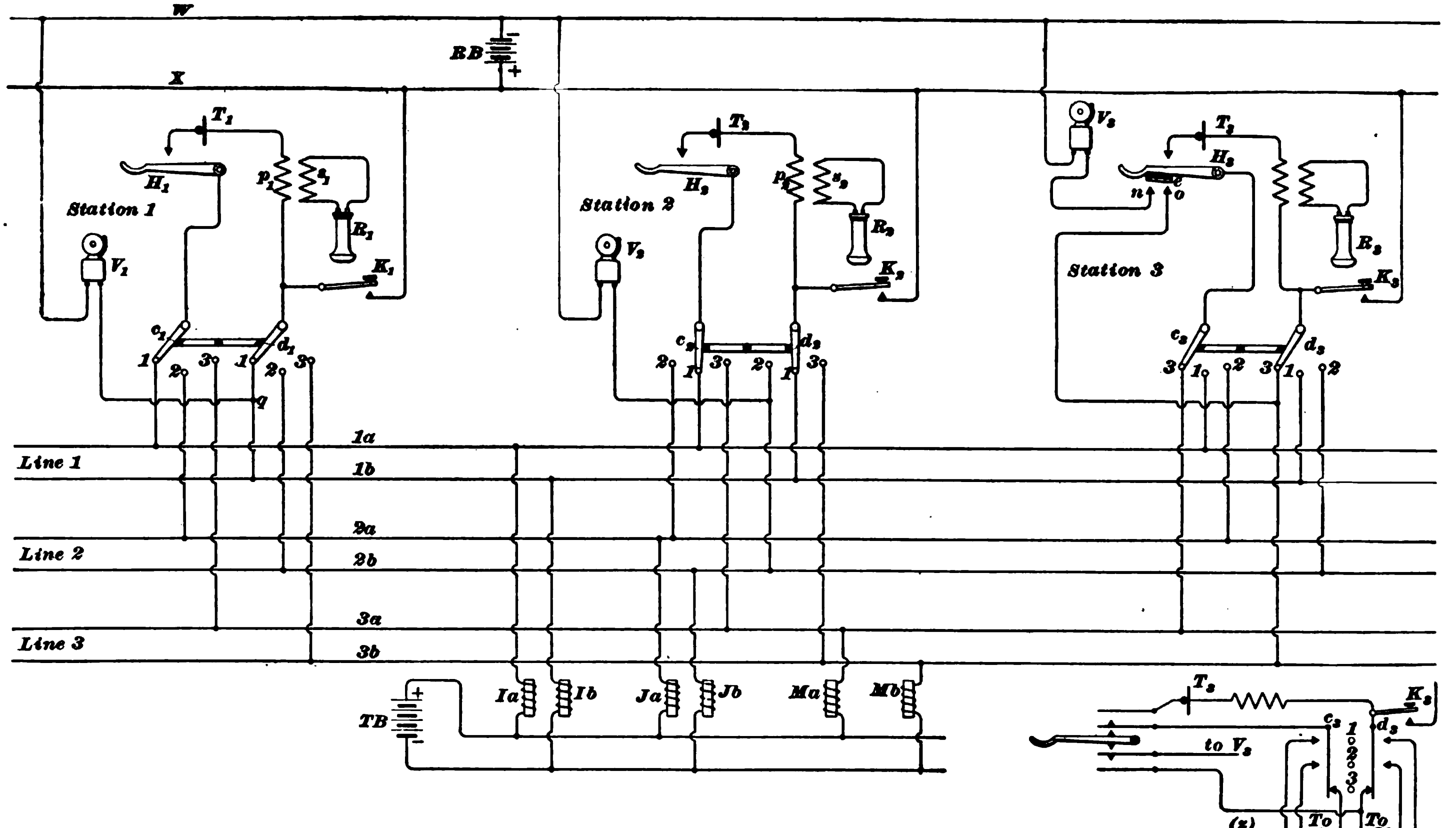

W
X
RB
Station 1
Station 2
Station 3
Line 1
Line 2
Line 3
1a
1b
2a
2b
3a
3b
TB
Ia
Ib
Ja
Jb
Ma
Mb
to V3
(x)
To 3a
To 3b

FIG. 11

21. Operation.—To call up station *1* from station *2*, turn the switch so that c_2 and d_2 rest on contacts *1*, *1* and close the push button K_2. Current then flows through RB–K_2–d_2–*1*–wire *1 b*–q–V_1–W–RB. When the receivers are removed from the hooks, the battery TB supplies both transmitters with current through the impedance coils Ia and Ib, and the fluctuating voice currents flow through T_1–p_1–d_1–*1*–*1 b*–*1*–d_2–p_2–T_2–H_2–c_2–*1*–*1 a*–*1*–c_1–H_1–T_1. These fluctuating currents induce currents in s_1 and s_2, thereby affecting the receivers R_1, R_2.

The bell at any station can be rung from any other station, even if the switch has not been returned to its home position, but the conversation cannot be held until the switch at the station called is returned to its home position, which is usually a desirable feature. As in practically all non-secret intercommunicating systems, there is nothing to prevent a third station from listening to a conversation of two others, if the switch at the third station is turned to the proper contacts. However, the parties conversing can usually tell that such is being done from a click or a decrease in the loudness of the tone.

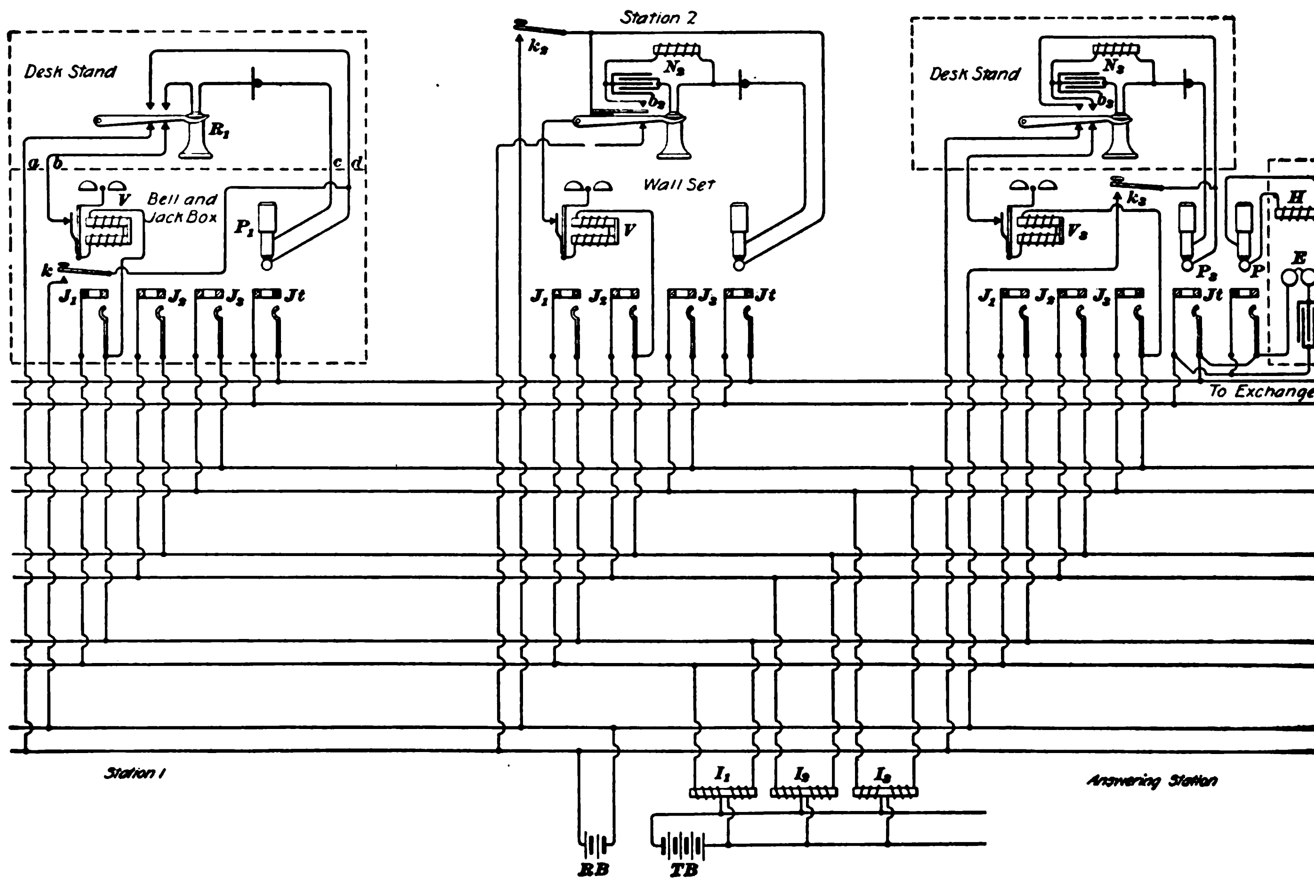
22. The Couch & Seeley Company applies its .push button and automatic restoring switch to a system of this kind. The wiring for one station, which is shown at (z), is practically the same as shown at station *3*. This push-button switch has the advantage over the form of switch shown at stations *1*, *2*, and *3* in that it is easier for one station to call up and hold a consultation with two or more other stations, and also the advantage due to the automatic return of the switches to their home positions when the receivers are hung up. This automatic switch will be explained presently.

23. In a similar system made by The Sumpter Telephone Manufacturing Company, the ringing battery consists of three cells giving about 4½ volts, and the talking battery consists of eight cells giving about 12 volts. The induction coil and transmitter are so designed that the current through the transmitter during conversation is slightly in excess of .114 ampere, and should never fall below .08 ampere. The batteries can deteriorate considerably before unsatisfactory transmission will result; in fact, good transmission is possible with a current of approximately .005 ampere. The dimensions of the impedance coils connected between each line wire and the talking battery in the same system are as follows: The core, made of best Norway iron, is $\frac{11}{32}$ inch in diameter and $3\frac{1}{2}$ inches long; the heads are $\frac{7}{8}$ inch in diameter and $\frac{3}{32}$ inch thick; the winding space is $2\frac{1}{2}$ inches long; the coil is wound with No. 32 B. & S. single silk-covered copper wire to a resistance of 80 ohms; the coil is covered with an iron shell and iron heads to increase its impedance and to prevent cross-talk when coils are mounted in close proximity to one another.

CONNECTION BETWEEN INTERCOMMUNICATING AND EXCHANGE TELEPHONES

24. It is often very desirable to be able to connect a telephone belonging to a city exchange with an intercommunicating system. Whether such connections can be made, depends on whether the local exchange company will allow it, and furthermore, intercommunicating telephones should be so arranged as not to interfere with the proper operation of the exchange telephone and the switchboard signals. Intercommunicating systems are being used to some extent, in place of small private branch switchboards, to afford connections between the various local stations of the intercommunicating system and the city exchange.

25. Kellogg System.—In Fig. 12 is shown the central-energy intercommunicating system made by the Kellogg Switchboard and Supply Company. It is a complete metallic-circuit system. The telephone instruments differ from those used in the regular Kellogg central-energy exchange systems in having a vibrating bell and push button, for signaling purposes, instead of a polarized bell. The battery bell has two gongs, which gives it the appearance on the outside of a



Desk Stand
Station 2
Wall Set
Desk Stand
Bell and Jack Box
To Exchange
Station 1
Answering Station
RB
TB

FIG. 12

polarized bell. Two sets of dry batteries are required, one *TB* for talking and the other *RB* for ringing the bells. For five to ten stations with 1,000 feet of cable, the talking battery should contain three cells and the ringing battery six cells; with 2,000 feet of cable, the talking battery should contain four cells and the ringing battery seven cells; for eleven to twenty stations with 1,000 feet of cable, the talking battery should contain six cells and the ringing battery six cells; with 2,000 feet of cable, the talking battery should contain eight cells and the ringing battery seven cells.

26. Instruments.—Two classes of telephone instruments are made—one called the major and the other the minor. The major has a receiver and condenser in series, the two being connected in parallel with an impedance coil, as shown at station *2*. The minor instruments have the same apparatus, but the condensers and impedance coils are omitted, the transmitters being connected simply in series with the receiver, as shown at station *1*. The impedance coil in a major instrument forms a path of low resistance for the battery-transmitter current, which the condenser excludes from the receiver, while the fluctuating currents, since they pass through a condenser more easily than through an impedance coil, readily flow through the receiver-condenser circuit. The condensers, which have a capacity of $\frac{1}{2}$ microfarad each, measure $2\frac{3}{4}$ inches, including terminals, by $1\frac{1}{4}$ inches by $\frac{3}{4}$ inch.

At station *1* is shown a minor desk-stand set; at station *2*, a major wall set; and at the answering station, a major desk-stand set equipped as an answering station. The answering station is provided with two trunk jacks *Jt*, instead of one, as at the regular intercommunicating stations, an extra plug *P* for holding the exchange trunk line, and an extra box in which is mounted the holding coil *H* and a polarized bell *E* and condenser *C* that are bridged, as an ordinary extension-bell set, across the exchange trunk line to serve as a signal from the exchange to the answering station.

27. In Fig. 13 is shown a major wall set mounted in a case made of mild steel. The steel wall sets may be equipped for any number of stations up to eighteen and the wooden wall sets up to twenty stations. They are made with the jacks in the front or side of the case, as desired. A suitable opening is made in the back of the box for all entering conductors. The ends of the instrument conductors are soldered to the ends of connectors on one side of a hard-rubber terminal block, while all incoming conductors from other stations are soldered to the corresponding ends of the connectors on the other side of the block. Thus, an easy method is provided for locating trouble in the wiring external to the instrument without unsoldering the wires leading to the

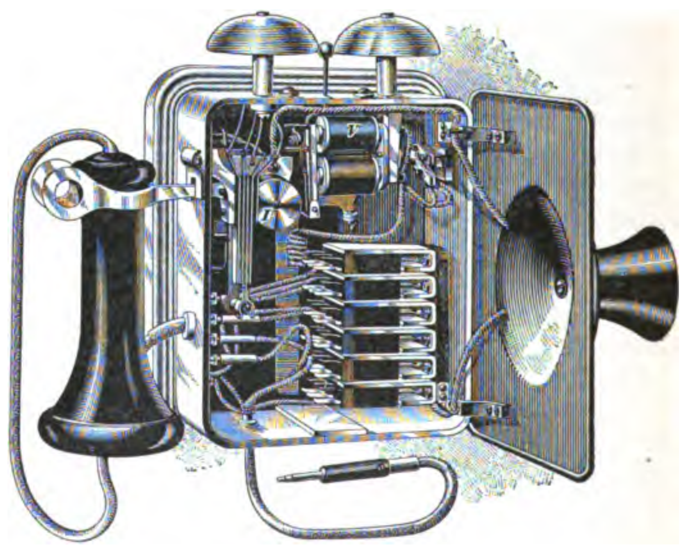


FIG. 13

apparatus in the instrument itself. The transmitter in the steel sets is mounted nearly flush with the front of the door, and its working parts are, therefore, claimed to be dust- and moisture-proof and well protected.

The thimbles or bodies of all jacks are nickel plated except the one used as the home jack, which is copper plated. The jacks may then be numbered consecutively from 1 to as many stations as are installed, and the copper-plated, or home, jack will be number 1 on the first instrument, number 2 on the second instrument, and so on.

28. Operation.—In the operation of this system, the subscriber inserts the plug into the jack of the line over which he wishes to converse and presses the button, which closes the battery circuit through the bell of the desired party and causes the same to ring. The parties then remove their receivers from the hook, which disconnects the bell and ringing battery from the line and closes the contacts for the transmitter, receiver, and talking battery, and the parties may then carry on their conversation. When the parties have finished talking, they hang up their receivers, leaving the plug in any number or out of the jacks altogether, and yet if any other party desires to call, they may do so without ringing any other bell except the one corresponding to the line in which the plug is inserted.

In cities and towns where telephone companies are operating, answering telephone stations are so equipped that any department may talk with outside parties and may call outside parties through any station of the intercommunicating system. It is the usual custom to make an answering station out of a telephone used by some party who is likely to be in close range of this telephone at all times. One of the exchange jacks at the answering station is used for talking purposes and the other for holding the line until the party wanted has answered.

All incoming calls from the city exchange are answered by the party at this answering station, who, after receiving the signal from central, inserts the plug that is associated with his talking circuit, into one of the trunk jacks Jt. After learning the department wanted, the answering party inserts the plug P across whose cords is connected the holding coil H into the second jack of the trunk line, withdraws the regular talking plug from the other jack of the trunk line, and inserts the same into the jack corresponding to the party with whom the party on the trunk line wishes to talk, and presses the ringing button, which rings the bell of the called party. As soon as the called party answers, he is notified by the party at the answering station to answer on the exchange line; the called party takes the plug out of the intercommunicating jack and inserts the same into the trunk jack and the answering party withdraws both plugs from the jacks, restoring this station to its normal condition. When through talking, the receiver is hung up, which automatically gives the disconnect signal at central. To talk with an exchange subscriber, the intercommunicating subscriber merely inserts his plug in his trunk jack and takes down his receiver; this operates the exchange line signal and the exchange operator connects this line with the exchange subscriber desired in the usual manner.

29. Stromberg-Carlson System.—In Fig. 14 is shown the central-energy intercommunicating system made by the Stromberg-Carlson Telephone Manufacturing Company and the way in which it may be connected to a telephone instrument belonging to a magneto-exchange system. One may communicate from any station on the intercommunicating system with outside parties, but the central exchange cannot be called, nor can the central-office operator ring the bell of any telephone belonging only to the intercommunicating system. It is necessary to place one intercommunicating telephone, which is termed the answering station, near the exchange telephone, or an extension bell connected to it, so that the party who answers the exchange telephone may signal the intercommunicating station desired, and also signal the exchange operator when some one at another intercommunicating station calls up and requests the answering station to do so.

Each individual line wire is connected through one of the impedance coils I_1, I_2, I_3, to the negative terminal of the talking battery TB. At each station, there is one push button for ringing purposes, one plug, and as many jacks as there are stations in addition to one exchange jack. The left-hand jack at each station in this figure is the home jack, and the plug should normally be left in that jack. However, if the

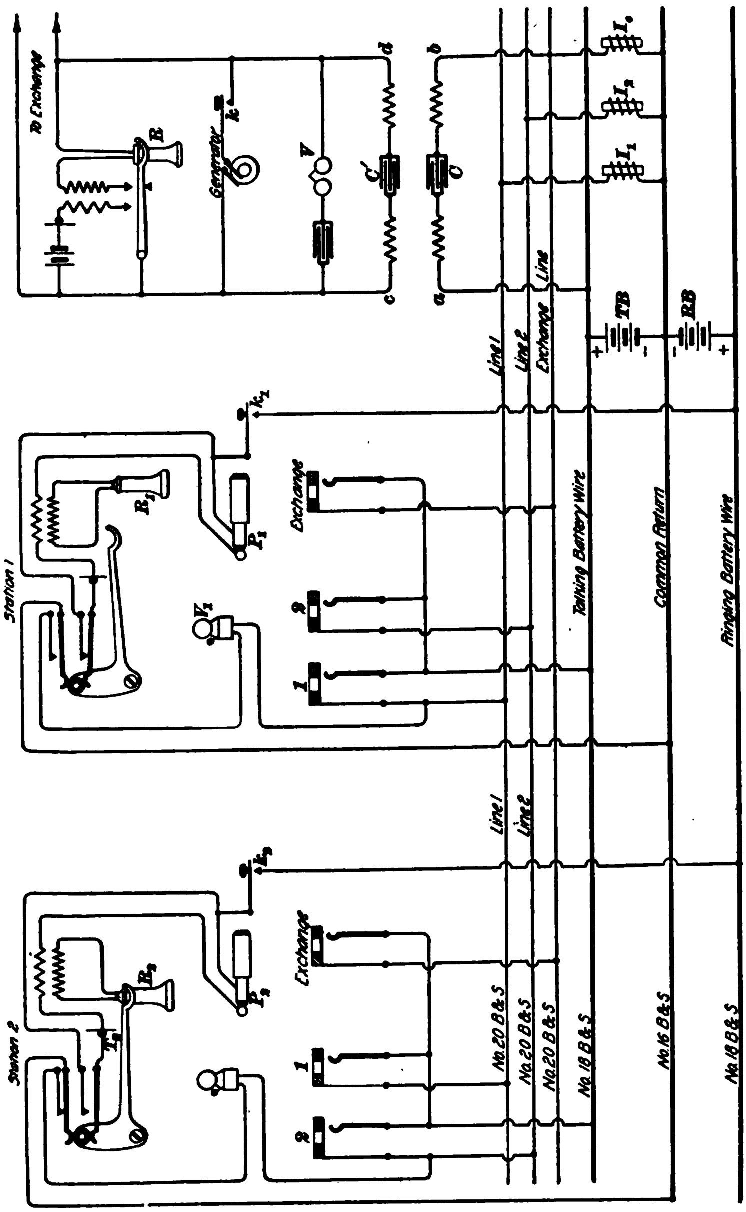

To Exchange
Generator
Station 1
Station 2
Line 1
Line 2
Exchange
Line
Talking Battery Wire
Common Return
Ringing Battery Wire
TB
RB
No. 20 B & S
No. 20 B & S
No. 20 B & S
No. 18 B & S
No. 16 B & S
No. 18 B & S

FIG. 14

plug is not in that jack, the bell can still be rung, but nothing can be heard at the station called until the plug is inserted in the home jack. The exchange telephone is connected to the intercommunicating system by means of the repeating coil *a b*, *c d*. The condenser *C*, connected in the middle of the winding *a b*, prevents a constant waste of current from *TB* through this winding, and the condenser *C'* is necessary to avoid short-circuiting the ordinary 1,000-ohm polarized bell *V* in the exchange telephone instrument. In the cable made especially for this system, the two battery and common-return wires are covered with weather-proof insulation and the other line wires with two reverse layers of cotton, heavily paraffined.

30. Operation.—If station *1* and the exchange instrument, or its extension bell, are the instruments located near each other and the bell connected to the exchange circuit rings, the party at station *1* answers by inserting the plug P_1 in the exchange jack and taking down the receiver R_1. After learning what party is desired, the plug P_1 is then inserted in the proper jack, and the push button k_1 closed. When the party who answers is informed that an outside party desires to talk with him, the party at the answering station returns the plug to jack *1*, its normal position and hangs up his receiver. The party at the intercommunicating station called inserts his plug in his exchange jack and communicates with the outside party through the repeating coil *a b*, *c d*. By having it understood that a certain signal, say three rings, signifies that the party called is wanted on the exchange circuit, the party called can immediately insert his plug in the exchange jack, take down his receiver, and converse with the outside party.

If some one, at station *2* for instance, desires to communicate with an outside party, the plug P_2 is placed in jack *1*, and the push button k_2 closed, which causes the bell V_1 at the answering station to ring. When the party at the answering station replies, he is requested to call up the exchange, which he does by first hanging up his own receiver, and then turning the generator in the exchange instrument, the circuit at *k* being automatically closed when the armature revolves. In the meantime, the party at station *2* withdraws his plug from jack *1* and inserts it in the exchange jack.

31. Where the exchange telephone is a central-energy instrument, an extra plug and two-way locking key are provided at the answering station. To answer on the exchange circuit, the extra plug is inserted in the exchange jack, the receiver taken down, and the key thrown forwards, which connects that station's talking circuit across the exchange line. On learning the station desired, this key is thrown in the opposite direction, thereby connecting across the exchange line an impedance coil whose resistance is such that the disconnect signal at the exchange is not operated, and thus the line is held. The regular plug at the answering station is then used in the regular manner to call up the local party desired who is requested to answer on the exchange line. The party at the answering station then returns the regular and extra plugs to their normal positions. If, however, the answering station fails to do this, the hanging up of his receiver will automatically open the impedance coil and talking circuits so that the disconnect signal at the exchange may be given when the receiver at the intercommunicating station is hung up.

32. Holtzer-Cabot System.—In Fig. 15 is shown one way in which local-battery telephone instruments of an intercommunicating system may be connected with the instrument located at station *3*, which is supposed to be connected with a central-energy city-exchange system. No change whatever is made in the wiring of the central-energy instrument, which is located at station *3*, the line wires simply being connected from the binding posts *a*, *b*, to the pair of wires *3* running through all the stations in the intercommunicating system. At station *1* is shown the plan of wiring used by the Holtzer-Cabot Electric Company in connection with its Ness automatic intercommunicating switch, which will be presently described. The two levers *w*, *v* are insulated from

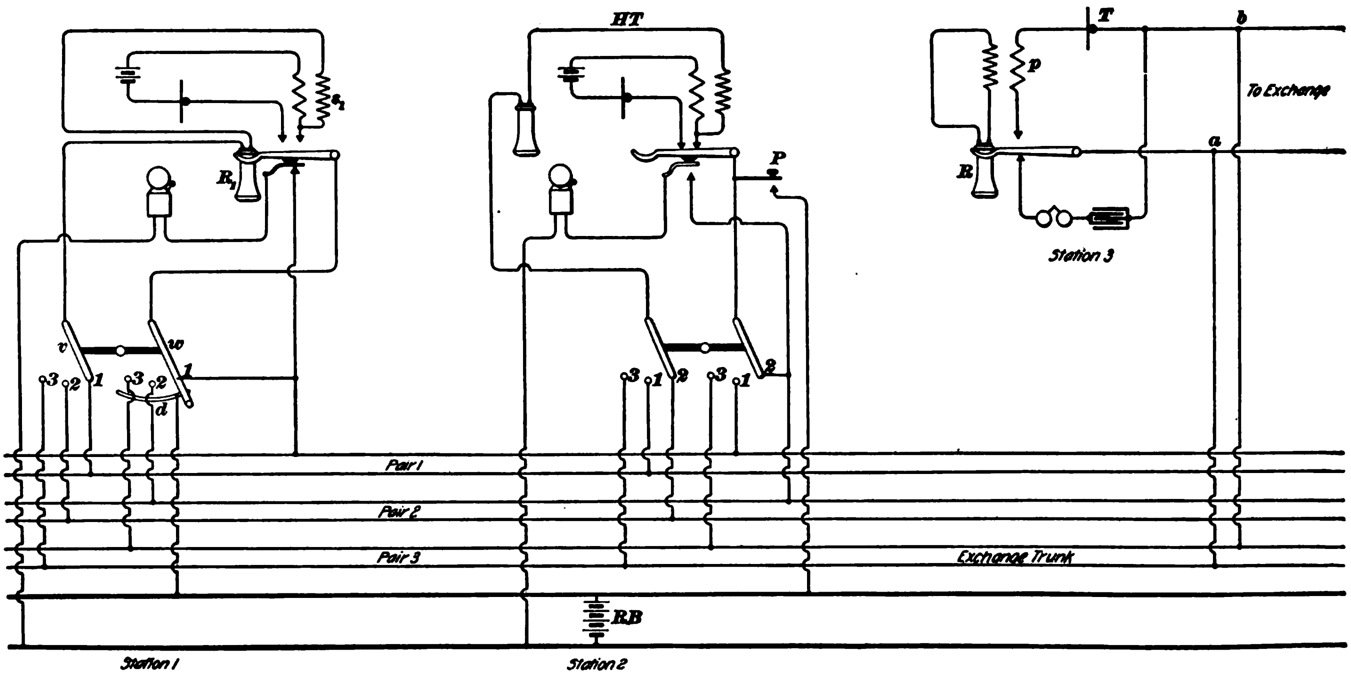

HT
T
b
p
To Exchange
a
R_1
s_1
R
P
Station 3
v
w
3
2
1
d
Pair 1
Pair 2
Pair 3
Exchange Trunk
RB
Station 1
Station 2

Fig. 15

each other, but mechanically connected together, so that moving *w* by its handle moves both levers. Pressing the lever *w* by its handle against the strip *d* allows current to flow from the ringing battery *R B* through the contact button and line wire to which *w* is turned.

33. At station *2* is shown practically the same arrangement, except that an automatic switch is not necessary and a push button *P* is used in place of the ringing strip *d* in the Ness automatic switch. If the city-exchange instrument is operated on the central-energy plan, the resistance of the secondary s_1 and the receiver R_1 must be of approximately the same resistance as that of the transmitter *T* and primary coil *p* in the central-energy system, in order that hanging up and taking down the receiver at the intercommunicating telephones will properly operate the signals at the central-energy exchange. The central-energy exchange may be called up from any instrument on the intercommunicating system, by turning the intercommunicating switch, in this case to contact *3*, and taking the receiver off the hook. It is impossible and not usually necessary for the exchange to ring the bell at any of the intercommunicating telephones, and for this reason one of the intercommunicating instruments must be placed alongside the exchange instrument. The party who answers the exchange instrument at station *3* must call up the proper intercommunicating station, by means of the intercommunicating instrument alongside it, and inform the party who answers to turn his switch so as to connect his instrument with the trunk line running to the city exchange, then hang up the receiver *R* of the exchange telephone, and also the receiver belonging to the intercommunicating instrument at the answering station.

AUTOMATIC SWITCH SYSTEMS

34. With some of the older intercommunicating systems, it was absolutely necessary for the calling party to return the intercommunicating switch to the home position when a conversation was finished in order to avoid leaving the station cut out, and considerable trouble was caused by people, not accustomed to its operation, constantly forgetting to return the switch to its home position. This led to the development of the automatic-return switches and systems. An **automatic intercommunicating switch** restores all connections to their normal positions when the receiver is hung on the hook. With the ordinary intercommunicating systems as now wired, it is not usually necessary to return the intercommunicating switch to its home position in order not to leave the station cut out when the receiver is hung up, although it is desirable and often necessary before another station can converse with a station whose switch is not in the home position.

HOLTZER-CABOT AUTOMATIC SYSTEM

35. Fig. 16 shows a very reliable automatic switch manufactured by the Holtzer-Cabot Electric Company that will automatically restore the switch lever *L* to the home button when the receiver is hung up. The lever *L* is adapted to slide over the various buttons *1*, *2*, *3* and make

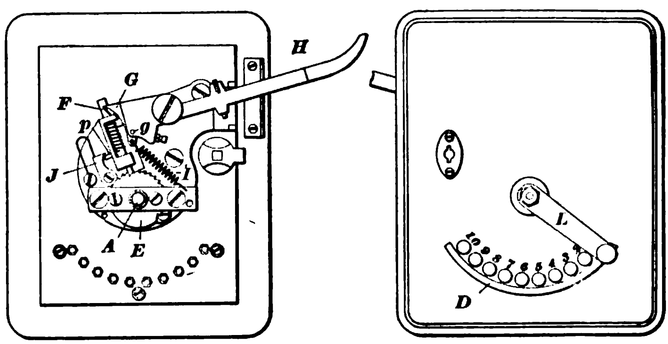


FIG. 16

contact always with the one over which it lies. The curved contact piece *D* is so arranged that the lever will not normally touch it, but, by pressure on the handle of the latter, the two may be brought into electrical contact. *H* is the usual hook switch. The lever *L* is mounted on a shaft *A* passed through the front board of the box, which shaft carries a ratchet wheel *E* of hardened steel. A coiled spring around the shaft tends to rotate it, so as to bring the lever always to the home position. *F* is a sliding pawl normally held in its lower position by a coiled spring surrounding it. This pawl is therefore adapted to retain the lever in any position to which it has been moved, by engagement with any one of the teeth on the ratchet wheel. *G* is a dog of hardened steel, pivoted at *g* on the short arm of the hook lever. This dog is pressed into engagement with a notch *F* by the spring *I*, one end of which is secured to the frame of the mechanism. When the lever *L* is moved into contact with any one of the buttons on the front of the box, the ratchet *E* is turned with it and is held from turning back by the pawl *F*. If the receiver is removed from the hook, the dog *G* passes downwards and into the notch of the pawl, it being allowed to slide over the surface of the pawl by virtue of its flexible connection at the pivot *g* with the hook lever *H*. When the user has finished his conversation, he hangs up his receiver, and the upward movement of the short end of the hook lever causes the dog *G* to raise the pawl *F* out of engagement with the ratchet wheel. At the extreme upper limit of the short arm of the hook, the dog *G* is withdrawn from the notch, so as to allow the pawl *F* to again come in contact with the ratchet wheel, in order to be in position to engage it when the lever arm *L* is next moved.

In order that the ratchet wheel and the lever may be given sufficient time to move back to the normal position, a small auxiliary dog *J* is provided, which passes under a pin *p* on the pawl when the latter is raised, and holds the pawl in its raised position until the lever arm reaches the home button, when a pin on the lower surface of the ratchet moves the dog *J* out of engagement with the pin *p* and allows the latter to drop into the home notch of the ratchet wheel.

36. Common Ringing-Battery System.—Fig. 17 shows the application of the Holtzer-Cabot automatic switch to a system having a common ringing-battery *C B*, local transmitter batteries, a common call wire, and a common talking wire. Passing through all stations, there are two common wires in addition to one wire for each station in the system. The connections of the telephone instruments are shown complete only at stations *1* and *4*. In each of these, *M* is

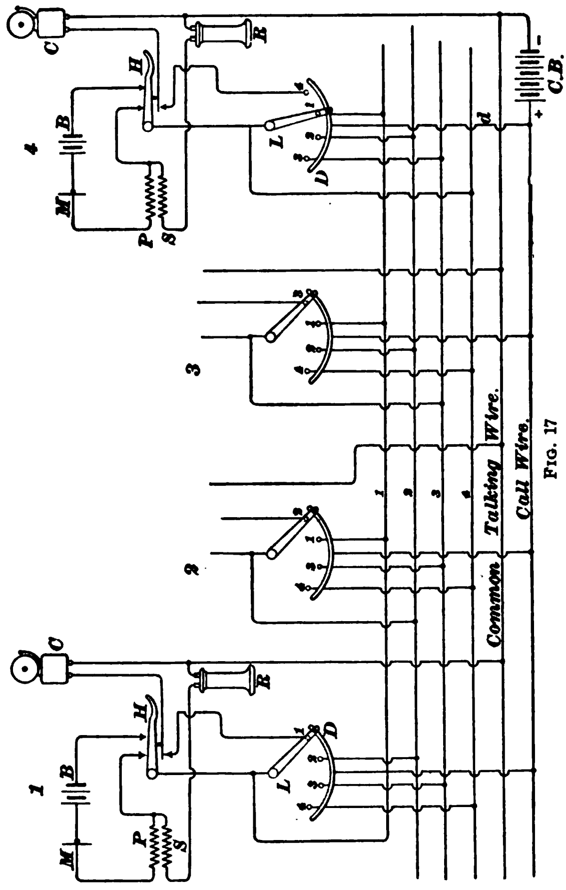


Fig. 17

the transmitter; *B*, the local battery; *P* and *S*, respectively, the primary and secondary windings of the induction coil; *C*, the vibrating call bell, and *R*, the receiver.

37. Operation.—In the position shown, station *4* is supposed to be calling station *1*, and for that purpose the lever *L* is moved into contact with button *1*, all the levers at the other stations being in engagement with their respective home buttons. When the handle of lever *L* at station *4* is depressed against the curved strip *D*, the bell at station *1* is rung. The circuit through the call bell at station *1* may be traced from the positive pole of the battery *CB* through the wire *d* to the curved contact *D* at station *4*; thence by means of the lever *L* to button *1* at station *4*, with which that lever is in contact; thence by wire *1* to the lever *L* of the switch at station *1*; thence by the button *1* and through the lower contacts of the switch hook to one terminal of the bell *C*. The return circuit is made by means of the common talking wire to the negative pole of the call battery. When both parties remove their receivers from the switch hooks,

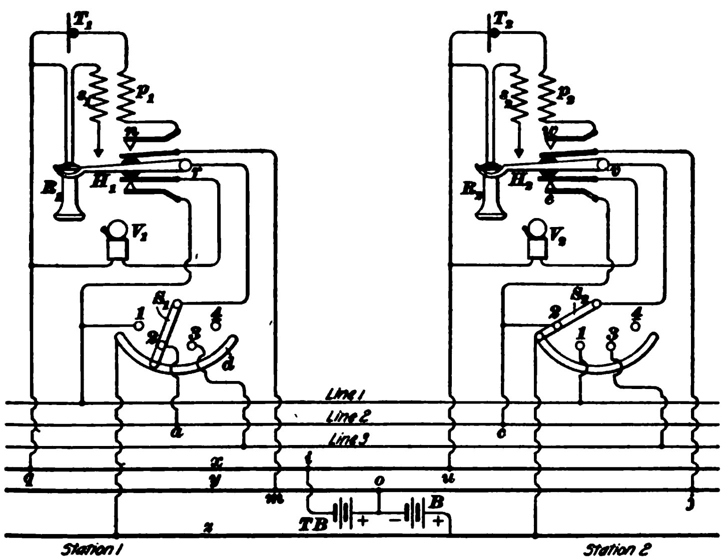


Fig. 18

the primary circuits are closed in the ordinary manner. The secondary or talking circuit may be traced from the secondary winding *S* at station *4* through the receiver *R* to the common talking wire, thence through the receiver *R* and secondary *S* at station *1* to the hook lever *H*, and thence by wire *1* to station *4* and through button *1*, switch lever *L*, switch hook *H*, and back to the secondary coil at station *4*.

38. Automatic Central-Energy System.—Fig. 18 shows the application of the Holtzer-Cabot automatic switch to a central-energy intercommunicating system. There is one battery *TB* for supplying all transmitters with current and three common conductors in addition to one for each station in the system. Both batteries *TB* and *B* are used in series for ringing the bells.

To call station *2*, turn the switch to button *2* and press the lever S_1 into contact with strip *d*, current will then flow through *B*–common conductor *z*–strip *d*–lever S_1–button *2*–*a*–line *2*–*c*–*e*–V_2–*u*–*i*–*TB* and ring the bell V_2. When the receivers are taken down, current flows through *TB*–*o*–*m*–*n*–p_1–T_1–*q*–*i*–*TB* and through a similar circuit at station *2*. Voice currents flow through s_1–R_1–*q*–common conductor *x*–*u*–R_2–s_2–*v*–S_2–button *2*–*c*–line *2*–*a*–button *2*–S_1–*r*–s_1.

COUCH & SEELEY AUTOMATIC SYSTEM

39. The automatic switch made by the Couch & Seeley Company may be applied to almost any intercommunicating system. The wiring of the telephone may vary slightly from those previously given in order to suit their special form of push-button switch. With this switch, the outside appearance of which is shown in connection with a wall telephone, Fig. 19, it is only necessary to push in a button corresponding to the number of the station with which connection is desired. The mechanism is also so arranged that each push is released and restored to its normal position when any other button is pushed in, although any number of stations may be connected together by simultaneously pushing in the necessary buttons. When the switch forms part of a wall set, it is usually arranged so that the act of hanging the receiver on the hook automatically releases any or all buttons, thereby restoring all connections to their normal positions.

Fig. 19

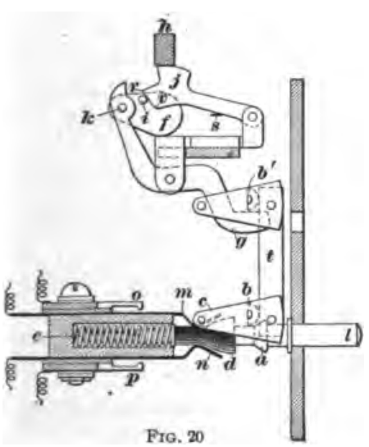


Fig. 20

40. The mechanism of this automatic switch is shown in Fig. 20. When any button *l* is pressed in, the shoulder *a* first lifts the piece *b* that is pivoted at *c*, then *b* falls in front of the shoulder *a* and holds the button in, so that the hard-rubber piece *d*, which is fastened to *l*, presses the spring *m* against *o* and *n* against *p*. When the receiver is removed and the hook lever *h* rises, a long flat spring *s*, that can be shown only in section in this figure, causes the piece *j* to follow it, and the pin *i* that is fastened to *f*, after being lifted a short distance, slides down past the point *r* into the position here shown, the piece *f* having sufficient weight for this purpose. The piece *f* is pivoted at *k* in one end of a lever. When the receiver is hung up and the hook lever *h* moves down, it pushes down *j*, causing the inclined surface *v r* to push back the pin *i* and the end *k* of the lever *k g*, thereby causing the other end *g* of the same lever to lift the system *b′ t b* so that *b* is raised above the shoulder *a* and the spring *e* returns the button *l* to its normal position. The springs and buttons are arranged in rows of five each, there being one long bar *b* or *b′* for each row, the pieces in each row being mechanically joined together by vertical bars *t* at each end, so that the lifting of one bar *b′* lifts all similar bars. In any one switch, all the springs *o* are connected together; and the springs *p* are also connected together.

By making *d* of metal and omitting the contact springs *o*, *p*, the switch may be applied to a system using one instead of a pair of wires for each station. In this case, all the lower springs will be connected together and will correspond to the lever of a strap switch while the separately insulated upper springs will correspond to the button contacts. The lowest button *r*, Fig. 19, is pressed in to ring the telephone selected and springs out again when released by the finger. It is not controlled by the automatic device.

41. Automatic Common-Battery Metallic-Circuit System.—The Couch & Seeley Company applies its push-

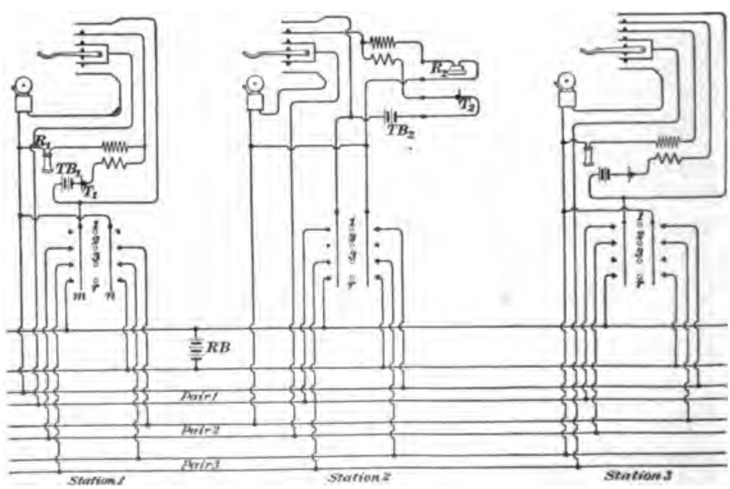


FIG. 21

button and automatic restoring switch to various systems, including the one illustrated in Fig. 21. In this figure, *m* and *n* represent two metal pieces used in the place of the levers shown in Fig. 11. By pressing the push button *1*, *2*, or *3*, Fig. 21, the corresponding contact springs on each side are firmly held against the pieces *m* and *n*. The springs corresponding to the home station (opposite push button *1* at station *1*, and opposite push button *2* at station *2*, etc.) are blank because they are not required. The push button *r* at the bottom of each switch is used for ringing purposes, and, unlike the other push buttons, returns to its normal position as soon as released. The other push buttons only return to their normal positions when the receiver is placed on the hook or another push button is pressed. To call up station *2*, for instance, the push button *2* at station *1* is pressed and will remain in. Then the ringing push button *r* is pressed long enough to ring the bell at the desired station, after which the receiver is removed from the hook. The conversation will be held over the wires designated as pair *2*. When the conversation is over and the receiver is hung up, the automatic restoring device will allow button *2*, which was pressed in, to spring into its normal position. If desirable, two or more buttons may be simultaneously pressed, so that several parties may be called at the same time and a consultation held, which is often a very convenient feature in large factories and other establishments. Hanging up the receiver will readily restore any number of buttons to their normal positions. Any number of telephones in pairs may be in use at a time without disturbing one another either while talking or ringing.

42. This system requires one ringing battery *RB* and one pair of battery wires, in addition to one pair of wires for each station. Only three stations are shown in this figure; nevertheless any number of stations up to ten or twenty may be used. The connections at station *2* are suitable for a hand microtelephone set, the handle, containing the receiver and transmitter, being hung up on the hook switch when not in use, and therefore requiring no switch in the handle itself. This push-button automatic switch has the advantage over the ordinary lever form of switch, in that it is easier for one station to call up and hold consultation with one or more other stations, and also the advantage due to the automatic return of the switches to their normal positions when the receivers are hung up. The same form of switch and automatic restoring device is applied also to the method of wiring shown in Fig. 11. At station *3*, Fig. 21, is shown an arrangement preferable in one respect; namely, no current can flow from *R B* through the receiver when the ringing push button *r* is closed, because this circuit is open at an extra contact spring on the hook switch when the receiver rests on the hook.

DE VEAU AUTOMATIC SYSTEMS

43. Automatic Common Battery-Ringing System. Fig. 22 shows the application of the De Veau automatic switch to an intercommunication system having one common battery *R B* for signaling purposes and one wire per station in addition to two common wires running through each station. At station *1* is shown the automatic switch mechanism and the wiring of a wall set; the general appearance of the same set with the back open is shown at station *2*. Since the principle of the automatic switch is practically the same for all sets, it is not shown in detail at stations *3* and *4*, which represent desk sets. Inside the telephone box are two insulated plates (see station *1*) s_1 called the sliding plate (same as s_2 at station *2*) and in front of s_1 in this view, the fixed plate r_1 (same as r_2 at station *2*), which is called the ringing plate. Behind these plates, in this view, are push buttons, the handles of which project through the front of the case.

44. The push-button part of the mechanism is shown separately and enlarged in Fig. 23, in which the sliding plate *s* is drawn upwards by a spring f_1, which is shown only in Fig. 22. When *a*, Fig. 23, is pressed, the shoulder *b* draws the sliding plate *s* to such a position that *b* can pass

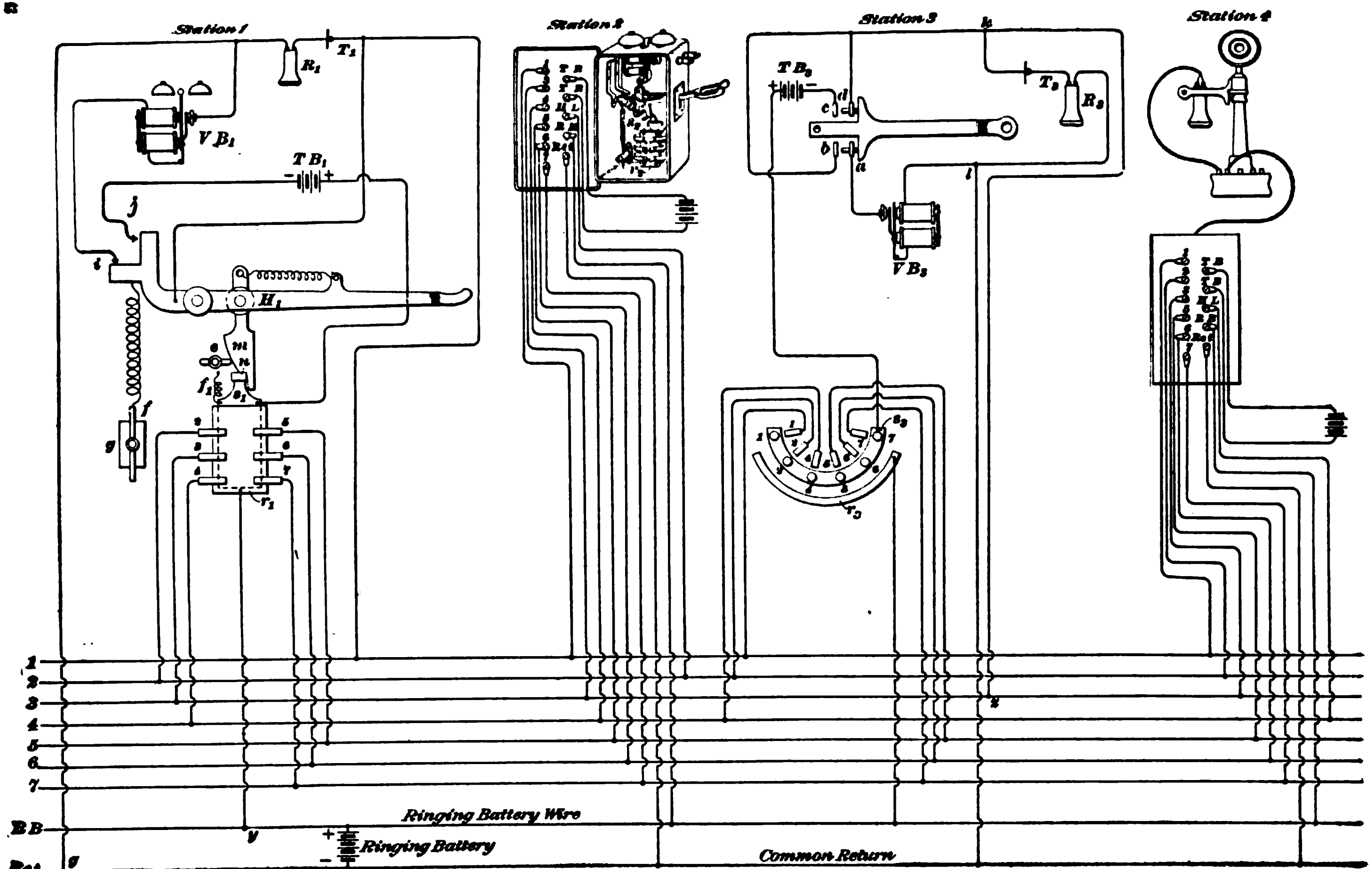

Station 1
Station 2
Station 3
Station 4
Ringing Battery Wire
Ringing Battery
Common Return
B B
Ret

FIG. 22

through the hole in it. If pressed in as far as it will go, the phosphor-bronze spring *2* will touch the ringing plate *r*. When released, the flat shoulder of *b* will be pressed upwards by spring *2*, against the rear surface of *s*, and thus keep the spring *2* in contact with the plate *s* through *b*. This is what happens when any button is pressed, whether the receiver is on or off the hook.

When the receiver is placed on the hook, *m* presses the sliding plate s_1 down and the pin *e* causes the piece *m* to move to the right until the end *n* is released by the shoulder on *m*; then the sliding plate s_1 is drawn up by the spring f_1. As the sliding plate moves down and all the holes in it come just opposite the shoulders on all the push-button rods, all the push buttons that may have been pressed in are pushed out by their springs *2*, *5*, Fig. 23, to their normal positions as the hook switch moves down. At *g*, Fig. 22, is shown a convenient arrangement for adjusting the tension of the spring *f*. No induction coils are used and, when talking, the two transmitters, two receivers, and one talking battery are connected in series between the common return and one of the other wires. Good results can readily be obtained by this arrangement for ordinary intercommunicating systems where the lines are not unusually long.

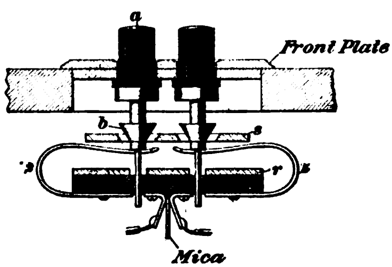


FIG. 23

45. Operation.—To call station *3* from station *1*, press in push button *3* as far as it will go. Current then flows from the positive terminal of the ringing battery through y–r_1–*3*–line *3*–*z*–*k*–*b*–*a*–VB_3–*l* to the negative terminal of the ringing battery. But very little of the ringing current will flow from *k* through T_3–R_3–*l*, because the path through *k*–*b*–*a*–VB_3 has much less resistance. The bell has a resistance of only about 3 ohms, while the receiver has a resistance of about 10 ohms, and the transmitter anywhere from 25 to 85 ohms. The spring *3*, when released, returns part way and rests against the sliding plate s_1. When both receivers R_1 and R_2 are removed from their hooks, current flows from $+TB_1$ through s_1–*3*–line *3*–*z*–*k*–T_2–R_2–*l*–common return–*g*–R_1–T_1–H_1–*j* to $-TB_1$, thus enabling the two parties to hold a conversation. One station can call up and hold a consultation with several stations by simultaneously pressing in the buttons corresponding to the stations wanted. The several stations called will be in parallel with each other, and in series with the station that called them. The talking efficiency will be diminished somewhat, but not enough to prevent a consultation between three or four parties.

The current from the talking battery flows in one direction through the receiver, when a station originates a call, and in the opposite direction when the station answers a call. Hence the current tends to demagnetize and weaken the receiver when it flows in one direction. It is doubtful if the strengthening effect when the current flows in the opposite direction fully eliminates this objection.

46. Secret Button System.—The DeVeau system may also be wired as shown in Fig. 24. The lower right-hand button *w* on each switch is called the secret button and controls the key, or switch K_1, which is drawn larger and a little out of its real position in order to show it better. By means of this button, a secret conversation can be held between any two stations and no one on the system can break in or hear what the two persons are talking about. This is a very valuable feature in banks and other institutions. Although the switch shown at each station has a capacity for six stations, it is only necessary to show here the wiring for two stations. The wiring is very much the same as in Fig. 22. The normal positions of the automatic and secret button switches are shown at station *1*.

To ring up station *1* from station *2*, press button *1* as far as it will go, thereby ringing the bell VB_1. A conversation can be held as soon as both receivers are removed from their

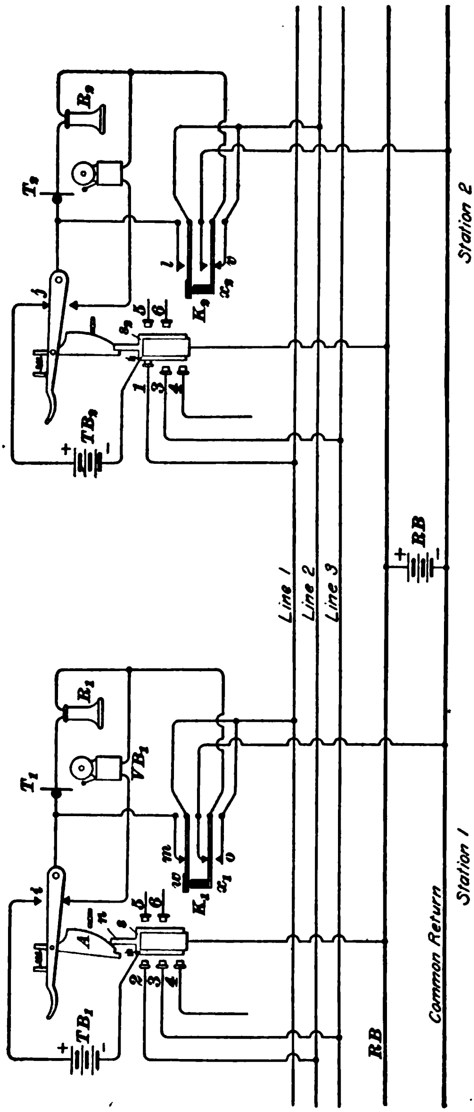

Station 1
Station 2
Line 1
Line 2
Line 3
Common Return
RB
TB1
TB2
T1
T2
B1
B2
VB1
K1
K2

Fig. 24

hooks. If it is desired to hold a secret conversation, station *2* requests *1* to simultaneously press in buttons *2* and K_1 and station *2* also presses in simultaneously the two buttons *1* and K_2. This position of the two switches is indicated at station *2*. Current then flows from TB_2 through j–T_2–R_2–x_2–v–line *2*–spring *2* at station *1*, which is now supposed to be pressed in–sliding plate s–TB_1–i–T_1–R_1–x_1–o (x_1 and o are now supposed to be in contact while w and m are now supposed to be separated)–line *1*–spring *1* at station *2*–sliding plate s_2 to TB_2. The two batteries are now in series in the talking circuit, whereas only one battery is used when the secret buttons are not pressed in. Moreover, lines *1* and *2* are now used and the common return is open at both stations, hence no third party can ring either bell, cut in, or overhear the conversation.

If any two stations are holding a secret conversation, any third station can short circuit them, if the third station knows what two stations are talking, and wants to do so. For instance, if stations *2* and *3* (the latter is not shown) were holding a secret conversation, station *1*, by pressing buttons *2* and *3*, would short-circuit lines *2* and *3* and thus interfere with the conversation, but a party at station *1* could not even then hear the conversation, for his own line *1* and also the common return would be open at both the other stations. This cannot very well be called a serious objection.

SPEAKING-TUBE TELEPHONE SYSTEMS

47. Telephones connected on this plan usually have a common talking circuit; therefore, only one conversation can take place at a time, whereas in the intercommunicating system as many conversations can take place at the same time as there are pairs of instruments. A **speaking-tube telephone system** may also mean one that provides for communication between an office and any outlying station, but not between any two outlying stations. It is not very suitable for a system having a large number of stations, but it is often a useful method where it is not desirable to go to the expense of the regular intercommunicating plan. Sometimes, the instruments of the speaking-tube system are rung up separately; at other times, the plan is such that all the telephones are rung up at the same time and a code of signals is employed so that the different stations can tell when they are called. Where a number of detached buildings some distance apart are to be connected together, a system with magneto-telephones connected in multiple is sometimes employed.

The principal plans of connecting up speaking-tube systems are as follows: (*a*) Magneto-telephones in multiple or "bridged"; (*b*) battery-call telephones in multiple having local talking and ringing batteries; (*c*) battery-call telephones in multiple, centralized talking and ringing batteries with or without induction coils; (*d*) battery-call telephones with common talking wire and selective signaling circuits. The first three systems have either been explained or are so simple as to require no explanations or diagrams.

COMMON-TALKING AND SELECTIVE-SIGNALING-CIRCUIT SYSTEMS

48. Three-Common-Wire System.—Fig. 25 is a very simple example of the fourth class of speaking-tube telephone systems mentioned in Art. **47.** At each station, there is one push button associated with a line wire running to each of the other stations. The only other apparatus necessary at each station is an ordinary battery-bell, receiver, transmitter, and hook switch. The battery B furnishes current for the transmitters and also for the bells, the line wires *1*, *2*, *3* being used only for signaling purposes. By pressing push button P_2 at station *1*, current flows through P_2 and rings the bell V_2. When the receivers are removed from their hooks, the two parties can converse, each transmitter being supplied with current from the battery B through the line wires y, z.

An arrangement of this character is intended, as its name implies, for a small system in which only inexpensive and simple apparatus is desired at each station. The wire x is not necessary, but it should improve the transmission because it puts two receivers in parallel with each other but in series with whichever transmitter is being spoken to, so that more fluctuating currents should pass through the listening party's receiver than would be the case without this wire. The current in the listening party's receiver, if wire x is not used,

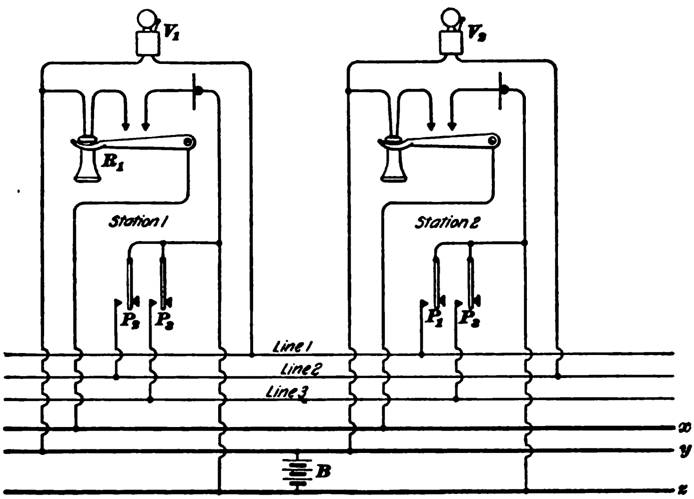


FIG. 25

would be due merely to cross-talk as it were, caused by the internal resistance of the common battery B to which both talking circuits are connected in parallel.

TELEPHONES FOR APARTMENT HOUSES

49. In the vestibules of modern apartment houses, or flats, there is usually a row of push buttons that ring bells in the different apartments and a row of speaking tubes for communicating with the tenants. Telephone systems may be used to advantage in place of the speaking tubes. The telephone systems for such cases should be very simple and all batteries should be located preferably in the janitor's quarters. Callers should be able to communicate with any tenant and any tenant with the janitor. In addition, it is sometimes desirable to arrange for communication between the tenants. It should only be necessary for a caller to press one push button associated with the telephone of the desired tenant and to take down the receiver. No system requiring the manipulation of a switch of any kind by the caller, who may not be familiar with such a system, is admissible.

50. Push-Button Bell System.—Fig. 26 shows a system suitable for apartment houses and it can be installed where push-button bell circuits have been used. The original bell circuits include the push buttons P_1, P_2, P_3, P_4 at the entrance, the bells V_1, V_2, V_3, V_4 in the various apartments,

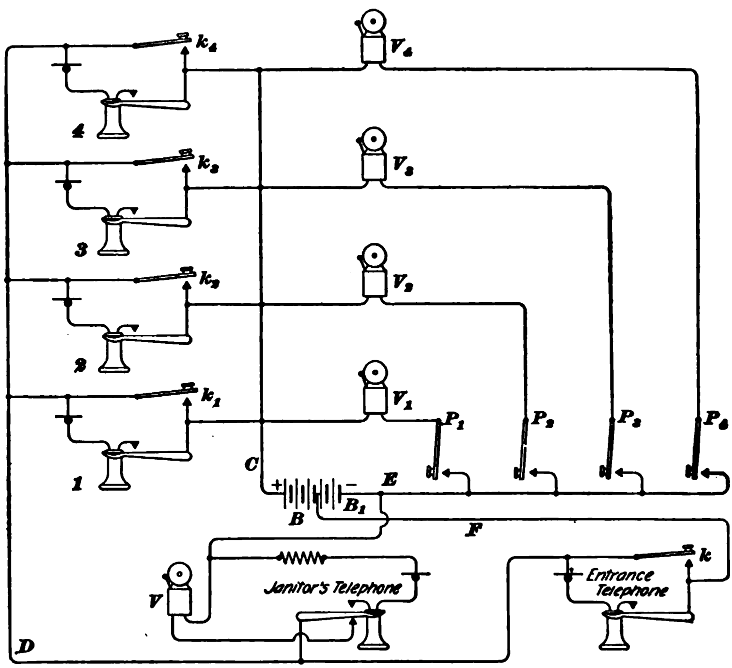


FIG. 26

the common-return wire C, and battery. It will usually be necessary in order to place a telephone in each apartment to run a third wire D or to use a ground return in its place. In each apartment, there is a simple telephone with a transmitter and receiver in series, a push button and a battery bell. One terminal of the entrance telephone is connected to an intermediate point in the battery in order that it may be used to talk with either the janitor or tenants. In most cases, the entrance telephone would be nearer the janitor's telephone than any tenant's telephone, hence a fewer number of cells would be required in B_1 than in B, while the entire battery would be required for conversations between the janitor and tenants.

This arrangement requires one wire from the front door to each flat for the push buttons and bells, a common con-

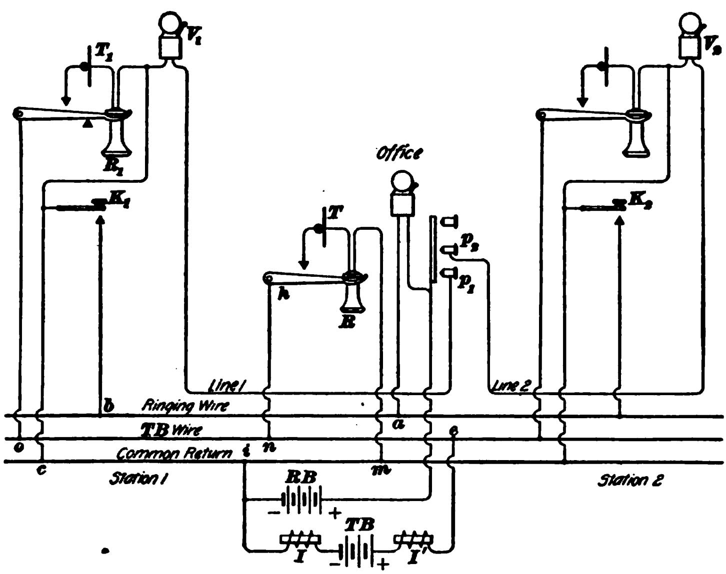


FIG. 27

ductor E from the battery to one side of all front-door pushes and to the janitor's telephone, a common conductor D from the hook switch of the janitor's telephone to the transmitter terminal of all the other telephones, a common conductor C from the battery to each telephone and bell in the various flats, and a wire F from the battery to the entrance telephone. The push buttons k, k_1, k_2, etc., when pressed, ring the janitor's bell V.

51. Couch & Seeley Speaking-Tube System. Fig. 27 shows a better central-energy speaking-tube system made by the Couch & Seeley Company. It is suitable for a house, flat, or building requiring only three or four telephones and where communication between a central office and the substations only is required. No provision is made for calling one substation from another substation, but each substation can call up the central office and the central office can call up any substation. Only push buttons are required as switches, one push button at each substation and as many push buttons at the central office as there are substations.

The battery TB supplies all the current for the transmitters; and the battery RB all the current for ringing purposes. Impedance coils I, I' are connected between the battery TB and the two wires over which flows the current for all the transmitters.

52. Operation.—To call up the central office from station *1*, for example, it is only necessary to press the push button K_1. When the receivers R_1 and R are removed from the hooks, current flows through $TB-I'-e-n$, where it subdivides, part flowing through $h-T-R-m-i$ and part through $o-T_1-R_1-c-i$, where the currents reunite and flow through I to TB. The rapidly fluctuating voice currents flow through $T_1-R_1-c-m-R-T-h-n-o-T_1$. When the central office wishes to call a substation, say station *1*, the push p_1 is pressed.

There are three wires running through all stations, and also one wire from the central office to each substation. If the parties at the central office and one substation are talking, a party at the other substation can take down the receiver and hear all that is being said. However, this system is merely intended as a simple substitute for a speaking tube, and is not supposed to meet all the requirements of a complete intercommunicating system.

53. Holtzer-Cabot Apartment-House System. Fig. 28 shows what the Holtzer-Cabot Electric Company terms its **vestibule system** for apartment houses. In the vestibule is placed a telephone, equipped with the Ness automatic switch, for calling and talking to any tenant. In the janitor's apartment is an annunciator provided with one signal and immediately below it a jack for each suite or apartment, one bell *V* through which all annunciator circuits return to the battery *B*, one plug *P* for answering ordinary calls by inserting it in the jack under the displayed signal, a pair of plugs P_1, P_2 for connecting together any two apartment telephones by inserting them in the proper jacks, and a push

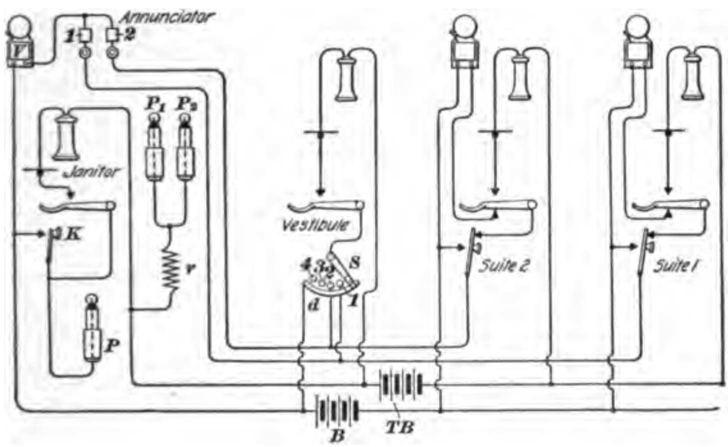


FIG. 28

button *K* for ringing, through plug *P* and the proper jack, the bell in any apartment. Each suite is provided with a telephone, bell, and push button; by means of the latter the annunciator and bell in the janitor's apartment may be operated.

To call any suite from the vestibule, the switch *S* is turned to the desired number and pressed to make contact with strip *d*, which will cause the desired bell to be rung with current from *B*. When the two receivers are taken down, the talking battery *TB* is connected in series with the two transmitters and two receivers. Hanging up the receiver in the vestibule restores the switch to its normal home position.

HOTEL TELEPHONE SYSTEMS

54. In a hotel, any small switchboard system can be used, but it is customary to install only those systems that require no batteries in the telephone instruments or in the guests' rooms; moreover, for the sake of economy, the substation instruments should be simple and require little or no expert attention. For these reasons, simple central-energy systems are generally employed. In most cases, communication between the substations and the office only is required, but sometimes a system is desired that will allow communication between the substations by means of plugs and jacks at the central-office switchboard, as in the simplest form of exchange systems. In large city hotels, it is becoming quite customary to install a private-branch switchboard with lines running to a telephone in each guest's room. The telephone in any room may then be connected to any other telephone in the hotel or in the entire city exchange system.

Very often a telephone system is to replace, or to be added to, an annunciator system, the wiring for which is already installed. In such cases the same wires between the various rooms and offices can and must generally be used for the telephone system. Most annunciator systems have one or two wires that run through all stations, and one or two wires that run between the office and each substation.

ANNUNCIATOR TELEPHONE SYSTEMS

55. Automatic Switch System.—Fig. 29 shows a Couch & Seeley system suitable for a small hotel. The office is equipped with a telephone, an annunciator, and a Couch & Seeley automatic switch, a talking battery TB, two impedance coils i, j, and a ringing battery RB. From the office annunciator, one wire runs to each station and two wires, the common-return and ringing-battery wires, run through all stations.

To call station *2* from the office, press in button *2* (which will remain in until the office receiver R is taken down and hung up) and also press the ringing push button *p*; the bell V_2 will ring until *p* is released by the finger. When both receivers have been taken down, the transmitter circuits of the two telephones are in parallel, both being supplied with current from the battery *TB* through the impedance coils *i*, *j*.

To call the office from station *1*, press the push button k_1,

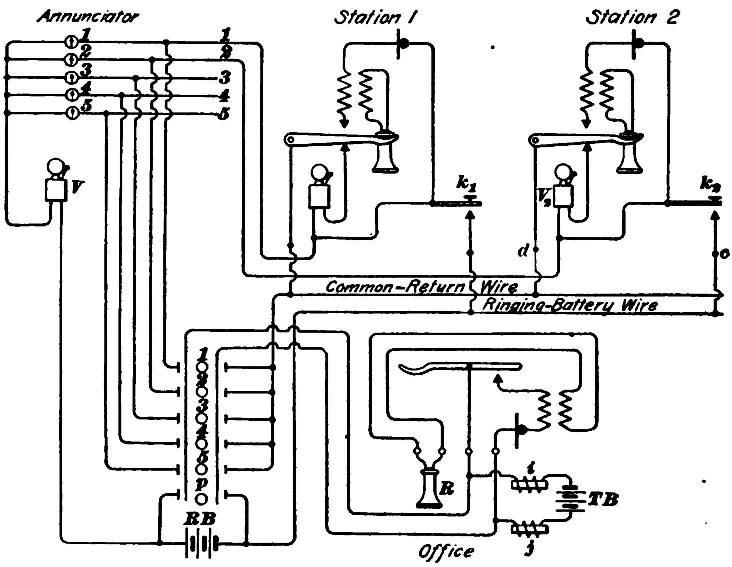


FIG. 29

which will operate the annunciator *1* and bell *V* in the office. The office attendant pushes in the corresponding button *1* on the automatic switch, restores the annunciator, takes down his receiver, and attends to the call.

HOTEL SWITCHBOARD SYSTEMS

56. Communication Between Office and Substations Only.—In Fig. 30 is shown a simple hotel switchboard system that admits of communication between the office and any substation and vice versa, but does not admit of cross-connecting between any two substations. The connections

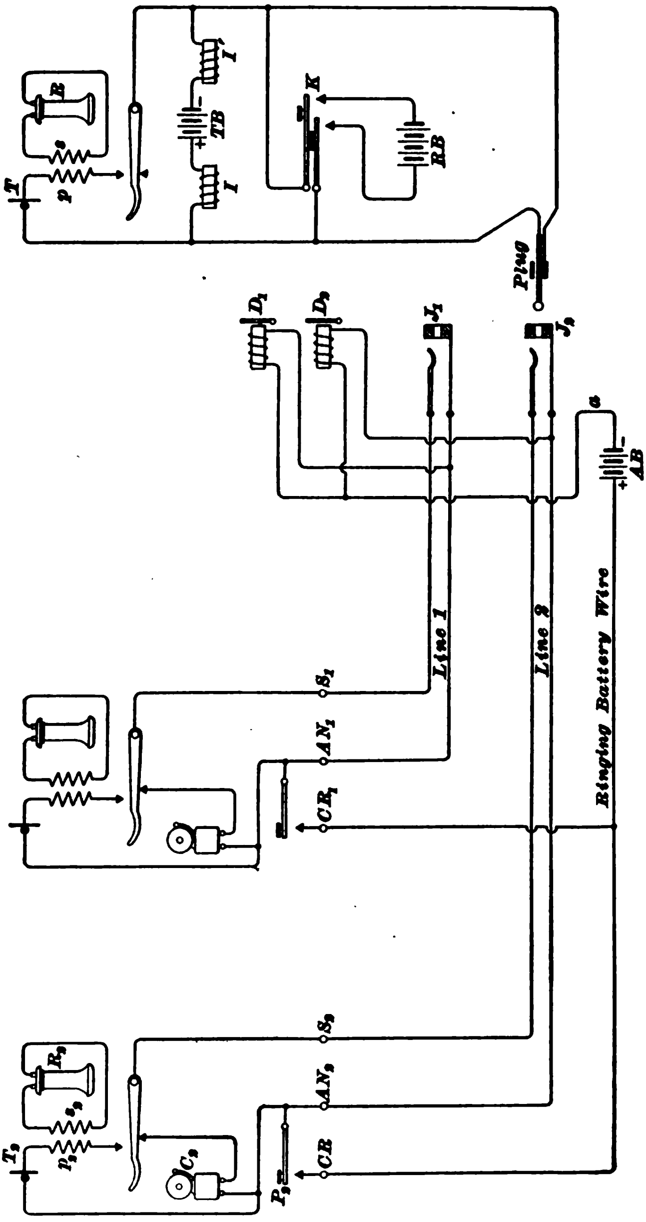

T
R
s
p
I'
TB
I
K
RB
Plug
D_1
D_2
J_1
J_2
a
AB
Line 1
Line 2
Ringing Battery Wire
S_1
AN_1
CR_1
S_2
AN_2
CR
R_2
s_2
T_2
p_2
C_2
P_2

Fig. 30

are practically the same as in a system made by Couch & Seeley Company. All batteries are centrally located. D_1 and D_2 represent the annunciator electromagnets of an ordinary hotel annunciator, and J_1 and J_2, the spring jacks of a simple plug switchboard. One ringing-battery wire runs from the office through all stations and a pair of wires from the office to each substation. The talking battery *TB* is connected through two impedance coils I, I', to the cords of the plug and supplies all the current for talking purposes. The substation instrument can be simplified and cheapened by connecting the receiver and transmitter directly in series, omitting the induction coil. The spring jacks and plug may be replaced by a simple, or automatic, two-wire intercommunicating switch.

57. Operation.—Any substation calls the central office by merely pressing a push button, and it makes no difference whether the substation receiver is on or off the hook. For instance, the pressing of P_2 operates the annunciator D_2, the annunciator battery *A B* supplying the current; the office attendant inserts the plug in the correspondingly numbered spring jack J_2 and takes the office receiver *R* off its hook. Conversation can then be carried on between the central office and substation *2*.

To call up any substation, as *2*, the office attendant inserts the plug in jack *2* and closes the ringing key *K*, thereby ringing the bell C_2. When both receivers R_2, *R* are removed from their hooks, the two parties can converse. *R B* and *A B* may be the same battery and, if desired, a bell or buzzer may be included in the circuit at *a*, so that it will ring whenever any drop is operated.

58. Communication Between Any Two Stations. The simple system shown in Fig. 31 allows communication not only between the office and any substation, but also between any substations through the office plug board; this is a system designed by Couch & Seeley Company for ordinary hotels. It requires one wire from the office to each substation and two wires common to all stations. All

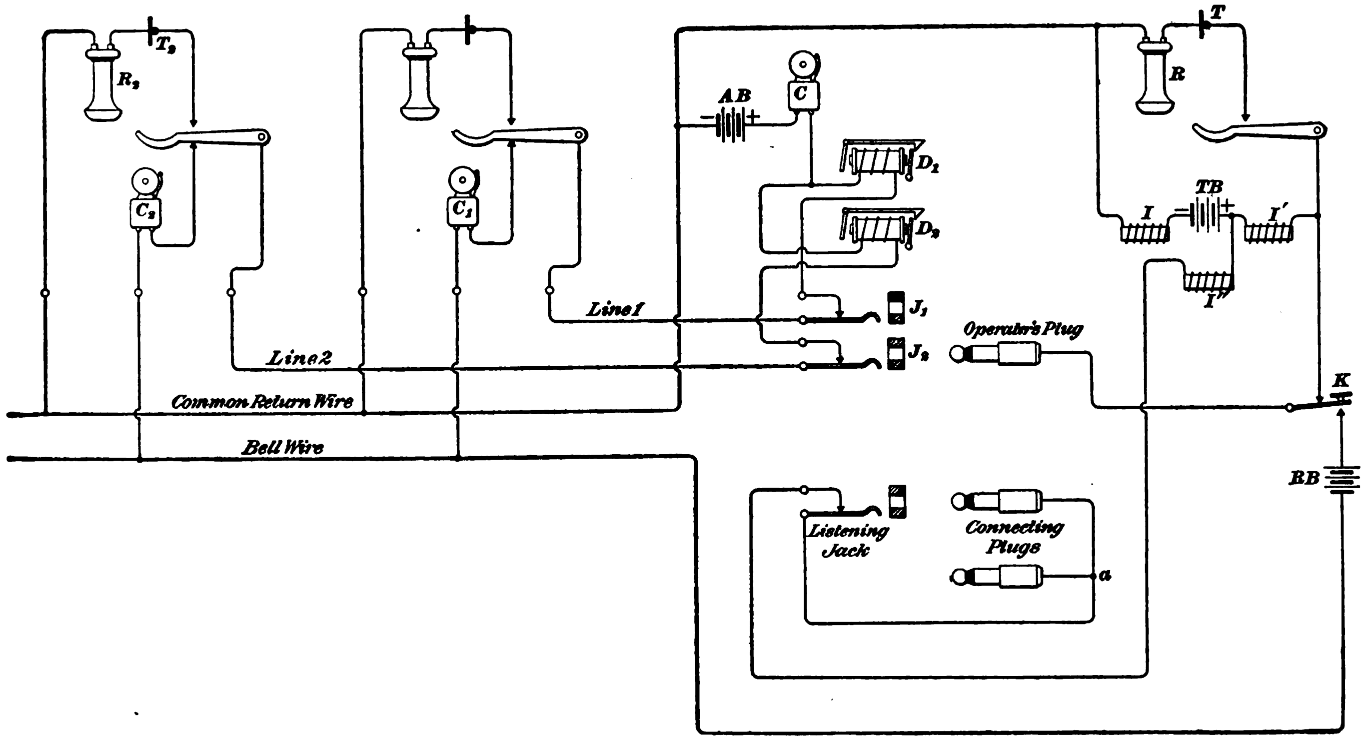

T
R
TB
I
I′
I″
K
RB
AB
C
D_1
D_2
J_1
J_2
Operator's Plug
Connecting Plugs
a
Listening Jack
Line 1
Line 2
Common Return Wire
Bell Wire
T_2
R_2
C_2
C_1

FIG. 81

batteries are located in or near the central office, where an ordinary annunciator, plug board, connecting cords, and plugs are also provided. This is not intended for use where more than two substations would need to be connected together at any one time, although there could be two or more listening jacks and two or more pair of connecting plugs. Only three impedance coils I, I', I'', one talking battery TB, one bell battery RB, one annunciator battery AB, one office bell or buzzer C, one listening jack, one operator's plug, and one pair of connecting plugs would be required, no matter how many stations there may be on a small system, for which this arrangement is only intended.

59. Operation.—The removal of a receiver at a substation is all that is necessary to call up the office. For instance, if R_2 is removed from the hook, current flows from $+AB$ through C–D_2–J_2–line 2–T_2–R_2–common-return wire to $-AB$; thus operating the annunciator D_2 in that line and ringing the bell C. The office attendant inserts the operator's plug in the correspondingly numbered jack J_2. The plug, when inserted, connects with the line spring only and opens the circuit running to the annunciator electromagnet. A conversation can then be held between substation *2* and the office. In this case, the two telephone sets are directly in series, the battery TB and impedance coils I, I' being bridged accross the wires connecting them. If substation *2* desires to talk to substation *1*, the operator's plug is withdrawn from jack J_2, inserted in jack J_1, and the ringing key K closed, thereby causing current from the ringing battery RB to flow through and ring the bell C_1. As soon as substation *1* replies, the operator's plug is removed, and the connecting plugs inserted in jacks J_1 and J_2, then the parties can converse. While substations *1* and *2* are conversing, current from $+TB$ flows through the impedance coil I'' and listening jack to the point a, where it subdivides, flowing through line wires *1* and *2* and substations *1* and *2* to the common-return wire, where the currents reunite and flow back through I to $-TB$. For the voice currents, the two substations are in series through the wire connecting the two plugs, and also a portion of the common-return wire between the two substations.

The office attendant must insert the operator's plug in the listening jack to determine, by listening, when the conversation is completed. When listening, the coil I' is substituted for I'' and the operator's set is practically in parallel with the two substations. When the conversation is completed, all plugs are withdrawn and the annunciators restored to their normal position.

60. Return-Call Annunciator-Telephone System. In Fig. 32 is shown a Holtzer-Cabot telephone system, suitable for a hotel. Since exactly the same line wires are used as in the Holtzer-Cabot return-call annunciator system, it is a simple matter to convert their return-call annunciator system into this telephone system. If the push button K_1 is pressed, current flows through TB–K_1–e–push button P_1–bell V_1–H_1–c–TB and rings the bell V_1 at station *1*. When the plug P is inserted in the jack J_1 and the receivers R, R_1 are removed from their hooks, the office and station *1* may commence talking with each other, the talking battery TB supplying current for both transmitters. No induction coils are used in this arrangement, the transmitters and receivers being connected directly in series with the line circuits.

61. To call up the office, for instance from station *2*, push button P_2 is pressed, and current flows from the annunciator battery AB through P_2–line *2*–J_2–K_2–annunciator drop A_2 and bell V, thereby causing the shutter of annunciator A_2 to fall and the bell V to ring. The central-office attendant responds by inserting the plug P in jack J_2 and restores the annunciator A_2. If the party at station *2* desires to communicate with station *1* for instance, the operator will remove the plug P from jack J_2 and insert the plugs M, N in the jacks J_1, J_2. In this case, the battery B supplies current for talking. The two circuits now connected together may be traced from B through the ring-off drop O–plug M–jack J_1–line *1*–transmitter T_1–receiver R_1–hook H_1–c–d–H_2–

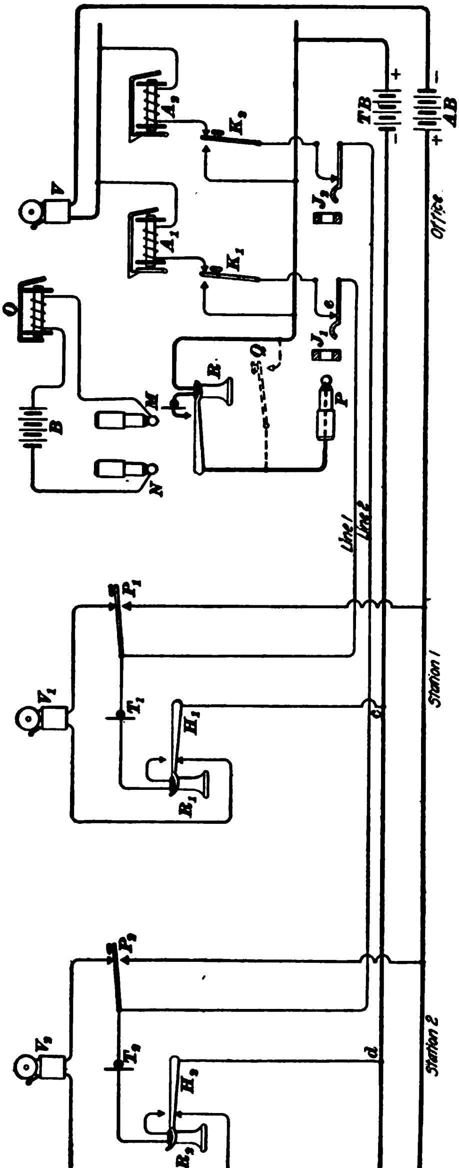


FIG. 32

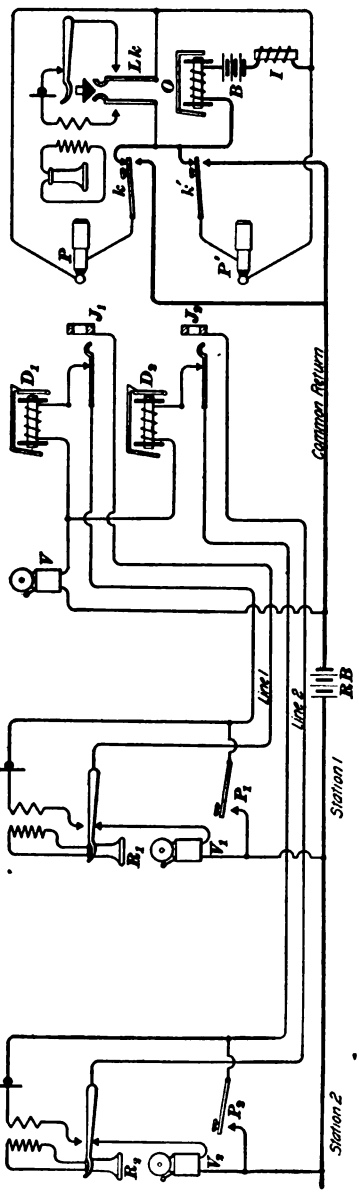


FIG. 33

R_2–T_2–line 2–jack J_2–plug n–battery B. Neither battery TB nor AB can now send current through the circuit just traced. When the receivers are hung up, the circuit is broken at the hook switches, and hence current from battery B can no longer flow through the clearing-out drop O, and its shutter is released, this drop being so constructed that it does not show a signal when sufficient current flows through it to hold up its shutter.

It is not necessary in this system to have a double-contact push button, such as K_1, in each circuit, but instead, one simple push button may be connected as shown at Q, and the contact e in each jack permanently connected to the corresponding annunciator. In this case, each annunciator will be connected direct to one contact spring in its corresponding jack. It will then be necessary, in order to ring up any station, to first insert the plug P in the jack belonging to the desired station, and then to press the push button Q.

This system requires one line wire between the office and each station, and two wires that run from the office through all the stations.

62. Holtzer-Cabot Hotel Switchboard System.—In Fig. 33 is shown what the Holtzer-Cabot Electric Company calls its hotel or school system. It has a centrally located switchboard, centralized talking and ringing batteries, and connecting cords for intercommunication between the various stations. It requires two wires between the office and each station, and one common wire running through all the stations. In the common connection of the annunciator drops is the bell *V*, which, therefore, rings whenever any annunciator shutter falls. The battery *R B* supplies current for ringing purposes.

If the push button P_1 is pressed, current from the battery *R B* will operate the annunciator D_1 and ring the bell *V*. The office attendant responds by inserting one of the plugs *P* in jack J_1 and closing the listening key *L k*. The battery *B* now supplies current for both the office and substation transmitters. Each receiver is connected in a local circuit with the secondary of an induction coil. If the party at station *1* desires to be connected with station *2*, the office attendant will insert the plug P' in jack J_2. When the receiver at station *2* is removed from its hook, the two parties may communicate; the battery *B* supplies current for both transmitters and it also energizes the clearing-out drop *O*. When the conversation is finished and both receivers are hung on the hooks, current can no longer flow through the clearing-out drop, and its shutter is released, which signifies that the two parties are through their conversation and both plugs should be withdrawn from the jacks. The impedance coil *I*, having the same resistance and inductance as the clearing-out drop *O*, causes the system to be evenly balanced.

63. Couch & Seeley Company's hotel switchboard system, shown in Fig. 34, allows communication not only between the office and any substation, but also between any two substations through the office switchboard. This system,

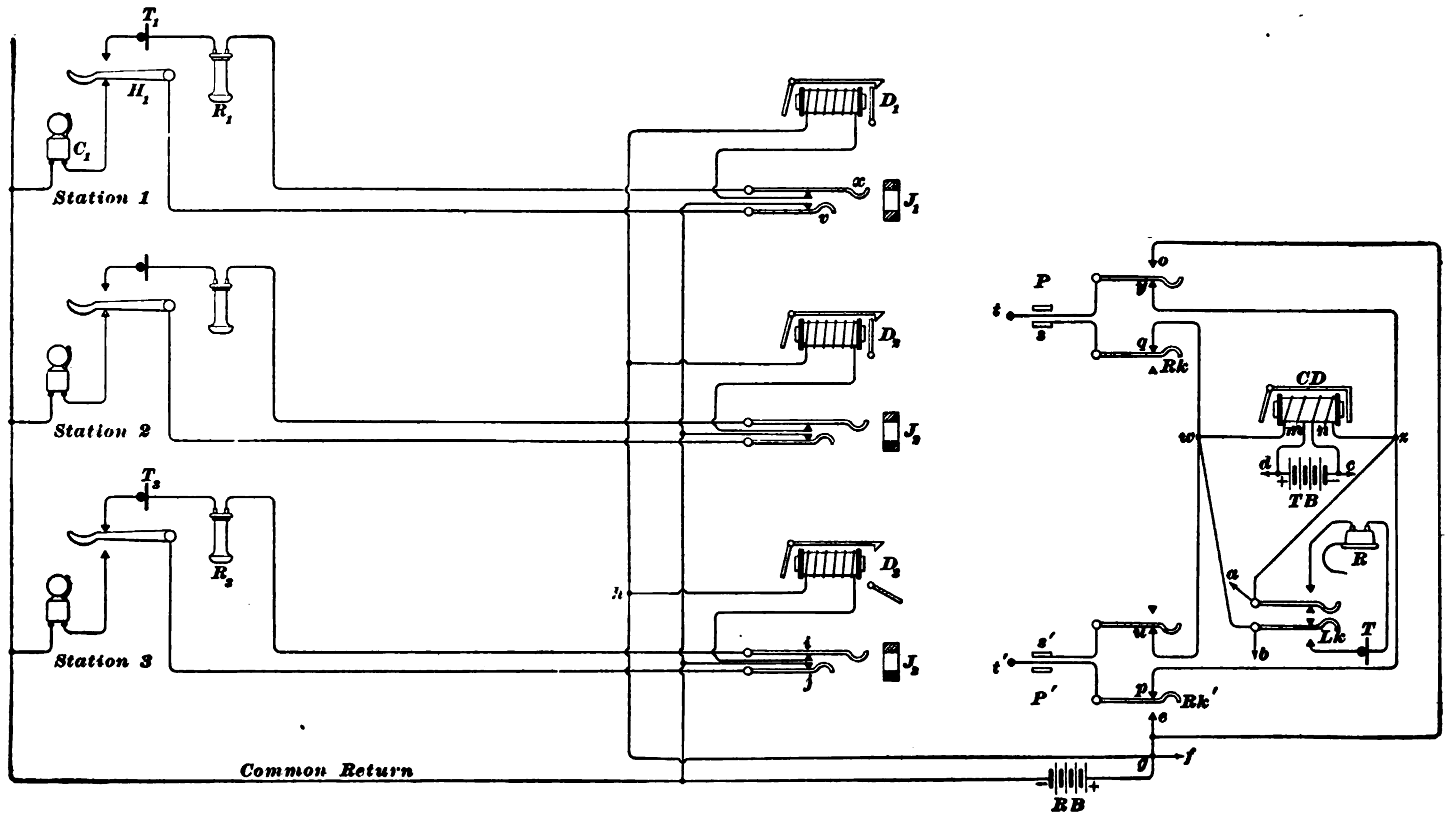


FIG. 34

being more elaborate and complete, is suitable for a larger hotel than the one illustrated in Fig. 31. It is a central-energy system, the talking battery *TB* being connected through two impedance coils *m*, *n* across each cord circuit. The two impedance coils in each cord circuit are wound on one iron core and so arranged as to constitute a clearing-out drop *CD* for that cord circuit. There is one listening key *Lk* and two ringing keys *Rk* and *Rk'* for each cord circuit. There is a separate battery *RB* for ringing the subscribers' bells and operating the line drops D_1, D_2, and D_3. From the office, there are two line wires (one pair) running to each substation and one common-return wire running through all the stations.

64. Operation.—If the receiver R_2 is removed from the hook, current flows through RB-g-h-D_3-i-R_2-T_2-j-RB, thereby dropping the shutter of D_3. The operator inserts one plug, say P', into the corresponding line jack J_3, and closes the listening key *Lk*; this bridges the battery *TB*, through the coils *m*, *n* of the clearing-out drop, across the cord circuit and also across the operator's receiver *R* and transmitter *T*, thereby supplying both the substation and the operator's set with current from *TB* and enabling the operator to converse with the substation. Furthermore, the shutter of the clearing-out drop is raised. If substation *1* is desired, the operator will insert the other plug *P* of the same pair in jack J_1 and close the ringing key *Rk*, thereby causing current to flow through RB-g-o-t-v-H_1-C_1-common return to *RB* and ring the bell C_1.

When the receiver R_1 is removed from the hook, current flows from *TB* through *m* to *w* where it divides, part flowing through q-s-x-R_1-T_1-H_1-v-t-y-z and part through u-s'-i-R_2-T_2-j-t'-p-z, where the two currents reunite and flow through *n* to *TB*. The voice currents flow through T_1-R_1-x-s-q-w-u-s'-i-R_2-T_3-j-t'-p-z-y-t-v-H_1-T_1. When both receivers are hung up, no current can flow through the coils of *CD* and the drop is so constructed that the shutter then falls. The shutter remains up only while one or both receivers are off the hook. The clearing-out signals are in a retired position when the plugs are disconnected from the jacks and when the plugs are in the jacks, but with both receivers of the connected stations on their hooks. While this would not be a very satisfactory arrangement for a large switchboard, it is found to be no great inconvenience for a small switchboard, for which this system is only intended.

65. There may be as many cord circuits and clearing-out drops as required. One operator's set may be connected to each listening key by leads *a*, *b*; the lead *f* runs to contacts *o*, *e* on each ringing key, and leads *c*, *d* to each clearing-out drop. No one plan of wiring will meet all conditions, and it is usually found that each party requiring a telephone system, whether it be an exchange, hotel, speaking-tube, or intercommunicating system, has his own ideas as to just how it should operate.

TESTING OF TELEPHONE CIRCUITS

(PART 1)

MEASUREMENTS OF RESISTANCE, INSULATION, AND CAPACITY

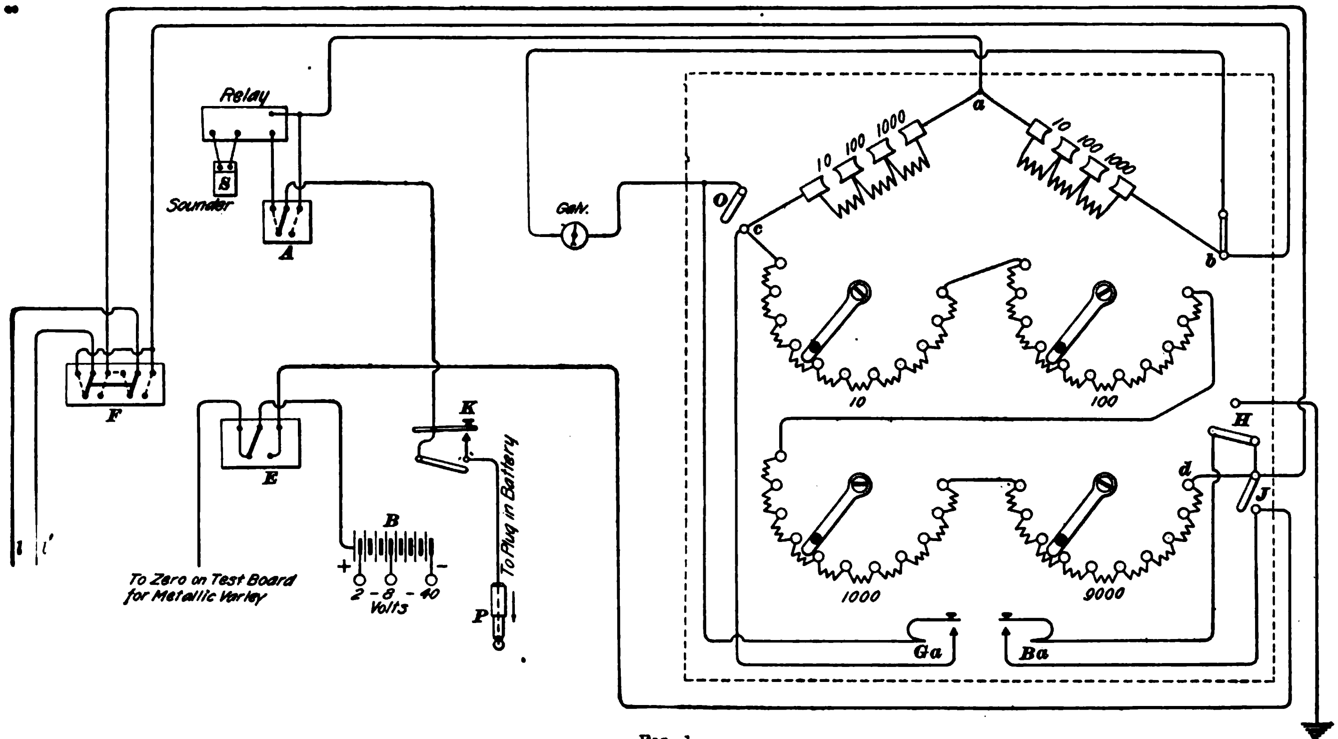
RESISTANCE MEASUREMENTS

1. The testing of circuits, line wires, and apparatus is an important matter in all branches of electrical work. The methods described in *Electrical Measurements*, Parts 1, 2, and 3, are, as a rule, directly applicable to general testing, but directions applying especially to line and cable testing will be given here.

2. The Wheatstone Bridge.—Measurements of resistance are usually made by means of the **Wheatstone bridge,** which is very accurate for all resistances except those very large or very small, and possesses the additional desirable features of great simplicity and portability. The methods of using the Wheatstone bridge have been fully treated in *Electrical Measurements*, Parts 1 and 2. However, it may be said that the form of bridge best adapted for general testing purposes has a rheostat capable of being adjusted to any resistance from 1 ohm to about 11,000 ohms. The arms by which the ratio is obtained should be capable of having the values of 10, 100, and 1,000 ohms, thus being able to obtain multipliers from $\frac{1}{100}$ to 100.

The galvanometer for ordinary resistance measurements is preferably mounted in the same case as the resistance coils of the bridge and with the keys for opening and closing the galvanometer and battery circuits. Some form of D'Arsonval galvanometer is best suited for this work. In some portable bridges, a battery is mounted in the same case with the other parts of the apparatus, this forming a very desirable feature and adding greatly to the ease with which rapid tests may be made, inasmuch as it is not necessary to carry extra batteries and connect them up every time a test is to be made.

3. Bridge Testing Set.—Fig. 1 shows a testing set including a Wheatstone bridge, galvanometer, and various keys used by the American Telephone and Telegraph Company. The arms *a b* and *a c* are the ratio arms and *c d* is the rheostat, or balance arm. The latter consists of four rotating arms; the first one controls the use of ten 1-ohm coils, the second one controls ten 10-ohm coils, the third one controls ten 100-ohm coils, and the fourth one controls nine 1,000-ohm coils. These arms are said to give fully as low resistance contacts as plugs, and they are more convenient. *J* is a switch by which the battery key *B a* may be short-circuited, that is, permanently closed. *O* is a similar switch by which the galvanometer key may be short-circuited. *H* is a switch by which the point *d* may be connected to ground. *A* is a switch by which the telegraph relay may be short-circuited and thus cut out of the battery circuit. *K* is a telegraph key or a switch by which the battery circuit may be opened or closed. *E* is a switch by which the positive terminal of the battery may be connected to the point *J* when the arm is turned to the right; when the arm is turned to the left, the positive terminal of the battery is connected to a so-called zero contact on the test board. The latter contact may be grounded. *F* is a switch that enables the connections between the two line wires *l*, *l'* and points *b*, *d* to be reversed. By means of the plug *P* and three suitable jacks connected to three points along the battery, 2, 8, or 40 volts may be obtained for testing.



Relay
S
Sounder
A
Galv.
O
c
a
b
10
100
1000
10
100
1000
10
100
1000
9000
H
d
J
F
E
K
B
+
-
2 - 8 - 40
Volts
To Plug in Battery
P
To Zero on Test Board
for Metallic Varley
l
l'
Ga
Ba

FIG. 1

4. High Resistance by Wheatstone Bridge.—A resistance x that is somewhat too high to be measured by a given Wheatstone bridge in the ordinary way, may still be determined by connecting it in parallel with as high a resistance y as can be conveniently and accurately measured with the bridge, and measuring their joint resistance z; then,

$$x = \frac{y z}{y - z}$$

When y can be accurately measured and x is not too high, this is a very good method and it may also be used to check up resistances that have been measured separately.

5. Measurement of Line Resistance.—In measuring the resistance of a line by means of the Wheatstone bridge, the terminals of the line circuit should be connected in the unknown arm of the bridge. Sometimes, it occurs in the case of a grounded circuit that earth currents will interfere to such an extent as to render accuracy impossible. In this case, if a parallel wire is available, the resistance of which is known, it may be connected at the distant end to the wire to be measured, and the resistance of the two in series measured. The resistance of the first will then be the difference between the total measured resistance and that of the known wire. Or, if both wires run on the same poles or in the same cable, so as to be of equal length and if both are the same size, then the resistance of one may be taken as half the resistance of both as measured.

If the distant end of one line wire can be grounded but cannot otherwise be brought into electrical connection with the bridge, join the available end to one post of the unknown arm of the bridge and ground the other post of the unknown arm of the bridge and also ground the distant end of the line wire. Then measure the resistance of the circuit so formed, which includes the ground resistance. The latter will have to be neglected if not known.

6. Line Resistance When Three Conductors Are Available.—The best method for measuring the resistance of a line wire, where there are three or more line wires or two line wires and a ground-return circuit, between the same two offices is as follows: Let the resistance of the three line wires be x, y, and z, respectively. At the distant station have the ends of x and y joined together, then, by means of a Wheatstone bridge at the home station, measure the resistance of the loop so formed and let it be a ohms. Then have the distant ends of x and z joined and measure the resistance of this loop, calling it b ohms. Similarly, have the distant ends of y and z joined, measure the resistance of this loop, calling it c ohms. Then, $x + y = a$; $x + z = b$; $y + z = c$. Solving these equations for x, y, and z gives:

$$x = \frac{a + b - c}{2} \qquad (1)$$

$$y = \frac{a + c - b}{2} \qquad (2)$$

$$z = \frac{b + c - a}{2} \qquad (3)$$

Hence, the resistance of any one or of each one of the three line wires may be calculated from these three measurements.

7. Resistance of Ground-Return Circuits.—The resistance of the ground-return circuit may be measured by the preceding method when there are two line wires between the two same offices. Let the resistance of the two wires be x and y ohms, respectively, and that of the ground circuit be z ohms. Measure the resistance of the loop formed by having the two distant ends of the two line wires joined together and call it a ohms. Then have the x wire grounded at the distant office and measure the resistance between the home ground plate and the home end of the x wire, and call it b ohms. Similarly, have the distant end of the y wire grounded, and measure the resistance between the home ground plate and the home end of the y wire, and call it c ohms. Then the resistance of the ground return z may be calculated by formula 3 in the last article. Usually most of this resistance z is located at the contact surfaces between the plates and the ground. The resistance of a good ground return should not exceed about 10 ohms. It is evident that the resistance of the two line wires may also be obtained by substituting the quantities a, b, and c in formulas **1** and **2** in the last article.

EXAMPLE.—It was desired to measure the resistance of two wires x and y, and also the resistance of the ground path z between two stations A and B. The party making the test at A instructed station B to join the wires x and y together. A measurement of the resistance of the loop so formed was made at A with a Wheatstone bridge, giving 2,490 ohms. The operator at B was then instructed to ground the wire x, and the operator at A measured the resistance between his end of the wire x and this ground; this gave 1,270 ohms. The operator at B was then instructed to ground the wire y, and the operator at A found the resistance between his end of y and his ground to be 1,300 ohms. What was the resistance of each wire and of the ground path?

SOLUTION.—By the formulas in the last article, in which a = 2,490, b = 1,270, and c = 1,300, we get the resistance of the wire

$$x = \frac{2{,}490 + 1{,}270 - 1{,}300}{2} = 1{,}230 \text{ ohms. Ans.}$$

$$y = \frac{2{,}490 + 1{,}300 - 1{,}270}{2} = 1{,}260 \text{ ohms. Ans.}$$

The ground path

$$z = \frac{1{,}270 + 1{,}300 - 2{,}490}{2} = 40 \text{ ohms. Ans.}$$

8. Elimination of Earth Currents.—Earth currents will often render measurements where the ground is used as a part of the circuit, as in the last method, very unreliable. These currents may oppose or aid the testing current. When the earth currents are fairly steady, their effect may usually be eliminated by making a measurement, then reversing the battery and making another measurement. The average of the two measurements should be taken as the correct result. For good results, the earth current should not only be steady but it should also be small compared with the testing current.

INSULATION AND CAPACITY MEASUREMENTS

9. The direct deflection methods, which are fully explained in *Electrical Measurements*, Part 2, are generally used for ordinary insulation and capacity tests of line wires and cable conductors.

When a number of cable conductors are bunched for an insulation test, their insulation resistance when thus connected in parallel is the same as though they were connected in series. To determine the insulation resistance per mile of single conductor, their lengths should be added. For example: 10 conductors tested in a bunch, each $\frac{1}{4}$ mile long, give a total length of 2.5 miles. Suppose the insulation resistance measures 500 megohms for the 2.5 miles of conductor, then the insulation resistance per mile is $500 \times 2.5 = 1,250$ megohms; and as each conductor is $\frac{1}{4}$ mile long, its total insulation resistance is $1,250 \times 4 = 5,000$ megohms; or, since there are 10 conductors having an insulation resistance of 500 megohms, each one has a total insulation resistance of $500 \times 10 = 5,000$ megohms, the same result as obtained above in a slightly different manner.

It is found that the insulation resistance of a conductor tested against the sheath and about 5 or 10 other conductors, including the mate of the pair tested, will be practically the same as if all remaining conductors were connected to the sheath. This is fortunate for it is often not possible, especially in a cable in use, to test more than a few pairs.

Insulation resistance may be very conveniently determined by means of a voltmeter. A very simple method used by some telephone companies is as follows: A voltmeter is purchased whose highest reading is 30 volts, for a 30-volt central-energy system, and having a resistance of exactly 10,000 ohms; then 10,000 ohms (the voltmeter alone) when connected across a battery of 30 volts gives a reading of 30. Consequently, a reading of 15 means a total resistance of $2 \times 10,000 = 20,000$ ohms, or an external resistance of $20,000 - 10,000 = 10,000$ ohms. Similarly, a voltmeter reading of 10 means an external resistance of 20,000 ohms;

a voltmeter reading of 7.5 means an external resistance of 30,000 ohms, etc. Or the following general formula may be used:

$$R = r\left(\frac{d}{d'} - 1\right)$$

in which R = desired resistance, which is connected in series with the voltmeter;

r = resistance of the voltmeter;

d = reading of the voltmeter when connected directly across the battery used throughout this test;

d' = reading of voltmeter when it is connected in series with the resistance R and the same battery used in obtaining the reading d.

10. The specifications of the American Telephone and Telegraph Company state that the capacity of a conductor varies directly as its length, whether the other conductors in the same cable are connected together in series or in multiple. For example: 10 conductors in a cable $\frac{1}{4}$ mile long measure .192 microfarad, one being measured against all the others connected to the sheath; what is the capacity per mile and per conductor? The capacity per mile is $\frac{.192}{10} \times \frac{4}{1}$ = .0768 microfarad. The capacity per conductor, which is $\frac{1}{4}$ mile long, is $\frac{.0768}{4}$ or $\frac{.192}{10}$ = .0192 microfarad. To consider the capacity to vary as the number of grounded conductors would seem to be strictly true only when one wire in each pair are connected together and tested against all other wires connected to the sheath.

LOCATION OF FAULTS

11. Classification of Faults.—Faults on a line may be of three kinds: First, the line may be broken; second, an unbroken line may be grounded at one or more points; and, third, an unbroken line may be in contact with another line. The first fault is called a *break* or an *open*, the second a *ground*, and the third, a *cross*.

A **break** may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired so as to form also a cross or ground. A **ground** or **cross** may be of such low resistance as to form a dead ground or a short circuit, respectively, or it may possess high resistance, thus forming what is termed a *leak*. The location of faults is a matter often involving much ingenuity and mathematical knowledge. The existence of a wire whose insulation and continuity are known to be good is termed a *good wire*. Such a wire is usually a great help in locating breaks, grounds, and crosses.

TESTS FOR LOCATING A BREAK

NO GOOD WIRES AVAILABLE

12. Measurements Made From One End Only, Using a Condenser.—When there is not a single good wire available, but the total capacity and length or capacity per mile of the conductor is known, the distance to a break may be determined as follows: Let d be the deflection, or throw, of a ballistic galvanometer obtained by charging or discharging through it a condenser of known electrostatic capacity C, and d', the throw when charging or discharging the broken line wire whose capacity is C', using the same battery in each case. Then,

$$C' = \frac{C \times d'}{d}$$

Now the electrostatic capacity per mile of the broken line must be known; then, by dividing *C* by this electrostatic capacity per mile the number of miles to the break is obtained. This electrostatic capacity per mile may be determined by measuring, by the foregoing method, the total electrostatic capacity of the line when it is in good condition, that is, free from breaks, grounds, and crosses and dividing this total electrostatic capacity by the total length of the line. The electrostatic capacity per mile may be obtained approximately from Table I.

TABLE I

Number and Gauge	Diameter Inches	Capacity, in Microfarads per Mile, 30 Feet Above Ground	
		Between One Wire and Ground (Grounded at Both Ends)	Wire to Wire, 12 Inches Apart
1	2	3	4
8 B. & S.	.128	.00958	.00854
9 B. & S.	.114	.00946	.00835
10 B. & S.	.102	.00935	.00818
12 B. & S.	.0808	.00913	.00785
14 B. & S.	.0641	.00892	.00754
16 B. & S.	.0508	.00871	.00726
12 B.W.G.	.109	.00942	.00828
14 B.W.G.	.0830	.00915	.00788

13. The electrostatic capacity of an overhead wire will depend on the number and proximity of other wires, and especially whether any of the neighboring wires are grounded. Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be higher. It will also vary with the number of insulator supports per mile and the moisture on them. When one overhead wire is grounded at one end and insulated at the other end, the capacity is twice as great as when both ends are grounded, that is, twice as great as the capacity given in column 3, Table I. When a high inductance, such as a high-resistance (1,200-ohm) bridging bell, is connected between one end of the line and the ground, the capacity for high-frequency currents will be very nearly as great as when the end is open and insulated.

The capacity C, in microfarads, per mile of one wire .104 inch in diameter, grounded at both ends and suspended at a height of h feet above the ground is given in Table II. If there are two such wires .104 inch in diameter, 1 foot apart, and grounded at both ends, the capacity between either wire and the ground is .01171 microfarad per mile when both wires are 20 feet above the ground, and .0115 microfarad when both wires are 30 feet above the ground.

TABLE II

h Feet Above Ground	C Microfarads per Mile
10	.010600
20	.009796
30	.009379
40	.009105

The capacity, in microfarads per mile, between two wires .104 inch in diameter, and forming one metallic circuit is .008503 when the two wires are 10 inches apart, .008218 when 12 inches apart, .007992 when 14 inches apart, .007806 when 16 inches apart, and .007649 when 18 inches apart.

14. Measurements Made From Each End, Using a Condenser.—Another method for locating a break when no good wire is available is as follows: Determine the discharge deflection d from the broken wire at one end of the cable, also the discharge deflection D from a condenser of known capacity C. Then, from the other end of the cable determine the discharge deflection d' from the other end of the broken wire, and the discharge deflection D' from a condenser of the same capacity, or preferably from the same condenser. Let L be the length of the cable; then the distance x to the break is given by the formula:

$$x = \frac{d \times L}{d + \left(\frac{D}{D'} \times d'\right)}$$

The same amount of battery must be used for the tests at each end, but the same amount of battery need not be used at one end as at the other. This method gives very satisfactory results.

ONE OR MORE GOOD WIRES AVAILABLE

15. Three Good Wires Available.—A method that has been successfully used for the location of breaks in telephone cable conductors is shown in Fig. 2, in which *V* and *B* represent any suitable means for supplying a reversible, interrupted, or alternating current, in this case a rotating device, for reversing rapidly the current from the battery *B*.

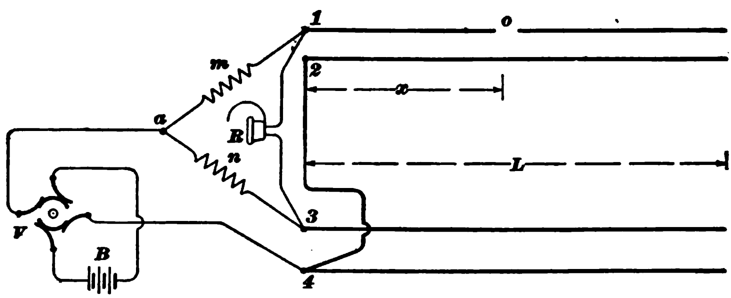


FIG. 2

The conductor *1* is open at *o*, while its mate *2* and the pair *3*, *4* are supposed to be good wires; *m*, *n* represents two adjustable arms of a Wheatstone or slide-wire bridge and *R* a telephone receiver. The connections are made, as here shown, at one end of the cable and the resistance in the arms *m*, *n* adjusted until no sound, or a minimum sound, is produced in the receiver *R*. Then the distance to the fault *o* is given by the formula:

$$x = \frac{n}{m} \times L$$

The wires *1*, *2*, *3*, *4* should be well insulated at the distant end. For cables 1,000 feet long, the battery *B* should give 60 to 120 volts, and the resistance in the arm *n* may have to be 100 or 1,000 ohms. The larger the capacity between the wires, the less need be the number of cells at *B* and the less the resistance in the arm *n*.

16. One Good Wire Available.—The capacity of the part of a wire bears the same relation to the capacity of the whole wire as the length of the part does to that of the whole. When one good wire, having the same capacity to ground per mile as the broken wire, is accessible, deflections may be taken on the broken wire and on the good wire with the distant end open.

Let d' = throw on the broken wire;
d = throw on good wire;
x = distance to break;
L = total length of good wire.

Then,
$$x = \frac{d' L}{d}$$

In a telephone cable, it is best to use the mate of the broken wire as the good wire and to ground to the lead sheath all the conductors except the one from which the deflection is being obtained. At least the mate of the faulty wire should be grounded at the testing end when the discharge deflection of the faulty wire is observed and both ends of the faulty wire should be grounded when the discharge deflection of its mate is being observed.

17. A slight modification of the preceding method, the results obtained by which it may be used to verify, is as follows:

Let d_1 = throw due to charging good wire, whose length is L with the distant end open;
d_2 = throw due to charging good wire, to the distant end of which is joined the farther part of the broken wire, this length is $2L - x$;
d_3 = throw due to charging broken wire, whose length is x.

Then, $x : d_3 = L : d_2 + d_3 - d_1$, or
$$x = \frac{L d_3}{d_2 + d_3 - d_1}$$

That this is true may be seen from the fact that d_2 is proportional to the capacity of $2L - x$; d_3, to the capacity of x; and d_1 to the capacity of L; then $d_2 + d_3 - d_1$ is proportional to the capacity of $2L - x + x - L$, that is, to the capacity of L.

EXAMPLE 1.—A test was made to find a break in a cable conductor near to which ran a good wire; the throw on the broken conductor was 35 divisions and that on the good wire was 80 divisions. What was the distance to the break, the total length of the cable being 3,100 feet?

SOLUTION.—Substituting in the formula $x = \frac{d' \times L}{d}$, gives

$$x = \frac{35 \times 3{,}100}{80} = 1{,}356 \text{ ft. Ans.}$$

EXAMPLE 2.—A break occurs in a cable 3 miles long. It is known that the capacity of the entire conductor was 1.17 microfarads or .39 microfarad per mile. On testing, it is found that with a standard condenser of $\frac{1}{3}$ microfarad and a suitable battery and shunt to the galvanometer, the deflection is 98, while with the same shunt and battery, the deflection obtained from one end of the cable is 141. How far from the testing end is the break?

SOLUTION.—Since the deflections are proportional to the electrostatic capacities of the condenser and conductor, we have, $C' = \frac{C \times d'}{d}$. Substituting the values $C = \frac{1}{3}$, $d = 98$, $d' = 141$ in this formula, gives

$$C' = \frac{\frac{1}{3} \times 141}{98} = .4796 \text{ microfarad}$$

Distance from testing end is $.4796 \div .39 = 1.23$ mi. Ans.

EXAMPLES FOR PRACTICE

1. In a test for the capacity of a cable, the capacity of the standard condenser was 2 microfarads; the throw produced by the condenser was 53 divisions, and that by the cable was 32 divisions. What was the capacity of the cable? Ans. 1.207 microfarads

2. A test was made to locate a break in a cable conductor; a good wire was accessible. The throw on the broken wire was 29 divisions and that on the good wire was 75 divisions. The length of the tested cable was 5,760 feet. What was the distance to the break? Ans. 2,227 ft.

---

18. Evans Method.—It is said that the distance to a break in a line wire that has not become grounded or crossed with another wire may be determined with considerable accuracy by the **Evans method,** which will now be explained. In Fig. 3, *I* represents an induction coil; one terminal of the secondary is grounded and the other connected to the point *A*, which is the junction of two resistances, at least one of each, say *n*, must be adjustable. *B A C* could be a high-resistance slide wire, *A* being the point that is adjusted along the slide wire, or *m*, *n* could be the two arms of a Wheatstone bridge. *B E* represents a good wire of similar size and length to the wire *C D*, which is open at some point *F*. The

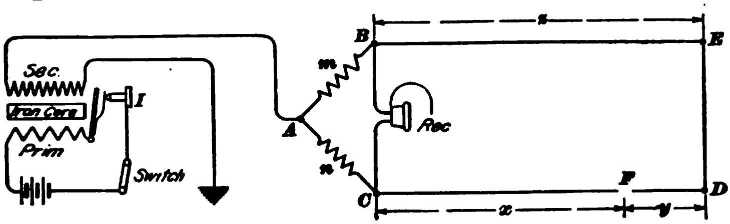


FIG. 3

ends *E*, *D* are joined together in any convenient manner. A telephone receiver is connected across the points *B C*.

Adjust the resistance *n*, or the position of the point *A*, if *B A C* is a slide wire, until the sound produced in the receiver by the current from the secondary coil, as it charges the open wires, is reduced to zero or at least to a minimum. The bridge arrangement is then balanced and we have $m : n = \frac{1}{z+y} : \frac{1}{x}$. The length of a wire is proportional to its capacity, but the opposition of a condenser to an alternating current is inversely proportional to its capacity. Hence, the resistances *m*, *n* are inversely proportional to the lengths of the open wires, as stated in the proportion. Solving the proportion for *x*, the distance along the broken wire to the break *F*, gives $x = m\frac{(z+y)}{n}$. If $z = x + y$, which is usually the case, then $y = z - x$; substituting this for *y* and solving for *x*, gives

$$x = \frac{2\,m\,n\,z}{n\,(n+m)}$$

The distances *x* and *z* may be in miles, feet, or any unit of length. If a slide wire is used, *m* is the length of the slide wire between *B* and *A*, and *n* is the length of the slide wire between *A* and *C*.

19. The method for locating a break in a line wire by comparing the capacity of the broken wire with that of a similar good wire is reliable, provided that the insulation resistance is high and the break is so complete that no current passes through the point of rupture. If, however, the cable is moist and the insulation resistance thereby low, capacity methods are not reliable. In using these methods, therefore, it is best to first measure the insulation resistance of the broken wire and also of the good wire. If the insulation resistance of the good wire is near 1 megohm capacity methods are not very reliable. The insulation resistance of the good wire should preferably be about 20 megohms in order to obtain reliable results. Breaks in cables cannot be located as accurately as grounds or crosses under favorable conditions, because the electrostatic capacity is much more non-uniform than the resistance of the wire; in fact, the electrostatic capacity of a conductor in a telephone cable may vary as much as 5 per cent.

TESTS FOR LOCATING A GROUND

20. Accidental connections with the ground occur much more frequently than breaks, and are often difficult to locate, especially if more than one ground occurs on the same line wire. Various methods for locating grounds will be given, as no one method is always applicable.

21. Ground on a Line of Known Resistance. Where there is a dead ground on a line whose length and resistance are known, it is a simple matter to locate the distance to the dead ground from the testing station. Let f be the known resistance of the line and L the length of the line, in miles; then, if the line wire is uniform in size and material, $\frac{f}{L}$ is the normal resistance of the line per mile. To locate the distance to a dead ground in such a case, measure the resistance between the home end of the line and the ground and let this be a ohms. Then, the number of miles x

from the testing station to the dead ground is given by the formula:

$$x = \frac{aL}{f}$$

EXAMPLE FOR PRACTICE

A wire touched the ground so that there was no resistance in the fault. A test was made at the station, and the unplugged resistance in the rheostat amounted to 326 ohms, a ratio of 1 being used in the balance arms. What was the distance to the fault, the resistance of the wire being 16.1 ohms per mile? Ans. 20 mi. 438 yd.

TESTS FROM BOTH ENDS WITHOUT A GOOD WIRE

22. Earth Overlap Method.—Where there is no available good wire and tests can be made from each end of a grounded wire, the **earth overlap method** may be used. It is especially valuable for the location of high-resistance

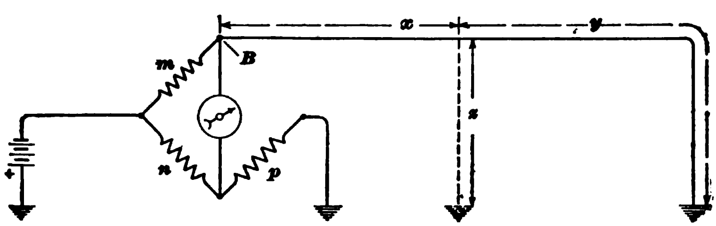


FIG. 4

faults; and experience seems to show that it is the best practical method for locating grounds in submarine cables, provided that there is only one ground and no good wire is available. Let x represent the resistance from one end of the conductor to the fault, and y the resistance from the other end of the conductor to the fault. First, measure, with a Wheatstone bridge, the resistance from the x end with the other end grounded, the connections being made as shown in Fig. 4. Call the resistance thus measured a ohms. Then,

$$a = x + \frac{yz}{y+z}$$

Second, measure, in the same manner, the resistance of the grounded wire from the other, or y, end with the other end grounded; call the resistance so determined b ohms. Then,

$$b = y + \frac{xz}{x+z}$$

Furthermore, if f is the normal or total resistance of the faulty wire, then

$$f = x + y$$

Solving these equations for x and y, gives

$$x = \frac{a(f-b)}{a-b}\left[1 - \sqrt{\frac{b(f-a)}{a(f-b)}}\right] \qquad (1)$$

$$y = \frac{b(f-a)}{b-a}\left[1 - \sqrt{\frac{a(f-b)}{b(f-a)}}\right] \qquad (2)$$

23. More accurate results are secured in the earth overlap method by sending, approximately, equal currents through the fault during the tests made from the two ends. For this

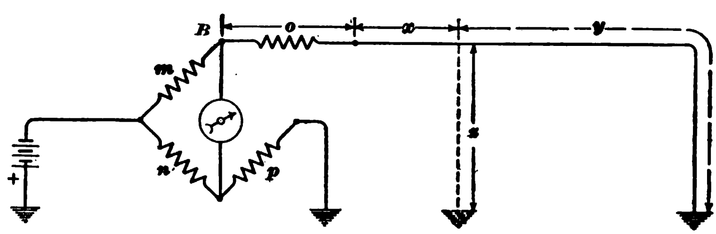


FIG. 5

reason, equal bridge ratios m, n and batteries of equal electromotive forces should be used at each end and a suitable resistance o inserted in series with the lower resistance end so as to approximately equalize the resistance on each side of the fault. The arrangement, when making the test from the lower resistance end x, is shown in Fig. 5. When this compensating resistance o is inserted in one end, the point B must be grounded, thereby leaving o in series with x, when the measurement is made from the y end, and $f + o$ must be substituted for f in the formulas given in Art. 22.

24. If o is adjusted so that equal currents flow during the measurements from each end, the formulas reduce to

$$x = \tfrac{1}{2}(f - o) \qquad (1)$$

$$y = \tfrac{1}{2}(f + o) \qquad (2)$$

The zinc, or negative, terminal of the battery should be connected toward the line and the tests in the earth overlap method should be made alternately and as rapidly as possible from each end, so that pairs of readings may be secured while the fault undergoes as little change as possible.

When one end of a good line is grounded and its resistance measured; the result, called its *apparent resistance*, will be less than the true resistance of the conductor when perfectly insulated. Better results will be obtained in the earth overlap method if for f the apparent resistance of the wire measured under normal conditions, that is, free from faults, is used, rather than its true resistance, which is usually determined from a wire table. The shorter the line or the better its insulation, the less is the error due to using the true resistance.

TEST FROM ONE END WITHOUT A GOOD WIRE

25. Blavier Test.—The **Blavier method** for locating a partial ground or an escape is about the only way where there is no available good wire and when the test must be made from one end only. However, this method is rather unreliable in practice, because, if the resistance of the partial ground changes between the two measurements, the result will be very unreliable, and moreover the normal, or total, resistance of the line must be known from some previous measurement, obtained from a wire table, or calculated from the length, size, and conductivity of the line wire. Let the total resistance of the line wire be f. First, measure the resistance of the line with the distant end open, as indicated in Fig. 6, and call the resistance so obtained b. Also, measure the resistance of the line with the distant end grounded, as shown in Fig. 7, and call this resistance c. Then, the resistance x to the partial ground from the testing station is given by the formula:

$$x = c - \sqrt{(b - c)\ (f - c)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurement, obtained from a wire table, or calculated by the length, size, and con-

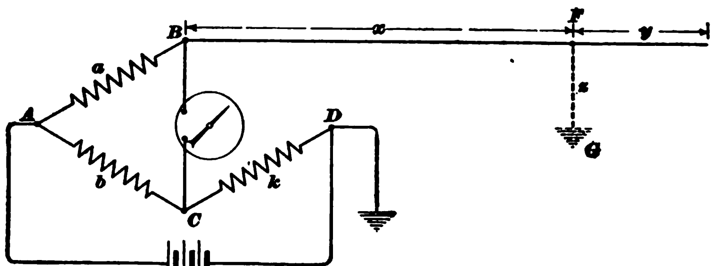


FIG. 6

ductivity of the line wire, the distance to the partial ground is obtained. If L is the length of a cable and f the total resistance of the bad wire to the distant end of the cable, the distance to the fault equals $\frac{x \times L}{f}$.

The accuracy of the result obtained by this test depends on

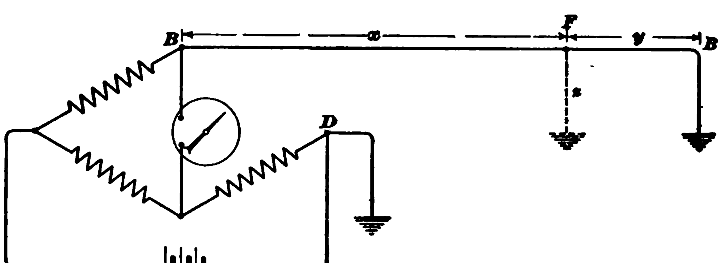


FIG. 7

the resistance z of the fault remaining the same during both measurements. The farther the fault lies from the tested station, the more accurate will be the result; so the more reliable result will be that obtained by making the test from the end farthest from the fault. However, if two faults exist, the best result is obtained by making the test at the end nearest to the one to be located. Where a series of observations is taken, the most accurate result is secured by using the lowest of all the readings taken with the distant end open and the lowest with the distant end grounded; but if the resistance of the fault is very unsteady the means of each series may be used.

NOTE.—The formula for the Blavier test is derived as follows: Let the resistance of the home end of the line to the fault F, where the partial ground occurs, be x ohms, the resistance from F to the distant end be y ohms, and the resistance of the fault be z ohms. Calling f the normal resistance of the whole line, then $x + y = f$. When the partial ground is present but the distant end open, $x + z = b$. Finally, when the partial ground is present and the distant end grounded, y and z are in parallel with each other, but in series with x; then,

$$x + \frac{yz}{y+z} = c$$

Solving these three equations for x, we get the resistance from the testing station to the partial ground or escape,

$$x = c \pm \sqrt{(b-c)\ (f-c)}$$

Evidently, the minus sign (−) must be used, because x cannot be greater than c.

26. Ayrton Test.—The Ayrton method is a modifi-

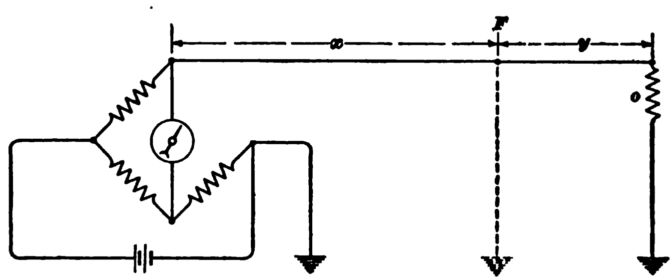


FIG. 8

cation of the Blavier, not so convenient as the latter, but suitable when the resistance f of the line is not known with sufficient accuracy for the Blavier method. Besides measuring the resistance b of the line with the distant end open and the resistance c with the distant end grounded, it is necessary to make a third measurement of the resistance d with the distant end grounded through a known resistance o, as shown in Fig. 8. Then the resistance x from the testing station to the ground at F is given by the formula:

$$x = b - \sqrt{\frac{(b-d)\ (b-c)\ o}{b-c}} \qquad (1)$$

The resistance y from the fault to the distant end is given by the formula:

$$y = \frac{(x-c)\ (x-b)}{b-c} \qquad (2)$$

Furthermore, $$f = x + y \qquad (3)$$

Then the distance to the fault equals $\frac{xL}{f}$ in which L is the length of the cable. The resistance of the fault is equal to the term that is subtracted from b in formula **1.** This method can only be used occasionally, because the resistance of the fault is generally too variable while three measurements are being made to give reliable results.

LOOP TESTS WITH ONE OR MORE GOOD WIRES

27. Varley Loop Test.—Where there is one available good wire, the **Varley loop method** is probably the

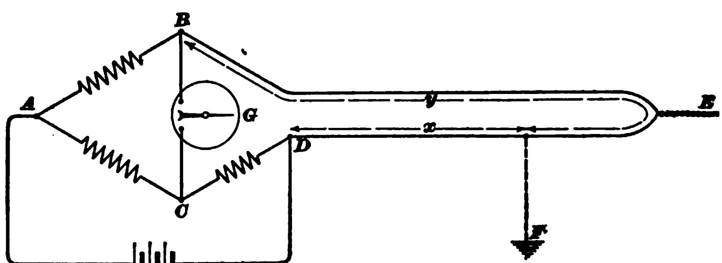


FIG. 9

most convenient and best method for locating a ground or cross on a line. The distant ends of the good and bad wires are joined together and the resistance of the loop so formed is measured with the Wheatstone bridge, if not already known from some previous measurement, by connecting as shown in Fig. 9. G is a reflecting galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; AB and AC are the ratio arms of the bridge, and CD is the rheostat or variable arm. DE is the faulty line, BE the good line, and F the location of the fault, assumed to be a ground in this figure. The ends B, D of the loop are connected across the terminals of the bridge, so as to form the unknown resistance or fourth arm of the bridge. The battery is connected between A and D. Balance the bridge and let the resistance of the loop, found by working out the bridge proportion as usual, be R. Then connect one end of the battery to the ground, instead of to D, as shown in Fig. 10. Call y the resistance of the loop from B through

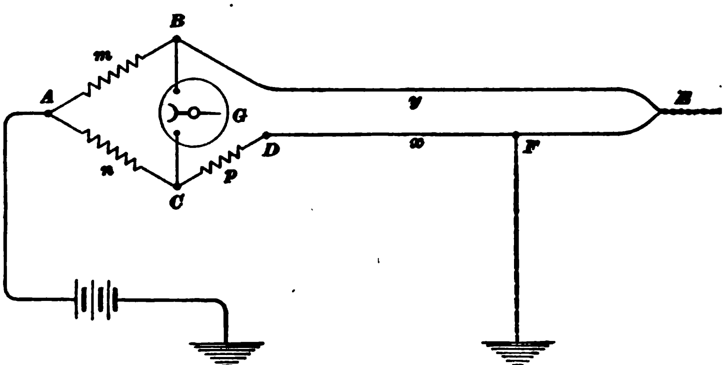


FIG. 10

E to F, x the resistance from D to F, and R, the total resistance of the loop, is equal to $x + y$. Then, when the bridge is balanced, $\frac{m}{n} = \frac{y}{p+x} = \frac{R-x}{p+x}$; $mp + mx = nR - nx$; $mx + nx = nR - mp$. Hence, the resistance,

$$x = \frac{nR - mp}{m+n}$$

This is entirely independent of the resistance of the fault or of any earth currents that may exist. Having found x, and knowing the resistance of the wire per foot, the distance to the fault is readily calculated.

EXAMPLE.—A ground occurred on one conductor of a cable 10,000 feet long, composed of three No. 14 B. & S. gauge insulated copper conductors. At the distant end, the grounded conductor was joined to one good conductor. On testing, with the connections shown in Fig. 10, the bridge was balanced with the following resistances: $m = 10$ ohms, $n = 1{,}000$ ohms, and $p = 4{,}642$ ohms. One good wire was used to complete the loop. Where is the ground, the resistance per thousand feet of the conductor being 2.521 ohms at the temperature of the test?

SOLUTION.— $R = 2 \times 10 \times 2.521 = 50.42$ ohms, or R could have been actually measured by connecting the bridge as shown in Fig. 9 and balancing it. Then, the resistance

$$x = \frac{1{,}000 \times 50.42 - 10 \times 4{,}642}{1{,}000 + 10} = 3.9604 \text{ ohms.}$$

Distance from testing station is $\frac{3.9604}{2.521} \times 1{,}000 = 1{,}570.9$ ft. Ans.

28. Check-Method.—A check on the result obtained by the last method may be obtained by reversing the connections of the good and bad wires with the bridge, the connections being otherwise as shown in Fig. 10. If m', n', and p' are now the resistance in the bridge arms required to give a balance, we have, $\frac{m'}{n'} = \frac{x'}{p' + y'}$; solving for x' gives $\frac{m'}{n'} = \frac{x'}{p' + R - x'}$, $p' m' + m' R - m' x' = n' x'$, $p' m' + m' R = n' x' + m' x'$, $x'(n' + m') = m'(p' + R)$, or the resistance

$$x' = \frac{m'(p' + R)}{m' + n'}$$

The average of x obtained by the formula in the last article and this x' will give a more correct result than either one, if both have been measured under the same conditions and with equal care.

If x' is the result obtained by the above formula and x the result obtained by the formula in Art. **27**, and two lead wires are used between the bridge and the line wires in making the Varley loop test, and s is the resistance of the lead wire in series with the bad wire, the corrected average resistance x'' of the bad wire to the fault is given by the formula:

$$x'' = \frac{x + x' - 2s}{2}$$

If the two lead wires are negligible in resistance, compared with the resistance along the bad wire to the fault, no corrections need be made for them.

29. Corrections for Lead Wires.—For very accurate results, corrections must be made when lead wires are used between the bridge and the line wire in the Varley loop test. If both the lead wires are of the same size, length, and material, use one-half their combined resistance as the resistance of the lead wire in series with the faulty wire.

H. W. Fisher gives the following method for determining the resistance of the lead wire in series with the bad wire when both ends of this lead wire cannot be directly connected to and its resistance directly measured by the Wheatstone bridge. Let s be the resistance of the lead wire in series with the bad wire. Connect the bridge as in Fig. 10, and let p be the resistance in the arm CD, m the resistance in the arm AB, and n the resistance in the arm AC when the bridge is balanced. Completely reverse the position of the lead wires, with respect to both the bridge and the line wires; use the same ratio resistances m, n as before and let p' be the resistance required in the arm CD to again balance the bridge. Then join the distant ends of the lead wires and obtain their resistance S with the bridge in the usual manner. Then the resistance s of the lead wire in series with the bad wire is given by the formula:

$$s = \frac{S}{2} + \frac{m(p' - p)}{2(m + n)}$$

30. Total Resistance of Bad Wires.—By the Varley loop method, the resistance of the bad wire to the fault is obtained. If, in addition to this, the total resistance f of the faulty wire to the distant end of the cable can be determined correctly, the resistance x to the fault can be divided by this total resistance f, which gives a ratio that when multiplied by the length L of the cable or line gives the distance d to the fault; that is, the distance

$$d = \frac{x \times L}{f}$$

31. Total Resistance of Bad Wire When Only One Good and One Bad Wire Are Available.—The total resistance f of the bad wire to the distant end cannot be very accurately determined when only one good and one bad wire are available. When the good and bad wires are in the same layer in the cable and are both the same size, the total resistance of the bad wire may be taken as half the loop resistance R. If lead wires are used between the bridge and the line wires, their resistance S must be subtracted from the loop resistance and the result divided by 2 to get the total resistance t of the bad wire; that is,

$$t = \frac{R - S}{2}$$

32. If the good and bad wires are of different but known lengths and sizes and both at the same temperature,

Let l = length of bad wire;
r = resistance per 1,000 feet of bad wire, according to a reliable wire table;
l' = length of the good wire;
r' = resistance per 1,000 feet of the good wire, according to the same table;
R = resistance of loop, as measured by Wheatstone bridge in making first part of Varley loop test;
S = measured resistance of lead wires used.

Then the following formula gives, according to H. W. Fisher, the total resistance t of the bad wire:

$$t = \frac{l \times r \times (R - S)}{(l \times r) + (l' \times r')} \qquad (1)$$

If the length or size of the good wire is not known, but the length and size of the bad wire are known, the resistance t of the latter can only be determined approximately by the use of a wire table; that is,

$$t = \frac{l \times r}{1{,}000} \qquad (2)$$

in which r = resistance of bad wire per 1,000 feet;
l = total length.

33. Total Resistance of Bad Wire When One Good and Two Bad Wires Are Available.—It frequently happens that there is available for a test only one good wire and two or more bad wires of the same size and length, as in a bad cable. In order to locate a fault under such conditions, especially if the Varley loop test is used, it is usually necessary to determine the resistance of the good wire and one bad wire to get the distance to the fault. Under such conditions, use the following method for determining their resistance. Let the resistance to the distant end of the cable of one good wire be u, of one bad wire v, and of a second bad wire w. First, measure the resistance of the good wire u in series with one bad wire v, and let this resistance be a ohms. Then, $a = u + v$. Second, measure the resistance of the good wire u in series with the other bad wire w, and let this resistance be b ohms. Then $b = u + w$. Third, measure the resistance of the good wire u in series with the two bad wires v, w in multiple and let this resistance be c. Then, $c = u + \frac{v\,w}{v + w}$. Solving these three equations gives

$$u = c - \sqrt{(a - c)(b - c)} \qquad (1)$$

$$v = a - c + \sqrt{(a - c)(b - c)} \qquad (2)$$

$$w = b - c + \sqrt{(a - c)(b - c)} \qquad (3)$$

NOTE.—These formulas may be derived as follows: The first measurement gives $u = a - v$, and the second, $u = b - w$; hence, $a - v = b - w$, or $v = a - b + w$. The third measurement gives $c = u + \frac{v\,w}{v + w}$. Substituting $b - w$ for u and $a - b + w$ for v in the last equation, gives $b - w + \frac{(a - b + w)w}{a - b + w + w} = c$.

Solve this for w as follows:

$$a\,b - b^2 + 2\,b\,w - a\,w + b\,w - 2\,w^2 + a\,w - b\,w + w^2$$
$$= a\,c - b\,c + 2\,c\,w;$$
$$-w^2 + 2\,b\,w - 2\,c\,w = b^2 - a\,b + a\,c - b\,c$$

Add $(c - b)^2$ to each side, and reverse all signs,

$$w^2 + 2\,w(c - b) + (c - b)^2 = (c - b)^2 - b^2 + a\,b - a\,c + b\,c$$
$$(w + c - b)^2 = a\,b - a\,c - b\,c + c^2$$

Extract the square root of each side,

$$w + c - b = \sqrt{a\,b - a\,c - b\,c + c^2};$$

or,

$$w = b - c + \sqrt{a\,b - a\,c - b\,c + c^2}$$

But, $a\,b - a\,c - b\,c + c^2 = a(b - c) - c(b - c) = (b - c)(a - c)$

Hence, $w = b - c + \sqrt{(b - c)(a - c)}$

As given above, $v = a - b + w;$

hence,

$$v = a - b + b - c + \sqrt{(b - c)(a - c)} = a - c + \sqrt{(b - c)(a - c)}$$

Similarly,

$$u = a - v = a - a + c - \sqrt{(b - c)(a - c)} = c - \sqrt{(b - c)(a - c)}$$

This method is very satisfactory and can often be applied to advantage when all the wires of a cable become bad, provided that one good wire outside the cable is available. This method of finding the resistance of the bad wire cannot be applied with absolute certainty when the faults on the bad wires occur at different points, unless the resistances of the faults are high and the resistances of the faulty wires are comparatively low; in the latter case, this method gives quite accurate results, even though the faults be a considerable distance apart.

When a number of wires fail in a cable at the same time, it can generally be assumed that the faults are all located at the same point. However, if the trouble has been caused by lightning, this may not be true.

34. Total Resistance of Bad Wire When Two Good Wires Are Available.—The total resistance of the bad wire can be accurately determined and hence the distance to the fault accurately located when two good wires whose terminals are accessible to both ends of the faulty wire are available. It is not necessary that the two good wires have the same resistance, nor that they follow the same route as the faulty cable. All three wires can differ widely in resistance and not in any way affect the result, neither is it necessary that the lead wires between the Wheatstone bridge and the line wires be of the same resistance, but the resistance of these two lead wires must be measured. This method is given by H. W. Fisher. Let g, g' represent the resistances of the two good wires, and S the resistance of the two lead wires. First, have one good wire g and the bad wire b joined together at the distant end, measure their loop resistance, and let it be u ohms; then $u = b + g + S$; second, have the other good wire g' and the bad wire b joined together at the distant end, measure their loop resistance, and let it be v ohms; then $v = b + g' + S$; third, have the two good wires g, g' joined together at the distant end, measure their loop resistance, and let it be w ohms, then $w = g + g' + S$. The same lead wires are supposed to be used in each of these three measurements. Then,

$$b = \frac{u + v - w - S}{2} \qquad (1)$$

and

$$g = \frac{u + w - v - S}{2} \qquad (2)$$

The formula for g is given because this method may be used to determine the resistance of two of three wires, when lead wires are also used.

35. Murray Loop Test.—The **Murray loop test** is quite similar to the Varley loop test. Under favorable and suitable conditions, the Varley loop test gives more correct results, but the great simplicity of the Murray loop test recommends it, especially for underground cable work, where it is generally only necessary to locate the fault between manholes. First, have the distant ends of the available good

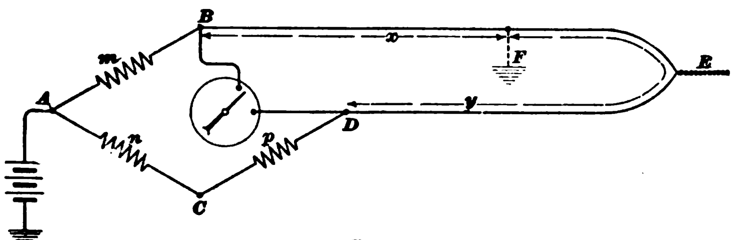


FIG. 11

and bad wires joined together. Then connect the loop so formed to the bridge, as shown, in Fig. 9, for the Varley loop test, and measure the resistance of the loop. Let this resistance be R. Evidently, $R = x + y$. Then connect the loop and battery as in Fig. 11, thus having really only two adjustable arms, because AC and CD form only one arm now. F is now the junction between the arms x and y. When the bridge is balanced, we have

$$\frac{m}{n + p} = \frac{x}{y}$$

But,

$$x + y = R$$

Solving these two equations for x, the resistance of the line wire to the fault, gives,

$$x = \frac{mR}{m + n + p} \qquad (1)$$

A test made by this method gives a result that is independent of the resistance at the fault. If the good and bad wires constitute a pair of wires in a cable or at least two wires of equal length, size, and material, x may be called the distance to the fault while twice the length L of the cable may be used for R. The formula may then be written,

$$\text{the distance to the fault} = \frac{2mL}{m+n+p} \qquad (2)$$

EXAMPLE.—In order to locate a ground on one conductor in a cable, the Murray loop method was used. At the distant end of the cable, the bad wire was joined to a good wire and the resistance of the loop so formed was measured by the Wheatstone bridge and found to be 63.44 ohms. One end of the galvanometer was then disconnected from the junction C between the arms n and p, and was joined instead to the point D between the arm p and the good wire, as in Fig. 11. The bridge was then balanced and it was found that there was 1,000 ohms in the arm m, 1,000 in n, and 282 in p. Each conductor in the cable consisted of one No. 12 B. & S. gauge insulated copper wire, having a resistance of 1.586 ohms per 1,000 feet at the temperature of the test. What was the distance in feet from the testing station to the fault?

SOLUTION.—By substituting R = 63.44 ohms, m = 1,000, n = 1,000, and p = 282, in formula **1**, we get as the resistance along the bad wire to the fault, $x = \frac{1{,}000 \times 63.44}{1{,}000 + 1{,}000 + 282} = 27.80$ ohms. Then, the distance to the fault, in feet, from the testing station is

$$\frac{27.80 \times 1{,}000}{1.586} = 17{,}528 \text{ ft., or } 3.32 \text{ mi. Ans.}$$

36. A check on the result obtained by the Murray loop test may be secured by reversing the connections of the good and bad wires with the bridge, obtaining another balance and result. If m', n', p' represent the resistances in the arms for the second balance, if the tests have been correctly made, $m'(n'+p')$ should be equal to $m'(n+p)$. The result obtained by this check-method is

$$x' = \frac{(n'+p')R}{m'+n'+p'} \qquad (1)$$

and the average of the two values x and x' which usually gives the best result is

$$x'' = \frac{x+x'}{2} \qquad (2)$$

37. For reliable results by the Murray loop test, the good wire should have an insulation resistance of at least ten times that of the bad wire. Some good wire should be selected and the insulation resistance of the good and bad wires measured or compared by some suitable and convenient method to determine if this condition is fulfilled.

It is best to connect the good and bad wires directly to the bridge, but if lead wires must be used, R in the formula for this test must be increased by the resistance of the two lead wires and the resistance of the lead wire in series with the bad wire must be later subtracted from the calculated resistance to the fault to get the correct result. If the leading wires are short and differ by one or two sizes only from the cable wires, the error introduced does not amount to more than a few feet, which is usually negligible, if the length of one of the two equal lead wires is added to the length L of the cable in formula **2**, Art. **35**, and then this same length is subtracted from the final result.

38. Murray Loop Test With Slide-Wire Bridge.—A very simple, and sometimes a very convenient, way of

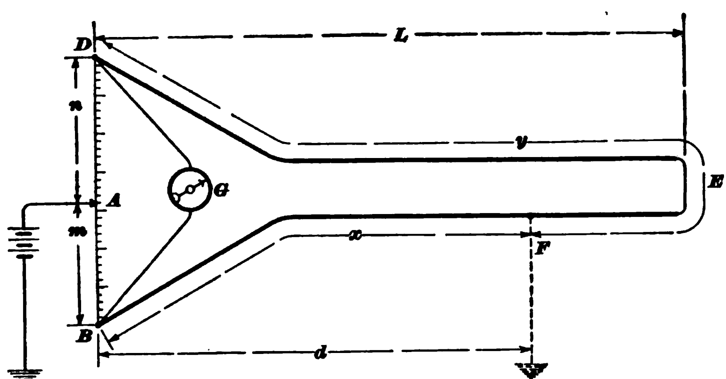


Fig. 12

locating a ground on a line wire consists in using a slide wire in place of the two adjustable arms of a Wheatstone bridge in the Murray loop method. In Fig. 12, BD represents a wire of uniform resistance stretched over a uniformly divided scale and F is a grounded point on the conductor BE that it is desired to locate. Then, if A is a point on the slide wire touching which, produces no deflection of the galvanometer, we have $\frac{n}{m} = \frac{y}{x}$; adding 1 to each side of the equation, gives $\frac{n+m}{m} = \frac{y+x}{x}$; but $y + x = R$, then $\frac{n+m}{m} = \frac{R}{x}$; hence,

$$\text{resistance } x = \frac{mR}{n+m} \qquad (1)$$

in which x will be the resistance along the bad wire to the ground and R the resistance of the loop, which must be determined, if not already known, by another measurement or calculated by means of a wire table. This method is especially useful, however, when both x and R are considered as distances in miles or feet. $\frac{R}{x}$ and $\frac{m}{n+m}$ are merely ratios. Moreover, if the two line wires are of the same size, length, and material, their resistances are proportional to their lengths; hence,

$$\frac{\text{resistance } R}{\text{resistance } x} = \frac{2 \times \text{length } L}{\text{distance } d}$$

Consequently this may also be written,

$$\text{distance } d = \frac{2mL}{n+m} \qquad (2)$$

in which L = length of one line wire, or length of a cable containing line wires;

d = distance from B to the fault F.

The length $2L$ will usually be twice the length of one line wire plus the length of any lead wires, preferably of the same size and material as the line wire that may be used to connect the two line wires to the points B, D.

EXAMPLE.—A test was made by this method to locate a ground on a line of No. 19 B. & S. wire 3 miles long. The point of balance on the slide wire, which was divided into 1,000 equal divisions, was found to be 210 divisions from the end to which the bad wire was joined. How many miles is it to the ground?

SOLUTION.—In this case, $m = 210$, $n + m = 1{,}000$, and $L = 3$; hence,

$$x = \frac{2mL}{n+m} = \frac{2 \times 210 \times 3}{1{,}000} = 1.05 \text{ mi., or 1 mi. and 264 ft.} \quad \text{Ans.}$$

39. If all the conductors in a cable have become defective, but some are much more heavily grounded than others, the Murray loop test may still be used with fair success, provided that there is no disturbing difference of potential from an outside source between the two wires selected for the test. Even if all the conductors in a cable are heavily or equally grounded, the Murray loop test may still be successfully applied if there is available a good aerial wire or conductor in another cable that can be joined to the faulty conductor at the distant end.

40. Murray Loop Test Requiring Two Good Wires. Where a good wire of the same size as the faulty conductor

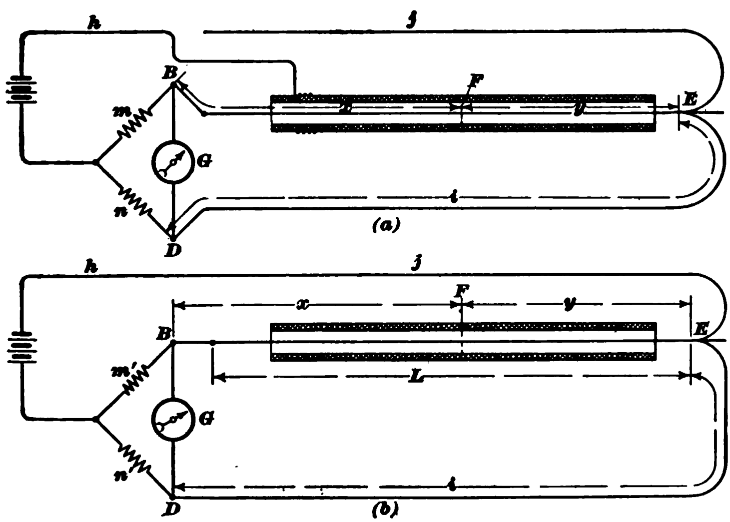


FIG. 13

is not available, but where two good wires of any size and material, either inside or outside the cable, are available, the following modification, made by H. W. Fisher of the Murray loop test, may be used. It must be possible to connect together at the distant end the faulty conductor BE and the two good available wires i, j as shown in Fig. 13. These conductors are connected together at E and to the bridge, as shown in Fig. 13 (a). The arms m and n are adjusted until the galvanometer gives no deflection and their values recorded. The wire h running from the battery to the lead sheath of the cable is then connected to the conductor j as shown in Fig. 13 (b), after which the bridge arms are adjusted until values m' and n' are obtained that again produce no deflection of the galvanometer. If L is the total length of the faulty conductor and x the distance to the fault, then,

$$x = \frac{m(m' + n')L^*}{m'(m + n)}$$

41. In the application of this method, the resistance of conductors i, j may be quite different without affecting the result, hence before the test is made, long enough lead wires may be used at either end for making the connections with the conductors i, j. Usually, the same values for m and m' can be used, thereby reducing the calculations. If the faulty wire cannot conveniently be connected to the Wheatstone bridge a wire of the same size and material as the cable conductor may be used to make the connections, then it will be necessary to add the length of this wire to the length of the bad wire or cable, using this total length for L in the formula, and then subtract the length of this lead wire from the calculated distance x to the fault.

---

*This formula may be derived as follows: The first balance gives $\frac{n}{m} = \frac{i+y}{x} = \frac{i+(L-x)}{x}$, or $i + (L - x) = \frac{nx}{m}$ and $i = \frac{nx}{m} - (L - x)$ $= \frac{nx}{m} - L + x = x\left(\frac{n}{m} + 1\right) - L = x\left(\frac{n+m}{m}\right) - L$. The second balance gives $\frac{n'}{m'} = \frac{i}{x+y} = \frac{i}{L}$, or $i = \frac{Ln'}{m'}$. Equating these two values of i, gives $x\left(\frac{n+m}{m}\right) - L = \frac{Ln'}{m'}$, or $x\left(\frac{n+m}{m}\right) = L\left(1 + \frac{n'}{m'}\right) = L\left(\frac{m'+n'}{m'}\right)$, from which $x = \frac{L(m'+n')m}{m'(n+m)}$.

EXAMPLE.—A cable 800 feet long was tested to locate a ground between one conductor and the sheath. A piece of wire, 10 feet long, of the same size and material as the cable conductor was used to connect the cable conductor to the bridge. Two good wires were available so that the method just explained was selected. With the connections shown in Fig. 13 (*a*), a balance was obtained when $m = 100$ and $n = 301.5$ ohms. The connections were then made as shown in Fig. 13 (*b*) and a balance obtained when $m' = 100$ and $n' = 120.5$ ohms. What is the distance to the fault?

SOLUTION.—The length L of the conductor during the test was $10 + 800 = 810$ ft. Substituting the known values for the letters in the formula $x = \frac{m(m' + n')L}{m'(m + n)}$, gives

$$x = \frac{100 \times (100 + 120.5) \times 810}{100 \times (100 + 301.5)} = 444.8, \text{ or } 445 \text{ ft.}$$

From this must be subtracted the 10 ft. of connecting wire, giving as the distance to the fault from the home-office end of the cable 435 ft. Ans.

42. Goodrum Slide-Wire Bridge Method.—One of the best and simplest loop methods for locating grounds and crosses where two good wires are available is that proposed by C. L. Goodrum. Theoretically, it is the same as the method just explained, but a slide-wire bridge is used instead of a

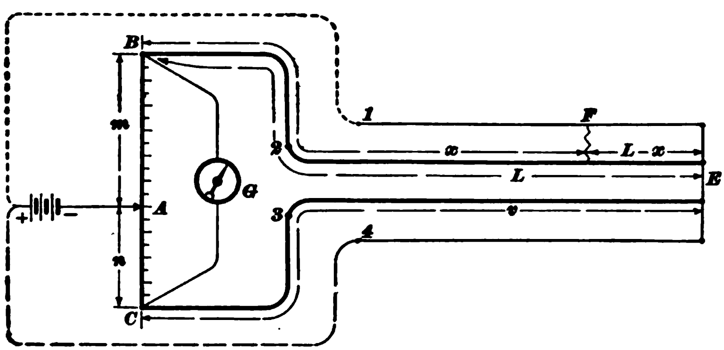


FIG. 14

regular Wheatstone bridge, thereby simplifying the test. In Fig. 14, *B C* represents a slide wire, which may be a piece of No. 24 B. & S. German-silver or iron wire stretched between posts *B C* so as to be over a scale divided into exactly 1,000 equal divisions, preferably millimeters. The smoother and more uniform the diameter and material of the wire *B C*, the more accurate will be the results. This method may be used to determine the distance x to a fault at F, which may be either a ground on wire *2* or a cross between wires *1* and *2*.

Have all the wires joined together at the distant end and at the testing end join B to *2*, C to *3*, and the battery to *4*; the dotted line connection is not now made. G represents a galvanometer or a sufficiently sensitive millivoltmeter connected from B to C. Adjust the pointer along the slide wire until a point A is found where G gives no deflection. Then,

$$\frac{L}{v} = \frac{m}{n}$$

in which L = length of cable;
v = length of wire *3*;
m = distance BA, that is, the scale reading from the end B to the point of balance A;
n = distance AC, that is, the length $BC - m$.

The connecting wire from B to *2* should be sufficiently short or large in diameter or both, so that its resistance may be neglected.

If line *2* is crossed at F with line *1*, connect the positive terminal of the battery to this wire *1*, as represented by the light dotted line instead of to line *4*, as represented by the dash line. If line *2* is grounded at F, connect the positive terminal of the battery to ground instead of to line *1*. In either case, the procedure is as follows: Again, balance the bridge and let m' be the new reading on the slide-wire scale from B to the new point of balance. Then,

$$\frac{x}{L - x + v} = \frac{m'}{n'}$$

Solving these equations for x gives

$$x = \frac{m' L}{m}$$

43. Although two good wires *3* and *4* are required, they may be of any reasonable size, material, or length, and they may be wires inside or outside the cable. The distance x to the ground or cross is merely a certain ratio $\frac{m'}{m}$ of the total length L of the cable and this distance is independent of the length of the faulty or good wires. The only requisite necessary for extreme accuracy is that the faulty wire 2 shall twist in the same uniform manner throughout the entire length of the cable. If it starts as an inside wire, it must continue as such. Most loop tests not only assume this to be the case, but also assume that the good and faulty wires are of exactly the same length, which is not true when one is an inside wire and the other an outside wire in a cable, because the latter twists around the inner wires and is therefore somewhat longer than any wire inside of it. This method requires only two balances and only one connection has to be changed. An apparatus, called the *lineman's faultfinder*, has been placed on the market for locating faults by practically this method.

44. Allen Loop Test.—Allen's modification of the Murray loop test gives a very simple and quick method of testing where the resistance of the loop is not already

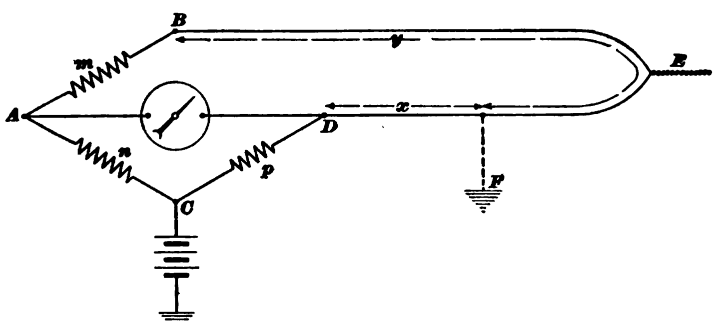


FIG. 15

known. The loop BED is connected to the bridge, as shown in Fig. 15, and a balance obtained. Then,

$$\frac{m + y}{n} = \frac{x}{p}$$

Now, reverse the connections of the loop with the bridge, joining the bad wire to B and the good wire to D. Obtain new balance on the bridge, then

$$\frac{m' + x}{n'} = \frac{y}{p'}$$

Solving these two equations for x gives the following formula:

$$x = \frac{p(m n' + p' m')}{n n' - p p'}$$

This formula simplifies when m, m', n, and n' are multiples of 10, as they usually are in practice. A measurement made by the Allen loop test is independent of the resistance of the fault.

45. For the location of grounds, some form of loop test is usually superior to all others. When the leakage along the lines is great, the loop tests may be seriously vitiated thereby, in common with other methods. The next best method is the earth overlap, which is more suitable than the Blavier method for a fault that has a varying resistance or much polarization. Since the earth overlap method requires tests from both ends of the line, it is not always applicable, in which case the best alternative method is the Blavier, and under certain conditions the Ayrton method.

OTHER METHODS OF LOCATING GROUNDS

46. Receiver Method.—The following method is said, by A. B. Dungan, who has used it successfully, to be very simple and reliable for locating grounds on aerial cable conductors, provided that the cable is free from dead grounds against other cables and guy wires. In Fig. 16 is shown the necessary connections consisting of a lead-covered cable with

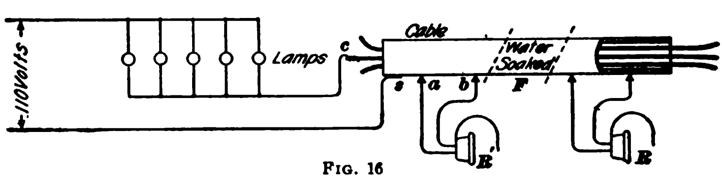


FIG. 16

its sheath connected to one side of a 110-volt lighting circuit; the conductor or conductors that are grounded at some point F, are connected through a suitable resistance, such as five 110-volt 16-candlepower lamps in parallel, to the other side of the 110-volt lighting circuit; either direct or alternating current may be used. If a portion of the cable is water soaked or the cable is injured so that one or more conductors are more or less grounded on the lead sheath, then some current will pass from the conductors at the fault to the sheath through which it returns to the office. If an ordinary head-telephone receiver, wound to a very low resistance, about $\frac{1}{500}$ ohm, has its two terminals touched to two points *a*, *b*, as far apart as convenient on the lead sheath of the cable at any place between the exchange and the point *F* a noticeable click will be heard in the receiver, due to a part of the current passing through it. If the same connection be made beyond the point *F* no sound whatever will be heard in the receiver. The points *a*, *b* should be kept the same distance apart for all comparative tests. In this way, the most inexperienced lineman is said to be able to locate such a ground in a cable within a few inches.

47. Stabler Test With Millivoltmeter.—When all the conductors in a cable are so badly grounded as to preclude the application of any loop test, H. B. Stabler says the following simple test, which resembles the preceding, has been successfully used to locate a ground on conductors in

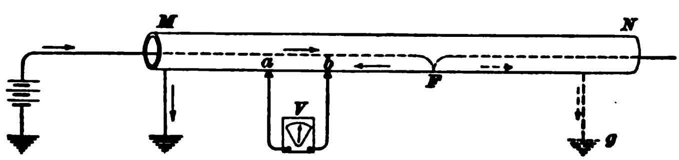


FIG. 17

lead-covered aerial cables. The test can only be made when the lead sheaths are comparatively well insulated from the ground, or if heavily grounded, provided that it is only at some certain known point or points.

In Fig. 17, let *MN* represent an aerial lead-covered cable, whose sheaths and supporting wire are in contact only with the dry wood of cable boxes, poles, and cross-arms and hence normally insulated fairly well from the ground. A battery or other suitable source of direct current is connected between the ground and the one or more conductors that have become grounded on the lead sheath at some point *F*. By applying the terminals of a galvanometer or millivoltmeter to two points *a*, *b*, a few feet apart on the lead sheath of the cable between *F* and *M*, the presence and direction of the current in the cable sheath will be indicated by the deflection of the needle. By repeating the tests at other points along the cable, the point *F* where the current first reaches the sheath may be located, for there will be no current flowing in the cable sheath beyond the point *F*.

If the cable sheath should be already grounded at two or more points, the test may still be made. For, if the sheath is also grounded at *g*, the point *F* can be located, not by the absence of a deflection beyond it, but by deflections in opposite directions on each side of *F*.

This method fails where there is a high resistance in the cross between the conductors and the sheath, as a large enough current cannot then be conveniently obtained in the sheath to give suitable deflections. The amount of current required, is not, however, very large. For instance, with a cable sheath whose resistance is .1 ohm per 1,000 feet, the difference of potential between two points on its surface 4 feet apart will be .1 millivolt when carrying a current of .25 ampere. In a central-energy telephone system, such a current may often be fed from the central office through cable conductors to the desired point, in order to save the party making the test the trouble of transporting a suitable battery to the end of the aerial cable. This method will fail when the cable sheath is grounded at points on each side of *F* if there already exists a difference of potential between these points due to the leaking of current from external wires to the cable sheath.

48. Exploring Coil Method.—In underground telephone cables, a ground may be located by passing an alternating current through the grounded circuit and then carrying a large exploring coil, in series with which is connected a receiver, along the street directly over the cable at fault. The alternating current will induce current in the exploring coil, even though a few feet away from the cable, which will produce a sound in the receiver. When the grounded point is passed, the noise will cease, which shows that the coil has been carried beyond the grounded point. Where this method can be properly applied, faults may be located with considerable accuracy. An effective exploring coil can be made of a bicycle-wheel rim with the groove filled with fine wire and the ends connected to a receiver. To locate faults in concealed house wiring, a coil 6 to 8 inches in diameter, wound with No. 30 B. & S. or smaller wire to a rather high resistance, will answer the purpose.

Another method used by power companies for determining a ground on a cable is to pass a current that changes its direction about once in 3 seconds through the cable and placing a compass over the cable to be tested at each manhole in succession. The compass needle will slowly vibrate from one side to the other as the current changes direction, until the manhole beyond the ground is reached. The ground is thus between the last two manholes and that portion of the cable is withdrawn for repairs. A special machine is now made by the General Electric Company for this test. It consists of a motor that drives a commutator at such a speed that a direct current is reversed once in 3 seconds. This method will not apply if the alternating or pulsating current passes through the two wires constituting a pair in series, because the return current will neutralize the effect produced by the outgoing current. By passing a current through only one wire or through the two wires of a pair in multiple this method can still be used for the location of faults.

49. Location of Ground by Voltmeter.—The distance to a ground on a line can be determined only approximately by means of a voltmeter and then only when the resistance at the ground is negligible compared with the resistance of the bad wire from the testing end to the ground. The lower the resistance of the voltmeter, the more accurate is the method. To estimate the distance to the ground, connect the voltmeter across the terminals of a suitable battery (usually a few dry cells will answer this purpose), and call the reading d. Then connect the same battery and voltmeter in series with the line to be tested and the ground, thus forming a circuit through the battery, voltmeter, line, and ground. Let the voltmeter reading be d'. Then the resistance of the circuit is $R = r\left(\frac{d}{d'} - 1\right)$, in which r is the resistance of the voltmeter. This is the same formula used in determining the insulation resistance of a line. Since the line is grounded at some point, R is only larger than r by the resistance of the line, earth return, and ground contacts. Hence, the resistance x to the ground is $R - r$ and is given by the formula:

$$x = r\left(\frac{d}{d'} - 2\right)$$

LOCATING CROSSES

50. Where the two crossed wires run parallel and have the same resistance per mile, it is rather a simple matter to locate a cross. Where such is not the case, the resistance of each wire per mile must often be considered. The loop methods given for locating grounds can generally be used also for locating crosses, in which case one of the crossed wires is used instead of the ground.

RESISTANCE AT THE CROSS NEGLIGIBLE

51. To Determine the Resistance of Cross.—It is first necessary to determine if the resistance at the cross is negligible. This may be done as follows: Connect the lines with a Wheatstone bridge, as shown in Fig. 18, so as to measure the resistance from B to D through the cross F; call this a. Then,

$$x + y = a$$

Now have the wires connected together at the nearest station beyond the cross and again measure the resistance; call this b. If b is only a little less than a, the resistance of the cross is probably negligible, but not necessarily perfectly so. For if the cross is near the testing station and the resistance of the line wires to the next station where the lines are intentionally connected together is very high, the second measurement b may be but little less than the first measurement a, in spite of the fact that the resistance of the cross is not perfectly negligible.

52. Cross Between Two Wires of the Same Size and Material.—If the resistance of the cross is negligible, and if the two wires are of the same size and material and run along parallel the whole distance from the testing station

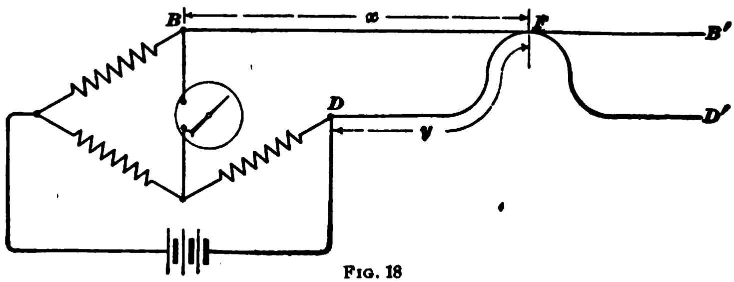


FIG. 18

to the cross, the distance x to the fault, in miles, is given by the following formula:

$$x = \frac{a}{2s}$$

in which s = resistance per mile along one wire;
a = resistance of loop through the cross.

53. Resistance of Two Line Wires per Unit Length Not Equal.—If the wires are still parallel with each other, but the resistance of one is w ohms per mile and the other v ohms per mile, the formula becomes,

$$x = \frac{a}{w + v}$$

RESISTANCE OF CROSS NOT NEGLIGIBLE BUT CONSTANT

54. Varley Loop Method.—First insulate the distant ends of the two crossed wires. Then connect as shown in Fig. 19, and measure the resistance from D to B through the cross at F. Let the resistance of the cross be z ohms, and the resistance found by balancing the bridge be R ohms. Then,

$$R = x + y + z$$

Now ground either wire, say $D E$, anywhere beyond the cross, as at G, and connect as shown in Fig. 20. When the bridge is again balanced, we have

$$\frac{m}{n} = \frac{y + z}{p + x}$$

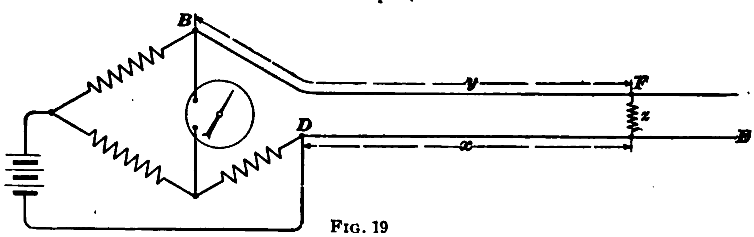


FIG. 19

From these equations we get the formula,

$$x = \frac{n R - m p}{m + n}$$

which is exactly the same as the formula for locating a ground by the Varley loop method.

Then, by dividing x by the resistance of the wire $D E$ per unit length, we have the distance from D to the fault along the wire $D E$. The resistance of the cross z elimi-

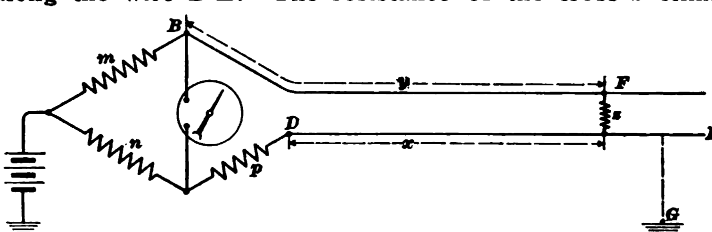


FIG. 20

nates and the method is accurate, provided that the resistance z has remained the same during both measurements. The Murray loop method can also be used for the location of crosses.

55. Method Requiring Three Measurements. Measure, as in the preceding method, the resistance from B

to D through the cross whose resistance we will call z ohms, connecting the bridge as shown in Fig. 19 with the distant ends of the two crossed wires open. Let the resistance so measured be a; then,

$$x + z + y = a$$

Now measure the resistance of the line $B B'$, as shown in Fig. 21, by having the distant end B' grounded, and the ends $H D'$ open. Let this resistance be b; then,

$$x + u = b$$

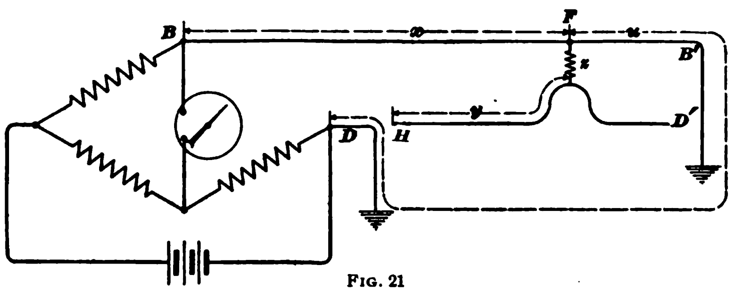


FIG. 21

Finally, measure the resistance through y, z, and u, by connecting the bridge as shown in Fig. 22. Let this resistance be c; then,

$$y + z + u = c$$

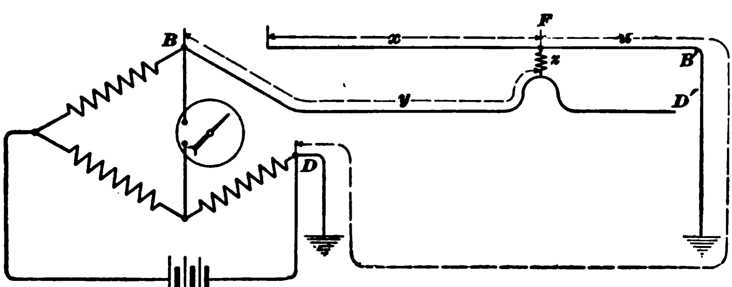


FIG. 22

Subtracting the last equation from the sum of the first two and then solving for the resistance x from the testing station to the fault gives the following formula:

$$x = \frac{a + b - c}{2}$$

Dividing x by the resistance of the wire x per mile gives the distance, in miles, to the cross F. It will be noticed that the resistance of the cross z eliminates, so that if z remained constant during the second and third measurements, the formula is accurate and independent of the value of z.

RESISTANCE OF CROSS NEITHER NEGLIGIBLE NOR CONSTANT

56. A method will now be given in which the resistance of the cross is eliminated, whether constant or variable, and the test requires, moreover, only two resistance measurements. However, the ordinary bridge connections have to be slightly modified, which is an objection.

First, connect up as shown in Fig. 21 and measure the resistance of the line BB', including the ground return path. Let this be a; then,

$$x + u = a \qquad (1)$$

Then connect the bridges as shown in Fig. 23, using only two arms p and n of the bridge; the third arm m, being on

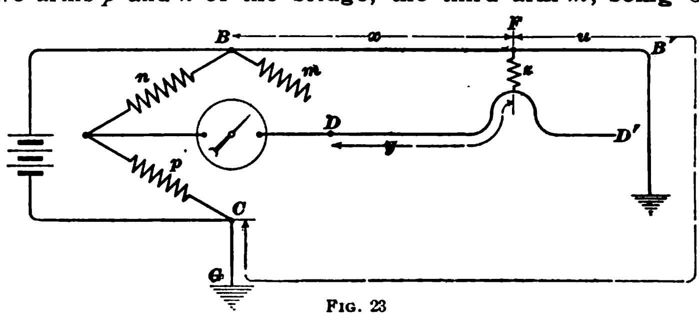


FIG. 23

open circuit, is not used. The galvanometer, instead of being connected to the end of the arm m, is connected to the end of the wire y. Thus, BF forms the third arm and $FB'C$ the fourth arm of the bridge. The resistance of the cross z and that portion y of the line DD' is included in the bridge or galvanometer circuit, and, therefore, this resistance z and y will not enter into the result for the same reason that the resistance of the galvanometer never does in measurements made with the Wheatstone bridge method.

Hence, the resistance of the cross does not enter into the measurement, and, furthermore, the final formula is entirely independent of this resistance whether it is constant or not. The resistance u, from F through B' and back through the ground to G, forms the fourth arm of the bridge. From the well-known principle of the bridge, after adjusting it until there is no deflection, we have

$$\frac{n}{p} = \frac{x}{u} \qquad (2)$$

Solving these equations for x, we obtain the following formula for the resistance along the wire $B\,B'$ to the cross:

$$x = \frac{n\,a}{p + n} \qquad (1)$$

Finally, by dividing x by the resistance of the line $B\,B'$ per mile, we get the distance in miles from B to the cross F.

If more convenient to do so, the end B of the wire may be joined to the end of the arm m. In this case, x in equation (2) must be changed to $m + x$ and we get the following formula for x:

$$x = \frac{n\,a - p\,m}{p + n} \qquad (2)$$

57. To locate a cross between two wires of equal size by means of a slide-wire bridge, connect as shown in Fig. 24. A good wire is necessary in addition to the two

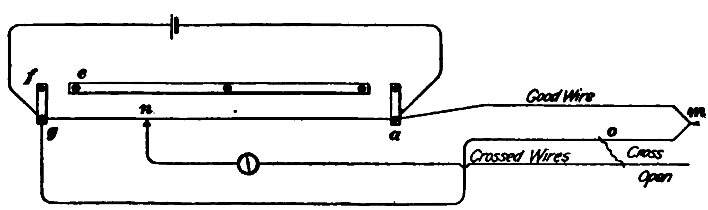


FIG. 24

crossed wires, and it is connected to either of the crossed wires at some point—beyond the cross; the home end of the crossed wire, to which the good wire is connected, is joined to the bridge at g; and one terminal of the galvanometer is connected to the other crossed wire which must be open at the distant end. Then find a point n on the slide wire that produces no deflection of the galvanometer. Then the

$$\text{distance } go = \text{distance } goma \times \frac{\text{length } gn}{\text{length } ga}$$

For the distance $goma$, twice the length of one line wire or twice the length of a cable being tested may be used. This result is independent of the resistance of the fault, even if it varies during the test. This is practically the Murray loop test made with a slide-wire bridge.

58. One Wire in Use.—The method about to be described may be used to determine the resistance of one wire or the distance to a cross between that wire and another wire while the latter is in regular use as a telegraph line. The result is not, however, independent of the resistance of the cross. By this method, low-resistance crosses and grounds may be located and if a balance can be secured while the fault exists, swinging crosses and grounds may be approximately located.

The connections for this test are shown in Fig. 25, in

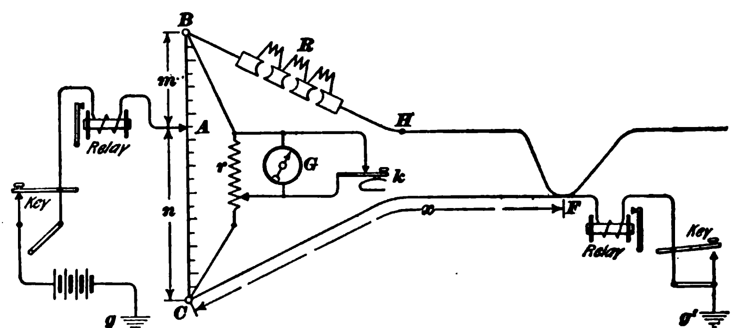


FIG. 25

which BC represents a slide-wire bridge; R, a known resistance; G, a sensitive galvanometer with its usual shunt r and short-circuiting key k; CFg', the wire in use; and HF, the line wire, which is crossed at F with the other line wire and is open beyond the cross. To make the test, set the slide about midway along the slide wire BC, short-circuit or remove all the resistance at R, open the galvanometer short-circuit key k, and adjust the position of A along the slide wire until the galvanometer returns to its normal position of rest. The telegraph relays may be in service all the time the test is made, although the test is more readily made with this relay circuit permanently closed. Remove or open the galvanometer shunt, and readjust n if necessary, until the galvanometer gives no deflection and note the lengths m and n. Then remove the plugs from R, that is, insert the resistance R between B and the crossed wire HF; move the pointer A until the bridge is balanced again in the same manner as before and note the lengths m' and n'. The resistance x of the working wire from C to the cross F may then be calculated by the formula,

$$x = \frac{n \times n' \times R}{(m' - m)(m + n)} \quad *$$

$m + n$ is the total length of the slide wire and is usually 1,000 or 100. The resistance used at R should be enough to make the two points of balance quite different. The greater the resistance of CF, that is, the greater the distance to the cross, the greater must be R.

EXAMPLE.—A wire having a resistance of 13.3 ohms per mile was tested for a cross with another wire. The first balance, when there was no resistance at R, gave the distance $AB = 490$ divisions. When a resistance of 50 ohms was inserted at R, the point of balance gave $AB = 580$ divisions. The slide wire was 1,000 divisions long. What is the distance, in miles, to the cross?

SOLUTION.—From the first balance, $m = 490$ and $n = 1,000 - 490 = 510$; from the second balance, $m' = 580$ and $n' = 1,000 - 580 = 420$;

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*This formula is derived as follows: The first balance gives $\frac{m}{n} = \frac{BHF}{x}$; the second balance gives $\frac{m'}{n'} = \frac{R + BHF}{x}$. Solving both equations for BHF and equating their values, gives $BHF = \frac{mx}{n}$ and $BHF = \frac{m'x}{n'} - R$, or $\frac{mx}{n} = \frac{m'x}{n'} - R$; solving for x, gives $\frac{m'x}{n'} - \frac{mx}{n} = R$, $x\left(\frac{m'}{n'} - \frac{m}{n}\right) = R$, $x\left(\frac{m'n - n'm}{n'n}\right) = R$, $x = \frac{n'nR}{m'n - n'm}$. But $n' = n + m - m'$, then $\frac{n'nR}{m'n - m(n + m - m')} = \frac{n'nR}{m'n - nm - m^2 + mm'} = \frac{n'nR}{m'(n + m) - m(n + m)} = \frac{n'nR}{(m' - m)(n + m)}$.

furthermore $m + n = 1{,}000$. Substituting these values in the formula, gives

$$x = \frac{510 \times 580 \times 50}{(580 - 490)\ 1{,}000} = 164.3 \text{ ohms}$$

The distance to the fault is therefore $164.3 \div 13.3 = 12.4$ mi. Ans.

TESTING OF TELEPHONE CIRCUITS

(PART 2)

TESTING

ROUGH TESTS

1. It is frequently necessary to make rough tests to show whether circuits are continuous or broken, whether crossed, grounded, or properly insulated. These tests do not require accurate measurements, they being merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists.

TESTS WITH MAGNETO-GENERATOR AND BELL

2. Magneto Testing Set.—A very common and useful form of testing instrument is that consisting of a magneto-generator and polarized ringer, together with some simple form of telephone, all mounted compactly in a box provided with a strap for convenience in carrying. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt. The circuits of one form of magneto testing set are shown in Fig. 1, in which the polarized bell *R* is connected in series with the generator *G* when the switch *S* is in contact with the center button. When the switch is thrown to the left, the bell is cut out of circuit and the generator only is connected across the line terminals, this condition being advantageous when it is necessary to signal a distant station over a line that may be partly grounded or crossed. When the switch is thrown to the right, the magneto-telephone *T* is connected across the circuit, and may be used as either a transmitter or a receiver in communicating with another party on the line. When the generator is at rest and the switch is thrown to the right, the telephone *T* alone is connected in the circuit between the binding posts, the generator being shunted out of circuit by the automatic shunting device. If, however, the generator should be operated while the switch is in this position, the current from it will pass through the telephone and to line, thus producing a buzz in the telephone. By means of this, the party testing can often form some idea of the resistance or capacity of a circuit by the loudness of the buzz produced when ringing through the telephone.

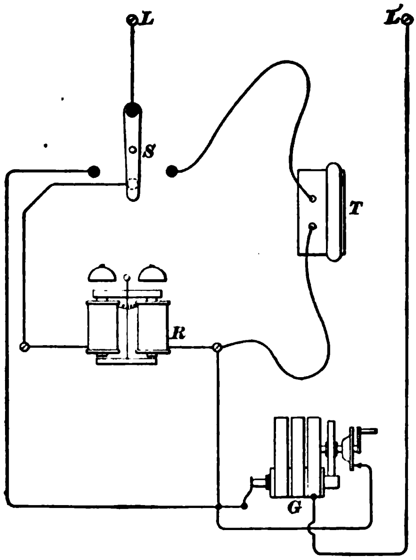


FIG. 1

3. **Continuity Tests.**—In testing wires for continuity, the terminals of the magneto-set should be connected to the terminals of the wire and the generator operated, the switch of the testing set being thrown so as to include the bell and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and cables, because it may be that the capacity of the line wires themselves will be sufficient to allow enough current

to flow through the bell to operate it, even though the line or lines are open at some distant point.

4. **Testing for Crosses.**—In testing a line for crosses, either with the earth or with other conductors, one terminal of the magneto-set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto-set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross.

An experienced telephone lineman can often tell with considerable accuracy the approximate location of a cross on a line by the sound produced by the bell or by the pull of the generator crank when the generator alone is thrown on the circuit. Here, again, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists, if the line under test is a very long one. The insulation may be perfect and yet a sufficient current may pass to and from the line, through the bell, to cause it to sound, these currents, of course, being due to the static capacity of the line itself.

5. In testing very long lines or comparatively short lines of cable, the magneto-set must be used with caution and intelligence, on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied on as being accurate. Ordinary magneto testing sets are commonly wound in such a manner that the generator will ring its own bell through a resistance of about 10,000 to 15,000 ohms, although some are wound and constructed to ring very lightly through 50,000 ohms. They may be constructed to ring only through about 10,000 ohms or through as much as 125,000 ohms. One that will ring its

own bell through 25,000 ohms is probably best adapted for all-around testing work. A very good generator, when rapidly rotated, will commence to ring its bell through about .1 microfarad, an ordinary generator through about .3 microfarad; each will ring stronger as the capacity is increased.

TESTING OUT CIRCUITS OF INSTRUMENTS

6. When a case of trouble arises in a telephone instrument, a careful inspection of the instrument will usually reveal about what the nature of the fault is. For instance, if in the ordinary series instrument, it is found that the instrument will both receive and transmit signals to the distant station, but refuses to either receive or transmit speech,

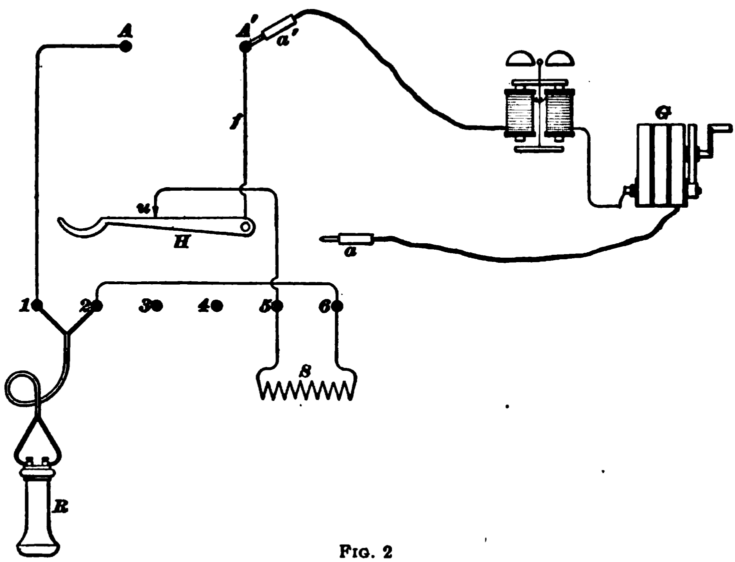


Fig. 2

the inspector would at once conclude that the signaling apparatus and circuits were all right, and that the fault was somewhere in the talking apparatus or circuits. Furthermore, from the fact that the instrument would not receive speech, he would know that the fault was not in the primary circuit because that circuit has nothing whatever to do with the receiving properties of the instrument. This would mean that something was wrong with the secondary circuit, and would probably indicate that this circuit was open at some point. A test to find out at what point this break occurs may be made as indicated in Fig. 2, where only the secondary circuit of an ordinary local-battery telephone is shown.

7. In Fig. 2, *1*, *2*, *3*, *4*, *5*, *6* are the binding posts at the bottom of the magneto-box, and S is the secondary of the induction coil. At the right of this figure is shown the testing set, consisting in this case of a magneto-bell and generator. A receiver and battery might be substituted for this, the test being performed in exactly the same manner. At a, a' are shown two convenient testing terminals, forming the ends of the testing circuit. The line wires should be disconnected from the telephone at the binding posts A, A'. The terminal a' should be touched to one of the binding posts A', and for convenience it may be inserted in the binding post in place of the line wire. The terminal a should then be touched to the opposite binding post A, when a failure of the polarized bell of the testing set to ring when the generator G is operated will show that the secondary circuit is open at some point.

8. To locate this point is now an easy matter. It is done as follows: The terminal a', Fig. 2, is left fastened in the binding post A' and the magneto-generator is kept turning, preferably by another party, while the terminal a is applied successively to all the wires in the parts forming the secondary circuit of the telephone. It would first be applied to the wire f, a ringing of the bell indicating that the circuit so far was unbroken. It should then be applied to the hook lever H, then to the upper contact u, and so on, point by point; the secondary circuit should be traced out with the point a. If, for instance, when the hook was up, the bell failed to ring, while the terminal a was applied to the upper contact u, while it had responded when applied to the hook H, it would clearly indicate that the circuit was still open between the hook H and the upper contact u, and this contact should at once be carefully inspected and repaired. If, however, it was found that the circuit was completed as far as the binding post *5*, while the bell failed to ring when the terminal was applied to the binding post *6*, it would show that the secondary coil was open; and if an inspection of the exterior circuits leading to the coil failed to show the difficulty, the coil should be removed and another substituted. In this manner, any circuit in a telephone may be readily tested out, and the fault located to a nicety, after which the repair is usually a very simple matter.

9. Telephone Testing Set.—In many forms of testing sets, microphone transmitters and batteries for operating them are also included, but the addition of this extra apparatus usually adds considerably to the weight of the testing set. The portable telephone testing set made by The Holtzer-Cabot Electric Company and known as its universal set is shown in Fig. 3. It contains a standard three- or four-bar generator, a 1,000-ohm bell, and other telephone devices. The receiver and transmitter are secured to one handle, the granular-carbon transmitter *t* being provided with a metal mouthpiece that prevents the breaking of the same. In the handle of the *microtelephone*, as it is termed, is a push button that, when closed, connects the batteries in the transmitter circuit. This prevents the exhaustion of the batteries when not actually in use for talking purposes. The door of the testing set may be closed when the microtelephone it outside. When the full voltage of the generator is desired for ringing on a line, the bell can be cut out of the circuit by means of a push button. The generator is provided with collecting devices by means of which either alternating or direct pulsating currents may be obtained; a switch *s* through which the desired current may be obtained is placed on the inside of the cover. The box has a strap with a snap catch *c*, by means of which the box may be easily suspended from a cross-arm or any convenient support. The door is opened by a push button and held closed by an automatic catch. The set is very solidly made, the corners of the box being protected with brass. All terminals are provided with thumb-nut binding posts, for tightening or loosening which no screwdriver is required. These terminals are

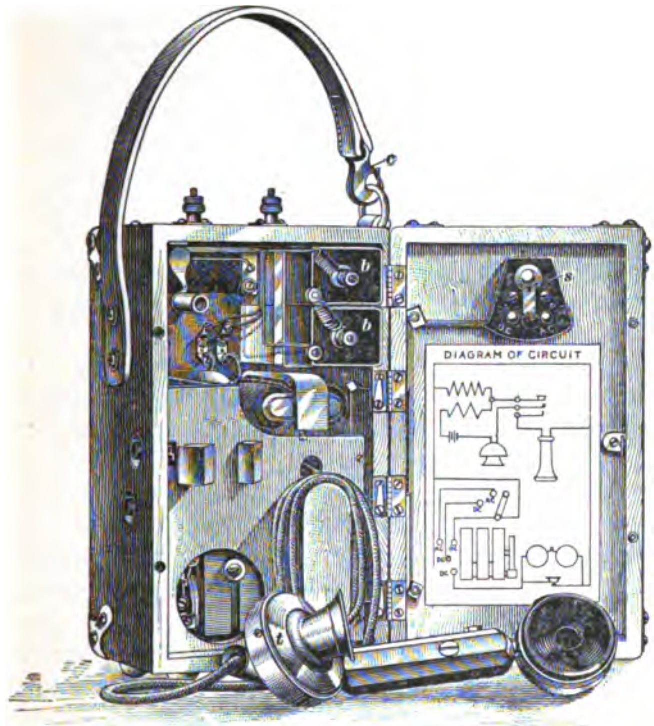


FIG. 8

put in readily accessible positions and the batteries *b*, *b* may be easily removed without disturbing the rest of the apparatus. A diagram of the wiring of the set is shown on the inside cover of the box.

TESTS WITH VOLTMETER OR CURRENT-DETECTOR GALVANOMETER

10. In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise in testing with a magneto-set, a cheap form of galvanometer for detecting currents, a voltmeter or millivoltmeter may be used. In testing for grounds or crosses, the voltmeter, or galvanometer, should be connected in series with several cells of battery, and one terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the needle may take place whenever the circuit is first closed, due to the rush of current that is necessary to charge the wire. If the insulation is good, the needle will soon return to zero; but if a leak exists from a line to ground or to the other wire with which it is being tested, the needle will remain permanently deflected. Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about fifty cells is used, but if a very high insulation resistance must be measured with more accuracy, more reliable methods should be used.

In testing for continuity, the distant end of the line should be grounded or connected with another wire, known to be good, and the voltmeter, or galvanometer, and battery applied, either between the wire under test and ground or between the wire under test and the good wire. In this case, a permanent deflection of the needle will denote that the wire is continuous; while if the needle returns to zero, it is an indication of a broken wire.

TESTS WITH TELEPHONE RECEIVER

11. The importance of the telephone receiver as a testing instrument is greatly underrated. A good receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than the magneto testing set or the detector galvanometer.

The ordinary watch-case receiver with a head-band for holding it to the ear of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed and may be used in testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat pocket of the user; and if two cells are used, they may be bound together, side by side, by a wrapping of ordinary adhesive tape. One terminal of the battery is connected to one terminal of the head-receiver, while to the remaining terminal may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both hands of the user.

12. For Grounds or Crosses.—In using the receiver for making rough tests for grounds or crosses on conductors in a lead-covered cable, one terminal of the testing circuit, including the receiver and battery, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from the other wires at each end. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must be carefully separated from one another and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire, even if it is properly insulated. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire; but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, the terminal of the testing set should be held against the wire, several seconds, then break and quickly remake the connection; if no sound is heard at the instant the connection is again made, the insulation is good; while a continuance of the clicks each time the circuit is remade will indicate that the wire is grounded. The loudness of the click depends on the sensitiveness of the telephone used, the number and voltage of the cells used, the electrostatic capacity of the conductor, the resistance of the insulation, the interval of time between the break and make. Under ordinary conditions with a telephone cable from 1,000 feet to a few miles in length, 1 second between a break and the next make, and a battery of 1 volt, no click usually means at least 50 megohms resistance between the conductor and the ground. This number increases about in proportion to the increase in electromotive force used.

13. For Continuity.—In testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires at the near end of the cable, the wires at this end all being carefully separated from one another. A continuation of the clicks, on tapping, will, in this case, indicate that the wire being tested is continuous, while the cessation, after a few taps, will indicate that it is broken. It is probably better, in making this test, to use an ordinary vibrating bell or buzzer instead of a receiver, for then, if the wire is only partly ruptured so as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it would allow enough to pass to produce a decided click in the receiver.

CABLE TESTING

NUMBERING OF CABLE CONDUCTORS

14. Cable conductors are numbered from 1 up; the odd number represents the first conductor of a pair and the even number its mate. As a result of a custom established when ground circuits were used in telephone practice, the odd-numbered conductor is called the *line* and the even-numbered conductor the *test*. If a cable splicer connects his telephone or test set with a certain conductor, to communicate with another splicer similarly associated with the other end of the conductor, he is said to *meet* the other splicer on the conductor. For example, if the splicer connects his telephone with conductor No. 1, using the earth as a return, and his assistant at the other end of the cable tries each conductor with his testing set until he finds No. 1 and communicates with the splicer on it, he is said to meet the splicer on No. 1; and since No. 1 is an odd-numbered conductor, he meets the splicer on the line of No. 1 pair. On communication being thus established, the helper will be directed to meet the splicer on the test, and on receipt of this instruction, he will connect his test set with conductor No. 2. When a telephone man thus connects his test set with a conductor for the purpose of communication, he is said *to go on the conductor*. When he connects his test set with both the line and test of a pair of conductors, and thus talks over a metallic circuit, he is said *to go metallic*.

The same conductor should have all its terminals, both in the central office and outside of it, numbered the same; for which purpose a test is necessary whenever a new cable is installed, whenever a defective section is replaced by a new cable, and whenever a system is changed from open wire to cable, or from aerial circuits to underground cable. The nature of the test and the method of making it depends on the conditions to be met.

IDENTIFYING WIRES IN CABLES

15. It is frequently necessary, when a certain wire has been picked out at one end of a cable, to identify that same wire at the other end in order that connection may be made with it. In order to do this, the wire desired should be grounded at one end, being carefully insulated from all the other wires. At the other end, the wires should be separated from one another and be free from the ground. A circuit containing a battery and a receiver, galvanometer, voltmeter, or ordinary vibrating bell or buzzer should then have one of its terminals grounded, while the other terminal should be applied successively to the various wires in the end of the cable. A continuation of the clicks in the receiver, a permanent deflection of the galvanometer, or voltmeter, or a ringing of the vibrating bell will indicate when the wire desired has been touched.

A bell or buzzer can be used for testing in two ways. Either the battery can be connected to one end of the wire to be found and a search made at the other end with a grounded buzzer, or the battery with the buzzer in series is connected to one end and a search made at the other end with a receiver. In this latter case, when the proper wire is touched, the sound of the buzzer at the other end is heard in the receiver. The advantage of using the buzzer lies in the fact that the receiver of the talking set can be permanently connected to the talking wire, which is not the case when only receivers are used.

16. The ability to talk over a pair of wires is not a sure test of their continuity because it is often possible to talk over a wire with one end open. A battery in series with a receiver is claimed to be reliable because a closed circuit is necessary before a battery current can flow; however, this method is open to the objection that a click may be produced when the circuit is first closed even when open at the distant end. While several methods are employed for testing cables after they are spliced, the following battery-receiver method is considered the most practicable by some cable testers.

The office end is formed up and numbered first. The man in the office connects his receiver across wires 1 and 2 and connects one end of a feeler wire, or third leg as it is termed, to wire 1. He then touches the other end of the feeler wire to ground and waits for the man on the pole to find him, which he does by grounding one terminal of a battery, connecting the other terminal to a receiver and with a wire attached to the other terminal of his receiver he runs over the insulated ends of the wires until he gets a click in his receiver, which he does when he touches wire 1 or 2. He connects his receiver only across the pair of wires 1, 2 so found and one terminal of his battery to wire 2. The two men now have a complete metallic circuit consisting of wires 1 and 2 for talking. When he is ready, the pole man tells the office man to touch wire 3 with his feeler, the other end of which is connected to wire 1. As soon as the man on the pole finds this wire 3 by touching his feeler to it (the other end of this feeler is connected through the battery to wire 2), both men get a decided click in their receivers. A code of signals can be arranged to save talking; thus three clicks may mean all right. Then the office man goes on the next wire with his feeler and so on until all the wires are tested. If a wire is bad, the pole man can tell the office man and they can skip the bad wire until the last; if it cannot then be found, an extra pair can be substituted for it. Do not try to talk with the office-feeling wire on the wire picked up, as the office receiver is then shunted. This is said to be a very fast method of working and can be used on working cables where a common battery is not used.

17. If some of the subscribers have a ground or common-return circuit, the ground or common-return circuit terminates at the cable pole; from there through the cable to the office the circuits are complete metallic. When testing a working cable on such a system, ground the outside end of all the switchboard-cable wires used in this way, disconnect them from the cable to be tested and disconnect the grounded-cable wires at the pole from the ground. Find a pair of wires not in use and proceed to test in the way described in the preceding article, except that the office man must have the battery, as going through the cable with the battery at the pole would throw the drops at the office.

18. Identifying Without Cutting.—It is frequently desirable to identify a wire at some intermediate portion of a cable without cutting the wire. This may be done by removing the sheath, or the outer coating, if the cable has no sheath, and loosening up the wires so that each one may be touched. The same test as that explained in Art. **15** may then be made by using, as a terminal to the testing circuit, a needle that will readily pierce the insulation and make contact with the conductor within. This method will be found to save much trouble in the testing of switchboard cables, where it is often necessary to lead off branch wires from intermediate points of certain wires in the cable.

When testing a working cable on a central-energy system, ground one side of the receiver and use a needle or a penknife to push through the insulation on the wires in the cable, which has been previously opened. On good working lines, a click will be heard and when the operator answers, ask her for the drop number and tag the wire with the proper cable-line number. Lay aside all the dead pairs as found. After picking out all the working pairs, test the dead pairs as explained in Art. **16.**

19. It is desirable to have the two ends of a telephone cable connected to the terminal heads or frames and numbered in a similar manner. One end of the cable is first connected, usually the office end, and then the conductors must all be tested out in order to connect and number them in a similar manner at the distant end. The first thing to do is to test out a pair that may be used for communication during the rest of the test. A common method of locating this talking pair is to have the man at the distant end *M*, Fig. 4 (*a*), connect his head-receiver between one conductor and the lead sheath, all conductors at that end being preferably fanned out and at least insulated from the conductor that is being tested. The man at the office end *O* then connects one terminal of his head-receiver to the sheath, and the other terminal to two or three dry cells *B*, while with the free end *d* he taps all the conductor terminals, one at a time, until both men get a decided click in their receivers, which indicates to them that the wire to which the pole man *M* has his receiver connected has been found by the office man *O*. The other wire *2* of this pair can be readily found, and, if necessary, tested in a similar manner. The connections shown at both ends of Fig. 4 (*b*) are then made, and the pair *1–2* used to talk over. The pole man *M* then

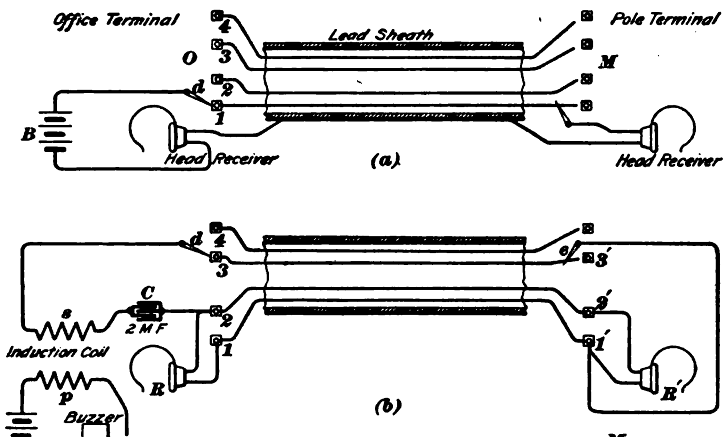


FIG. 4

connects his terminal *e* to any wire whose location and number he desires, and the office man *O* feels for this wire by touching, with *d*, all his terminals until a loud hum indicates to both of them that the desired wire has been picked up by the office man *O*.

The buzzer makes and breaks the circuit containing the primary winding *p* of an induction coil, thereby inducing an alternating electromotive force in the secondary winding *s*. This may, at all times, produce a slight hum in the receivers due to the slight charging and discharging of the 2-microfarad condenser *C*, but the hum will be very much louder when the circuit of *s* is completed through a conductor.

The current arriving at *2* divides about equally through *2–R–1–1′* and *2–2′–R′–1′*, reuniting at *1′* and returning through *e–3–d–s*. The office man *O* then removes his needle *d* from the conductor just found and tells the pole man *M* its number, so that the latter can connect it to the terminal of the same number at his end. Should the loud hum be also obtained when the office man *O* touches his needle to *4*, while the pole man *M* keeps his needle against *3′*, conductors *3* and *4* are probably crossed, and if the loud hum should be obtained when the office man *O* touches the sheath, the conductor touching *e* is probably grounded. In this way, each conductor may be tested for a cross or ground. This test is very similar to that explained in Art. **16,** except that a buzzer, induction coil, and condenser are required, in addition to a battery, and the source of current is placed at the office end instead of at the pole terminal. When testing cables while in use on central-energy systems, the source of current should be at the office end in any case. As the charging and discharging of an open cable line, especially a long one, may cause a click or a hum in a receiver, many prefer to use a buzzer, as will be explained, in place of a receiver for such tests.

20. When a new cable is placed in position, the pairs are taken at random and connected to the main distributing board in regular order. An assistant is then sent to the distant office or terminal with a test set consisting of a buzzer and talking outfit. The cable splicer then connects two dry cells and a buzzer to the line of the first pair, or, what is the same thing, on conductor 1, the other side of his test set being grounded on the lead sheath, or otherwise, and instructs his assistant at the other office to meet him on conductor 1. The assistant having reached the far office, connects one side of his buzzer to ground and, with a wire attached to its other side, touches each conductor in succession. When the proper conductor is reached, a circuit will be formed along it to the other office, thence through the first buzzer and battery to ground, and the buzzers at both ends will sound. The two men then talk to each other over this conductor with their test boxes, and the splicer then directs his assistant to meet him on the test. This having been done in the same manner, the assistant enters this pair into the positions to be occupied by conductors 1 and 2. He then proceeds to find the next pair in the same manner. This is illustrated in Fig. 5, where *a*, *b*, *c*, *d*, etc. represent conductors in a cable running between the two central offices *F*, *F'*. At the office *F* is the buzzer *T* and battery connected to the conductor *d*, while at the office *F'* the wire connected to the buzzer *T'* will be seen to be just about to touch the conductor *d* at *x*. If the two buzzers do not work well in series, short-circuit the vibrating contact on either, as represented by the dotted line on *T'*. When contact with *d* is made, a circuit will be formed over the conductor *d* through the two

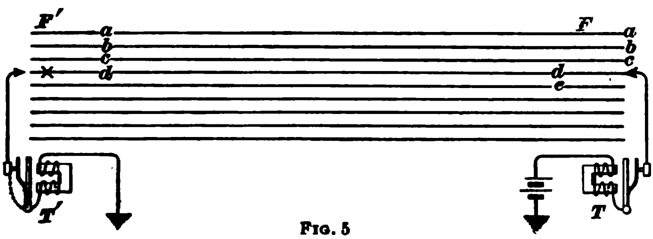


FIG. 5

test boxes and through the earth as a return. From this diagram, it will be seen that the conductors at *F* having been arranged according to a certain order, their other ends at *F'* can be arranged in the same manner when tested out in this way.

When the conductors have been all tested out, the two men, starting from the first, go metallic on every pair. In making these tests, one conductor that has been tested out is set aside for a talking wire, and should the assistant fail to meet the splicer on any given conductor, owing to its being in trouble, he is always able to communicate the fact over the talking circuit, thus saving unnecessary delay. The cable having been thus tested out and its conductors entered properly on the rack in the two offices, is ready for service.

21. Cables With Branches.—In testing out cables having branches, the method employed is necessarily different. Some claim that the testing should be done from the branch terminals instead of from the central office, because the conductors are located at the branches. Suppose that in Fig. 6 *A* represents the central-office end of a 200-conductor cable, and *B* its main terminal. Suppose that at the branch terminal *C* conductors *1–50* are to appear, and at branch terminal *D* conductors *51–100* are to terminate, the remainder being carried through to *B*. In making the splice at *C'*, fifty conductors are taken at random and a Y splice is made. In making the splice at *D'*, fifty more conductors are selected at random, the cable splicer being sure not to get any of the first fifty, as those have already been turned aside, as it were. This work having been done, the conductors are entered into the terminal boxes at *C*, *D*, and *B* in the proper order. The conductors appearing at *C* have been given the numbers *1–50* and they must take the first twenty-five pair of terminals on the terminal rack; so that it will be seen that the test must be made from the cable box *C*. The cable splicer goes on the line of pair 1 with his buzzer and battery, and the assistant at the exchange finds it on the rack and connects it to spring 1. The test of this pair is then found in the same manner. When all fifty conductors have been located and properly entered on the rack, they talk metallic on each pair, which finishes the test. The cable splicer then goes to cable box *D*, goes in with the buzzer and battery on the line of twenty-six pair, or conductor 51, and his assistant meets him at the exchange. The test wire is then found, and the pair entered on the rack. This process is continued until all these conductors have been located and entered on the rack. The same process is then repeated from the terminal *B*. The

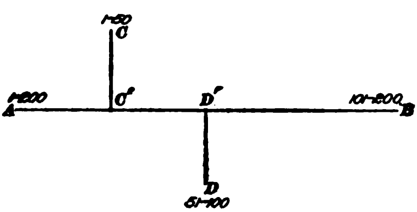


Fig. 6

conductors having been all entered on the main distributing rack and soldered to the arrester springs, the cable is ready for service.

22. Another way used by cable splicers is as follows: At the office, bunch wires *1–50* and test from *C'* before splicing into the branch *C*. At the office, ground the bunched wires and at *C'* ground one terminal of a battery, connect the other terminal to a receiver, and with the other terminal of the receiver connected to a feeler run over all the wires. On fifty wires, a click should be heard and no click on the rest; after picking out the fifty, remove the ground at the office end and touch one of the fifty. If no click is heard, they are all clear; if a click is heard, separate all the wires at the office end and test for the grounded wires with a battery and receiver, a click being heard on the grounded wires for which a spare pair should be substituted. The wires in branch *C* can be spliced at *C'* at random to the fifty pair picked out at *C'* and then tested and numbered to correspond with the office end after the splice is completed. The wires *51–100* are picked out, spliced, and tested in the same manner at *D'*.

23. It is necessary to test out cables on which branches are bridged in a somewhat different manner than that employed in the case of split branches. In the case of split branches, if the start is made at the branch nearest the central office, the conductors can always be selected at random, since there is no danger of making two splices on the same pair. With a bridging cable, however, it is different, and since all conductors pass the entire length of the cable, care must be taken, after the first branch has been spliced, not to include in any subsequent branch any of the conductors included in the first splice. Referring to Fig. 7, suppose that the first splice is made at *B*, the pairs having been selected at random. The cable splicer then goes to the cable box *B'*, straps all the conductors together and grounds them. He then goes to the point *C* where the second splice is to be made and with one terminal of his buzzer and battery connected with the ground he goes over the conductors with the other terminal. Obviously, if he touches any of the conductors that have been bridged at *B*, he will get a closed circuit and his buzzer will sound. All other wires will test open. He selects a sufficient number of conductors that test open and splices them. Should there be more than two branches on the cable, he straps all conductors to a ground at *C'*, goes to the place of the third splice, and proceeds as before. The testing out, for the purpose of entering the conductors properly on the main rack and in the cable box, is made from the cable boxes toward the central office in the manner already described, the ground connections previously made being first removed. Some

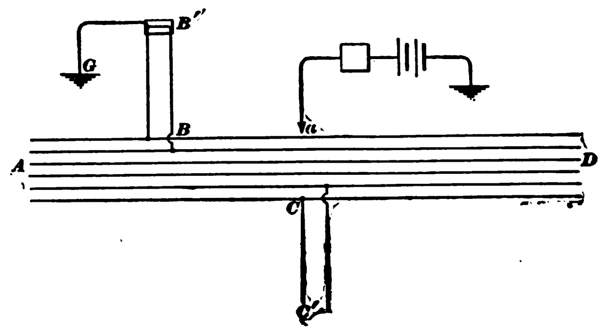


FIG. 7

prefer a receiver for this test in place of the buzzer, and claim that the office end of the cable should be connected up first and all testing done from there.

24. Replacing Cable.—It often happens that a section of cable must be replaced because it goes bad through age or from injury. The work of replacing bad sections must be done on cables that contain a number of working wires, and it therefore becomes necessary to carry it on with as little interruption to the service as possible. Indeed, defective sections can be replaced, if the work is done properly, without any interruption to the service whatever. In Fig. 8, let *1*, *2*, *3*, *4*, etc. represent conductors in a cable that has become defective between the points *A* and *B*. A new section of cable, whose conductors are indicated by the numbers *1'*, *2'*, *3'*, etc., is pulled through a spare duct between the points *A* and *B*, which are always manholes in the case of underground cables. In the manhole *A*, the new section is spliced to the old by using the bridging splice. In this way, each conductor is opened only for an instant. Before making this splice, care must be taken to open the end of the new cable in the manhole *B* and spread the conductors to prevent the occurrence of short circuits and crosses.

This splice having been made, the splicer goes to the manhole *B*. Now, obviously, if the assignment of the conductor

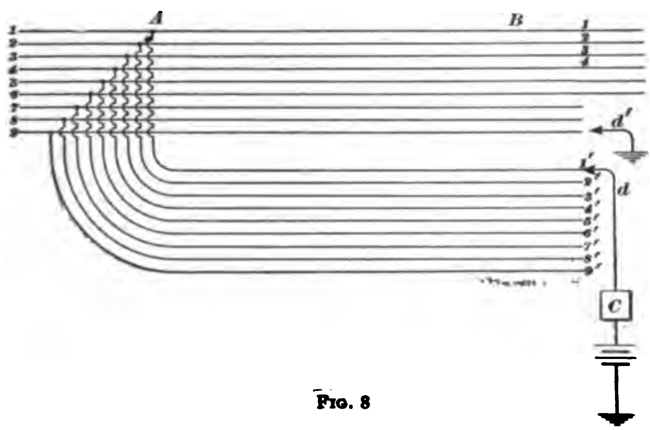


FIG. 8

is to remain unchanged after the new section has been cut into service, the conductor in the new cable that has been spliced to conductor *1* in manhole *A* must also be spliced to conductor *1* in manhole *B*, and so on. To insure this, a buzzer and battery shown at *C* is connected by wire *d* to conductor *1'*, the other side of the battery being grounded. The conductors of the old cable are then touched in succession with a grounded needle *d'* until the buzzer is heard, which is an indication that conductor *1* has been found. Conductor *1'* is then spliced to conductor *1*, and the process continued until all have been spliced. The conductors of the cable between *A* and *B* are then cut, and sleeves are wiped on at *A* and *B* in the usual manner. The multiple splice should be made in the manhole farthest from the central office. Some prefer a receiver and battery in place of the buzzer and battery.

25. Testing Cables Without a Helper.—Usually two men—a tester and a helper—are required to test out and properly connect the wires in a telephone cable to the cable terminals. By the arrangement shown in Fig. 9, one man can do this without assistance. After forming up one end, the cable tester grounds wire *1*. He then connects together *2* and *3*, *4* and *5*, *6* and *7*, and *8* and *9*, leaving the last wire, *10* in this case, open. This is shown at the *A* end of the cable. He then goes to the other end *B*, separates the ends of all the wires there, so as to have each one insulated and open, and tests for the grounded wire. When found, he knows it to be conductor *1* and the wire twisted with it he knows to be conductor *2*. Then, connecting one terminal of his testing set to wire *2* instead of to the ground wire as in the preceding test, he tests with the other terminal of his testing set for conductor *3*, which is connected to conductor *2* through the jumper he put on at the other end. Conductor *4* is the wire twisted with conductor *3*. He then tests for conductor *5*, and so on until the cable is finished. He knows the last wire because it will test open and also because it is the only wire left. It is evident that a cable of any number of pairs could be tested in this way. It would be well to add that if the tester came across some wire other than the last one that was also open, possibly broken inside the cable, no more wires could be tested without assistance or at least without another trip to the *A* end of the cable. However, this would not often happen.

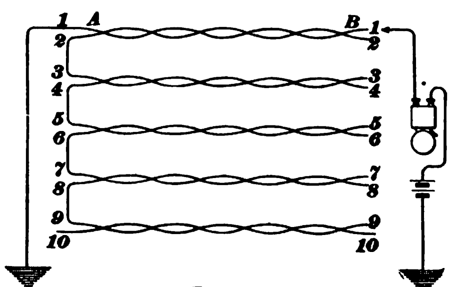


FIG. 9

LOCATING PAIRS IN COMMON-BATTERY CABLES

26. It is often necessary to locate pairs of conductors in a cable extending from a central-energy exchange, while the cable is in use, in order that a new multiple tap may be bridged on to the conductors. As the exchange battery is constantly connected to such circuits, and as a ground on one side of the line will usually cause an unintentional display of the line signal, the methods of locating pairs that are used in magneto-systems are not applicable. The circuits and methods tried and found thoroughly practicable by a large telephone company will now be given.

27. In Fig. 10, *a*, *b*, *c* represent wires in a cable; the office terminal, new terminal, and old terminal being located in the relative positions shown in the figure. Each condenser has a capacity of 2 microfarads. As the buzzer *E* may be used for several hours at a time, it is liable to give considerable trouble by getting out of adjustment and by burning at the contacts. This may be overcome by using, at *B*, two dry cells connected in parallel and a condenser *C* in parallel with the buzzer. The condensers C_1 and C_2 are inserted in the circuit to avoid giving a permanent signal in the office while testing on the working lines. The impedance coil *I* reduces the sharp peaks of the current produced in the secondary coil *s*. If this is not done, subscribers are apt to complain that their lines are noisy. An induction coil *p*, *s* that steps up the voltage in a ratio of about 1 to 20 gives the best results.

28. A pair of wires *a*, *b*, Fig. 10, are first located for use as a talking circuit. To do this, the feeler *m* at the central office is attached to one or both wires of a good idle pair and the tester goes to the new terminal and there locates this pair by going over all the wires with one terminal of his receiver *R'*, the other terminal of which is directly grounded, until he locates the wire or pair of wires over which he receives a test current, that is, a hum. He then connects his receiver *R'* across this pair *a*, *b* and sends his helper back

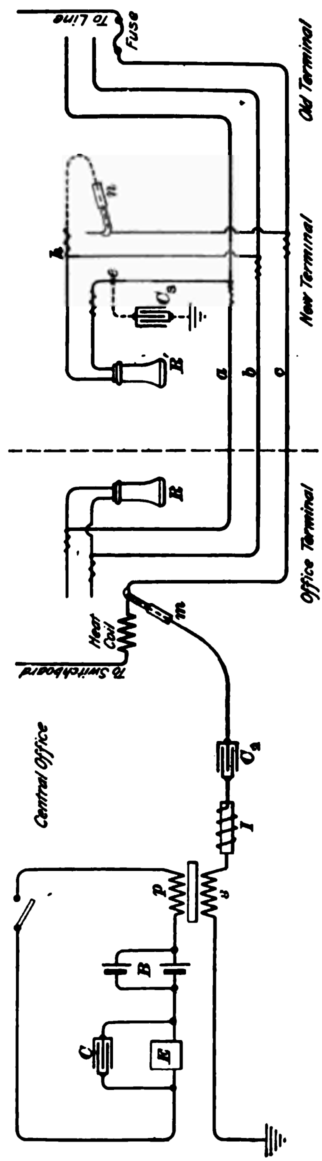

To Line
Fuse
Old Terminal
New Terminal
Office Terminal
Heat Coil
To Switchboard
Central Office

FIG. 10

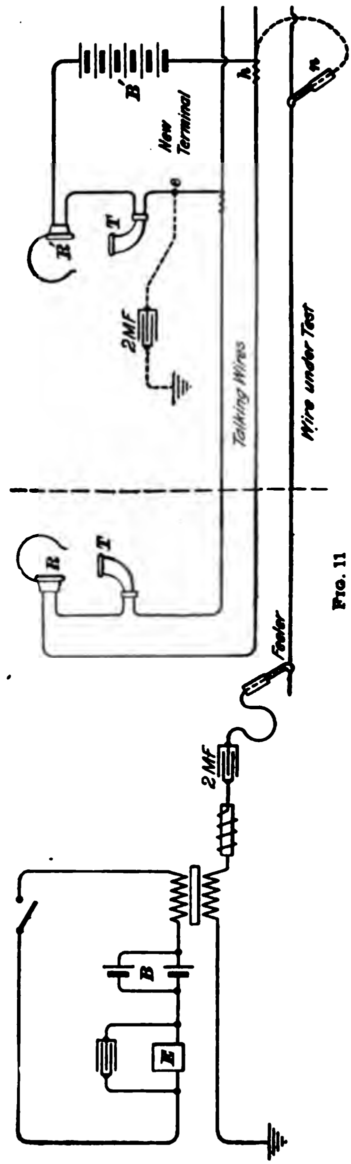

New Terminal
Talking Wires
Wire under Test
Feeler
2MF

FIG. 11

to the central office to disconnect the feeler and to connect a receiver R across the same pair a, b. Thus a clear line is available for talking.

The tester now grounds one terminal of his receiver R' through the condenser C_1 and connects a feeler n to the other terminal of his receiver. He then touches his feeler n to a third conductor c and tells his helper in the office to run his feeler m slowly along the office terminal. When the feeler m touches the conductor c, both will hear a hum due to current that passes through m–n–h–$\left\{\begin{matrix}R'\\R\end{matrix}\right\}$–$e$–$C_1$–ground–secondary s–impedance coil I–condenser C_2. The helper then tells the tester the number of the wire and the latter inserts his end of the wire c into its proper place in the new terminal. In this manner, all the wires may be properly connected in the new terminal.

29. For rapid testing and to insure no mistakes being made in giving the conductor numbers over the talking wires, excellent results are obtained by inserting, as shown in Fig. 11, about six dry cells B' in series with the talking wires and using a breastplate transmitter T and receiver R at each terminal. The connections are otherwise the same as in the preceding figure. This saves time by allowing the men the use of both hands while testing and also eliminates the shouting through receivers, which is regarded as a disagreeable feature of most cable tests.

LOCATING FAULTY POINTS IN SPLIT PAIRS

30. It occasionally happens that a wire belonging to one pair of conductors has been carelessly and incorrectly connected to a wire of another pair at some cable joint or transposition. Both pairs are then said to be split. To locate the faulty point is not always easy. In Fig. 12 (a), s represents one pair of conductors, t another pair, and $2, 3$ are the wires incorrectly joined at y. Later an attempt is made to remedy this condition at some other splice z in the cable, or perhaps at the main distributing frame or extreme end of the cable. This brings about the condition shown in Fig. 12 (*b*), which will give the worst kind of cross-talk in a long cable and yet each conductor will appear to be in proper condition when tested in the usual way with a volt-

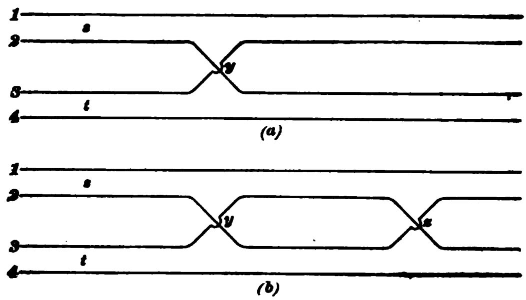


FIG. 12

meter or Wheatstone bridge. If only one pair out of the four wires is used, it will be noisy or a source of noise, especially if it is used as a toll trunk.

31. The point at which the split, that is, the incorrect connection was made has been approximately located with much

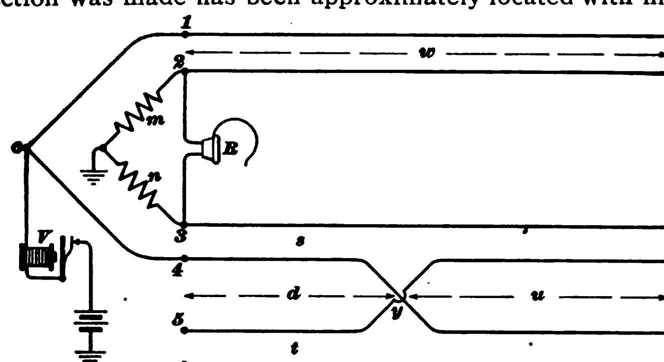


FIG. 13

success, according to Adolph Jameston in The American Telephone Journal, by the following method: In Fig. 13, *w* is a pair of wires in good condition the full length of the cable and *s* is the split pair being tested, the conductor *4* of which is connected with one wire *5* of the other split pair t at y. R is a telephone receiver connected across the arms m, n of a Wheatstone, or slide-wire, bridge and V is a buzzer or other means of supplying a variable, or alternating, current to the point o. Adjust m, n until no sound or a minimum sound is heard in the receiver. Then m and n are inversely proportional to the capacities and hence also to the lengths w and d; that is, $\frac{m}{n} = \frac{d}{w}$ or

$$d = \frac{m \times w}{n}$$

in which m, n are expressed in ohms or divisions of a slide wire and d, w in feet or any other convenient unit of length. A more reliable result may be obtained by making the measurement from each end and taking the average of d and $w - u$ so found. This test is not infallible, because such things as a slight ground on either conductor of the split pairs, more than one splice in the split pairs, or many branch circuits or leads to terminal heads tapped on either split pair will cause an error in the result. Still, it is claimed that with all these chances for error, it is better than opening the cable indiscriminately until the trouble is found.

BUZZER TONE TEST

32. An arrangement of apparatus and circuits for testing purposes is shown in Fig. 14 (a), in which B is a battery composed of a few closed circuit cells, connected through a simple switch S to a rather high-resistance buzzer, which should be placed so that it can be heard in any part of the terminal room. In parallel with the buzzer coils is one winding of a high-resistance repeating coil (about 300 ohms). One terminal of the other winding is grounded and the other terminal is connected to a brass, or copper, bus-bar, from which circuits lead to various parts of the exchange wherever a tone test may be useful. The dotted lines represent the extra circuit required for the tone test only. Connected to the binding posts h, i is a flexible lamp cord long enough to reach to any part of the terminal room and ending in a cable clip at *fj*, which should be suitable for use with the type of terminal frame installed. The circuits *c–i–f–j–h* and *c–i–d–e–h* and one winding of the repeating coil are all in parallel with the buzzer coils; these circuits are, therefore, all opened when the buzzer armature is attracted.

33. The following are some of the uses of this testing apparatus: To test for grounds after a lightning storm, ground the suspender clip *e*, close switch *S*, which will allow the buzzer to vibrate continuously, and with the feeler *d* run

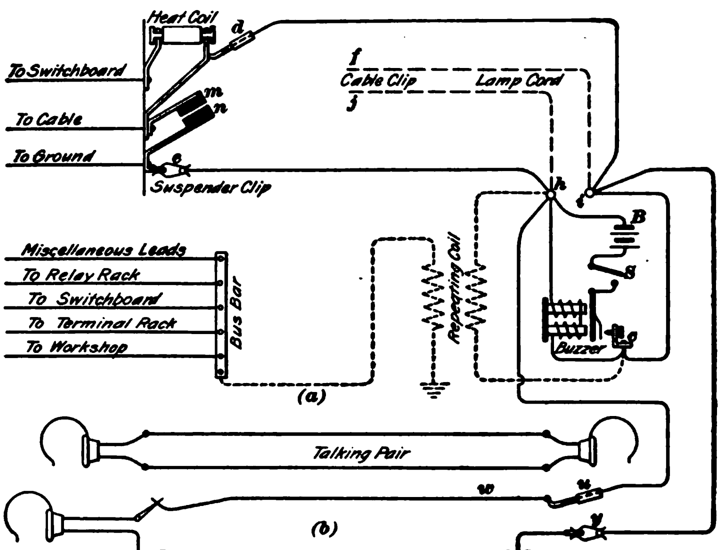


FIG. 14

over the cable or line springs, as indicated in the upper part of the figure. A ground between two carbons *m*, *n* will cause the buzzer to cease vibrating as the closed circuit *h–e–m–n–d–i–c–* short-circuits both the buzzer coils and the battery. The ground is removed by taking out and cleaning the carbons.

To ascertain if a pair of conductors is good, insert the cable clip *fj* into the springs of the exchange cable head, close switch *S*, and send a lineman to the manhole or cable box, where he can connect his head-telephone across the pair to be tested. If he can hear the buzzer, the pair is good. He then short-circuits the pair with his screwdriver or otherwise, which practically short-circuits the buzzer winding and also the battery, thus stopping the buzzer and thereby attracting the attention of the terminal man, who can then connect a head-receiver to the pair and talk to the lineman. The receiver resistance is usually high enough not to short-circuit or stop the buzzer.

34. To test a new cable after the office connections and pothead at the outside terminal have been made and the outside cable wires spread to prevent crosses and grounds, the lineman at the outside terminal can find, with his head-telephone, the pair to which the clip *f j* has been connected in the office, this pair then being used, as shown in Fig. 14 (*b*), as a talking pair. The suspender clip *y* is grounded, the feeler *u* is held on the conductor *w*, the lineman is instructed to ground at *g* one terminal of his receiver, and to touch the other terminal *o* to the ends of the cable wires until he finds the one through which he can hear the buzzer. The other conductors are tested in a similar manner. Each conductor should have fastened to it a label bearing the proper number, or else connected to the proper terminal screw when tested.

To test circuits other than those mentioned, use one of the leads from the repeating-coil bus-bar. These leads may also be used to provide a test for lines in trouble and for a howler, for which purpose one lead may be connected to one or two plugs or spring jacks at each section of the switchboard.

TESTS WITH VOLTMETER

35. The most general use of the voltmeter about an exchange is in testing lines for crosses, grounds, short circuits, etc. The battery, voltmeter, and line to be tested are usually connected in series. Such an arrangement for testing for short circuits on the line is useful, both in central-energy exchanges having condensers at substations and in magneto-exchanges using local battery. In central-energy systems, the condensers at subscribers' stations frequently become short-circuited, allowing current from the battery to flow through the line and through the defective condenser and ringer coils, thus operating the line relay and displaying the line signal, besides wasting current. This condition would be indicated by the voltmeter showing a reading of, say, 40 volts when testing with a 50-volt battery a line on which the ringer magnets are wound to 1,000 ohms resistance.

If the line wires are crossed, the resistance of the cross will very likely be much less than 1,000 ohms, giving a higher reading on the scale of the instrument. A loose connection might be the cause of a continuous movement of the needle from about 33 to 43 volts, while a swinging cross will probably cause the needle to kick from perhaps 0 to near maximum reading.

If the inside wiring of the substation or telephone cords is wet or damp, or there is moisture in the cable, the needle will, perhaps, deflect to 40 volts and gradually sink to, say, 5 to 10 volts, showing that the insulation resistance between the two wires is extremely low, and giving an idea of the drying-out effect produced by the rather large current used in testing.

36. In the magneto-exchange, of course, a perfect line will not be expected to measure open, as the ringer coils in the subscriber's instrument will cause the voltmeter to show a deflection. A little practice usually gives an idea as to whether the deflection noticed is due to the resistance of the ringers or is caused by trouble on the line. This is especially so in the use of a voltmeter reading to but 3 volts, the coil of which will probably measure 500 ohms, more or less. In this case, a perfect line will very likely give a deflection of about 1 volt, if the ringer magnets are of 1,200 ohms resistance. In case there is no deflection, it indicates at once that the line is open. A loose connection will be shown by the same reading that is usually obtained when the ringer is connected across the line and then falling almost to zero, which indicates a high resistance.

37. Determining the Side of Line Grounded.—In a central-energy system, on account of the condenser keeping the line open so far as the direct current is concerned, the side of line grounded may at once be determined. In the magneto-system, however, on account of the ringer movement being across the line, should one side be grounded, a reading will be obtained indicating that both sides are grounded. In order to ascertain the side grounded in the latter instance, it will be necessary to open the line at the substation, preferably at the instrument posts, so as to leave the arrester at the house included in the line tested. Arresters, naturally, are frequently the cause of lines being grounded. By connecting the battery and voltmeter in series between each line and the ground in turn, it can be readily determined whether one or both sides are grounded, or whether the previous reading for both sides was caused by the ringer coils only.

Grounds on both sides of a line cause a short-circuit reading; also a short circuit or cross on a line, if one side is grounded, will indicate that both sides are grounded. A cross on a line not due to a ringer connected across the circuit will have the same effect on a voltmeter, one terminal of which is grounded, as that produced by a ringer across the line.

The inspector, after some little experience, can, with remarkable facility, go almost direct to the cause of a 30-volt short circuit or a 50-volt one-side ground that he is sent to clear. The wire chief in a central-energy exchange, on obtaining a 50-volt short-circuit reading, will direct the inspector to look perhaps for a receiver off its hook; on obtaining a 42-volt short-circuit reading he will very likely give the inspector a condenser to replace the one he thinks has been punctured on the line under test.

38. Test for Balance on a Metallic Circuit.—The voltmeter may be used to determine whether a metallic circuit is balanced, that is, whether each wire has the same resistance. This test is made about as follows: Clear the line of all shunts, bridging telephones, and grounds; then short circuit and ground both wires at the arrester or elsewhere at the distant end. For a voltmeter, use preferably one reading only to 2, 3, or 5 volts, or, better still, use a milliammeter reading to about 600 milliamperes. Connect the voltmeter or milliammeter and a suitable battery, say one giving about 40 volts, between one line wire and the ground, then between the other line wire and the ground; if the two readings are equal, the line is well balanced as far as the resistance is concerned. The actual resistance of the line may be calculated from the voltage of the battery and the reading of the instrument. If they are not equal, look for bad joints or loose connections in one or both sides of the line. Transposing the lines will frequently make the resistance of the two sides of the line more nearly equal.

The voltmeter may also be used to roughly measure the resistance of a coil, drop, or subscriber's line. For such a measurement, it will, of course, be necessary to know the resistance of the voltmeter. Various other tests may be made with the voltmeter and battery, such as going over cable heads in a magneto-exchange after a thunder storm to detect lines having grounded carbons, etc.

39. It is a good plan, when purchasing an instrument, to obtain, if possible, a voltmeter having two scales, one reading from 0 to 3, 5, or 15 volts, and the other from 0 to 150 volts. Most up-to-date exchanges have portable instruments of this type, thus enabling the wire chief to use either scale. By both the wire chief and inspector becoming familiar with the various readings given by the voltmeter in the various tests, they can usually obtain a comparatively intelligent idea as to the character of the trouble.

40. Testing Condensers.—The condensers in a central-energy substation instrument may be tested by connecting the receiver across the line with the condenser in series, and if central answers, the condenser is short-circuited. Or put it across the line and charge it; an instant later, short-circuit it with a pair of pliers or a wire; a spark indicates that the condenser will retain a charge and can be replaced in the ringer circuit. Sometimes, short-circuited condensers are placed across a 110-volt direct-current circuit and blown out. Few condensers used in telephone circuits will stand such a test across 500 volts.

41. General Remarks.—It not infrequently happens, in cases of crosses and grounds, that the source of trouble itself possesses considerable resistance. When this is the case, the voltmeter method of testing leads to erroneous results regarding the location of the trouble, and in order to correctly locate the fault, it is necessary to use some loop test. Where the trouble is in a cable, a loop test is necessary in order to locate it satisfactorily, as inspection in this case will avail nothing.

In the case of an open-wire line, however, it is advisable, where the trouble cannot be located by the ordinary test, to patrol the line and attempt to locate it by inspection, as this can usually be satisfactorily accomplished. Where bare copper or iron line wires are used for open-wire lines, there is, as a rule, no difficulty in locating an open circuit by inspection, but this does not always apply where insulated conductors are used, as numerous cases have arisen where the insulation has remained intact, while the conductor itself was broken; trouble of this nature will usually prove difficult to locate.

42. When the exchange can call and hear subscribers until a connection is made between two subscribers, the line is probably short-circuited or opposite sides of the two lines are well grounded. This will more frequently happen where there are common-return lines coming into metallic-circuit cables and a metallic-circuit switchboard. If a pair of cable lines become reversed, the grounded side of one line will be connected with the ungrounded side of another line through the switchboard, while the ungrounded side of the former is connected to the grounded side of the latter, making a short circuit. As long as there is no connection, the operator can converse with the subscriber.

43. Although central-energy systems do not have batteries at the subscribers' instruments, which have to be inspected, nor magnetos, which burn out, central-energy systems are not free from trouble. From the fact that the lines are all connected together at the central battery from which they are supplied, it follows that a short circuit or ground on one line affects all the rest to a greater or less extent. In most central-energy systems, the lines are normally open and only a small amount of current is supplied to each line in use. Should one line, however, become short-circuited, current from the battery flows through the short circuit and operates the line signal; it should also operate the heat coil. Although an unintentional operation of the line signal indicates at once that there is trouble on the circuit, it drains the battery to such an extent sometimes, especially if the heat coil does not operate promptly, that other subscribers have difficulty in signaling the exchange. Moreover, central-energy line circuits must be very carefully insulated, because if there is a small leakage on each line it may amount to considerable for all the circuits, and therefore cause quite a drain on the common battery. Besides causing a loss of current, it might cause cross-talk, unless the battery has a very low resistance. Moreover, leakage from the line circuits may cause considerable trouble in signaling the exchange.

CUT-AND-TRY METHODS FOR LOCATING TROUBLE

44. Open Circuits.—The **cut-and-try method** generally used for locating open circuits, whether swinging or otherwise, or whether on one or both sides of the line, is as follows: The point at which the open circuit occurs is located by making successive attempts to communicate with the exchange and subscriber at the opposite ends of the line at various accessible points throughout the length of the line. The lineman will connect his testing set to the first point accessible outside of the exchange, probably a cable box. If he can raise the exchange but not the subscriber, the open circuit is between that point and the subscriber. In this manner, he will proceed until he reaches a point from which he cannot raise the exchange, but can call the subscriber. The open circuit will evidently lie between the last two points.

The fact that neither drop at the extremity of a toll line can be rung down and that no conversation can be carried on over a line indicates that the line is open. Toll lines usually have test points, such as at the distributing boards, cable boxes, test poles, and the several exchanges through which a long toll line may pass. In the latter case, the trouble will, of course, be located between exchanges before a lineman is sent out to test and locate the trouble along the line.

45. Short Circuits.—The cut-and-try method of clearing short circuits is similar to that for open circuits, with one very important exception; namely, that when a line is open, the portion of the line on each side of the opening can still be used for conversation, but in the case of a short circuit, the whole line is put out of service, and before communication can be reestablished, the short circuit must be cleared. The method of testing consists in cutting out the defective portion of the line during the test by temporarily opening the line at the point of testing. For example, the lineman goes to the first testing point and opens both line wires. He first tests toward the exchange; if he can raise the operator, that side of the line is all right and he disconnects himself from that portion of the line and connects himself to the opposite portion where he finds the short circuit. After again joining the line wires, he proceeds to the next testing point and makes a similar test both ways. In this manner, the trouble can be located and after clearing it the lineman should be able to raise either the exchange or the subscriber.

46. Crosses act like short circuits by throwing the whole line into trouble. If two adjacent conductors are crossed, cross-talk may be heard on any portion of either of these two lines; for even when only one conductor of each line is in contact, a closed metallic circuit results through the instruments and drops on each line. The method of locating crosses resembles that employed in locating short circuits, but is more complicated. To the first cable box, the lineman will connect his test set on either one of the two lines and ring. On so doing, the drop and the telephone bell on one line will be operated in the usual manner, while those on the other line will be operated over the circuit formed at the cross, unless the resistance of this contact should be very high. The two operators and probably both subscribers will answer the call, and the lineman, listening in, will hear the conversation on both lines. If one of the crossed lines is opened at the testing point and a test made toward the exchange, the cross-ringing and cross-talk will not appear on that line, provided that the cross is on the other side of the test point from the exchange. If, however, still keeping the line open at this point, a test is made toward the subscriber, and the cross-ringing and cross-talk should still be found, the cross is evidently on the line toward the subscriber's station. The same test should also be repeated on the other two wires constituting the remaining sides of the two metallic circuits, as a measure of safety, because where only a single cross exists, other trouble may accompany it; and with a view to locating it, both the affected lines should be tested thoroughly. The same test should be repeated at the next test point, and, in this manner, the two points between which the cross occurs can be located.

47. Grounds.—Experience is of more value in locating grounds than in any other kind of trouble, because all grounds, except the slightest escape, make the line defective, more or less noisy, and the character and intensity of the noise will usually determine not only the nature of the ground, but also its location. The lineman should go from one test point to another and listen in on the line, noting the nature and intensity of the noise. At each point, he should also open the line and test in both directions in order to determine which portion is free from trouble. By repeating these tests at the various test points, the point of trouble can usually be located. However, if the line is dead-grounded on both sides, probably no noise will be produced and the conditions will be the same as produced by a short circuit.

48. Swinging or **intermittent faults** probably cause more trouble to the testing force than any other difficulty with which they are called on to deal. The swinging of the lines in the wind often causes temporary crosses. The continual rubbing of an insulated conductor against a tree may result in the destruction of the insulation to a sufficient extent to produce a ground on the line, this being particularly apparent in wet weather, and appearing and disappearing with the movement of the wire. Improperly soldered joints or resin joints, as they are sometimes termed, are also a source of considerable annoyance and are often difficult to locate.

Swinging crosses, grounds, and cut-outs, especially when caused by loose joints, are particularly hard to locate, especially on long toll lines, for the reason that, since the trouble appears only at intervals, the lineman cannot feel sure that, when getting an "O. K." on either end, the portion of the line in trouble has been cut out, for the O. K. may be merely due to the fact that the trouble did not occur when the test was being made. Hence, it is well, when making tests for troubles of this nature, to allow the test set to remain connected to the circuit for some time.

49. Trouble Inside the Exchange.—The troubles that occur in the exchange itself do not, as a rule, admit of location by test from the wire-chief's desk, on account of the small resistance and capacity that the interior lines possess and the consequent necessity of extreme accuracy of the testing methods employed. It is usually a difficult matter to determine the exact nature of the trouble that exists on a line in an exchange, and the actual location of such a fault can only be determined by inspection and trial. There are times when troubles arise in central-office apparatus that the most elaborate series of tests will fail to explain. A successful inside troubleman depends, to a large extent, on his intimate knowledge of the location of the equipment and also on his knowledge of its weak points.

The inside troubles may be divided into grounds, crosses, open circuits, short circuits, and adjustment of instruments. The adjustment of relays is rather difficult, and requires considerable experience. A peculiar feature that affects the operation of central-energy exchanges is the great number of false signals that are conveyed to the operators after lightning storms. These signals are the result of the passage of a portion of the lightning discharge through the carbon arresters in the line to the ground, the current carrying with it a sufficient amount of carbon dust to connect the grounded and non-grounded carbon and to throw a permanent ground connection on the line. This results in the operation of the line relay and the consequent illumination of the line signal. In the majority of instances, trouble of this kind can be cleared by the operator, who inserts a plug in the line jack and rings over the line.

TESTING CIRCUITS FOR WIRE CHIEF

50. Arrangement of Testing Apparatus.—In large exchanges, it is usual to arrange a voltmeter, telephone, hand generator, and sometimes a Wheatstone bridge on a special desk, or testing table, to which the power generator, testing battery, and various circuits used in making tests are connected. In many large exchanges, the testing equipment is arranged in duplicate and installed in a two-position testing desk, in order that two men may be able to test at the same time. In addition to the testing equipment, the desk is built to contain a filing case or drawer in which are kept card records of the subscribers' lines entering the exchange. The filing case is usually so arranged that the tester has easy access to the line cards while testing. The line records that are shown on the cards contain all the information regarding the line that it is necessary for the wire chief to know, such as the name and address of the subscriber, the cable conductors and cable by which the line leaves the exchange, the jack and panel on which the line terminates in the office, the point at which the line changes from a cable to an open-wire line, and the route that the line follows; also, information regarding the poles, cross-arms, and pins on which the line is carried, and the terminal pole or distributing box from which the line is led to the subscriber's station.

With this information, and knowing the size and materials of the conductors in the cables and in the open-wire lines, the wire chief is able to gauge accurately the result of his tests, and to tell approximately the pole or manhole near which a specific trouble exists. The efficiency of any arrangement of testing circuits in practical use is so thoroughly dependent on the personality of the man at the testing table that it is not possible to say just what testing arrangement is the best.

WIRE-CHIEF'S TESTING CIRCUIT FOR A MAGNETO-EXCHANGE

51. A testing circuit suitable for the use of wire chiefs in medium-sized magneto-exchanges is shown in Fig. 15. Jacks *1* to *11* may be mounted in a position to suit the testing apparatus. Jacks *1* and *4* connect to the line side and jacks *2* and *3* to the switchboard side of the test clip adapted to fit in the arrester springs at the terminal rack. Any circuit can thus be tested toward the switchboard or line. To jacks *5*, *6*, and *7* are connected two batteries of any suitable voltage. If B_1 has a voltage of 5 and B_2 of 20, then 5, 20, or 25 volts are available, and by means of the resistance r the strength of the current may be regulated, provided that jack *7* is used. Jack *8* is connected to a good ground. Jacks *9* and *10* are connected to a two-conductor plug at the switchboard, where it may be inserted in any line to be tested from that point for grounds, crosses, short-circuits, etc. Jack *11* and its drop is connected with a jack and drop at the switchboard, so that inspectors may be connected to the wire chief when they call up the exchange from any subscriber's station. The wire chief may also ring up the operator over the same circuit by inserting the plug P in jack *11* and closing key N.

The testing plugs are connected to a number of keys that are normally open. If it is desired to test a subscriber's instrument, the testing plugs may be inserted in jacks *1* and *4* or in *9* and *10*. Then, closing K' should ring the subscriber's bell with current from the power generator; if it is desired

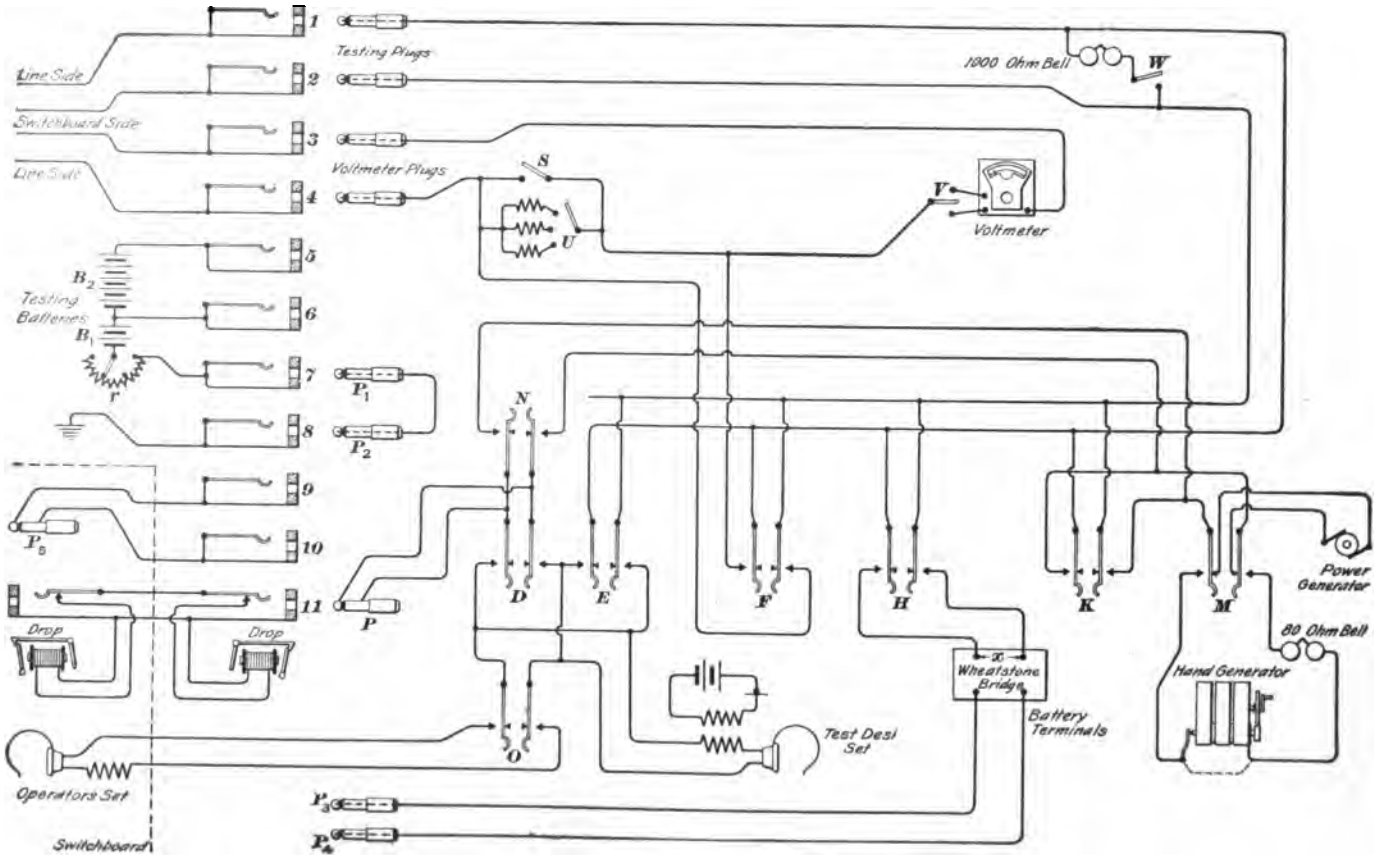

Line Side
Switchboard Side
Line Side
1
2
3
4
5
6
7
8
9
10
11
Testing Plugs
Voltmeter Plugs
B_2
Testing Batteries
B_1
r
P_1
P_2
P_5
P
P_3
P_4
Drop
Drop
Operators Set
Switchboard
S
U
V
Voltmeter
1800 Ohm Bell
W
N
D
E
F
H
K
M
O
Wheatstone Bridge
Battery Terminals
Test Desk Set
Power Generator
80 Ohm Bell
Hand Generator

FIG. 15

to use a hand generator and an ordinary 80-ohm bell, close key *M* in addition to key *K*. A cross or open circuit in local apparatus or on short lines, where the electrostatic capacity is not large, may be determined by using the hand generator and bell. By closing switch *W*, the ability of a subscriber's generator to ring a 1,000-ohm, or other suitable bell, may be tested.

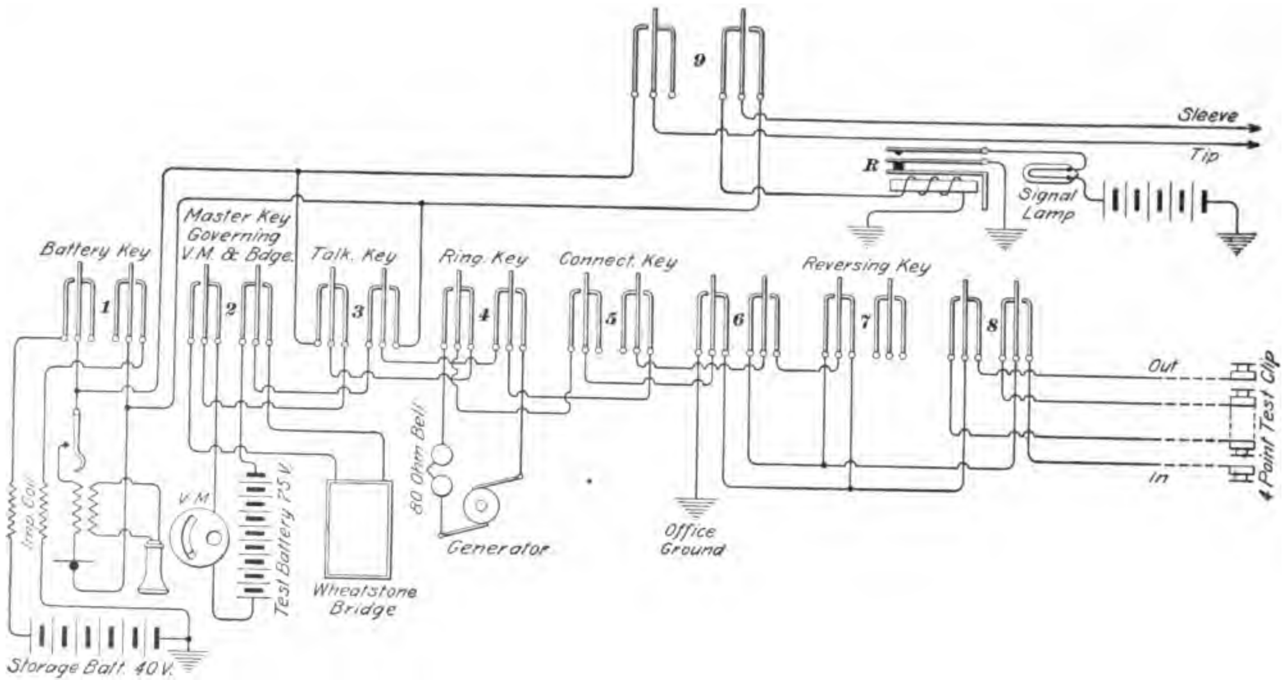
52. By closing the key *H*, the Wheatstone bridge may be connected to the testing plugs for a resistance or loop test on any line or either side of any line. The battery terminals of the bridge are connected to plugs so that the testing battery, terminating at jacks *5*, *6*, *7*, may be used and also to facilitate the making of loop tests. To measure the loop resistance through the two sides of a crossed or grounded line, insert the testing plugs in jacks *1*, *4*, close key *H*, and insert plugs P_3, P_4 in jacks *6*, *7*, for instance. To obtain the second balance, which requires one side of the battery to be grounded, remove the proper plug P_3 or P_4 from jack *6* or *7*, and ground that side of the battery by connecting that jack to jack *8* with the plugs P_1, P_2. Where the testing set has its own battery, it will only be necessary to have one side of its own battery connected to one plug for insertion in the grounded jack *8* for the second balance. If the ground seems to be on the wrong side of the line, reverse the position of the test plugs in the jacks. As to which side of a line is grounded can be readily determined by means of the voltmeter. These connections are very convenient for making loop tests.

53. To test for insulation resistance or crosses with the voltmeter, insert the voltmeter plugs in the jacks of the testing battery, one of the testing plugs in the jack of the line to be tested, and the other testing plug in jack *8*, Fig. 15, and close key *F*. The switch *V* allows either scale of the voltmeter to be used, the switch *S* allows the voltmeter to be connected directly across the testing battery, and the switch *U* enables readings of the voltmeter to be taken across any one of three known resistances. This is convenient for estimating the resistance, by voltmeter readings, to a ground or cross, for with the same battery the reading of the voltmeter will be inversely proportional to the total resistance of the circuit. Closing the key *E* connects the test-desk set across the testing plugs; closing *D* connects it across the calling plug *P*, which may be used to call up an operator or to converse with an inspector. Closing key *O* connects the test-desk set through an order wire to a switchboard operator's set. The keys *O*, *D*, *E*, *F*, *H*, and *M* should be keys, or cams, that will remain in either position, but keys *K* and *N* should return to their normal positions, as indicated in the figure, when released.

WIRE-CHIEF'S TESTING CIRCUIT FOR A CENTRAL-ENERGY EXCHANGE

54. In Fig. 16 is shown the circuits, etc. of a wire-chief's testing table used in connection with a central-energy exchange. With this arrangement, the wire chief may make tests with a voltmeter or a Wheatstone bridge, ring or talk out over the line metallic, or from either side to ground. By using a four-point plug or test clip suitable for insertion in the terminal head where the heat coils are located, tests can be made on a circuit, either out on the line or through the exchange. The telephone may be used independent of test circuits as an ordinary instrument. The generator has an 80-ohm ringer in series with it, so as to obtain the same results as when testing with a magneto-generator. An extra key could be readily connected in the circuit so that either the power or a hand generator could be used.

55. The operation of the set is as follows: After inserting the test plug between heat-coil springs on the cable terminal, key *5* is thrown. This puts the voltmeter and test battery across the line. To test one side to ground, key *6* is thrown; and by throwing both keys *6* and *7* the other side is tested to ground. To listen on the line, key *3* is thrown. This cuts out the voltmeter, and if it is desired to talk, close key *1*, which supplies both wire-chief's telephone



Sleeve
Tip
R
Signal Lamp
9
Master Key Governing V.M. & Bdge.
Battery Key
Talk. Key
Ring. Key
Connect. Key
Reversing Key
1
2
3
4
5
6
7
8
Out
In
4 Point Test Clip
80 Ohm Bell
Generator
Office Ground
V.M.
Test Battery 75 V.
Wheatstone Bridge
Imp. Coil
Storage Batt. 40 V.

Fig.

and subscriber's telephone with battery. Ringing is done with key *4*. Key *2* places the Wheatstone bridge in circuit instead of the voltmeter and battery; and by using key *8*, the wire chief can talk, ring, or test back toward the exchange.

The test telephone may be used as a regular instrument by throwing key *9*. This places the wire-chief's telephone across a line running to the switchboard, and the operator receives his signal in a similar manner to that of a subscriber. Should an operator wish to signal the wire chief, she may do so by inserting a plug in the jack corresponding to his telephone number. In doing this, she puts positive battery on the sleeve of the jack, which connects with the relay *R* that controls the signal lamp on the testing table. When the wire chief answers by throwing key *9*, the relay circuit is opened, putting out the lamp. It is not necessary to use key *1* in talking through the switchboard.

A TEST-CIRCUIT APPLIANCE

56. The simple testing circuit shown in Fig. 17 may prove of assistance in locating permanent or swinging grounds, short circuits, and, especially, crosses with telegraph lines. One subscriber's circuit is shown terminating in a jack *J*. Single-point jacks *Y*, *Z*, located near the test set, are connected with a two-point plug *P* at the switchboard. The testing apparatus consists of a 250-ohm telegraph relay *R*, a telegraph key *K*, a vibrating bell, or 4-ohm telegraph sounder *S*, a two-point switch *W*, a battery *B*, for which enough open-circuit cells to give about 20 or 40 volts will answer the purpose, a local battery *L B* for operating the bell or sounder, for which enough open-circuit cells to give from 2 to 4 volts will suffice for a 4-ohm sounder, and two single-point plugs P_1, P_2, connected as shown.

57. Ground or Cross.—To test a line for a ground or cross with a telegraph line, with the circuits shown in Fig. 17, have plug *P* inserted in jack *J*. Then either side *M* or *N* may be tested by inserting P_2 in either *Y* or *Z*. If there exists a ground of low enough resistance, the bell *S* will ring when *W* rests on *c* and key *K* is closed. With a given electromotive force at *B*, it can be experimentally determined once in a while just how much resistance must be included in the relay circuit to just prevent the relay from working. Then the ground resistance must be less than that amount if the bell rings. In case of a cross with a telegraph line, the battery may be cut out by placing *W* on *d*, thereby leaving the relay in a condition to be operated by the telegraph current only. To test for a short circuit, insert plugs P_1, P_2, in jacks *Y*, *Z*. If the wires *M*, *N* are short-circuited

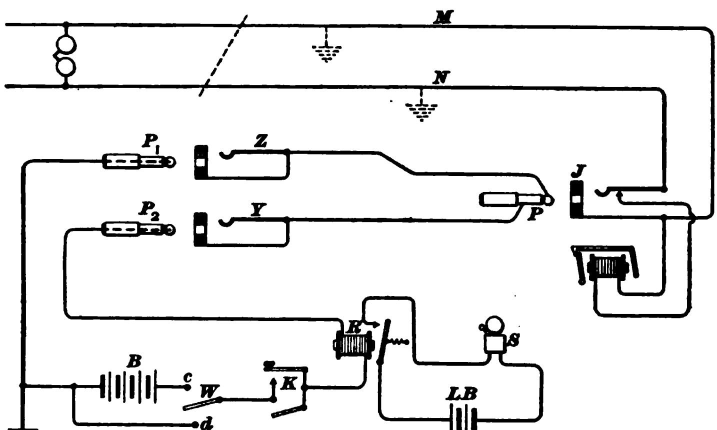


FIG. 17

or crossed through a small enough resistance, the relay will be closed when *W* is placed on *c* and *K* is closed.

A cross between two wires forming one pair can only be detected by this arrangement, provided that its resistance is very much lower than the normal resistance of the circuit. For this purpose, the number of cells or the adjustment of the relay, or both, must be such that the relay will not be operated unless the resistance of the circuit is much lower than its normal value. In case a test made with this arrangement of apparatus shows that a ground, short circuit, or cross exists, a regular loop test or other measurement may be made to definitely determine the distance to the trouble.

58. Open Circuit.—If the trouble is determined to be an open circuit, the brake may be located between certain points in the following manner: Have an assistant short-circuit the line, beginning at a convenient point as near as possible to the testing set. The bell *S*, Fig. 17, will ring each time the assistant short-circuits the line until he passes beyond the break. The break will be between the last two places where he short-circuited the line.

59. By using a voltmeter instead of the relay, the insulation resistance of either line wire may be readily determined by the method already given for that purpose. A record should be kept of the insulation resistance of long lines determined in both wet and dry weather, in order that succeeding tests, which should also be recorded, may be compared with the original tests. However, succeeding tests need, as a rule, only be made in wet weather.

This circuit with the voltmeter in place of the relay *R* may also be used to determine whether a short circuit or cross exists inside the exchange. For this test, connect P_1 and P_2 with two wires, at any convenient place in the exchange, between which a short circuit or cross is suspected. If the voltmeter reading with *W* on *c* is the same, or very nearly the same, as that obtained by connecting the voltmeter directly across the terminals of the battery, the lines are crossed or short-circuited.

60. Test-Panel Circuit of American Telephone and Telegraph Company.—An arrangement used by the American Telephone and Telegraph Company, called its **test-panel circuit**, for testing long toll lines, is shown in Fig. 18. It is said to facilitate the testing of long toll lines because it takes the work of testing out of the hands of those at small stations who are generally incompetent to make satisfactory tests.

K, *L*, *M*, *N* represent carbon lightning arresters; *H*, *J* are heat coils, one in each side of the line; and *D* is a drop bridged across the two line wires but cut out when a plug is inserted in jack *Z*.

Let us suppose that the line is grounded somewhere between stations *A* and *C*. The wire chief at *A* will instruct the operator at *B* to open wires *1* and *2* east, which is done by inserting plug *P* in jack *X* and *Q* in *Y*. If the ground caused a noise and the noise now ceases, it indicates that the ground is beyond *B*. Should the noise continue, it indicates that the trouble is between *A* and *B*, including office *B*, and

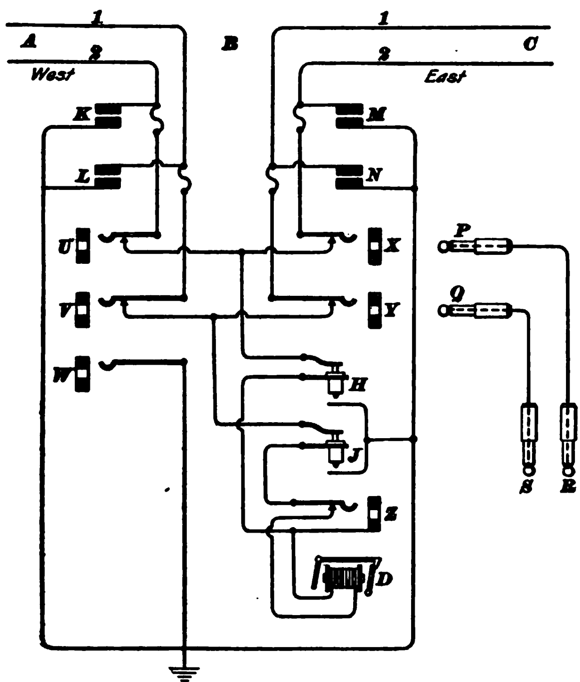


FIG. 18

the operator is directed to open west, which is done by withdrawing plugs *P*, *Q* from jacks *X*, *Y*, and inserting them in jacks *U*, *V*. If no noise can now be heard at *A*, the trouble is evidently in office *B*, probably in the carbon arresters or heat coils. If no noise can be heard when the line is open east, only the operator is instructed to *strap through*, that is, insert plug *P* in jack *X*, *R* in *U*, *Q* in *Y*, and *S* in *V*, which cuts out the heat coils *H*, *J* and the drop *D*. This process is continued until the trouble is located between two offices and then a test (usually a loop test) is made to locate the fault and a man sent out from the nearest office to remove it.

If the wire chief is located at the west end of the line, each operator is instructed to open east as soon as she finds the line in trouble and if no operator west of her has already opened the line, she reports the trouble to the wire chief. If each operator has opened east, the wire chief will call up *B*, test through that station and if no trouble is found will tell her to strap through, and so on down the line until the trouble is located.

MISCELLANEOUS SOURCES OF TROUBLE

TROUBLES IN BRIDGING JACKS—THEIR LOCATION AND REMEDIES

61. The most common and frequent causes of trouble, peculiar to bridged-multiple jacks in central-energy exchanges are the following: A permanent signal on some particular line; this is usually caused by a short circuit on the line itself—that is, the tip and sleeve wires being crossed—or the sleeve wire of this particular line being crossed with the first, or third (tip or ring wire) of some adjoining line, or a ground on the battery side of the line. If a subscriber complains that he cannot get the central office at times, and if this trouble is not caused by a loose connection on the line, the chances are that it is caused by the third wire, or ring, of this particular line being crossed with the sleeve wire of some adjacent line. This will hold good if the subscriber does not complain of cut-offs during connections, as this will indicate that there are no loose connections in the talking wires.

62. If a subscriber complains that he is often called and hears other people on the line, and if the trouble is in the exchange, the most likely place for it to exist is between the sleeve wire of this line and the sleeve wire of some adjoining line. Complaints from the operating department that the line tests busy with no connection on the same, are due to crosses between the ring wire of this particular line and the same wire of some adjoining line. If the operating department complains that the signal does not disappear after plugging in to answer a subscriber, it may be due to a break in the ring conductor of the cord circuit or to an open circuit in the winding of the cut-off relay, or to a cross between the third wire of this line and the tip wire of some adjoining line. If the operating department complains of getting signals from the line pilot lamp, but no line signal, look for a defective lamp in the position thus affected, or a loose connection at the line relay, or intermediate distributing board. If a subscriber can be answered through the multiple jack but not through the answering jack, the trouble may be due to an open jumper on the intermediate distributing frame or a loose connection at this place, or possibly, a loose connection at, or defective adjustment of, the answering jack. If the operating department complains of a loud buzzing noise on some particular line, look for a cross between the ring and sleeve wire of same. This is a brief description of the most prevalent troubles and their probable causes.

63. Detailed explanations of the best method to employ in locating and clearing some of these troubles will now be given. A test employed very extensively in large multiple

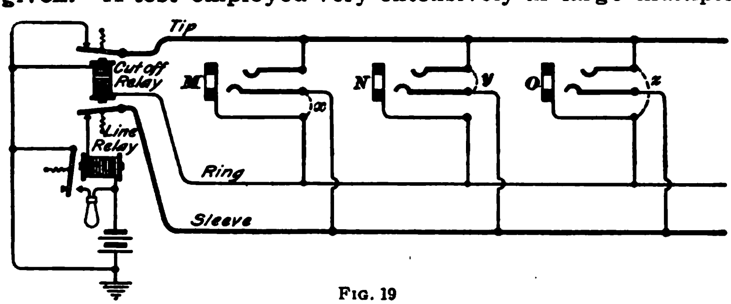


FIG. 19

exchanges consists of the simple arrangement of listening on the line in trouble with the ordinary head-telephone, or receiver, connecting the same to the tip, ring, or sleeve of the plug in order to meet the different conditions for which the test is being made. Suppose that there is a cross, as indicated at *y*, between the tip and the sleeve wires at jack *N*, Fig. 19. The results of this, as will be readily seen from the circuit, will be a permanent signal at the answering position. To locate the exact jack in which this cross exists, insert an ordinary plug, across the tip and sleeve of which is connected a receiver, into the first jack on the switchboard, noting the volume of click produced in the receiver at this point. If it is found to be quite audible, it will indicate that the trouble is still farther on, and it will be necessary to move on to the next section, again making the same test. When close to the jack that is in trouble, the click will diminish in proportion to the resistance remaining in the circuit; and when inserted in the jack where the trouble is in existence, the click, in most cases, will not be audible, its intensity depending on the resistance of the cross. The trouble itself may be due to some foreign article, such as the point of a lead pencil, the metal tip of a plug, or some other metallic substance. It may also be caused by the springs on the back of the spring jacks being in contact.

64. At jack *M*, Fig. 19, a cross is indicated at *x* between the ring and sleeve of this particular line. The result of this cross will be a rather vigorous vibration of the cut-off relay, causing quite a "hum" or "buzzing" on the line in question. When the armature of the cut-off relay is released, its coil and the battery are connected across the ring and sleeve conductors, which magnetizes the cut-off relay until it attracts its armature and thus breaks the circuit, thereby making it act like an ordinary buzzer, or circuit-breaker; hence, the noise on the line. To locate the trouble, connect the receiver to the sleeve and ring of the plug, and proceed with the test as described for locating the cross at *N*. A low-resistance ground on the ring conductor or a cross between the ring and sleeve conductors anywhere will produce the same result.

65. At jack *O*, Fig. 19, a cross is indicated at *z* between the tip and ring wires. The result of this trouble will be the inability to put out the line signal when answering a subscriber, this being due to the fact that the current supplied over the ring conductor of the cord, instead of flowing through the winding of the cut-off relay to ground, flows from the ring side of the line over the cross to the tip conductor of the line and to ground direct. To locate this trouble, connect the receiver to the tip and ring conductors of the plug and proceed in the manner described for locating the cross at jack *N*.

66. An open circuit in the multiple, as well as loose connections and crosses that appear at times only, can also be located by the use of a receiver. The idea is to listen in the last jack of the multiple, while an assistant goes from section to section of the switchboard and gently taps each jack of the line in trouble. This will cause a variation of the resistance of the cross or loose connection, giving rise to a disturbance in the receiver. In making these tests, arrange the wires being tested so as to have the battery connected between them.

67. To Extract Broken Plug Tip From Jacks.—A tip broken from a plug and remaining in a jack is one of the most obstinate cases of trouble to clear; even if the strip of jacks is removed and worked with from the back of the board, there is a great chance of producing other troubles on that strip. On a large board where the plugs have a steel core, or tip, which is generally the case, the following simple arrangement of apparatus has been successfully used: In a relay coil of suitable, or convenient, resistance insert a small soft-iron core of such a size that it will clear the tip spring when inserted in a jack. In series with the relay coil insert a suitable amount of resistance, preferably non-conductive, such as an incandescent lamp, and about 8 feet of lamp cord terminating in a lamp-socket plug, so that a suitable amount of current may be taken through a lamp socket in front of the board from the 110-volt lighting circuit. About 200 ohms in series with a 125-ohm relay coil will give about the right amount of current. The connections are shown in Fig. 20. It is well to mount the magnet on a small wooden handle and connect a switch in the circuit so that the heating of the coil may be reduced by cutting it out when not in use. By means of a flexible cord arrange another circuit containing a small lamp, such as is used for a line signal and which may be easily inserted in a jack, this lamp being supplied with current from the operator's transmitter circuit or other suitable source of current. This will

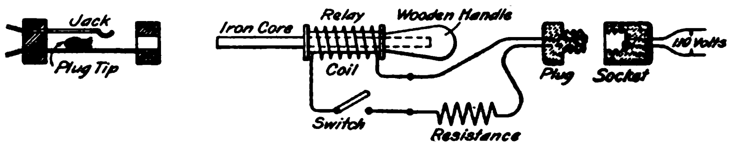


FIG. 20

give a good light by which to work. After locating the tip in a jack insert the lamp in a jack near the one in trouble, and then by using the relay magnet energized from the lighting circuit, the tip can be very readily extracted, provided that it has a steel core.

68. Cleaning Jacks With Air Pump.—In maintaining a telephone switchboard and its appurtenances, there is no element so productive of faults and troubles as the natural accumulation of dust, dirt, and corrosion, from which it is almost impossible to keep the operating and apparatus rooms entirely free. The customary way of cleaning is by hand, using a hand bellows or an air pump for blowing out the dust where it cannot be removed with a feather duster, and wiping the plugs by hand with a polishing cloth, which, of course, is a very slow, expensive, and tedious process.

To enable the exchange equipment to receive a thorough, systematic, and economical cleaning, J. E. Peavey designed and put into service an apparatus consisting of a $\frac{1}{8}$-horsepower motor, belted to a small air blower, the blower having attached about 20 feet of rubber hose with a nozzle. One end of the motor shaft is extended and carries a buffer for cleaning the plugs, the whole being mounted on a wooden horse, or pedestal, which is on rollers and can easily be moved around the room. There is an extension cord and plug for connecting the electric motor with any regular lamp socket along the switchboard or room fixtures, it not being necessary to do any extra wiring whatever. With this apparatus, one man can accomplish in a day more than two or three men in as many days.

When the motor is started, the fan delivers a strong air blast; then the nozzle is inserted into jack after jack and the blast is allowed to impinge on the springs for a few seconds. This is usually sufficient to clean out all the dust. In the same manner, the key springs can be gone over; in fact, from all parts of the board otherwise inaccessible dust may be removed. In the largest exchanges, it is well to go over the switchboards every night. By this means, a high degree of cleanliness is secured and maintained with a consequent prolongation of the life of the switchboards and also a reduction in the complaints from subscribers.

69. Cleaning Jacks With Spring.—About the only method of cleaning jacks, other than by blowing air through them, that has not proved to be injurious to the switchboard, is to take a thin strip of watch spring or similar metal and poke it into the jack between the contact point and spring, thus dislodging any dust or dirt that may have accumulated. The metal springs should be smooth and clean so as not to injure the contacts, although it is suggested that a few scratches may be made on either side, crosswise, like a file, in order to cut away any oxidization on springs that are not provided with platinum contacts.

Another source of trouble is due to the operators lifting plugs from the sockets in the keyboard by their tips. By this means, their bare fingers come in contact with the metal and leave an oily deposit, which, in time, may be sufficient to break contact with the spring jacks.

70. Trouble Slips.—It is the general rule to make out slips for all cases of trouble. These slips, the inspector or troubleman should take with him, and when the trouble is found he should make a note of it on the slip, telling what it was, where it was, and what work was done. A note should also be made on the slip showing when the trouble was reported, and also when it was repaired. If the inspector is convenient to the subscriber's station, he should stop in and have the subscriber sign his name, stating that the line is all right. This latter is quite important and becomes especially so where "chronic kickers" are concerned; it protects the inspector from false accusations and also gives the company a reference where rebates for poor services are demanded. The inspector should keep a card index or a day book of the trouble as it occurs, giving the exact nature of the trouble, what was done, and who did it. Such records are very valuable as a reference, and from them all the trouble on each subscriber's line can be readily determined as well, as how long the line was out of use in each case. These records may seem like a needless amount of red tape, but in the end they far more than pay for themselves. They are among the handiest of the manager's reference records. To the inspector, they show the weak spots of the exchange and where to go to work to improve the service.

ELECTROLYSIS OF CABLE SHEATHS

71. Earth Currents.—Electrolysis means here the eating away of cable sheaths, underground pipes, rails, or other grounded or buried conductors by stray currents from street-railway or other circuits. Currents due to electric-railway or other systems carrying large currents, and using earth returns are likely, in choosing their path back to the power station, to select the sheaths of underground cables, or of any other metallic bodies that offer paths of comparatively low resistance. This phenomena in general may be illustrated by means of Fig. 21. In this, the return current at the remote end of the trolley line enters the earth, we will say, from the rails *R* and meeting with a line of water pipe *W*, which forms a route to the power house, selects this conductor as the return circuit. After a time, this line of pipe may come in proximity to the line of telephone cables *C* whose lead sheaths form a still better return path. The current will then follow this new-found conductor to some point where a more direct route is again found, and the current will emerge from the cable sheaths and enter the new conductor.

72. Danger Points.—Except in a few cases, the current in flowing from one kind of a conductor to another will be compelled to pass through the earth, and it is at the points where the current emerges from the conductor and enters the moist earth that electrolytic action occurs to the probable destruction of the conductor. Thus, in Fig. 21, the danger point on the cable sheath *C* would be that at which the current left the sheath in order to pass back to the earth and rails, no damage being likely to occur at the point where the current enters the sheath.

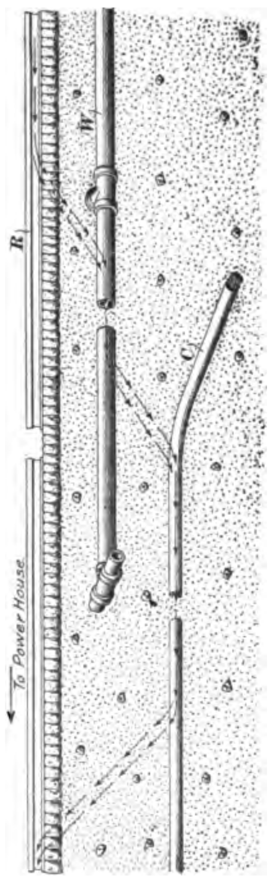


FIG. 21

73. Under certain conditions, the chemical actions produced where the current leaves a pipe causes no eating away of the metal pipe. This may be due to the fact that the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. Electrolytic action may also take place for a while and then cease owing to the character of the earth around the pipe having become changed by the decomposition of the salts contained therein and rendered incapable of acting longer as an electrolyte. Underground conductors may also become corroded by the simple chemical action of the salts in the earth. The only sure way of determining this point is to bury a similar-sized piece of exactly the same metal insulated from, but alongside, the metal that becomes pitted for about 6 months. At the end of that time note the difference, by weighing or by observation, in the effect on the insulated and uninsulated similar pieces of metal. The relative effects of corrosion from the two sources can thus be determined.

Lead is eaten away nearly twice as rapidly as tin, over twice as rapidly as zinc, over three times as rapidly as copper or iron, and over twelve times as rapidly as aluminum. Underground lead sheaths are, under similar conditions, eaten away very much more rapidly than iron pipe. Wrought-iron

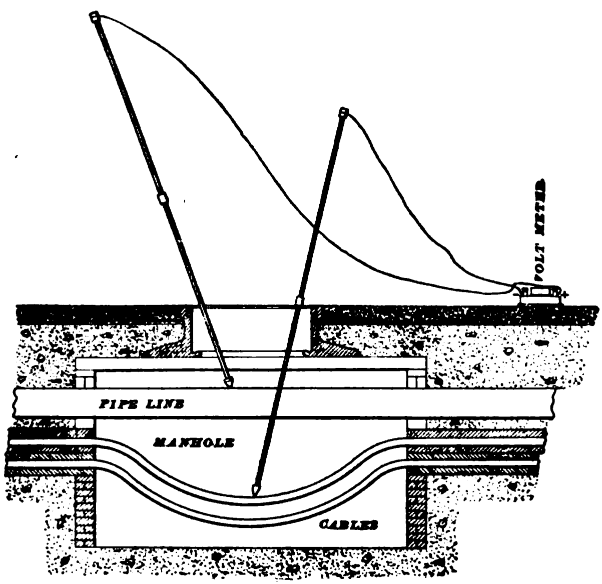


FIG. 22

pipe is eaten much more rapidly than cast iron, probably due to the impurities, which form a kind of scale on the cast-iron pipe and protect it.

The use of conduits of highly insulated material, such as vitrified clay, goes a great way toward preventing the effects of electrolysis, but it is found necessary to use other means of protection for the cables. Especially is this true in all forms of conduit where no attempt is made to insulate the cable sheaths from the surrounding earth.

74. Locating Danger Points.—The method of procedure in each case, in order to locate the danger points on a cable, is usually to measure the difference of potential, with a voltmeter, or preferably with a millivoltmeter, between the cable sheath and the surrounding conductors, such as water pipes or the rails of electric railways, at frequent intervals along the cable line. A convenient method of taking these measurements is shown in Fig. 22. Two brass rods of ⅜-inch stock, about 10 feet long, should be provided. They should each be made in two parts so as to be easily taken apart and put together again, and one should have a conical steel tip for making contact with the earth and other conductors, while the other should be provided with a wedge-shaped tip sufficiently sharpened to make a good contact with the cable and yet not so sharp as to injure it.

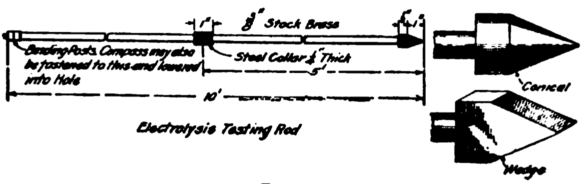


FIG. 23

The construction of these rods is shown in Fig. 23. On opening the manhole, the rods should be connected with the voltmeter by means of wires of suitable lengths, and the rod with the wedge-shaped tip should be touched to the cable, while the other one is successively touched to the earth, the duct, whatever pipes there may be in the hole, and to whatever other grounded conductors there may be in the vicinity.

Readings of the voltmeter should be taken at frequent intervals along the cable line, and the results recorded in some such form as that shown in Table I.

75. By means of such a table made out for the entire length of the cable line the danger points may be readily picked out. As long as the cable sheath is negative to all the surrounding conductors it is in no danger from electrolysis, for this indicates that the current is flowing from the surrounding conductors to the sheath. If, however, a point is found where the cable sheath is positive to the surrounding conductors, we know that the current is flowing from the cable to the other conductors through the ground at that point. The maximum positive point on the cable should be determined, and a heavy copper bond should be run from this point to the water pipe, or other conductor, to which the readings indicate the current to be flowing.

The record given in Table I will show that the maximum danger point in this case was at 1st Avenue and D Street, and a bond would therefore be required from the cable at that point to the gas pipe.

TABLE I

Location of Manholes	Reading From Cable				
	To Earth Volts	To Water Volts	To Gas Volts	To Duct Volts	To Track Volts
1st Ave. and A St. . . .	−.2	−1.2	−1.0	−.1	−4.0
1st Ave., bet. A and B Sts.	−.3	−1.2	−1.0	−.1	−4.2
1st Ave. and B St.	−.3	−1.2	−1.0	−.05	−4.3
1st Ave. and C St.	−.3	− .9	+ .2	−.05	−3.8
1st Ave. and D St.	−.4	−1.0	+ .4	−.05	−3.2
1st Ave., bet. D and E Sts.	−.4	−1.0	+ .3	−.05	−3.0

76. Herrick's Method.—The following method is recommended by A. B. Herrick as being much more reliable for determining the potential between a pipe or sheath and the adjacent earth than the older method of using a millivoltmeter.

An insulated pointed rod *a*, Fig. 24, is driven through the soil until the point comes in contact with the pipe. A second insulated rod *b* is driven in so that its point will come close to the pipe but will not touch it. Both rods are insulated and protected by running them through a piece of iron pipe lined with insulating material, as, for example, a piece of lined conduit such as is used for wiring buildings. The earth-potential point is covered with cadmium so that there will not be a local electromotive force set up, which will disturb the difference of potential due to the earth currents. Also, the electromotive force existing between the pipe and the test point is measured not by means of a voltmeter, which

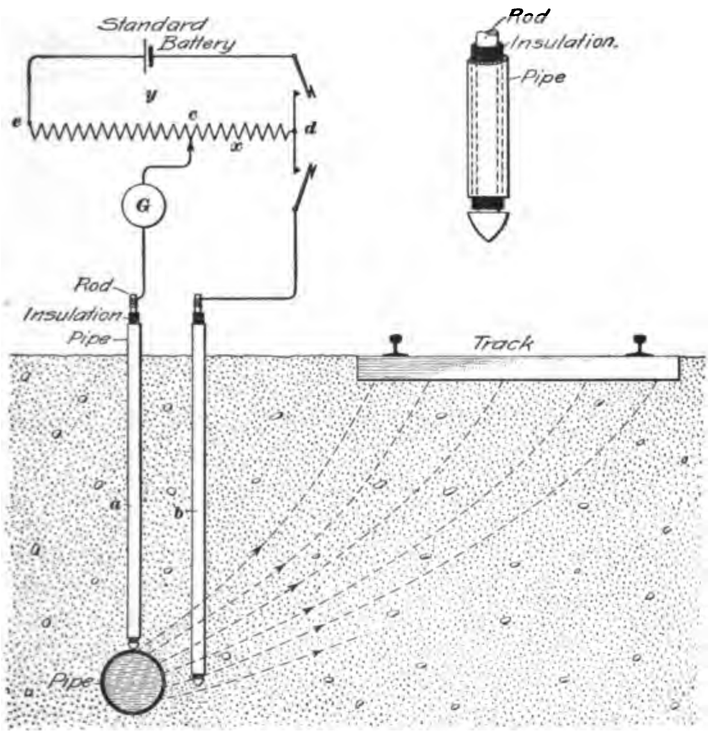


FIG. 24

would disturb the normal current flowing between the pipe and ground, but by balancing the unknown electromotive force against a known electromotive force from a standard battery. The resistance *cd* is adjusted until the galvanometer *G* indicates zero current, an the electromotive force between the pipe and ground then bears the same relation to the known electromotive force of the standard battery that resistance x between c and d bears to the total resistance y included between e and d; or,

$$E_1 = E\frac{x}{y}$$

where E_1 = electromotive force between pipe and ground;
E = electromotive force of standard battery;
x = resistance $c\,d$;
y = total resistance $d\,e$.

It is not necessary to know the values of x and y, in ohms; if the ratio of their resistances is known it is sufficient. Resistance y can be in the form of a slide-wire bridge or a bare high-resistance wire wound on a cylinder and provided with a sliding contact and scale, so that the divisions read off for any position of the contact will be proportional to the resistance x.

EXAMPLE.—A test was made, as shown in Fig. 24, with a standard battery giving 5 volts and a sliding contact resistance divided into 100 equal parts. When the galvanometer gave no deflection, resistance x was represented by 30 divisions on the scale. What was the electromotive force between the pipe and ground?

SOLUTION.—In the formula $E_1 = E\frac{x}{y}$, since the resistances are proportional to the lengths of wire,

$$\frac{x}{y} = \frac{30}{100} \text{ and } E_1 = 5 \times \frac{30}{100} = 1.5 \text{ volts. Ans.}$$

77. Prevention of Electrolysis.—A large system of piping forms a conducting network of very low resistance in parallel with the track, hence it is a very difficult matter to prevent part of the current from leaving the track. However, if proper steps are taken, the bad effects of electrolysis can be largely avoided; the following are the main points that experience has shown should be observed:

1. The trolley wire should be made the positive side of the system.

2. The track should be thoroughly bonded and the bonds maintained in good condition.

3. Any metallic connections that may exist between piping or lead-cable systems and the track should be located and removed.

4. Return feeders should be run out from the station and connected to those pipes or cables that carry the greater part of the current. Thus, the current in the pipes or cables will be "drained" off without passing from the pipes or cables to the ground.

5. Where service pipes, cables, or underground conductors pass under tracks or through other regions where they are exposed to electrolytic action, they can often be protected by covering them with glazed tile or by placing them in a trough filled with asphalt.

6. If, in any part of a system, the rail return carries an excessive current, return feeders should be run so as to relieve the rail of part of the current and prevent an excessive fall of potential along the rail. The greater the fall of potential in the rails, the greater is the tendency for the current to pass off to neighboring pipes.

The remedy given in 3 is important. Very often accidental connections exist between the rails and pipe or cable so that the current can pass directly to the piping or cable system. This is especially the case where pipes or cables run across iron bridges that also carry railway tracks. Before attempting to drain off the current from a piping system, it is needless to say that all metallic connections between track and pipe or cable sheath must be removed. Where pipes or cables pass across iron bridges, the best plan is to insulate them from the bridge, or if this is impossible, insulate them by the insertion of insulating joints at either end of the bridge.

Remedy 4 is very commonly practiced and gives good results if properly applied. The return feeders should be attached to the pipes or cable sheaths that carry the most current and, as a rule, the current so returned to the power house will not be more than 5 or 6 per cent. of the total railway current; if it exceeds this amount, it is probable that there is a metallic connection somewhere between the track and pipes.

Service pipes, crossing under street-car tracks, are particularly subject to electrolytic action and when they are being laid or repaired it costs but little to cover them with tile or to run them in a box, as explained in 5.

78. Method of Bonding to Cable Sheaths.—With most telephone companies, a standard method has been adopted for bonding the cable sheaths. Bonds are placed between all the cables of an underground line in every manhole through which they pass. The wire used is No. 8 B. & S. gauge bare copper tinned. Fig. 25 illustrates the method adopted for soldering the bonds to the lead sheaths. The surfaces of all the sheaths are scraped clean of mud, of which they are nearly always covered. In doing this work, an old file will be found useful, but great care must be taken not to cut away too much of the sheath. The end of the bond wire *d* is then heated in a portable furnace, and placed on the bright surface of the sheath and solder applied. A soldering iron is then used to heat the sheath to the required temperature. The surface of the next sheath is then cleaned in turn, and the bond wire bent down and soldered to it.

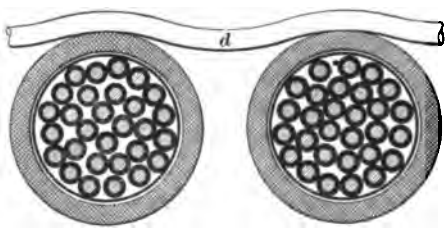


FIG. 25

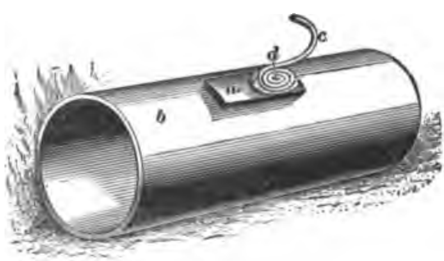


FIG. 26

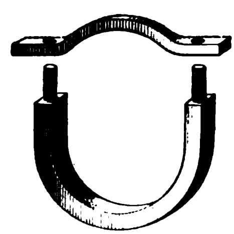


FIG. 27

79. If the bond wire runs to a gas pipe, it may be soldered as in Fig. 26, in which *a* is a piece of sheet copper, which is soldered to the surface of the pipe *b* that has been previously brightened and tinned. The bond wire *c* is then coiled as at *d* and soldered to the copper plate.

80. It is almost impossible to solder to a water pipe on account of the water rapidly conducting the heat away from the pipe itself. Where it is necessary to bond to a water pipe, a yoke, shown in Fig. 27, may be made of strap iron and securely clamped in place on the water pipe, the surface of which has been previously brightened. The whole should then be given a heavy coating of asphaltum, to prevent corrosion.

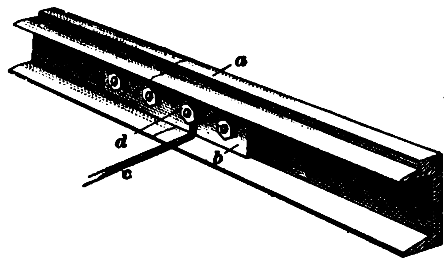


FIG. 28

The method of bonding to a rail is shown in Fig. 28, which needs no explanation, except to say that the contact surfaces must be clean and bright when the bond is made.

ELECTRICAL EXAMINATION OF GROUND POTENTIALS

81. By means of the telephone line wires, an electrical examination of the territory through which the cables extend may be made in a very rapid and simple manner. If one wire of each subscriber's line is grounded at his station, the difference of potential between the ground at the central office and at the substation may be obtained by inserting a plug, connected through a voltmeter to ground, into the subscriber's jack. A complete map of the territory, which will show the difference of potential at nearly every point to which the exchange cable extends, may be obtained by sending successively to substation after substation, one inspector who calls up the central office and notifies the inspector there to take the voltmeter reading, and then momentarily grounds one of the subscriber's line wires. From the data thus secured, a plot may be made on the map of the town, similar to Fig. 29, which was originally shown in The American Telephone Journal, by joining together with a line all the points having approximately the same voltage. *1* and *2* are

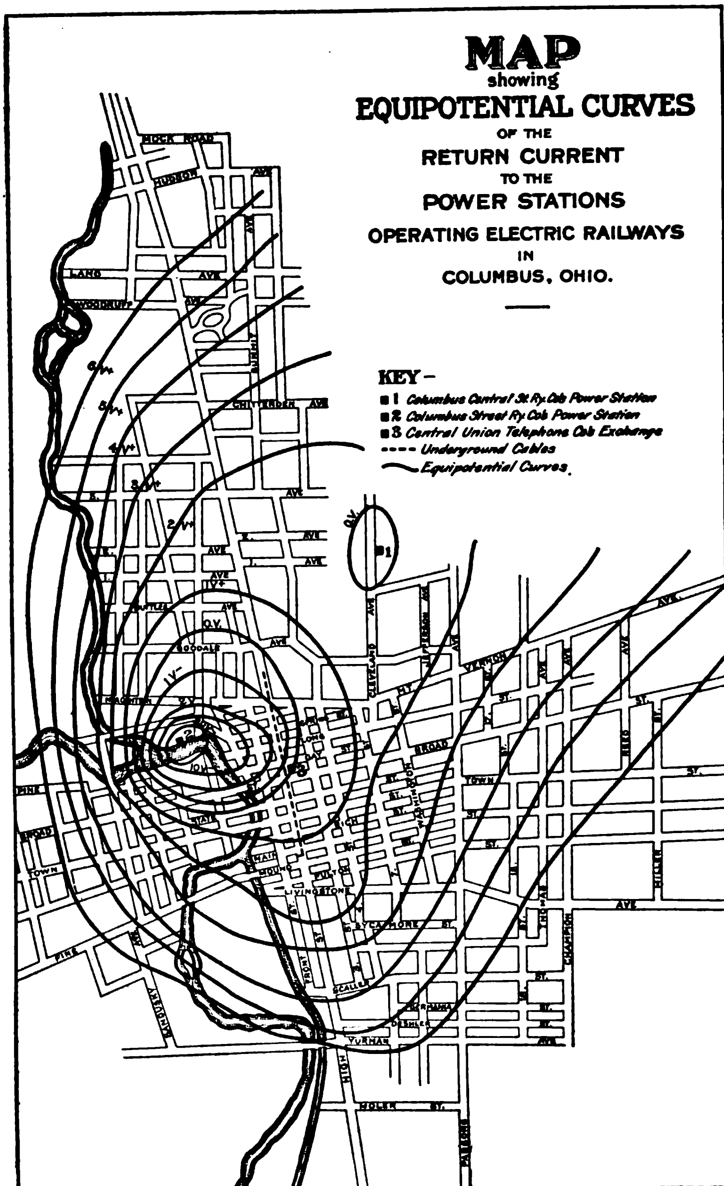

MAP
showing
EQUIPOTENTIAL CURVES
OF THE
RETURN CURRENT
TO THE
POWER STATIONS
OPERATING ELECTRIC RAILWAYS
IN
COLUMBUS, OHIO.
KEY-
1 Columbus Central St. Ry. Co's Power Station
2 Columbus Street Ry. Co's Power Station
3 Central Union Telephone Co's Exchange
---- Underground Cables
Equipotential Curves.
LIVINGSTONE
SYCAMORE ST.
MOLER ST.
HIGH
BROAD
CHITTENDEN AVE

Fig. 29

power stations and *3* the telephone exchange. A series of contour lines are shown in this figure, placed at intervals of 1 volt difference of potential. Points on any one of these equal potential lines will have little or no difference of potential, while points on a line that crosses one of these equal potential lines will have more or less difference of potential. Cables, therefore, that are parallel to the equal potential lines will not be subject to damage by electrolysis, while those that intersect them will be. While such an investigation does not entirely eliminate the desirability of voltmeter readings directly between the cable sheaths and the ground, it largely reduces the amount of time required to make the latter examination. It indicates invariably where such measurements should be made. As already stated, injurious action only arises where the current leaves the cable sheath. The object is to prevent absolutely such a departure of the current, for no matter how slightly a pipe or cable may be electropositive to the ground, it is an invariable indication of possible damage.

TO REDUCE ELECTROLYSIS

82. Two methods to reduce or eliminate electrolysis are as follows: Wherever an electropositive point on the cable sheath is found, the return conducting system of the railway should be reenforced in such a manner as to prevent current going into, and then leaving, the cable sheath. This may be accomplished by improving the bonding of the railway tracks or by introducing additional feed-wires into the railway return system or by providing an extra wire, which is attached by a large sleeve of ample area to the cable sheath and thus conveys the current away without allowing it to first pass into moist earth. Another method consists in providing at a danger point, a very large ground plate, which may be cheaply and efficiently provided by excavating a hole, at the bottom of which a ton or two of coke is placed, and on top of it a load of old iron, such as worn-out car wheels, old rails, chips from machine shops, etc. The cable sleeve should be connected to the ground plate by copper wire of good size. A large sleeve should be used to make the best possible metallic contact with the cable sheath that it is desired to protect, either by soldering the sleeve to the cable sheath, or by securing metallic continuity by the use of some flexible amalgam that is manufactured for making bonds with rails and similar purposes. The connection to the ground plate may be made in a manner similar to that with the lead sheath. It is well, however, where soldered joint connections are made and especially to the ground plate, to paint the soldered joint thoroughly with some good waterproof paint, in order to resist electrolytic action between the two kinds of metal at the joint. Since the copper wire is of much lower resistance than the surrounding ground, the current will usually follow the wire to the ground plate and thus the flow of electricity into the ground from the cable sheath and the resulting electrolytic action is reduced. Of course, there will be more or less electrolytic action at the ground plate, but this plate is so large that it will resist corrosive action for a long time, and moreover, it is cheaper to occasionally replace this ground plate, if necessary, than to have the cable sheath damaged by electrolysis. This is also usually cheaper than to provide a copper return cable or wire of sufficient size to carry the stray current back to the power station.

83. Since street-railway companies frequently change their roads, number of cars, and arrangement of their conducting system, a remedy once installed must not be relied on for too long a time. It is well, at least once a year, to make an electrolytic survey of the entire area in which the underground cables are located, in order to determine where the danger points, if any, exist, and to decide on the best methods for protection, and to also ascertain the efficiency of the methods that have been previously installed, and finally to make sure that all cables are sufficiently protected from electrolysis.

TELEPHONE-LINE CONSTRUCTION

(PART 1)

ORGANIZATION OF THE CONSTRUCTION DEPARTMENT

1. As its name indicates, the construction department has to do with the building of the telephone plant. In the early days, and today in connection with the smaller companies, the construction department had to do with the building of the lines, which includes both the overhead and underground lines. In the majority of companies, the construction department builds the subways in addition to drawing in the cables. In some cases, for example that of the New York Telephone Company, the subways are constructed by a separate company, so that the work of the construction department is limited to drawing in the cables and placing them in a condition to be used.

The work covered by the construction department, then, in a well-organized telephone company, consists of the following: Building overhead lines, building subways and subway lines, repairing both classes of these lines, and maintaining the line wires and cables. The department is presided over by a superintendent, who usually has an assistant and one or more gangs of linemen for building the overhead lines, the gangs being looked after by foremen and assistant foremen. For building the subways, one or more gangs of laborers are employed, each presided over by a foreman. The foremen report to the assistant superintendent.

For pulling in the underground cables and stringing the aerial cable, a gang of ground hands are employed. The work of splicing cables, making pot heads, and entering the cables on the distributing frames in the various exchanges, and into the cable boxes, is entrusted to one or more gangs of cable splicers, each gang being looked after by a foreman. This force reports to a chief of cable splicing, who also has under him a corps of experts who do testing on all completed cables, before they are cut into service, locate faults, and the like. In some companies, the construction department embraces the work of obtaining rights of way, so that in this case there would be an additional force, looked after by a right-of-way chief, whose duty it is to obtain the right, either from public or private parties, to build lines along the desired route. In considering in detail the work done by the construction department, the work of the last-named subdepartment will be considered first, as this is the natural starting point for the work.

2. The duties of the right-of-way man are very numerous. In the matter of interviewing private parties, the field extends from the washerwoman to the Vanderbilt or Astor. He must get permission to run a pole line past private property, he must often interview property owners on the subjects of running lines through the property, extending lines over buildings or along back-yard fences and must obtain franchises for running through the streets of cities and towns and along public highways.

The necessary rights of way having been obtained, the work of line construction is pursued by the gangs already mentioned. It might naturally be supposed that the duties of the construction department would embrace the work of installing switchboards, but this is not usually the case. The switchboard and accessory apparatus is generally built and installed by some contracting company. This work is done for the various local Bell companies by the Western Electric Company, who build the switchboards and accessory apparatus, with the exception of the transmitters and receivers.

3. New Line Orders.—Orders for installing a line for a new subscriber includes the running of bridle wires from the line to the entrance of the subscriber's building. In connection with this work, it will be well to follow the course of the orders issued for cutting in new subscribers. The orders for new subscribers' lines are issued from the general superintendent's office, and from here they proceed to the construction department, where the necessary information is copied and orders issued to the gang foreman, these orders containing the assignment of conductors that are to be used for the new line. The order is then turned over to the maintenance department, the assignment above referred to having been attached, when a second record is taken of the order, after which it is turned over to the wire chief, in whose district the line is situated. The wire chief, on the receipt of the order, does the necessary cross-connecting on the main distributing frame. A copy of the order is also made out for the use of the instrument setter. The construction gang on reaching the place where the bridle wire is to be cut in goes in with a test set on the conductors assigned and calls the wire chief. If the cross-connections have not yet been made in the exchange, he calls the wire chief on another line, and asks him to meet him on the conductors required. This having been done, the lineman cuts in the bridle wire, and builds it to the point of entrance of the building in which the telephone is to be located. When this work is finished, he again calls the wire chief, who on this occasion gives the line a thorough test to ascertain the condition of the bridle wire. Assuming the work to have been done properly, the lineman returns the order with the time of day at which the work was completed, and the name of the wire chief who gave him the O. K.

4. Changing assignments refers to the transfer of working lines from the present to new conductors. In large cities, this work is going on continually on account of the large number of cables in use, and the number that become defective or in which there are no unused conductors. This work of changing assignments must be done with considerable care and the wire chief in the district must always be notified by the foreman who does the work before he commences. In the case of substituting one cable for another, after the new cable has been placed, the conductors of the old cable are bridged to their substitutes in the new at the cable box. On the main distributing frame, a second cross-connection is run to the new assignment. On receiving notification from the foreman that the work outside is completed, the wire chief has the cross-connections cut off, the old conductors are cut out of the cable box, and the line left working through the new assignment. The wire chief always tests the line after this work is completed. When changes of assignment are made on an open-wire line, the lineman merely transfers the bridle from the old to the new conductors. This necessitates a suspension from service for a short while, not usually exceeding 15 minutes.

5. Numbering Conductors.—Conductors are numbered from 1 up in series. Old systems having a wire running along the top of the poles have this wire designated by zero; zero wire is never used, however, in modern construction. Standing with the back toward the exchange and facing the direction in which the pole line runs, the left-hand pin on the top arm is numbered 1 and the succeeding pins are numbered in series toward the right, the right-hand pin on the top arm being succeeded by the left-hand pin on the arm directly underneath, and so on. Assuming that the poles are equipped with five ten-pin arms, the first pin on the right-hand side of the top arm carries conductor number 10. Proceeding in this manner the right-hand pin on the fifth arm carries conductor number 50. A pair is always made up of an odd- and an even-numbered conductor; thus, conductors number 1 and number 2 would form pair number 1, conductor number 3 and number 4 would form pair number 2, etc.

All cables entering a central office are numbered in series and also with a number designating the exchange; the exchange is usually denoted by the hundred, as, for example, all cables entering the 38th street exchange in New York City, would be numbered 300 up to 399, all cables entering the 18th street exchange, 400 up to 499, etc. The conductors in the cables are numbered from 1 up in series. The conductor entering at the left-hand top spring of the arrester is number 1, that on the right-hand top spring, number 2, that on the left-hand spring directly beneath the top spring, number 3, etc. Where aerial cables, whether lead or rubber covered, enter cable boxes, their conductors are numbered from 1 up in series. That entering the top hole in the cleat is number 1, that in the hole directly beneath is number 2, etc. The aerial cables have a separate set of numbers from those used for the underground. It is the business of the construction department to keep a record of all pole numbers and pin numbers of the plant and the designation and location of every conductor, including also the number of all underground and aerial cables, together with the designation and location of their conductors. For example, a record may read something like this:

Telephone number 467, 38th St., takes U. G. cable 310, conductors 99 and 100, aerial cable 376, conductors 7 and 8. Location of terminal, top of house 346 east 39th St.

Telephone number 64, Morristown, takes U. G. cable 64, conductors 17 and 18, poles 1,340 to 1,379, pins 5 and 6, location of terminal pole 1,340.

These records are very important and useful in the matter of determining the facilities for connecting new subscribers and also for assisting the troubleman in the performance of his duties.

BARE-WIRE OVERHEAD LINES

THE POLE LINE

SELECTION OF ROUTE

6. The first important consideration in the erection of a pole line is the selection of the route. After the general route has been determined, right of way must be secured, and this is a matter involving as much business tact as engineering ability. If cross-country lines are being constructed, the most direct route is usually the most desirable, although, of course, the selection of the route must always be governed by the considerations arising in securing the right of way, by the configuration of the country, and by the nature of the soil. Pole lines are commonly run alongside the railroads as well as along the highways.

7. If a line is to be built along a country road, a reliable map of the country, showing the various turns in this road, should be obtained, if possible, and if not, one should be constructed by the best means available. A fairly accurate survey may be made by counting the revolutions of a wagon wheel driven over the road, or, better, by means of a reliable cyclometer on a bicycle or automobile. Notes should be taken at every bend in the road, and, in fact, every other landmark as to the distance passed over and as to the direction of the road, its grade, soil, etc.

POLES

8. **Selection of Poles.**—The **poles** used to the greatest extent in the United States are white cedar, Norway pine, chestnut, cypress, juniper, and tamarack. Norway pine denotes simply a variety of pine and does not apply necessarily to pine grown in Norway. While comparatively few poles are made from Norway pine, a good many cross-arms are made from that wood. The following table gives the average life of various poles:

TABLE I

Wood	Years
Chestnut (live, second growth)	15
Michigan and Canadian white cedar	12
Juniper	12
Tamarack	10
Cypress	5 to 8

9. White cedar is probably used to the greatest extent, and is, all things considered, the most satisfactory timber for poles. However, it is becoming scarcer and higher in price. Considering their strength, they are light in weight, and by some authorities these poles are considered the most durable, when set in the ground, of any American wood suitable for pole purposes. White cedar comes mostly from Michigan, Wisconsin, and Minnesota. Cedar poles from Oregon, Washington, and Idaho, are very straight and fine in appearance; but, having less taper than Michigan cedar, poles of the same size at the butt are heavier and not as strong as the Michigan cedar poles.

Chestnut is a tough, strong wood, and for that reason is often used at street corners and bends, while other poles are strong enough for the rest of the line. A chestnut pole the same size as a Michigan cedar easily possesses twice the strength, a great deal more elasticity, and about 1½ times the weight. Chestnut is tougher and more durable than tamarack poles. Chestnut poles are apt to be badly bent, and hence are not quite so good as cedar for nice pole lines in a city, although often used for such lines. Many prefer second-growth chestnut in preference to white cedar. Red-cedar poles are undoubtedly the most durable, but they are usually too dear, or too difficult to obtain. Tamarack poles are used in certain sections. The red variety will last from 10 to 15 years in upland soil, and, in such localities where 25-foot 6-inch top poles can be delivered at 60 cents each, they are said to be, even in the long run, cheaper than white cedar at the present prices.

There is considerable difference of opinion regarding the life of cypress poles, even in the southern part of the United States where they are used. Some say they will not last over 2 years, while others claim they will last over 8 years. Cypress is very heavy, being heavier than red cedar or juniper.

Pine poles sawed from the center of the tree have a life of 8 to 10 years, but the sap wood on the pine tree, that is, the outside of the tree, decays very rapidly, and lasts not more than 3 years when not treated with preservative compounds.

10. Slow-growth timber, i. e., timber that grows on barren soil, is found to be the best for poles. The selection of poles, however, must be governed to a large extent by the facility with which the various kinds may be procured in the particular locality under consideration. The poles should be well seasoned, straight, free from serious knots or cracks, and sound throughout. A bend one way, not exceeding 1 inch in every 5 feet in length commencing at a point 6 feet from the butt, is allowed on what are called reasonably straight or commercial straight poles. Poles should be cut in winter when the sap is down, for, with the sap in them, dry rot is sure to take place and the poles, although looking strong and fair, will lose their strength on account of rotting at the heart. A butt rot of 20 per cent. is allowed on some but not all poles in an order.

11. Sizes of Poles.—The best telephone lines in this country use no poles that have tops less than 22 inches in circumference. If the poles taper at the usual rate, the specification that a pole shall have a top 22 inches in circumference, or, approximately, 7 inches in diameter, is usually sufficient, for the diameter at the butt will then be approximately correct, no matter what the length of the pole may be. As the taper of poles varies considerably, however, it is well in ordering poles to make the specifications for live second-growth chestnut poles conform to Table II, taking one measurement at the top and one at a distance of 6 feet from the butt.

Since white (Michigan) cedar poles, are not so strong, they should be from 3 inches larger in circumference for the smaller sizes up to 40 feet in length to 6 inches larger for the larger sizes, including the 40-foot pole, at a distance of

TABLE II

SIZES OF POLES

Length of Pole Feet	Circumference at Top Inches	Circumference 6 Feet From Butt Inches	Depth of Pole Set in Ground Feet
25	16	25	4½
30	22	33	5
35	22	35	5½
40	22	37	6
45	22	41	6½
50	22	44	7
55	22	48	7
60	22	52	8
65	22	56	8

6 feet from the butt, but about the same at the top as given in Table II. Sometimes, 25-foot poles with a circumference at the top of only 20 inches are used.

12. Weight of Poles.—For white cedar and chestnut poles, the weight, in pounds, and the number of poles to a carload are approximately as given in Tables III and IV. Poles 35 feet and over must be loaded on two cars. Chestnut poles are about 50 per cent. heavier than white cedar, and for this reason chestnut poles cost more for freight, hauling, and raising.

Table IV, given by another authority, represents the approximate weight and number of poles to a car that has

TABLE III

Size of Poles		Weight Pounds		Number to Car Load	
Length Feet	Diameter of Top Inches	Cedar	Chestnut	Cedar	Chestnut
25	5	200	308	120	80
25	6	275	423	110	74
30	6	325	500	100	66
30	7	450	693	80	54
35	6	500	770	120	80
35	7	600	924	110	74
40	6	700	1,080	100	66
40	7	800	1,232	90	60
45	6	950	1,463	82	55
45	7	1,100	1,694	60	40
50	6	1,250	2,025	40	27
50	7	1,450	2,233	35	24
55	6	1,500	2,310	30	20
55	7	1,800	2,772	25	17

TABLE IV

	4-Inch		5-Inch		6-Inch		7-Inch		8-Inch	
Length Feet	Weight Pounds	Poles to Car Load	Weight Pounds	Poles to Car Load	Weight Pounds	Poles to Car Load	Weight Pounds	Poles to Car Load	Weight Pounds	Poles to Car Load
20	100	350	130	270	175	200	210	167		
25	155	226	200	175	250	140	350	100	450	80
30			275	131	350	100	450	80	575	61
35			400	88	450	80	575	61	730	48
40 (two cars)					600	58	730	90		
45 (two cars)					750	90	930	75		
50 (two cars)					950	71	1,175	60		
55 (two cars)					1,175	60	1,450	48		
60 (two cars)							1,800	40		

a capacity of 35,000 pounds. It is not always safe to estimate the number of poles to a car by allowing a certain weight per car, because the bulk may then be too great. However, 35,000 pounds per car is usually safe, because most modern cars will carry from 60,000 to 80,000 pounds.

13. Height of Poles.—A variation of 1 foot is usually allowed in the length specified for a pole. Where a pole line is to carry but few wires, poles with 5-inch or even 4-inch tops will sometimes answer. Poles at wagon crossings should be 30 feet long, and for crossing railroad tracks, about 50 feet. In determining the height of poles, several considerations must be borne in mind. The number of wires to be carried, and therefore the number of cross-arms, determines to some extent the general height of the pole to be used. A general rule to be followed in making this determination is to specify that at no point shall the wire be less than 18 feet from the ground.

14. Height of Line Wire Above Rails.—A railroad company has the right to pass a train of cars with a brakeman or other employe standing on the roof, beneath a line wire crossing the track and may require the wires to be so high as not to touch the man on top of the car. However, the telephone company cannot be required to string its wires at such a height as to clear a man on top of an unusually high car. The lowest wire should be at least 27 feet, preferably 30 feet, above the rail in hot weather, unless otherwise required by the law in the locality or by the railroad company's regulations. The poles should be at least 7 feet from the nearest rail when the lowest cross-arm is at least 22 feet above the rail. Double brackets, or preferably double cross-arms, should be used on poles each side of the track.

15. Height of Line Wires Above Road Crossings. Line wires, where they cross over country roads, must be high enough to allow all ordinary wagons and farm vehicles, such as threshing machines in their ordinary traveling form, to pass under them. If they are suspended at such a height, and such a vehicle breaks a wire, the owner of the vehicle is liable for damages. If the vehicle breaks a wire when it might have passed under without doing so, as, for instance, by pushing the wire out of the way, the owner of the vehicle would still be liable for all unnecessary damage to the wire. Generally, the lowest wire should not be less than 19 feet above the crown, or highest part, of the road.

16. Where these conditions are considered, the number of cross-arms on a pole, the distance between them, and the depth of the pole hole make the determination of the pole length an easy matter. The length of the pole must, however, be varied according to the lay of the land, as will be shown later, in order that the line of the pole tops may be as evenly graded as possible. Obstructions, such as the branches of trees, other wires, and buildings, must be avoided, and it is a good rule, wherever possible, to have the line go over rather than under all such obstructions.

17. Rotting of Poles in the Ground.—In countries where there is a large average rainfall, it is difficult to protect poles from rotting in the ground, in spite of the precautions sometimes taken to render the wood impermeable. Many attempts have been made to increase the life of poles by such processes as creosoting and vulcanizing, and some of these processes are used for poles and especially for cross-arms. In the United States, poles are usually set without any preparation whatever against the action of the elements. The poles should be cut at least a year before using, in order to give them time to dry and season, and they should be peeled, preferably before seasoning and while the sap is down, and all knots should be smoothly trimmed at the same time. The bark should be stripped off as soon as the tree is cut, to get rid of the insects under it, and also because the bark retains more moisture than the wood and thus tends to hasten the rotting of the sound wood. In order to prevent to as a great an extent as possible the action of the weather at a point just at the surface of the ground, the poles are sometimes coated with pitch for a distance of 6 or 7 feet from the butt, according to the depth to which they are to be set in the ground. The point on the pole at the surface of the ground is termed the *wind-and-water line*, and at this point poles usually, if not specially treated, first begin to rot, this action being due to the fact that the combined effects of the air and moisture are greatest at this point.

18. Treatment of Poles.—The following plan, invented by M. Dúbois, is said to prolong the life of the poles very much: The portion of the pole in the ground is surrounded by an earthenware pipe, very similar to a drain pipe. The end of the pipe should extend slightly above the surrounding soil. Into the space between the pole and the pipe, put a mixture of sand and resin, the latter being poured into the space in a melted state. When the resin solidifies, the mixture of sand and resin prevents the entrance of moisture and the rotting of the pole.

A method for the preservation of the butt ends of poles, given by J. C. Duncan, of Knoxville, Tennessee, is as follows: First, char the pole for first 4 to 6 feet on the butt end, $\frac{1}{4}$ inch in depth. Second, mix 1 gallon of 25-per-cent. crude carbolic acid with 5 gallons of coal tar. Put on one or two coats of this mixture after the pole is dried out; it should not be put on when the pole is green.

Another method is to remove the earth for 2 or 3 inches from around the pole and about 3 inches deep; pour a gallon of tar oil around the pole so that it is tarred just above and below the surface, then put back the earth. In Southern California, the earth is dug from around the poles to a depth of 1 foot, about 2 gallons of crude oil poured in and allowed to soak in and the earth then put back. Sometimes rock salt is put around the poles near the surface of the ground. The life of poles impregnated with creosote is at least 30 years. It is sometimes claimed that creosoting a pole weakens it and to handle the pole is undoubtedly hard on the hands, especially when freshly creosoted.

It is also claimed that the Hasselmann process greatly increases the life of poles and hardens and toughens the

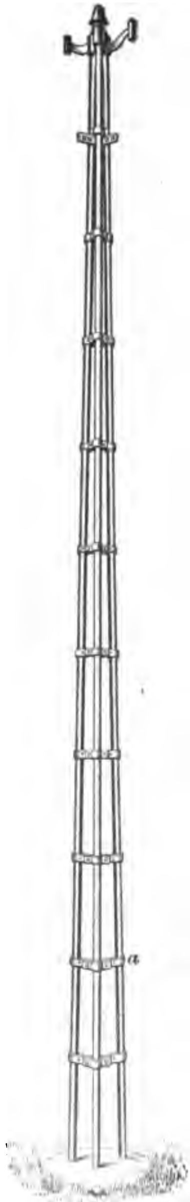


FIG. 1

fiber. This process consists in forcing into the pores of the wood under pressure in a tank a solution consisting of 20 per cent. of copper sulphate and 80 per cent. of iron sulphate mixed with some alumina and kainit, which is a mineral mined in Germany, and consisting mainly of sulphates of potassium and magnesium and chloride of magnesium. Either seasoned or green wood can be treated. The decay of poles, except red cedar, is generally caused by worms boring into the poles. This preparation will kill all eggs or worms that may be in the poles and prevent others from being deposited.

19. Steel Poles.—As the price of wooden poles is gradually increasing, the use of steel and concrete poles is increasing. A form of **steel pole** used is shown in Fig. 1. It consists of three **U**-shaped steel bars embedded in a hole filled with concrete and tapering gradually together toward the top. The pole should be set with one-tenth of its entire length below the surface of the ground. Steel or iron bands *a* at regular intervals hold the three upright bars in proper position relatively. Steel poles must be kept well painted to prevent rusting. Longer spans can generally be made with steel and concrete poles than with wooden poles.

20. Reenforced-Concrete Poles.—For terminal poles and special cases where extra strong, durable, and high poles have been required, **reenforced-concrete poles** have been used to some extent. About one hundred reenforced-concrete poles constructed by J. F. Weller are in use along the Welland canal.

The poles are manufactured on the ground with their butts immediately over the hole in which they are to be erected, as it has been found very expensive to transport them on account of their great weight; a 35-foot pole for ordinary line work weighs about 2½ tons, and a 50-foot one about 5 tons. Most of the poles so far made have been calculated for and have withstood when tested a horizontal pull at the top of 2,000 pounds. These poles were made square with the corners chamfered off, on account of ease in making and also on account of the saving in steel over any other section. The reenforcement consists of several steel rods, each rod being the full length of the pole. The size and number of the rods are calculated from the fact that the stress in a pole from a horizontal pull at the top gradually increases from the top downwards. The theoretical reenforcement would, therefore, be a rod tapering from nothing at the top to a certain diameter, depending on the strain, at the bottom. As these tapering rods are not rolled at present, the same effect is obtained as nearly as possible by welding different-sized rods together, the diameter increasing by ⅛ inch about every 10 feet. Several trials were made to overcome the necessity of welding the rods, but hook joints or lapping the bars over each other at the junction gave very poor results. The poles are molded in wooden forms, in a horizontal position, the top side being left open and finished with a trowel. Foot-steps are embedded in the soft concrete as the pole is being made and bolts for cross-arms also, or holes are left so that a bolt may afterwards be put right through the pole. The concrete is composed of one part by volume of the best Portland cement, two parts of clean sand, and four parts of finely broken stone or gravel.

The erection of such heavy poles requires considerable care. The cost of the poles will depend on local conditions. It is doubtful if concrete poles are much if any cheaper than structural steel poles of the same strength, although it is claimed that they cost 25 per cent. less. Concrete poles do not require painting and should last almost indefinitely. Steel poles should be painted every two or three years.

21. Spacing of Poles.—Practice varies as to the spacing of poles. Of course, the number and sizes of the wires to be carried are the most important considerations in determining this point, but the climatic conditions, especially with regard to heavy wind and sleet storms, should also be considered. In general, it may be said that the best lines carrying a moderate number of wires use thirty to forty poles to the mile, while, for exceptionally heavy lines, the use of fifty-two poles to the mile, or one pole to every 100 feet, is not uncommon practice. On the other hand, many pole lines carrying but few wires use only twenty-five, and sometimes as low as twenty, poles to the mile. As a general rule, which it is well to follow, in nearly all cases thirty-five or forty poles to the mile should be used. On toll lines, use forty poles to the mile. For city work, the poles should be set on an average not farther apart than 125 feet, and they should be painted and provided with steps.

LAYING OUT POLE LINES

22. Marking With Stakes.—Having selected the general route, the location of each pole should be determined and marked with a stake before the hauling of poles or other material is begun. In doing this, a 150-foot steel tape line is desirable. Several marking flags of white cloth, about 2 feet square and mounted on 10-foot poles, sharpened at one end, together with a light ax, will be the only other tools necessary in locating the poles. Assuming that the line to be constructed is to follow the southern side of the roadway shown in Fig. 2, that the average number of poles to the mile is to be forty, and that the maximum allowable distance between the poles under ordinary circumstances is 140 feet, the average being 132 feet, the work should proceed as follows:

Beginning at position *1*, drive a stake into the ground at a proper distance from the road center or fence, and measure off a convenient number of 132-foot lengths. In this case, it may be convenient to measure in this way as far as

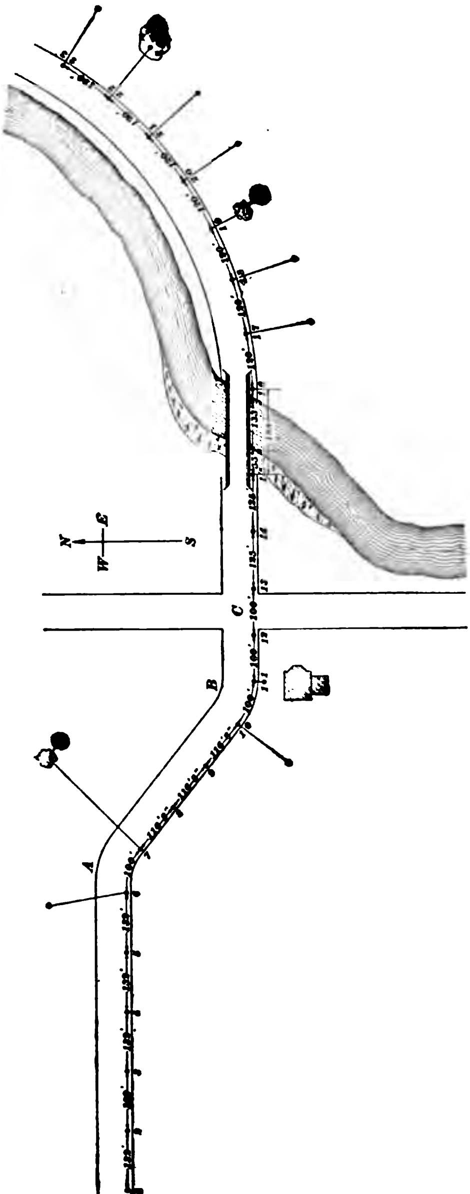


FIG. 2

the first bend in the road at *A*. Make a mark on the ground at each 132 feet, and leave a stake at each mark. Now have a helper place his flag at the position for the sixth pole, due care being taken that the distance from the center line of the road or from the adjacent fences is correct. As the section of road between positions *1* and *6* is straight, the intermediate stakes may be located directly in line with *1* and *6*, a sight being taken by the eye between a flagpole held on stake *1* and the flag at stake *6*. The helper locates the proper position for each stake by holding a flag in an approximate position and moving it to the right or left, according to signs given by the party sighting at stake *1*. After the proper location of stakes from *1* to *6*, all should be driven home and numbered, either by an ordinary tag, or, better, by marking with soft lead directly on the stake. Convenient stakes for this purpose are made of yellow pine, 20 inches in length and about $1\frac{3}{4}$ inches square. At *A*, a sharp bend occurs in the road, and as a side strain will be caused on the poles at that point, it is well to locate the two poles that are to stand this strain closer together. Stake *7* will therefore be placed at a distance of, say, 100 feet from stake *6*, and located at the proper distance from the road center.

Before locating the next poles, the conditions at the bend *B* in the road and at the cross-road *C* should be investigated. It will be better, as before, to make the turn at *B* on two poles placed at about 100 feet apart. Therefore, these two poles at *B* are located at proper distances from the road center, and in such manner that the distance between them will be nearly bisected by the angle in the road. The distance between the western pole at *B* and pole *7* is then measured and found to be 350 feet. This will make three spans $116\frac{2}{3}$ feet long, and as this short section of the road is straight, the two intermediate stakes *8* and *9* are located in a straight line between poles *7* and *10* by the method already indicated. Then, 132 feet from pole *11*, which is already located, would bring pole *12* into the center of the cross-road, while the span would be longer than

140 feet if pole *12* were located at the other side of this road. Therefore, it will be necessary to make another short span, and pole *12* is located 100 feet from pole *11*, as shown. The next span of 132 feet would more than clear the roadway, but inasmuch as this is a cross-road, where it is particularly desired not to have broken wires, it will probably be better to make another short span across it of, say, 100 feet. From pole *11* to the river is a straight stretch, and from pole *13*, located just on the east side of the cross-road, the distance is 250 feet.

23. The poles on the banks of the river must be located with great care, due consideration being taken of the nature of the soil, the elevation of the banks, and the length of the span across the river. The distance from water edge to water edge of this river at this point is found to be 133 feet, but the soil on the west bank is so marshy for a distance of 50 feet as to afford no proper footing for a pole. The nearest firm ground on the west bank is at a point 55 feet from the water edge, just near the entrance of the iron bridge spanning the river. A pole should therefore be located at that point. On the opposite side of the river, a solid rock rises abruptly from the water edge back for about 50 feet. This rock will make an excellent foothold for a pole, although, of course, powder or dynamite must be resorted to in blasting the hole. The pole is located, therefore, as close to the river as possible, its location being marked by a cross-mark scratched on the rock.

On measuring this span across the river, it is found that the distance between the poles is 188 feet, but as it is impracticable to locate them closer together, and as the bridge may afford no facilities on which to mount a bracket, this span must be tolerated, great care being taken, of course, in properly securing it in the future operations. The distance from the pole on the western bank of the river to pole *13* is found to be 250 feet, thus giving two 125-foot spans. From pole *11* to pole *16* is a straight line, and, therefore, the intermediate poles *12*, *13*, *14*, and *15* should be accurately located in line by sighting between the flags. After crossing the river, the roadway follows the river bank for about ¼ mile in an even curve northwards. It should be made a rule to place the poles somewhat closer together than the average on curves; but inasmuch as this curve is a gradual one, the normal length of span need not be reduced to a great extent. A distance of 120 feet between poles will therefore be decided on for all the spans on this curve. The succeeding poles are therefore located 120 feet apart, and each at a proper distance from the road center. If the roadway were not a smooth curve, the poles on all straight portions should be alined as described, while those on the curves should be made to follow curves as nearly smooth as possible.

The stakes should be located on a map, such as shown, and the distance between them clearly marked either on the map or on a separate table.

24. Locating Guy Stubs.—All poles on which turns are made should be securely guyed in such a manner as to entirely counteract the side strain produced by the line wires. In locating the poles, it is also well to mark the position of the **guy stubs**, or anchors, to which the guy wires are to be attached. In doing this, much judgment must be exercised, and right-of-way privileges must also be consulted. It is frequently a much more difficult matter to obtain permission to anchor a guy wire on a piece of property than it is to locate a pole. The anchor for the guy wire should always be located so that the direction of the guy wire will bisect the angle made by the line wires on that pole. It is evident that poles *6*, *7*, *10*, *11*, *17*, *18*, *19*, *20*, *21*, *22*, and *23* will need to be guyed, and note is made of this fact in locating the poles, and the guy stubs located by stakes in the same manner as the poles. The stubs should also be marked on the map. Poles *6*, *10*, *17*, *18*, *20*, *21*, and *23* will be guyed to stubs placed at the positions located. Poles *7* and *19* will be guyed to tree trunks, as indicated on the map, while the guy wire of pole *22* will be anchored in the convenient ledge of a rock, the ground at that point being too stony to erect a guy stub without undue trouble. At pole *11*, which is opposite a residence, no permission could be secured from the owner to plant a guy stub in his front yard, and, therefore, an anchor is provided, as will be described later, close to the base of the pole.

25. Grading Line of Pole Tops.—Where the line passes through a level country, all the poles may be of the same length, except where changes are necessarily made in order to avoid obstructions. In a hilly country, however, it is important that the line of the pole tops should be as nearly on a level as possible, and this necessitates the putting of long poles on the low ground and short poles on the

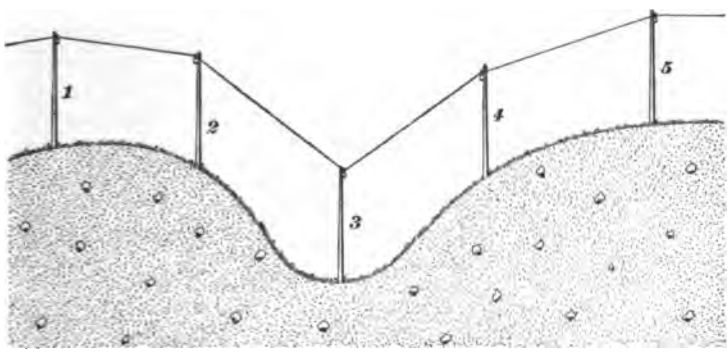


FIG. 3

high ground. That this is important may be seen by comparing Figs. 3 and 4. In Fig. 3, where all the poles are of the same length, a very heavy strain would be brought on poles *2* and *4*, and pole *3* would probably have an upward instead of a downward pull on it by the wires, thus serving to increase the strain on poles *2* and *4* rather than diminish it. Cases have been known where, owing to such faulty construction as that indicated in Fig. 3, the insulators were pulled off and even the pole in the hollow was lifted entirely out of the ground and hung suspended by the line wires. At any rate, a pole in such a position is much more likely to do harm than good. The drop or rise should not exceed 3 feet between two poles.

26. In Fig. 4, the unevenness in the profile of the line is corrected to some extent by the use of poles of varying lengths and by a different arrangement of the poles with respect to the configuration of the ground. As will be noted, two poles are used in the ravine, one on each side, instead of one in the bottom of the ravine, as in Fig. 3. Moreover, these poles are made longer and the poles on the

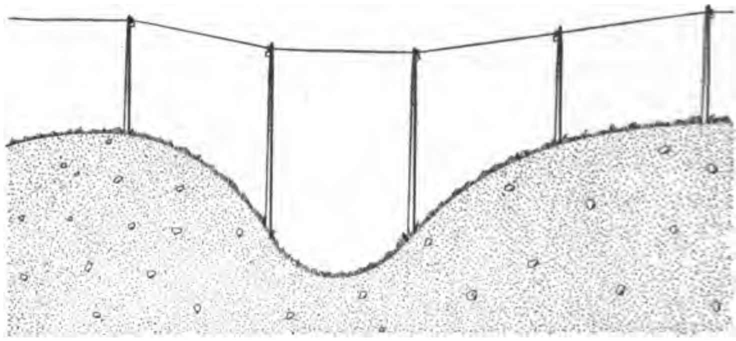


FIG. 4

hilltops shorter, thus maintaining a very fair grading of the pole tops without subjecting any of the poles to undue strain.

27. In a country having only slight undulations, the length of a pole required at any particular place can usually be determined by a mere inspection with the eye. If the country is very undulating, it is good plan, and one that should be carried out if possible, to make a profile map of the entire pole line with a surveyor's level and leveling rod. For this purpose, the level should be set up between stakes *1* and *2*, and a sight taken at the leveling rod while held above stake *1* by the helper. The helper should then go to stake *2*, and a sight should be taken on the rod when held above it, the level remaining at the same point. The readings so obtained are called *backsights* and *foresights*, respectively, and the difference between them indicates the difference in level between stake *1* and stake *2*. In the same manner, the difference in level between stakes *2* and *3* may be obtained. After the levels of all the stakes have been determined, an accurate profile of the country over which the line passes may be mapped out on a piece of section paper, and, after this is done, the profile of the line of pole tops may be drawn in such a manner as to remove all undue vertical bends, this being accomplished, of course, by varying the length of poles, as already described. After this, the lengths of poles may be scaled and a table made so that the proper length of pole may be hauled to each stake.

This method is not usually followed, and is unnecessary if the country is gently undulating, but, in a very hilly country, a careful following of this plan will result not only in a better line, but will actually save labor and expense.

ERECTING POLE LINES

28. Distribution of Poles.—After these preliminaries are arranged, the poles may be distributed by any means available. They should be laid with their butts near the stake and with their small ends pointing up hill, if there is a grade at that point. By following the latter point, much labor on the part of the raising gang will be saved. Another point that should be observed in the distribution of poles is that the heavier poles should be placed on the corners and on all points where a heavy strain is likely to occur.

29. Distribution of Poles Along a Railroad.—The poles should be dropped at the right place. Where heavy poles are handled, it is quite a saving in the expense of construction to avoid carrying the poles when the setting is being done. One plan of distributing from a car along a railroad is the following: The circumference of the driving wheel is previously measured or calculated from its diameter. Then, by dividing the distance by which the poles are to be separated by the circumference of the wheel, we have the number of revolutions to be made by the driving wheel between two poles. Hence, by placing a man on the engine pilot, he can tell, by counting the revolutions of the driving wheel, where to drop off a pole. When he reaches the proper point, he makes a long mark with an iron rod in the ballast alongside the track and the men on the car drop off the pole at that spot. In building a line parallel to or near railroad tracks, never set the poles less than 12 feet from the nearest track.

30. Gaining and Trimming.—When the pole is received, its butts should be approximately flat. If this is not the case, it should be made so before setting. Poles set in gravel or quicksand should always be pointed at the lower end, to make them stand well. Experience has proved that, when not pointed, the wind will vibrate the pole more or less, and the loose gravel or quicksand will keep working under the bottom of the pole and thus gradually lift it and render it less secure each year. Unpointed poles set in barrels in quicksand have been known to rise from 1 to 2 feet in a few years, on account of the vibration of the wind and the action of the quicksand.

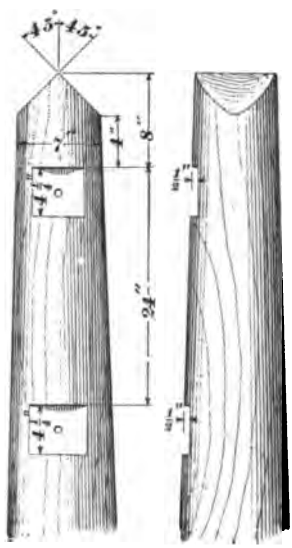


Fig. 5

Before raising the pole, the gains for the cross-arms should be cut and the small end of the pole made wedge-shaped by chamfering the top to an angle of 45°, the direction of the wedge being in a line parallel with the wires. It is customary to place the top edge of the upper gain 8 inches from the apex of the roof, and to make the distance between the tops of the cross-arms 20 to 24 inches, the latter being used on toll lines. A pole top prepared in this manner is shown in Fig. 5. The gains should not exceed 1¼ inches in depth in round cedar poles only 6 inches in diameter at the small end, and need not exceed ¾ inch in sawed redwood poles, or ½ inch where braces are used. The roof and the gains should be painted with two or three coats of the best white lead before the cross-arms are fastened in place. This treatment prevents the entrance of moisture into the grain of the wood and greatly prolongs the life of the pole.

31. Pole Steps.—Poles that are to be provided with **steps** should have the holes bored to a depth of 4 inches. Use galvanized-steel pole steps $\frac{5}{8}$ inch in diameter, 9 or 10 inches long, and turned up on one end $1\frac{1}{2}$ inches, placed on each side of the pole at right angles to the cross-arms. The steps should be staggered 30 inches on centers on each side of the pole, extending downwards from the lowest cross-arm to within 10 feet of the ground. If poles having a circumference exceeding 60 inches are used, the steps should be staggered 24 inches on centers on each side.

32. Cross-Arms.—The **cross-arms** should be made of sound, well-seasoned, straight-grained timber free from sap wood and such knots as will weaken them. Some prefer red or black cypress. However, yellow pine, especially the long-leaf variety, creosoted white pine, Oregon fir, and yellow poplar make excellent cross-arms. All cross-arms should be painted with two coats of good oil paint before leaving the factory. A good paint for this purpose consists of 7 pounds of Prince's metallic dry paint mixed with 1 gallon of pure linseed oil. Creosoted cross-arms are now extensively used; they do not require painting. Any cross-arm should stand being struck on the ground when held by one end, with as much force as a man can exert. The top of the arm should be arched or rounded so as to readily allow the rain to run off.

33. Size of Cross-Arms.—The size and length of cross-arms depend on the load they are to carry. Two

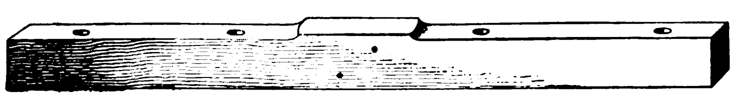


FIG. 6

regular sizes, however, are made, one termed the *standard cross-arm*, and the other the *telephone cross-arm*. The standard cross-arm is used for toll lines and all heavy work and in

TABLE V

Standard Cross-Arm					
Length Feet	Number of Pins	Spacings: End Inches	Spacings: Center Inches	Spacings: Sides Inches	Approximate Weight Pounds
3	2	4	28		9
4	4	4	16	12	12
5	4	4	18	17	15
6	4	4	22	21	18
6	6	4	16	12	18
8	6	4	18	17½	24
8	8	4	16	12	24
10	8	4	17½	15¼	30
10	10	4	16	12	30

Telephone Cross-Arm					
Length Feet	Number of Pins	Spacings: End Inches	Spacings: Center Inches	Spacings: Sides Inches	Approximate Weight Pounds
2	24	3	18		6
2	30	3	24		7
4	42	3	16	10	9
6	62	3	16	10	13
8	82	3	16	10	17
10	102	3	16	10	21
12	122	3	16	10	26

constructing a line that is expected to last well. Standard cross-arms are $3\frac{1}{4}$ in. × $4\frac{1}{4}$ in. and vary in length from 3 to 10 feet. They are usually bored for $1\frac{1}{2}$-inch wooden pins or for $\frac{1}{2}$-inch steel pins and provided with holes for two $\frac{1}{2}$-inch bolts, as shown in Fig. 6. Terminal arms usually measure $3\frac{1}{4}$ in. × $4\frac{1}{2}$ in. The number of pins and the distance between them for the various lengths of standard and telephone cross-arms are given in Table V.

The best sizes to use are as follow:

For two wires, $3\frac{1}{4}$ in. × $4\frac{1}{4}$ in. × 3 ft.
For four wires, $3\frac{1}{4}$ in. × $4\frac{1}{4}$ in. × 6 ft.
For six wires, $3\frac{1}{4}$ in. × $4\frac{1}{4}$ in. × 8 ft.
For eight wires, $3\frac{1}{4}$ in. × $4\frac{1}{2}$ in. × 10 ft.

34. The so-called telephone cross-arms are lighter, being $2\frac{3}{4}$ in. × $3\frac{3}{4}$ in., sometimes 3 in. × $4\frac{1}{4}$ in., and bored for $1\frac{1}{4}$-inch pins, and provided with two $\frac{1}{2}$-inch bolt holes. For light lines, these arms give satisfaction, but they are not recommended as they are not so strong or durable as the heavier arms. Cross-arms with which braces are to be used should be bored for one bolt $\frac{5}{8}$ inch in diameter at the center of the arm; also, for two carriage bolts $\frac{3}{8}$ inch in diameter, one on each side 15 or $17\frac{1}{2}$ inches from the center hole depending on the length of the cross-arm brace.

35. Lagscrews.—Cross-arms were formerly fastened to the poles by two $\frac{1}{2}$-inch lagscrews, such as shown in Fig. 7, of sufficient length to pass nearly through the pole, the length on standard construction being, usually, 7 inches.

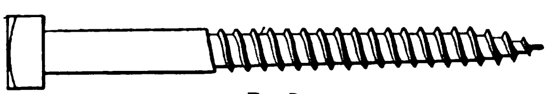


Fig. 7

For arms carrying six wires or more, the lagscrews should be $\frac{5}{8}$ inch in diameter by 7 inches long. It is much better to bore holes for the lagscrews than to drive them in. The latter method tears the fiber of the wood, and the lagscrews will not hold as well as when the holes are bored. The bit used should be $\frac{1}{8}$ inch smaller than the lagscrew, which should always be screwed up for the last 2 inches with a wrench.

36. Carriage Bolts for Fastening Cross-Arms.—It has been found that the entrance of a lagscrew destroys the grain of the pole to such an extent that it is seldom possible to put on new cross-arms after the pole has been in service for several years. A more recent and much better plan, therefore, than the use of lagscrews is to secure the cross-arms to the pole by a **carriage bolt,** such as shown in Fig. 8, the carriage bolt being $\frac{5}{8}$ inch in diameter and long enough (10 to 16 inches) to extend entirely through the pole and cross-arm. The threaded portion should be 4 inches long. A washer not less than $2\frac{1}{2}$ inches in diameter and $\frac{3}{16}$ inch thick with a $\frac{3}{4}$-inch hole in the center should be used under both the head and the nut of this bolt.

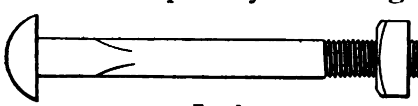


FIG. 8

37. Cross-Arm Braces.—In order to further secure the cross-arms, braces, called **cross-arm braces,** are used. All cross-arms over 6 feet long should be braced and 6-foot

FIG. 9

arms should also be braced on curves. One of these braces is shown in Fig. 9. They are made of galvanized wrought iron or a low carbon steel from 20 to 30 inches long and usually $1\frac{1}{4}$ inches wide by $\frac{1}{4}$ inch thick. The diameter of the hole in one end should be $\frac{17}{32}$ inch and in the other end $\frac{13}{32}$ inch. The method of attaching these to the pole and cross-arm is shown in Fig. 10, which represents a pole top equipped with three six-pin standard arms. Each pair of cross-arm braces is secured to the pole by a single $\frac{1}{2}$-inch lagscrew, 4 or 5 inches long, and a washer, while the other ends are each secured to the cross-arm above by a $\frac{3}{8}$-inch carriage galvanized-steel bolt 4 or $4\frac{1}{2}$ inches long so as to pass entirely through a washer, the cross-arm, the cross-arm brace, and another washer, the nut being on the brace side. A washer not less than 1½ inches in diameter and ⅛ inch thick is provided under the head of the lagscrew and under the head and nut of each carriage bolt. The hole through the arm for the ⅜-inch carriage bolt should be ½ inch in diameter.

When wires are heavily loaded with sleet, experience has proved that there is much less damage by broken cross-arms when they are braced than when they are not. A shallow

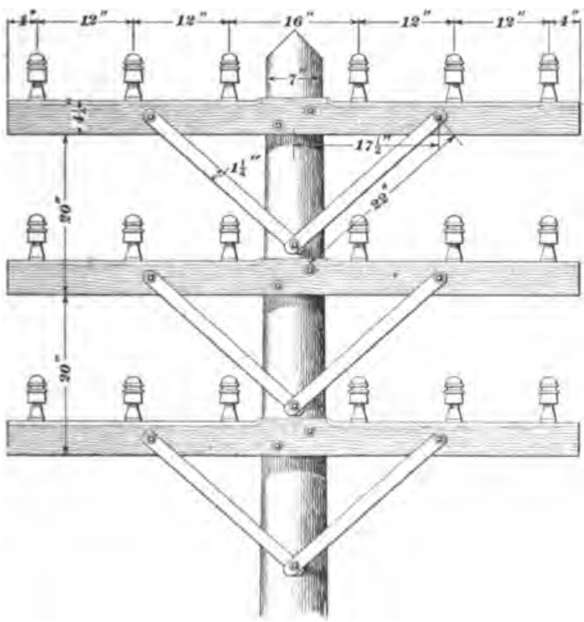


Fig. 10

gain can be used with braces, and this is certainly an advantage, because a deep gain reduces the strength of the pole, and the older the pole, the more damage results from deep gains during storms. The brace should be fastened to the front of the cross-arm opposite the pole. Some advise locating the bolt for holding the brace to the arm ½ inch above the center of the arm instead of at the center, claiming that this holds the arm better, and especially when subjected to a heavy load of sleet or wet snow.

38. Double arms, that is, an arm on each side of the pole, should be used on all office or terminal poles, at all railway and river crossings, on corners, on unusually long sections, and on curves where the angle between the line wires at a pole is 150° or less. On heavy lines, the first pole back from a corner should have double arms in order to carry guys to assist the corner-pole guys. Only the arms on the front or lead side of a pole need be braced. Double arms should have two blocks between the arms. A carriage bolt should pass through the block and both arms just outside of the end pins, and should be placed their width above the center of the arm. The nut should be firmly screwed up.

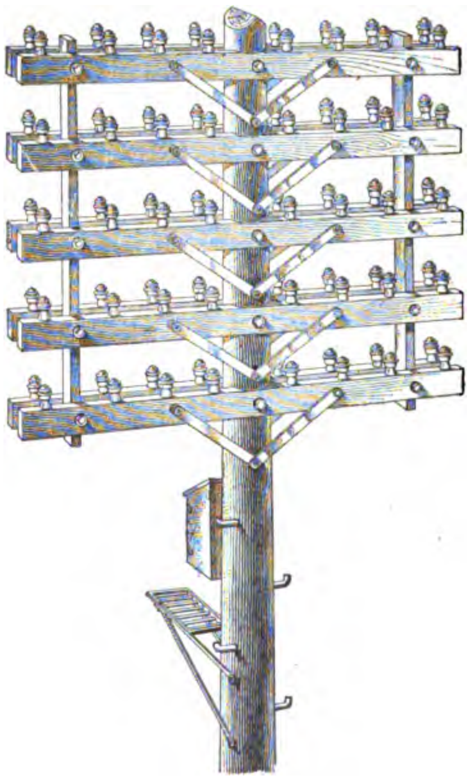


FIG. 11

39. In order to prevent the arms of cable poles from becoming loose and twisted by linemen climbing on them, the spreader blocks may be omitted between the ends of the double arms, with which cable poles are usually equipped, and instead a piece of 2-inch plank may be used, as shown in Fig. 11. These boards extend from above the top arm to a little below the bottom arm. The arms should then be bolted together through the strips. The strain on any arm, due to a man standing on it, will, by this construction, be distributed to all the other arms.

40. Wooden Pins.—Insulators are mounted on cross-arms by means of pins, as shown in Fig. 12. The three sizes of wooden pins used in telephone work are shown in Fig. 13: (*a*) is the ordinary line pin; (*b*) is the transposition pin, which is used where transpositions are to be made; and (*c*) is used for terminals or dead-ended lines. Wooden pins may be made of locust, chestnut, or oak, preferred in the order named, and are turned up with a coarse thread on the end on which the insulator is to be secured. The shank *k*, Fig. 12, is turned about $\frac{1}{32}$ inch smaller in diameter at the bottom than the hole in the arm. Standard cross-arms are usually bored for the $1\frac{15}{32}$-inch pins and the telephone arms for the $1\frac{7}{32}$-inch pins. The number of threads to the inch is usually 5 and the depth of threads is usually $\frac{1}{8}$ inch.

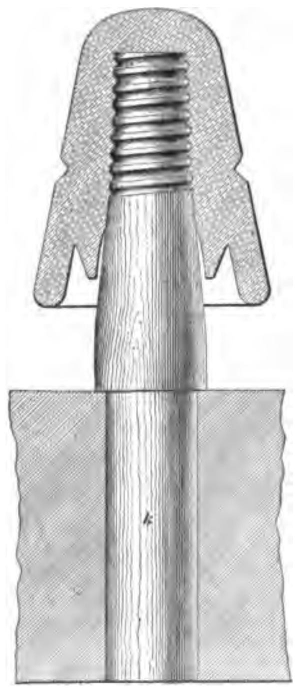


FIG. 12

Oak pins are now seldom used unless creosoted. First-class locust pins, not larger than $1\frac{7}{32}$ inches at the bottom, are satisfactory for telephone lines and are used the most, even with standard cross-arms which are bored to suit them.

The pin should be secured in the hole by driving a six-penny galvanized nail through the arm and the shank of the pin. This renders it difficult to extract the pin in case a new one is required, but prevents the pin from pulling out, which sometimes occurs where this precaution is not taken. The shank *k* of the pin is usually tapered slightly so the pin will fit tightly in the hole in the cross-arm.

41. From some tests made on 1¼-inch pins arranged to conform, as far as possible, to the actual conditions when

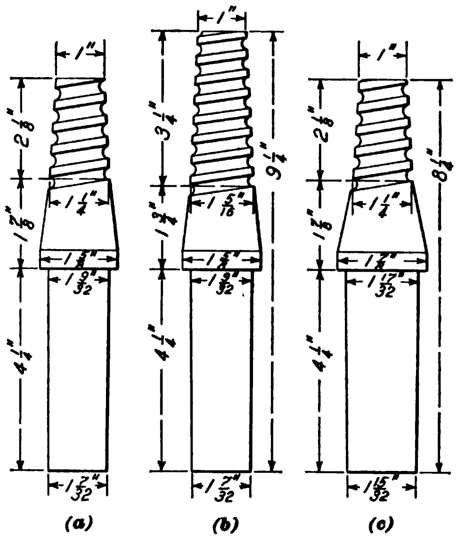


FIG. 13

placed on a cross-arm, the following results given in Table VI were obtained:

In Table VI, it will be seen that locust has a strength of nearly three times that of white oak, which is a fact well

TABLE VI

Kind of Material	Maximum Load in a Direction Parallel to the Grain Pounds	Maximum Load in a Direction at Right Angles to the Grain Pounds
Locust	3,200	3,100
Kalpa	2,100	2,000
Kalkeen	1,850	1,750
Hickory	1,100	1,200
White oak	950	950

worth remembering when sharp corners are to be turned and long spans are to be used. Just before breaking, the deflections would generally be less than $\frac{1}{4}$ inch. The tests seem to show that insulators will generally break before the pin, also that an ordinary cross-arm will give way to such an extent that the pin will pull out long before the maximum load will be applied. The outside pins on a 10-pin cross-arm will stand nearly as much load as the arm itself. A long-leaved yellow-pine arm of the standard size would stand an average maximum load of about 1,350 pounds, the arm being about equally strong in both directions.

42. Steel Pins.—**Steel pins** are now being used instead of wooden pins on the best constructed telegraph lines and also on some telephone lines. They are usually $\frac{1}{2}$ inch in diameter. On corners, or where there is a heavy strain, the pins should be $\frac{3}{4}$ inch in diameter. They are fastened by a nut on the under side of the cross-arm and have a wooden cap on which the insulator may be screwed.

43. Brackets.—If only one or two wires are to be placed on a pole, **brackets** of the kind shown in Fig. 14

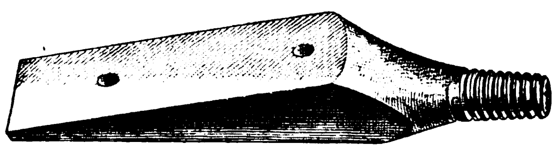


FIG. 14

are used. These are shaped at their lower end in such a manner as to allow the pins to project from the pole at an angle, and are each provided with two holes through which heavy spikes are driven to secure them to the pole.

44. Where a pole carries but few cross-arms, it is usually better to secure the arms and pins in place while the pole is on the ground, as it can be done much more easily then than later, and the extra weight does not interfere seriously with the raising of the pole. In very heavy work, however, this cannot be done, nor can it be done in cases where a pole must be raised through a network of wire, such as is frequently found in cities.

45. Lightning Conductors.—It is a good plan to protect the line wires from lightning discharges by putting conductors not less frequently than every fifth pole. Some telegraph engineers advise putting them on every pole. All office poles should be provided with such protecting wires. Heavy galvanized No. 8 B. W. G. iron wire should be used. At least 6 feet of it should be formed into a flat zigzag bundle, placed in the pole hole under the butt end of the pole, and the wire should be carried up and stapled to the pole on the side opposite the cross-arms, about 3 inches projecting above the top of the pole.

Where a pole has a bracket, this grounded wire should be put one-quarter way around the pole from the bracket and not opposite the bracket. This allows another bracket to be put up opposite the first without having to move the grounded wire.

46. Depth of Pole Holes.—After the poles are on the ground and ready for raising, the pole hole should be dug. No absolute rule can be laid down for the depth to which pole holes should be dug, as this depends on the nature of the soil, the height of the poles, the number of wires to be carried, the number of poles to the mile, and the frequency of heavy wind storms, and must, therefore, be left to a large extent to the judgment of the engineer. For average conditions, the depths given in Table II will serve as a guide for the depth of pole holes for various lengths of poles. In solid rock, the depth may be 1 foot less, while on curves, the depth should be 6 inches greater.

47. Digging Pole Holes.—A hole should be started with the marking stake as the center, and should be of sufficient size to allow the pole to slip easily into place. About 2 to 3 inches all around each pole is the proper space to allow for tamping; that is, make the hole 4 to 6 inches larger in diameter than the base of the pole. If the holes are dug smaller than this, the probabilities are that they will not be properly tamped at the bottom.

48. Number of Men Required.—In the construction of a pole line, it is a good plan to so proportion the work of the gang that poles will be set in all the holes dug at the close of each day. Assuming that the average length of pole is 35 feet, a gang of about six men will be required for

Fig. 15

Fig. 16

Fig. 17

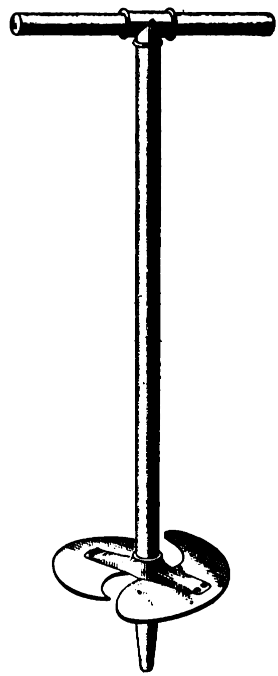


Fig. 18

raising. For longer and heavier poles, as many as fifteen men may be necessary. These men may all be employed in digging holes in the morning, and, under average conditions, the same gang can in the afternoon set poles in all the holes dug in the morning.

49. Tools Required.—It will be well to provide as many sets of digging tools as there are men, each set consisting of the following: one long-handled digging spoon; one long-handled, round-pointed shovel; one combined crow and digging bar.

The digging spoon, shown in Fig. 15, should preferably have an 8-foot handle; the round-pointed shovel, shown in Fig. 16, a 7-foot handle; and the digging bar, shown in Fig. 17, should be 8 feet long and constructed of $1\frac{1}{8}$-inch octagonal steel. It should be flattened at one end and pointed at the other. In some cases, various forms of post-hole augers have been found advantageous. One form is shown in Fig. 18. They are made 10, 12, and 14 inches in diameter. The use of 14-inch post augers in fair earth or in low wet places is by far the quickest and cheapest way of digging holes. They are not useful in hard or rocky ground.

50. Number of Poles Raised Per Day.—In average soil, one man can dig eight 6-foot holes in one day. However, in very hard or rocky soil, this rate cannot be even approached, so that it is a difficult matter to give a general estimate on work of this kind. Probably six holes might be taken as a fair average. The six men would, at the rate first mentioned, dig twenty-four holes in half a day; and to raise and set that number of poles in the afternoon of the same day should be the aim of the foreman of the gang.

51. Use of Dynamite.—Dynamite in small charges has been used to very great advantage in moving hard pan and frozen earth, and is very much cheaper than digging it with bar and spoon. It is well to remember that it is very dangerous to thaw out dynamite by placing it on or near a stove. People are sometimes killed by the explosion resulting from ignorance or carelessness in this matter. The best way to apply the dynamite is to bore a hole with a 2-inch auger bit, having a 4-foot stem and suitable handle, to the proper depth, say 3 feet. Then place in the bottom of the hole $\frac{1}{4}$ pound of 40- or 60-per-cent. dynamite, with an electric exploder and a wire properly attached to it; tamp the shell in carefully with fine loose dirt, and explode the charge. Generally, no more digging will be required and it is only necessary to spoon the dirt out of the hole, which, in most cases, will be found large enough. If necessary to prevent the dirt and rocks from flying all over, cover the hole with a lot of brush held together in bundles with chains before exploding the charge.

52. Raising Poles.—The following list of tools will usually comprise all those needed for an ordinary raising gang: two 12-foot pike poles; two 14-foot pike poles; two 16-foot pike poles; two dead men, 6 and 8 feet in length, respectively; one cant hook; two tamping bars; 1 short-handled shovel; two carry hooks; two iron digging bars or crowbars, or one piece of oak plank, 9 inches wide, 1½ inches thick, and 7 feet long; one set of 4-inch double-sheave block and tackle, with about 250 feet of ½-inch rope.

53. The **pike pole,** shown in Fig. 19, is frequently made of pine, and about 2½ inches in diameter at the largest end. At this end is carried a spike of pointed steel, which projects from the end of the pole about 3½ inches and is secured in place by a strong iron ferrule. The **dead man,** shown in Fig. 20, consists of a short, heavy, oak bar about 4 inches in diameter and provided with a two-tined fork having a sharpened projection at the center to prevent slipping. This is used to support the pole during raising while the men handling the pike poles are securing new holds. The **cant hook,** Fig. 21, consists of a short stout bar of oak or hickory to which is pivoted, at a point about 1 foot from the end, an iron jaw provided with a spike, as shown. These are used in rolling the pole on the ground, or in turning it to the required position after it is

FIG. 19

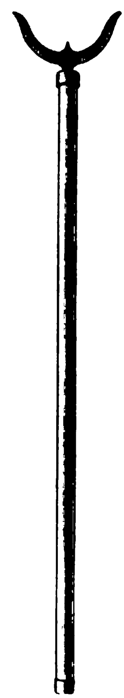


FIG. 20

raised. The **carry hook,** shown in Fig. 22, consists of two iron jaws pivoted and swiveled to the center of a stout oak handle about 5 feet long. These are used when it is necessary to carry the pole for short distances or to swing one end around into the proper position for raising. They are used mostly along railroads. In other places where poles have to be moved, it is better to use a "dinky" or small running two-

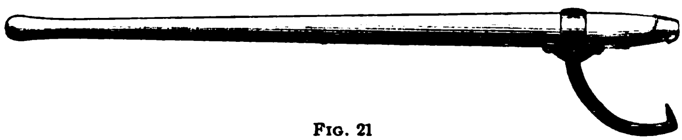


Fig. 21

wheel truck for placing the pole exactly where it is wanted. The oak plank is used for preventing the butt of the pole from crumbling away the earth on the side of the hole during the process of raising. However, it is more customary, because more convenient, to use two digging bars instead of the plank, in order that the butt of the pole may go in the hole easily. The block and tackle is frequently found convenient in pulling a pole up an embankment on which it could not be placed directly from the wagon.

Before raising the pole, it should be rolled by cant hooks, or by any available means, so that its butt lies over the hole.

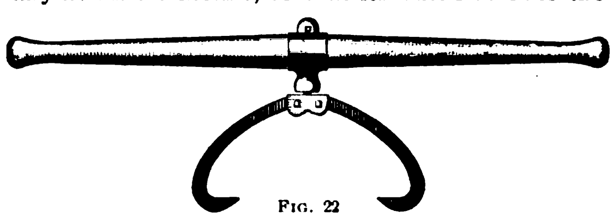


Fig. 22

The oak plank, or digging bars, should be placed in the hole on the side farthest from the pole, in such a manner as to form a guide for the butt of the pole in its descent. One man should then be assigned to the dead man, four to the pike poles, and one should be stationed at the hole, provided with a crowbar and cant hook so as to be able to guide the pole into the hole in the proper manner, and at the same time to instruct the raisers. The small end of the pole should then be raised by hand and supported by the dead man while the men obtain a new hold. As they raise it higher and higher, the dead man is moved toward the butt, at all times inclining slightly toward the butt, in order that it may have a tendency to push the pole toward the hole. When the pole is high enough to enable the use of the shorter pike poles, the pikes of these should be planted firmly on the under side of the pole and the pole raised still higher, the dead man at all times being kept in position in such manner as to ease the work of the men and also to prevent accidents. As the pole is raised higher, the longer pikes may be used.

54. The method of using pike poles and the dead man is shown in Fig. 23. The lower end of the pike pole is placed

FIG. 23

directly on the shoulder and held in that position by the hands. The pike pole should always have its upper end inclined toward the hole, and should be about in line with the body of the user, so as to allow him to push to the greatest advantage. The men should work as nearly under the pole as possible, but should spread out slightly, so as to steady the pole from falling sidewise. As the pole is raised, the men should, one at a time, shift to a lower hold, in order that an undue strain may not be placed on the others. The dead man should at all times be kept in position to take its share of the load. When nearly raised, the longer pike poles may be used to advantage, the change, of course, being made by one man at a time, as before.

An excellent way of raising poles, especially in towns and cities, is to do it with a derrick wagon, the pole being pulled up by the horse or horses.

55. Derrick Wagon.—A derrick wagon that has been successfully used is shown in Fig. 24. It is a simple con-

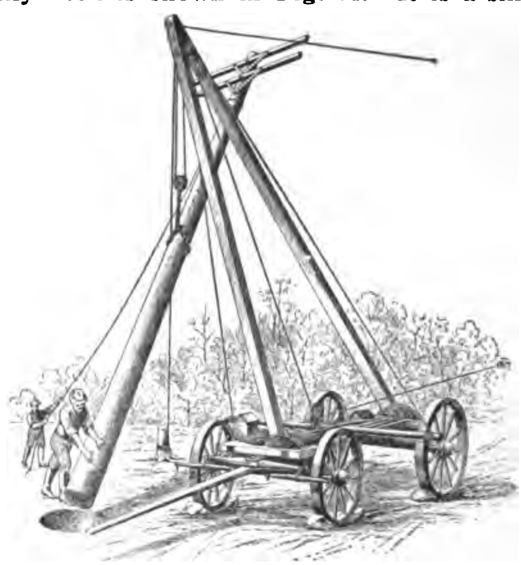


FIG. 24

trivance consisting of a heavy wagon with two 28-foot spars, or poles, standing like an inverted **V**, with one leg over each pair of wheels. After the derrick has been dragged to a pole hole, it is guyed to adjacent trees or rocks, so that a 2- or 3-ton pole may be lifted without overturning it. After the cross-arms and braces have been secured in place on the pole, a strong chain is passed around the pole, well above the center of gravity, and the horses are hitched to the draw-rope *a*, and, by a steady pull, the pole is raised clear of the ground. Two men guide the butt, and, as soon as it is over the hole, the horses back slowly and the pole sinks into place. The pole is held in place while one man climbs it and removes the chain, thus allowing the derrick to be moved on and placed in position for raising the next pole. The pole is then straightened up and the earth thoroughly tamped in around it. The derrick requires four men, two horses and a boy to drive it, replacing from twenty to thirty men, ordinarily used to raise a large pole. The difference in cost per day is said to be from $15 to $20 in favor of the derrick method of raising poles.

56. Fig. 25 shows a pole-raising derrick, designed by Frank D. Byler, of Morganstown, Pennsylvania. The machine shown is a model of the type used to raise poles of lengths from 25 to 50 feet. In a machine designed to raise longer poles, the upright braces are set 3 feet in front of the rear axle and some sort of a power appliance, such as a gasoline engine or electric motor, is placed on the front to raise the pole, instead of the winch, which is shown in this figure. The clamp that is used to hold the pole will grip the pole automatically, and loosen itself when the pole is set in the hole. When it is required to take a pole from the hole, the grip will tighten of itself and it is said that the pole can be easily extracted.

FIG. 25

57. **Climbing.**—Two forms of **climbers**, shown in Figs. 26 and 27, are in common use. These are termed, respectively, Western and Eastern climbers, and each style has its own advocates. In the Western climbers, the rod that is strapped to the leg is on the opposite side from the spur, and therefore is secured to the outside of the leg. In the Eastern pattern, the rod is on the same side as the spur, and is therefore secured to the inside of the leg.

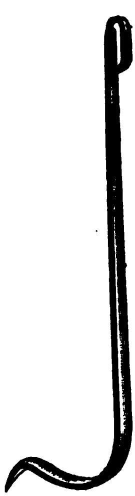


FIG. 26

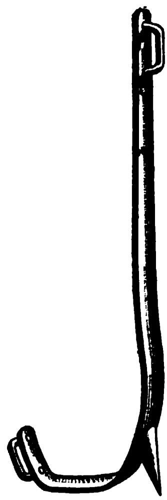


FIG. 27

Climbing is an art that can be attained only by practice, and the best way to learn it is to practice on the lower portion of a pole, without attempting to ascend to the top at first. The main points to be remembered in climbing are to secure a hold with the spur by a direct downward thrust of the leg, instead of with a side thrust toward the pole, as is the tendency with an amateur; also, the body should be held out at arm's length from the pole, the pole being clasped in the palms of the hands, instead of being hugged close to the body. It is more difficult to descend than to ascend, and therefore the beginner should be cautious about climbing too high at first.

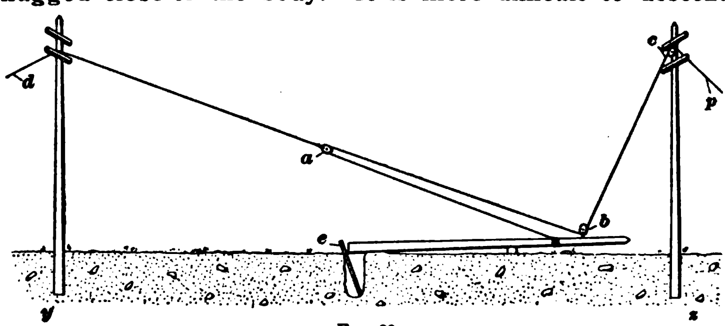


FIG. 28

58. Setting Pole Between Two Others.—To set a pole between two other poles already in position, the arrangement shown in Fig. 28 has proved convenient and successful. The line *d*, which may be a $1\frac{1}{4}$-inch rope, is tied near the base of the next pole or other suitable object to avoid putting any strain on the wires supported by the poles. At *a*, *b*, *c* single-sheave, or snatch, blocks, are used and a team of horses or other source of power is attached to *p*, which may be a $\frac{3}{4}$-inch rope, to raise the pole. At *e* is a stout plank used to make the butt slide into the hole as the pole rises.

59. Bracing Pole.—After the pole is brought to a vertical position, it should be turned by means of a cant hook until the cross-arms assume a position at right angles to the direction of the line. In doing this, it should be remembered that the alternate poles should have the cross-arms face in the opposite direction; the reason for this will be pointed out later. When in the proper position and vertical, the pole may be braced by means of four of the pike poles, having the pikes stuck in the pole about 8 feet from the ground and their other ends planted firmly in the ground.

60. Filling In and Tamping.—The pole is now in proper position for filling in, which should be done slowly by one man using the short-handled shovel. Meanwhile, the earth, as thrown in, must be thoroughly tamped by two men so that it is firmly packed around the pole on all sides through the entire depth of the hole. Much trouble is often caused by inattention to this detail, and it is therefore better to provide only one shovel in order that but one man may fill in, while the others are tamping. If the earth is thrown in more rapidly than it can be properly tamped, it will soon settle and result in a loose pole and subsequent trouble. The earth should be banked up around the pole at least 1 foot above the level of the ground.

While three of the men are engaged in the filling in and tamping, the others may proceed to the next pole, in order to place it in the proper position for raising. By an intelligent handling of the men, much time and expense may be saved, and, therefore, too much attention cannot be given to the proper proportioning of the work among them.

61. Pole Foundations.—When marshy ground is encountered, it is frequently necessary to provide a suitable foundation for the pole. The method shown in Fig. 29 is often used, and for most cases will prove effective. The foot-plate is formed of 2-inch oak planks about 3 feet long and 12 inches wide, fastened together by heavy spikes. The hole is dug much larger than usual, and, after its bottom is properly leveled, the foot-plate is put in place and the pole set on its center. Frequently, a framework of 4″ × 4″ oak lumber is built around the pole on the surface of the ground after the pole is raised, and it is securely fastened to the pole by long spikes, and braced according to any available method.

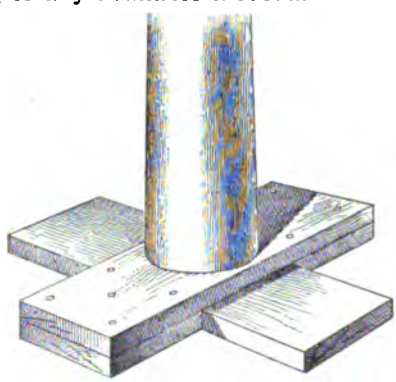


FIG. 29

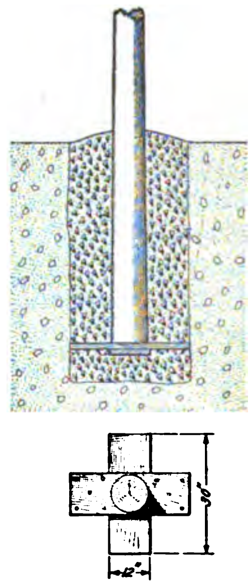


FIG. 30

Poles set in swamps or low wet places should, on straight lines, be guyed or braced alternately from each side. In case braces are used, they should be as nearly the same length as possible and set at exactly the same angle.

62. In many cases, it is impossible to dig a pole hole to the depth required in the specifications. This is especially true in cities, where subways, sewers, or pipe lines frequently run close to the surface and directly under the position that the pole must occupy, and in wet swampy localities. When this is the case, the hole should be dug as deep as possible and from 4 to 5 feet in diameter. A layer from 6 inches to 1 foot deep of good cement concrete should be placed in the bottom, after which the pole should be raised, and the hole filled in with concrete thoroughly tamped in place. A pole properly set in concrete with a foot-plate is shown in Fig. 30. The concrete used for this and similar purposes should be mixed according to the following formula: hydraulic cement, one part; sand, two parts; screened gravel, broken stone, or broken brick, five parts.

The cement and sand should first be thoroughly mixed while dry, and then a sufficient quantity of water added to form a soft mortar; the gravel, stone, or brick, previously sprinkled, should then be added and thoroughly mixed with it. The greatest diameter of the gravel, broken stone, or brick should not exceed 2 inches.

All poles set either in marshy ground or in conditions requiring a cement foundation, should, if possible, be strongly guyed in order to render them still more secure.

GUYING

63. It has already been stated that all poles on which a turn in a line is made should be guyed in a direction to resist the strain of the line wires on them. Guying is much preferable to bracing. The guying should be done before any wires are strung, the guy wires being pulled up tight enough to give the pole a slight lean toward the guy stub or anchor. The methods of guying are numerous, and much must be left to the judgment of the construction man for its proper execution. The best form of side guy is that shown in Fig. 31, which is commonly known as the **Y** guy. Where the guy is attached only to the top of the pole, there is a tendency for the pole to bend, brought about by the strain of the line wires attached below it. This strain is so great as to frequently cause poles guyed in this manner to break, the break usually occurring at the gain of the lower cross-arm. In a similar manner, if the guy wire extends to one point only, and that below the lower cross-arm, a similar strain in an opposite direction is placed on the poles, which is likely to produce the same result. The **Y** guy effectually remedies this difficulty by evenly distributing the strain throughout the pole.

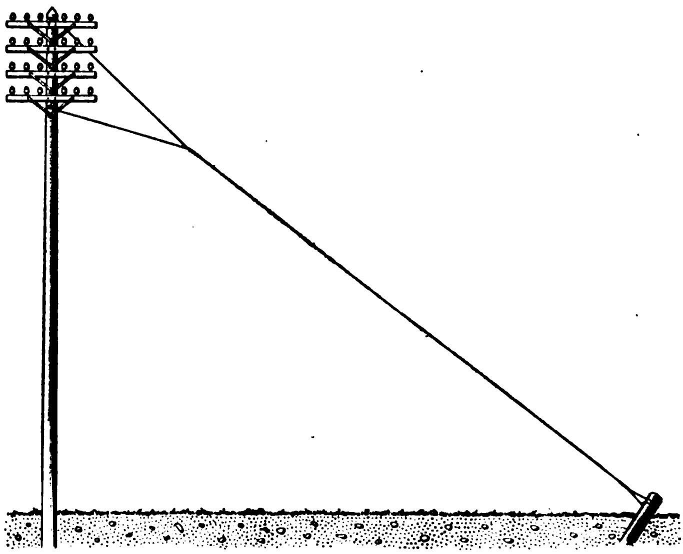


FIG. 81

64. The strains brought about by the line wires at every turn in the pole line are not the only ones that must be provided against. The side pressure, due to wind, is often very severe, and in countries subject to severe wind storms, side guys should be placed on both sides of the pole line at frequent intervals. This is especially true where heavy sleet storms occur, for the coating of ice formed on wires often reaches 2 or 3 inches in diameter, and this not only adds enormously to the weight carried by the poles, but also to the wind resistance.

65. Head-Guying.—Very heavy strains occur in the direction of the pole lines and must be provided against. Of course, the line wires themselves tend to assume a large portion of this strain, but in heavy wind storms they do not form a sufficient protection, and it is therefore well to guy the poles at frequent intervals against these strains.

A system of guying, commonly termed **head-guying,** is chiefly resorted to for this purpose, and is shown in Fig. 32. In this system, the top of each pole is guyed to the base of the next one to it in the manner shown. The guy should be fastened just below the bottom cross-arm and run to a point on the next pole 10 or 12 feet above the ground.

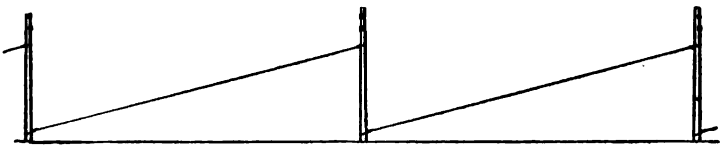


FIG. 32

After about three poles have been guyed in this manner, the direction of the guy wires should be reversed on the next three, so that the longitudinal strain of the line wires will be met in either direction. Another method of guying to resist longitudinal strains in either direction is shown in Fig. 33, and is known as **double head-guying.**

On lines carrying but few wires, head-guying is not, under ordinary circumstances, used, but for heavy lines extending over long distances it is an exceedingly important matter. It frequently prevents a long section of line from going down in wind storms, for, obviously, if one pole

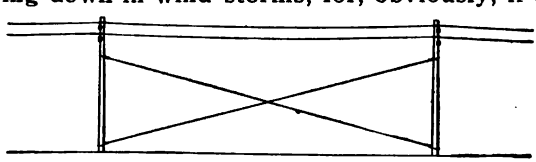


FIG. 33

gives way, a severe strain is produced on all the poles, not only by the weight and tension of the line wires, but also by the wind if it happens to be in that direction.

66. Facing of Cross-Arms.—The arrangement of cross-arms on opposite sides of alternate poles, which has already been mentioned, is a matter of great importance, and, when done, greatly assists in the prevention of undue longitudinal strains in the line. If a pole goes down on a line, and the cross-arms are all set in one direction, it is obvious that the cross-arms on all the poles on one side of the break might be pulled off the poles, while if they were alternately on opposite sides of the poles, only one span at most would fall, unless the pole should break, and this, of course, should be guarded against by head-guying.

67. Anchors for Guy Wires.—The method of anchoring guy wires must be varied according to existing conditions. The most common method is the **guy stub,** which

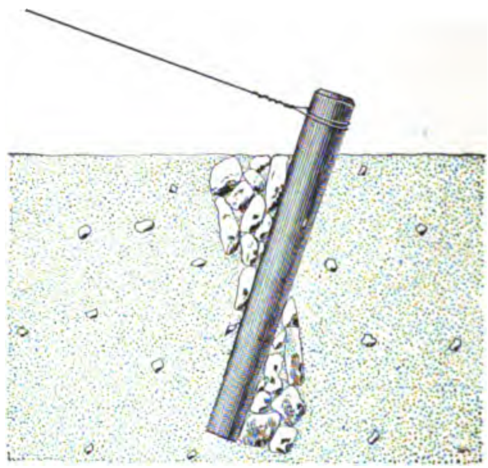


FIG. 34

is placed in the ground, as shown in Fig. 34. The guy stubs should conform to the same specifications as the poles regarding quality of wood, and are usually made from the parts of poles too crooked to be used as poles. For ordinary purposes, a guy stub should not be less than 8 inches in diameter at the small end, and its length from 7 to 10 feet. It is well, in setting, to wedge rocks in the hole as shown, dirt being firmly tamped about them, as in pole setting. Side guys running from anchors should be fastened to the pole just below the second cross-arm from the top.

68. Anchor Log and Rod.—Another common method of anchoring the guy wire is by means of the **anchor log** placed as shown in Fig. 35. The anchor log may be made of the same material as the pole, and, as in the case of the guy stub, may be formed from a portion of a pole. Railroad ties, where obtainable, are often used for this purpose. It should be from $4\frac{1}{2}$ to 8 feet long, and not less than 28 inches in circumference. The anchor rod, which is shown in Fig. 36, should be of good wrought iron not less than $\frac{5}{8}$ inch in diameter, and from 6 to 8 feet long. It should be threaded on its lower end for a heavy galvanized-iron nut, and should be further provided with a galvanized-iron washer $\frac{3}{8}$ inch in thickness and 4 inches square. At the top of the rod, there should be a welded eye, the opening being $1\frac{1}{2}$ inches across at the widest place. The guy rod should pass directly through the center of the anchor

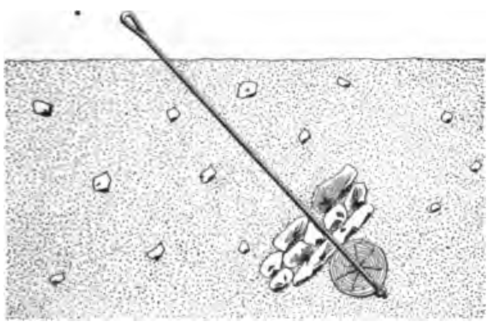


FIG. 35

log, as shown, and should extend about 6 inches above the surface of the ground. In burying the anchor log, it is well to pile heavy rocks above it in a direction to meet the strain of the guy wire, 5 or 6 feet being, in ordinary cases, a sufficient depth at which to place the anchor log.

A pole guyed in the manner just described may be further strengthened by bolting one 4-foot to 6-foot log at its center and in a horizontal position near the bottom of the pole on the side toward the guy rod and another similar log in a similar position but near the top of the pole hole and on the opposite side of the pole.

69. Guy Stub and Anchor.—Fig. 36 shows a good method of anchoring and setting a guy stub *c*. The guy stub is anchored by means of a wrought-iron guy rod *a*, which in turn is bolted to an anchor log *b* that should be from 4 to 6 feet in length.

70. Sustaining a Pole on Rock.—Fig. 37, which was given in The American Telephone Journal, illustrates a method that is said to be advantageously used in mountainous sections. Ordinarily, when it is desired to set a pole in

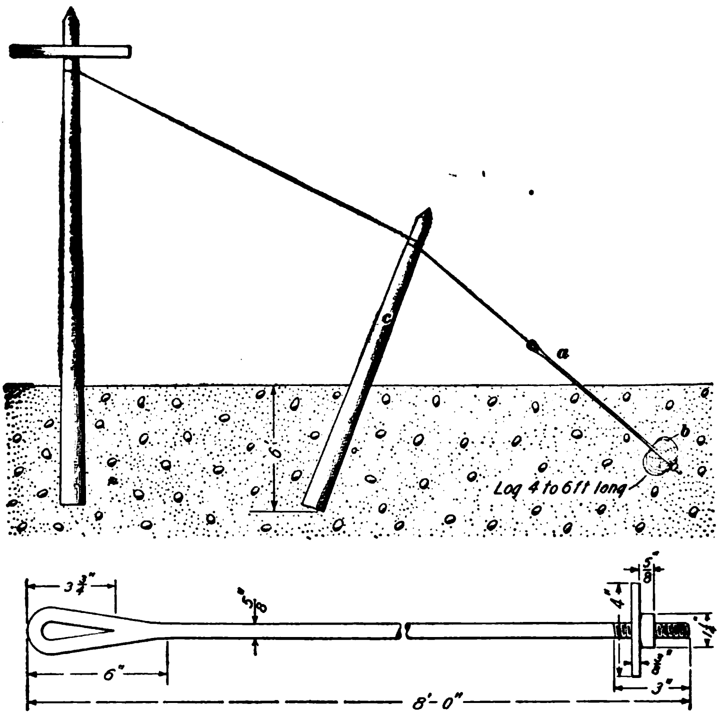


Fig. 36

rock, a hole is blasted. This takes a great deal of time and is very dangerous and expensive. It is impossible to blast a hole of small diameter. When a sufficient depth is reached, the hole is funnel shaped, being possibly 3 or 4 feet in diameter at the top and tapering to an approximate point at the bottom. With the method illustrated, all that is necessary is to drill five $1\frac{1}{4}$-inch or $1\frac{1}{2}$-inch holes in the rock as shown at *a, b, c, d, e*. In each of these holes, an iron pin is set. Over the central pin, the pole, in the butt of which a

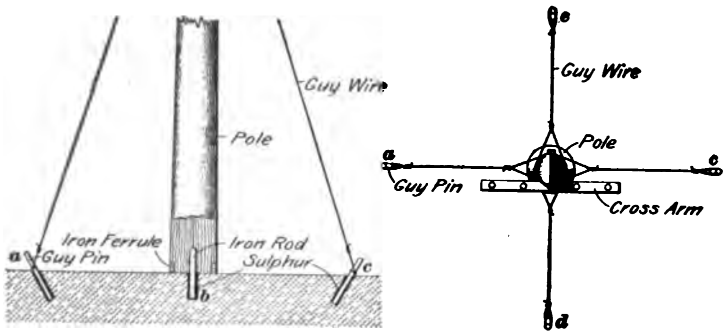


Fig. 37

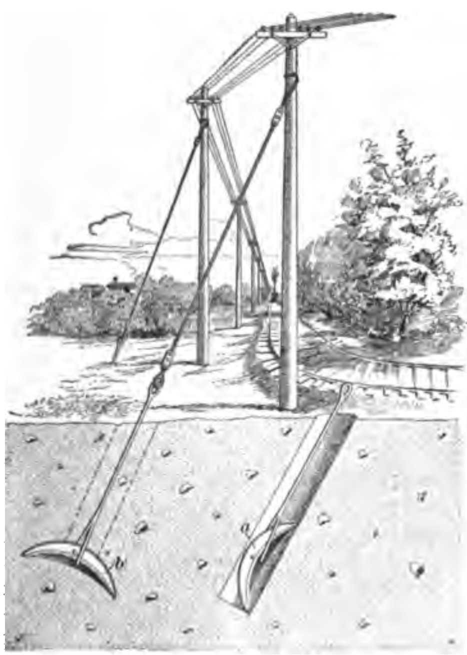


Fig. 38

hole has been bored, is placed. From the top of the pole, guy wires are then run to each of the other four pins. In order to secure the pins in the rock firmly sulphur or lead may be poured around them. The figure is almost self-explanatory and no further directions seem necessary. It is a good plan to place an iron ferrule around the butt of the pole, as shown in the figure, to keep it from splitting while being raised.

71. Miller Guy Anchor.—The guy anchor made by the Miller Anchor Company is shown in Fig. 38. A hole is made large enough to insert the anchor, as shown at *a*; when the pull is applied, the anchor assumes the position shown at *b*, that is, it turns at right angles to the anchor rod or cable, thus gripping the solid earth each side of the hole.

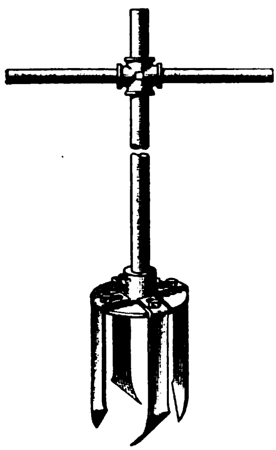


Fig. 39

The hole should be bored from 5 to 9 feet deep, about 1 inch larger than the anchor, and at the same angle as the guy will assume. After sliding the anchor to the bottom of the hole and before pulling on it, tamp the dirt in firmly for at least 1 foot. The rods will lift from 3 to 10 inches when the anchors are first pulled up into place. For boring holes, the manufacturers recommend the use of their combination auger, shown in Fig. 39, which has two boring heads, one for the No. 2 anchor and the other, which has adjustable

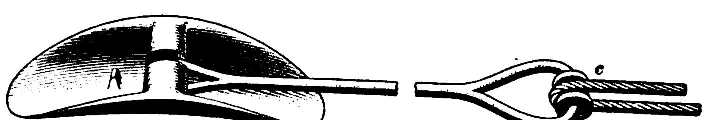


Fig. 40

larger blades, for anchors No. 3 and No. 4. Do not pound the auger down on the ground, as this tends to bend and break the blades, and do not use a larger anchor than is necessary.

The anchors are made of cast iron, the larger sizes in the form shown in Fig. 40, and the smaller sizes as shown at *a*, Fig. 38. The rods are made of wrought iron. The sizes of anchors and rods are as follows: No. 1 anchor, 5 in. × 10 in., $\frac{7}{16}$-inch rod, 6 feet long; No. 2 anchor, 6 in. × 13 in., $\frac{1}{2}$-inch rod, 7 feet long; No. 3 anchor, 7 in. × 15 in., $\frac{5}{8}$-inch rod, 7 feet long; No. 4 anchor, 8 in. × 19 in., $\frac{3}{4}$-inch rod, 8 feet long; No. 5 anchor, 10 in. × 25 in., 1-inch rod, 9 feet long.

The resistance when the anchor is put at a depth of 7 feet is nearly twice that at a depth of 5 feet. The great holding power of this type of anchor is due to the fact that when it is pulled into place it opens out and secures a firm grip on entirely undisturbed earth at the sides of the hole. The makers recommend that the size of the anchors to be used should be governed by the size of the rods they are fitted with. If a $\frac{1}{2}$-inch rod will stand the strain, set a No. 2 anchor; if it takes a $\frac{5}{8}$-inch rod, use a No. 3 anchor; and so on for all sizes, as they guarantee the anchors to be large enough to break the rods before they will pull up. Their large No. 5 anchors (see Fig. 40), are fitted with a 1-inch rod. This rod will stand a strain of 39,270 pounds. This anchor can be fitted with a $1\frac{1}{8}$-inch rod, if desired, and then will stand a strain of 49,700 pounds when set 8 feet deep. At *c*, Fig. 40, is shown a roller anchor eye made by the same company. The use of these eyes reduces the friction and therefore the pull required to draw the guy wires tight. The tensile strengths of the round iron rods used with these anchors are said to be as follows:

	Pounds
$\frac{1}{2}$ inch	9,800
$\frac{5}{8}$ inch	15,340
$\frac{3}{4}$ inch	22,090
1 inch	39,270
$1\frac{1}{8}$ inches	49,700
$1\frac{1}{4}$ inches	61,360

72. The Miller **rock anchor** is shown in Fig. 41. The rod *a* extends through the piece *b* and has a head *d* on the under side to keep it from pulling through. The comparatively smooth piece *b* is wedge-shaped, as is also the corrugated piece *c*; when these are placed together in a hole made in a rock, the corrugations on *c* take hold of the rock on the side of the hole, and the greater the pull on the rod *a* and hence on the smooth piece *b*, the greater do the two pieces *b*, *c* tend to spread apart due to their wedge shapes and the tighter they hold their position. These anchors can be used in any kind of rock in which a hole can be made. They are 1¼ inches in diameter and 3½ feet long, with a ⅝-inch rod. They will stand a strain of 15,000 pounds.

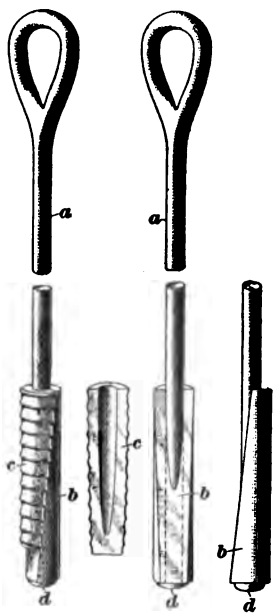


FIG. 41

73. The best practice in the construction of plants in large cities requires the use of heavy steel guy stubs. In place of the old wooden stub, a 12-inch I beam, with two pieces of half-round wood clamped on the two sides so as to give it a round appearance, is used. Two pieces of half-round section, 5-inch radius, ¼ inch thick and 20 feet in length with edges turned out and riveted, make good stubs when set in concrete. Standard steel pipe 10 inches in diameter also makes a good stub, but is more expensive.

74. An excellent anchor may be made from two pieces of timber 1½ inches thick by 16 inches square, placed together so that the grain in one piece is at right angles to the grain in the other. The anchor rod passes through the center of both, and the nut is screwed on. The whole, buried 4½ to 5 feet, will, if properly tamped, hold very heavy corners. In quicksand or live gravel, they should be 20 inches square. An older style of anchor (a 4-foot log) requires the moving of about two-thirds more earth than does this style, and does not answer the purpose any better.

75. Guying to Trees.—Where it becomes necessary to anchor to the base of a tree, heavy wooden blocks should be placed, as shown in Fig. 42, at intervals about the tree, in order to prevent the tree from being strangled by the guy wire. If this is properly done, the tree will not be injured, while a guy wire placed directly about the trunk of a tree will often kill it within a year. The guy wire should not even be wrapped around the tree, but only looped, as shown. In order to hold the blocks in place until the guy wire is permanently tightened and settled, an extra piece of wire may be wrapped around the blocks and fastened tight, but it should not be left on permanently. Too much care cannot

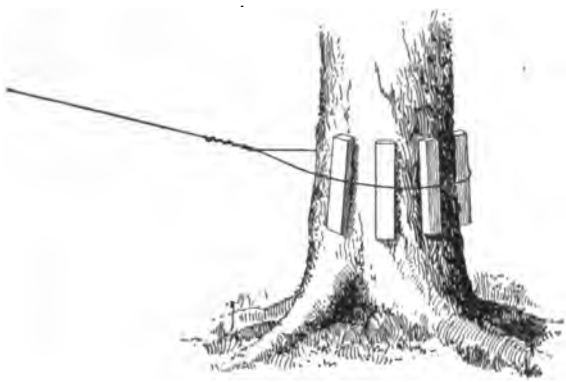


FIG. 42

be taken to protect shade trees in towns and cities. Consideration such as this should always be borne in mind, for right-of-way and guy-wire privileges are very hard to obtain, and a few instances where real damage is produced by their use will render the obtaining of subsequent privileges doubly hard. If it can be avoided, it is best not to use trees at all for anchors. The least swaying of a tree where a guy wire is anchored will soon loosen the pole.

76. Guy Wires.—It is best, especially for heavy construction, to use a stranded wire rope manufactured especially for guy wires and similar purposes. These ropes are commonly composed of seven strands of steel wire, the external diameter of the rope varying from $\frac{3}{32}$ to $\frac{1}{2}$ inch, the most common sizes for guying being $\frac{1}{4}$ inch and $\frac{3}{8}$ inch.

One way to fasten a stranded guy-wire cable, is by means of wrought-iron clamps, as shown in Fig. 43. They are made especially for this purpose. Where the guy rope is to be attached to an eye, as, for instance, in the top of an anchor rod, a thimble *a* is used to form an eye in the rope,

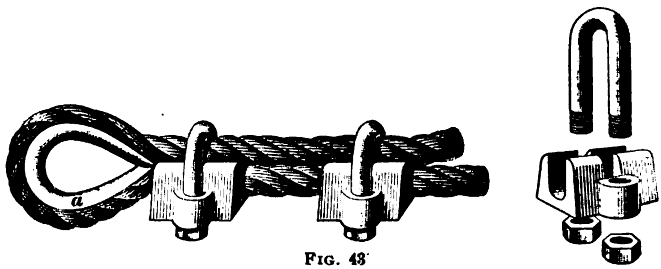


FIG. 43

this being made to interlink with that of the anchor rod. Where, however, the guy wire is to be secured to the pole or to a guy stub, the thimble *a* is not used, but the wire rope is passed twice around the pole as before, and then secured by means of the clamps. Guy wires fastened with clamps can be removed when necessary with no waste of material and much quicker than when twisted together, in the old way, with pliers.

Fig. 43 shows a two-bolt clamp. The stronger three-bolt standard clamp shown in Fig. 44 is a very much better clamp

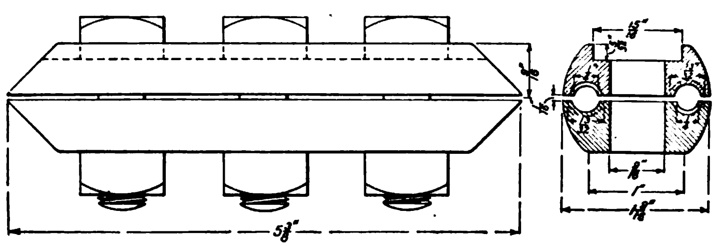


FIG. 44

and is now generally required. It should be made of the best quality of malleable iron with high carbon steel bolts. It is usually made to hold a $\frac{5}{16}$-inch wire cable.

77. Sometimes two strands of No. 9 iron wire twisted together will make a very satisfactory guy rope. In many cases, even a single strand of No. 8 or No. 6 is used. In tying the guy wire about the pole or guy stub, it is customary to pass it twice around the pole or stub and then to secure it by twisting the end around itself, as shown in Fig. 45. To prevent the guy wire from slipping away from its position on the pole or guy stub, it is recommended to secure each coil tightly in place with from three to six galvanized-steel staples. These staples should be $2\frac{1}{8}$ inches long and may be made from No. 6 B. W. G. galvanized-steel wire. Where steel rope is used, the strands should be untwisted before the tie is made and then wound around the main rope in parallel layers, as shown in the figure.

FIG. 45

78. Where to Use Guys.—According to a writer in the Telephone Magazine, the following general suggestions should be followed in guying pole lines:

On straight lines carrying one cross-arm, a head-guy and a side guy should be placed at least once in every mile. On lines carrying two cross-arms and more than ten wires, double head-guys and double side guys should be placed at least once in every mile. On lines carrying three cross-arms and more than thirty wires, double head-guys and double side guys should be placed every half mile. On lines carrying four cross-arms and more than forty wires, double head-guys and double side guys should be placed every quarter mile, and additional side guys should be used wherever it is considered necessary. The pole at the beginning of each curve should be head-guyed and side-guyed, and also such other poles on the curve as may be deemed necessary. An additional pole should be set within 75 feet of a terminal pole. The terminal pole should be head-guyed in

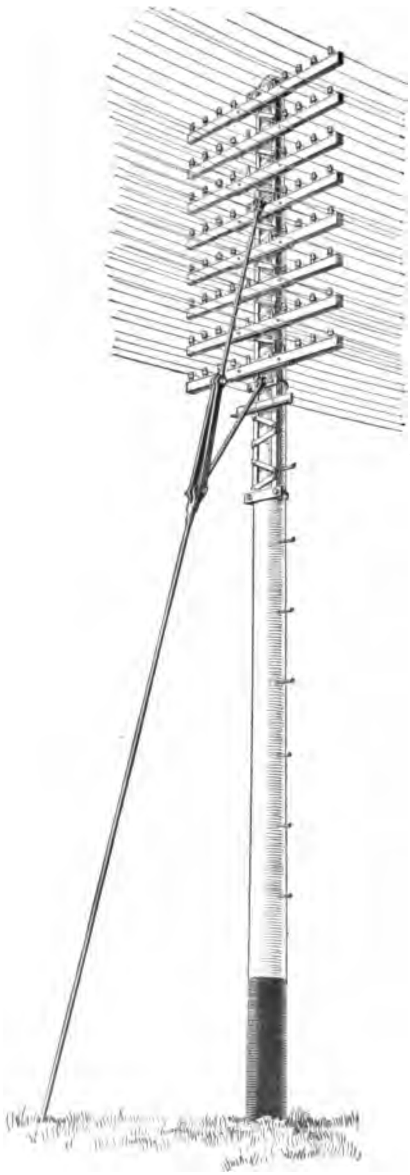


FIG. 46

both directions and the additional pole head-guyed to the terminal pole, if necessary. Head-guys should be placed on at least three poles before turning a corner.

79. Anchor Poles. Where an overhead line ends, it is necessary to thoroughly anchor the last pole in order to counteract the strain brought on it by the line wires, which in this case will be all in one direction. These strains are frequently very great, so much so that it is sometimes a very difficult problem to provide means to adequately stand them. In some cases, structural-iron poles are built especially for the purpose, these being cross-braced by means of iron latticework and thoroughly set, deep in the ground, in a large bed of concrete. This method, however, is very expensive, poles of this type costing from $150 to $800, according to the conditions to be met.

80. A cheaper pole, and one that, although much more expensive than the ordinary one, is far less expensive than the structural-iron pole, is a composite pole such as is shown in Fig. 46. This consists of a very heavy wooden pole braced at the top by means of an iron latticework on which the cross-arms are

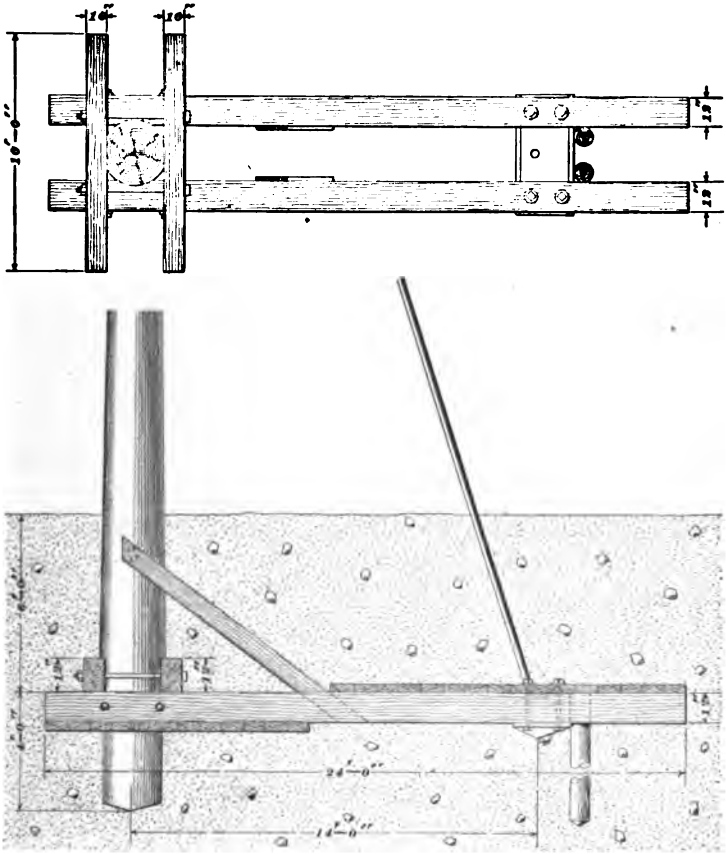


FIG. 47

mounted and to which the heavy iron guy rods are fastened, as shown.

A pole of this kind may be designed for meeting almost any strains that can be placed on it. The particular pole shown was of pine, 70 feet long, 16 inches in diameter at the top and 22 inches at the butt, and set 10 feet below the surface. It was designed to carry one hundred wires and four cables, all being dead-ended at this point. The latticework at the top was built of two 3″ × 7″ steel angle irons connected together by diagonal lattice pieces. At intervals of 16 inches, 3″ × 4″ angle irons were set, on which the cross-arms were mounted. This lattice was secured to the pole by means of **U**-shaped bands to which the two branches of the guy rod were attached. The manner of setting this pole in the ground is shown in Fig. 47. A heavy oak platform was built around the base of the pole, as shown, and afterwards covered with earth or stone. The object of the latticework was to relieve the pole of all bending strain. The pole itself served only to receive the downward component of the forces acting on it, while the tension in the line wires and cables was taken entirely by the heavy wrought-iron guy rod. Where poles of this description are used, it is of great importance that adequate measures shall be taken to prevent them from rotting, and, therefore, it is well to thoroughly coat the butts and the entire underground woodwork with tar.

81. The more expensive forms of anchor pole, such as have been described, are usually necessary only in cities.

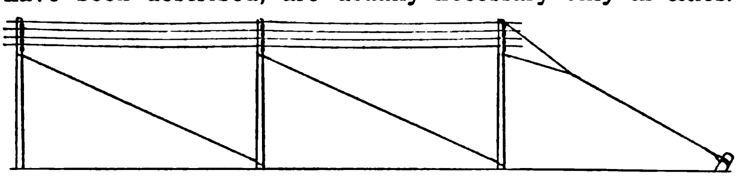
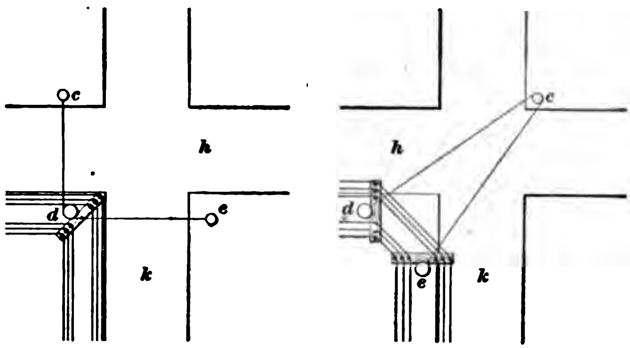


FIG. 48

Where the lines are not too heavy and where sufficient room may be had for planting a guy anchor, the method shown in Fig. 48 is used. The end pole is made very heavy and is set deep in the ground and heavily guyed by a **Y** guy to a guy stub or any other available anchor. Each of the next five or six poles are then head-guyed in a direction to resist the strain, thus all bearing a share of the excessive strain due to the wires.

TURNING CORNERS

82. One way to make a corner turn is to use a single pole, as shown in Fig. 49 (*a*). If there is plenty of room, the double-pole construction shown in Fig. 49 (*b*), may be used, but it is not much used by expert construction men,



(*a*) FIG. 49 (*b*)

because usually it is unnecessarily expensive. The corner pole should be head-guyed before the line wires are tied. The intersecting streets are *h*, *k*, while *dc* and *de* in (*a*) and *cd* and *ce* in (*b*) represent guy wires.

83. It is claimed that one of the best ways to turn a corner on a rural line having comparatively few wires is that shown in Fig. 50. On the corner pole fasten two cross-arms, so that *a* is parallel to *c* and *b* parallel to *d*. The wires *m*, *n*, *o*, *p* should be run in the usual manner and dead-ended at the insulators on the corner cross-arms. It is best to cross-connect the line wires with insulated wire, thereby eliminating the possibility of crosses at the corner pole. Only one guy wire is required for the corner pole. This method is claimed to be more economical than the one requiring two poles a short distance apart, as shown in Fig. 49 (*b*), and superior to the one shown in Fig. 49 (*a*) requiring only one pole and one set of cross-arms, because with the latter construction the distance between wires is considerably less near the corner pole than at the other poles and consequently crosses are more liable to occur in the spans on each side of the corner pole. In this method, the wires cross one another and insulated wire is used. For these

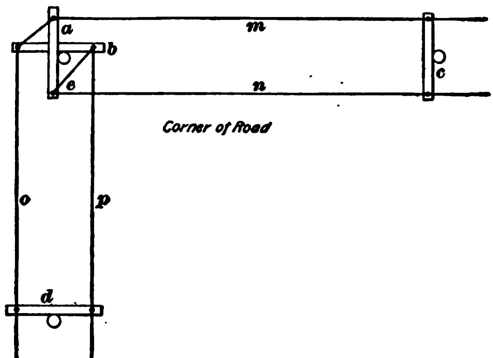


FIG. 50

reasons it does not seem much superior, except perhaps for a very few wires, to the method shown in Fig. 49 (*a*).

INSULATORS

84. Insulators used for telephone- and telegraph-line work in the United States are usually made of glass, while in Europe porcelain is more commonly used. When new, porcelain is a better insulator than glass, but it is more expensive, and, under the action of cold, the glazed surface becomes cracked. When this happens, the moisture soaks into the interior structure, and its insulating quality is greatly impaired. Tests made by F. W. Jones, electrical engineer of the Postal Telegraph Company, have shown that, when newly put up, the insulation resistance of porcelain insulators is from four to eight times better than glass, but that along railroads and in cities smoke forms a thin film on each material, so that at the end of a few months their insulating properties are nearly alike. On country roads, away from railroad tracks, the porcelain insulators maintain a higher insulation than the glass during rain storms, but in fine weather it is not so high. Porcelain has an advantage over glass in that it is not so brittle and therefore less likely to break when subjected to mechanical shocks, such, for instance, as being hit with stones by schoolboys and with bullets by hunters who make targets of them. Porcelain does not condense and retain on its surface a thin film of moisture so readily as glass, i. e., it is less hygroscopic. On the other hand, however, glass insulators are not subject, to such an extent as porcelain, to the formation of cocoons and cobwebs under them, the transparency of the glass serving to allow sufficient light to pass through the insulator to render it an undesirable abode for spiders and worms. As cocoons, cobwebs, etc. serve to lower the insulation of the line to a great extent, this is an advantage that it is not well to overlook.

85. As a rule, in the United States, the defective insulation due to the use of glass insulators is one of the smallest of the difficulties encountered in working telephone and telegraph lines. On turnpikes, the working is far more seriously impeded by the contact of tree limbs with the wires during the spring and summer, owing to the impossibility of securing the consent of property owners to properly trim the trees. Trees may have been trimmed so that their limbs are perfectly clear of the wires in dry weather, yet, when loaded with moisture, the branches are so bent as to interfere with the service more or less until the moisture has been evaporated by the wind and sun.

86. The form of insulator shown in Fig. 51 (*c*) is much used in telegraph and somewhat in telephone work. It weighs 22 ounces and is bell-shaped, with an interior thread and a double petticoat. The object of the double petticoat is to form a long path over which leakage currents from the line must pass before they reach the pin, and to keep the pin as dry as possible. The resistance of insulators follows the same law as the resistance of conductors. The longer the path afforded and the less the cross-section of the path, the greater is the resistance that the insulator will offer to leakage currents from the line. Hence, the length of the insulating surface, measured from the groove in which the wire rests, down the outside surface, and up the inside surface, to the contact surface between the insulator and pin, should be as great as possible. Furthermore, the diameter of the insulator, both external and internal, should be as small as is consistent with its strength, for the smaller this

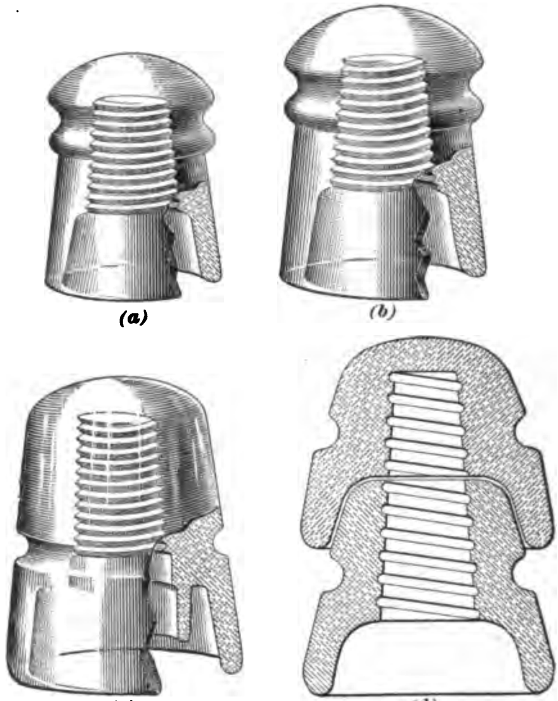


FIG. 51

diameter, the narrower will be the conducting film, and the greater its resistance.

The conducting path is over 20 per cent. longer on the double-petticoat insulator, Fig. 51 (*c*), than on the single-petticoat insulator, Fig. 51 (*b*), although the double-petticoat is a little larger in diameter. Furthermore, since a large part of the conducting surface on the double-petticoat insulator is underneath, it is sheltered and protected from the falling rain. On the other hand, the single-petticoat insulator, although not of such high surface resistance, seems to dry off quicker after the rain is over. All things considered, the double-petticoat insulator seems, in the United States, to be the better and is the most commonly used for telegraph lines, although the single-petticoat insulator shown in Fig. 51 (*b*) is also used. An excellent double-petticoat porcelain insulator is made in Germany and is extensively used there and in other countries, but not in the United States.

87. Pony and Hibbard Insulators.—The smaller single-petticoat insulator shown in Fig. 51 (*a*) and known as the **pony insulator** is much used for telephone lines, where No. 12 B. & S. hard-drawn copper wire is used. While not having such a high resistance as the double-petticoat insulator, still it dries more rapidly after a rain, and, on the whole, gives good satisfaction for telephone-line work. In Fig. 51 (*d*) is shown the Hibbard transposition insulator used where the telephone lines are transposed. There is also a good transposition insulator made in one piece. Transposition insulators are necessarily large and somewhat heavy, generally requiring especially large and heavy pins.

TELEPHONE-LINE CONSTRUCTION

(PART 2)

OVERHEAD LINES

WIRES FOR TELEPHONE LINES

COPPER WIRE

1. The best wire for telephone and telegraph lines is hard-drawn copper, which is replacing iron wire, though considerable galvanized-iron wire is still being used. Copper has the lowest specific resistance, and, therefore, the greatest specific conductivity, of any metal except silver. This feature alone would tend to make copper the most valuable of metals for electric-transmission purposes, except silver, which is but slightly better, and which is unavailable on account of its high cost. Tables I and II give the generally accepted values of the diameters, weights, and resistances for the various sizes of copper wire.

2. Pure annealed copper has a specific gravity of 8.89 at 60° F., 1 cubic inch of it weighs .32 pound, and its melting point is about 2,100° F. As first manufactured, **copper wire** did not possess enough tensile strength to well adapt it for line wire, and for that reason and because of its greater expense, it was used but little for that purpose. The process of hard-drawing copper wire has, however, greatly

TABLE I

DIMENSIONS, WEIGHT, ETC. OF BARE COPPER WIRE

American, or B. & S., Gauge

Gauge No., B. & S.	Diameter in Mils, or 1/1000 Inch	Area in Circular Mils C. M. = d^2	Area in Square Inches Area = $\frac{d^2 \times .7854}{1,000,000}$	Weights—Specific Gravity, 8.89				Resistance at 68° F., in International Ohms, Based on Matthiessen's Standard				
				Pounds per 1,000 Feet	Pounds per Mile	Feet per Pound	Ohms per Pound, Annealed	Ohms per 1,000 Feet		Ohms per Mile		Feet per Ohm, Annealed
	d	d^2						Pure Annealed	Hard Drawn	Pure Annealed	Hard Drawn	
0000	460.00	211,600.	.16619	640.5	3,381.4	1.561	.00007639	.04893	.050036	.25835	.26419	20,440.
000	409.64	167,805.	.13179	508.0	2,682.2	1.969	.0001215	.06170	.063094	.32577	.33314	16,210.
00	364.80	133,079.	.10452	402.8	2,126.8	2.482	.0001931	.07780	.079558	.41079	.42007	12,850.
0	324.86	105.534.	.082887	319.5	1,686.9	3.130	.0003071	.09811	.10033	.51802	.52973	10,190.
1	289.30	83,694.2	.065732	253.3	1,337.2	3.947	.0004883	.1237	.12649	.65314	.66790	8,083.
2	257.63	66,373.0	.052128	200.9	1,060.6	4.977	.0007765	.1560	.15953	.82368	.84239	6,410.
3	229.42	52,634.0	.041339	159.3	841.09	6.276	.001235	.1967	.20114	1.0386	1.0621	5,084.
4	204.31	41,742.0	.032784	126.4	667.39	7.914	.001963	.2480	.25361	1.3094	1.3392	4,031.
5	181.94	33,102.0	.025999	100.2	529.06	9.980	.003122	.3128	.31987	1.6516	1.6889	3,197.
6	162.02	26,250.5	.020618	79.46	419.55	12.58	.004963	.3944	.40332	2.0825	2.1295	2,535.
7	144.28	20,816.0	.016351	63.02	332.75	15.87	.007892	.4973	.50854	2.6258	2.6850	2,011.
8	128.49	16,509.0	.012967	49.98	263.89	20.01	.01255	.6271	.64127	3.3111	3.3859	1,595.
9	114.43	13,094.0	.010283	39.63	209.24	25.23	.01995	.7908	.80876	4.1753	4.2769	1,265.
10	101.89	10,381.0	.0081548	31.43	165.95	31.82	.03173	.9972	1.0199	5.2657	5.3848	1,003.
11	90.742	8,234.0	.0064656	24.93	131.63	40.12	.05045	1.257	1.2854	6.6369	6.7869	795.3
12	80.808	6,529.9	.0051287	19.77	104.39	50.59	.08022	1.586	1.6218	8.3741	8.5633	630.7

13	71.961	5,178.4	.0040672	15.68	82.791	63.79	.1276	1.999	2.0443	10.555	10.794	500.1
14	64.084	4,106.8	.0032254	12.43	76.191	80.44	.2028	2.521	2.5779	13.311	13.612	396.6
15	57.068	3,256.7	.0025579	9.858	52.050	101.4	.3225	3.179	3.2508	16.785	17.165	314.5
16	50.820	2,582.9	.0020285	7.818	41.277	127.9	.5128	4.009	4.0996	21.168	21.646	249.4
17	45.257	2,048.2	.0016087	6.200	32.736	161.3	.8153	5.055	5.1692	26.691	27.294	197.8
18	40.303	1,624.3	.0012757	4.917	25.960	203.4	1.296	6.374	6.5183	33.655	34.416	156.9
19	35.890	1,288.1	.0010117	3.899	20.595	256.5	2.061	8.038	8.2196	42.441	43.400	124.4
20	31.961	1,021.5	.00080231	3.092	16.324	323.4	3.278	10.14	10.372	53.539	54.749	98.66
21	28.462	810.1	.00063626	2.452	12.946	407.8	5.212	12.78		67.479		78.24
22	25.347	642.4	.00050457	1.945	10.268	514.2	8.287	16.12		85.114		62.05
23	22.571	509.45	.00040015	1.542	8.142	648.4	13.18	20.32		107.29		49.21
24	20.100	404.01	.00031733	1.223	6.457	817.6	20.95	25.63		135.53		39.02
25	17.900	320.40	.00025166	.9699	5.121	1,031.	33.32	32.31		170.59		30.95
26	15.940	254.10	.00019958	.7692	4.061	1,300.	52.97	40.75		215.16		24.54
27	14.195	201.50	.00015827	.6100	3.221	1,639.	84.23	51.38		271.29		19.46
28	12.641	159.79	.00012551	.4837	2.554	2,067.	133.9	64.79		242.09		15.43
29	11.257	126.72	.000099536	.3836	2.025	2,607.	213.0	81.70		431.37		12.24
30	10.025	100.50	.000078936	.3042	1.606	3,287.	338.6	103.0		543.84		9.707
31	8.928	79.70	.000062599	.2413	1.274	4,145.	538.4	129.9		685.87		7.698
32	7.950	63.21	.000049643	.1913	1.010	5,227.	856.2	163.8		864.87		6.105
33	7.080	50.13	.000039368	.1517	.801	6,591.	1,361.	206.6		1,090.8		4.841
34	6.305	39.75	.000031221	.1203	.635	8,311.	2,165.	260.5		1,375.5		3.839
35	5.615	31.52	.000024759	.09543	.504	10,480.	3,441.	328.4		1,734.0		3.045
36	5.000	25.00	.000019635	.07568	.400	13,210.	5,473.	414.2		2,187.0		2.414
37	4.453	19.83	.000015574	.06001	.317	16,660.	8,702.	522.2		2,757.3		1.915
38	3.965	15.72	.000012345	.04759	.251	21,010.	13,870.	658.5		3,476.8		1.519
39	3.531	12.47	.0000097923	.03774	.199	26,500.	22,000.	830.4		4,384.5		1.204
40	3.145	9.89	.0000077634	.02993	.158	33,410.	34,980.	1,047.		5,528.2		.955

TABLE II

COPPER WIRE—BIRMINGHAM WIRE GAUGE

Gauge Number (B. W. G.)	Diameters in Mils, or 1/1000 Inch	Area in Circular Mils C. M. = d^2	Weights		Resistances in International Ohms, Based on Matthiessen's Standard at 68° F.	
			1,000 Feet	Mile	Ohms per 1,000 Feet	Ohms per Pound
0000	454	206,116	624.	3,294.	.05023	.00008051
000	425	180,625	547.	2,887.	.05732	.0001048
00	380	144,400	437.	2,308.	.07170	.0001640
0	340	115,600	350.	1,847.	.08957	.0002560
1	300	90,000	272.	1,438.	.1150	.0004223
2	284	80,656	244.	1,289.	.1284	.0005258
3	259	67,081	203.	1,072.	.1543	.0007601
4	238	56,644	171.	905.	.1828	.001066
5	220	48,400	146.	773.	.2139	.001460
6	203	41,209	125.	659.	.2513	.002014
7	180	32,400	98.0	518.	.3196	.003258
8	165	27,225	82.0	435.	.3803	.004615
9	148	21,904	66.0	350.	.4727	.007129
10	134	17,956	54.0	287.	.5766	.01061
11	120	14,400	44.0	230.	.7190	.01650
12	109	11,881	36.0	190.	.8715	.02423
13	95	9,025	27.3	144.	1.147	.04199
14	83	6,889	20.8	110.	1.503	.07207
15	72	5,184	15.7	83.0	1.997	.1273
16	65	4,225	12.8	68.0	2.451	.1916
17	58	3,364	10.2	54.0	3.078	.3023
18	49	2,401	7.3	38.4	4.312	.5933
19	42	1,764	5.3	28.2	5.870	1.099
20	35	1,225	3.7	19.6	8.452	2.279
21	32	1,024	3.1	16.4	10.11	3.262
22	28	784	2.4	12.5	13.21	5.565
23	25	625	1.9	10.0	16.57	8.756
24	22	484	1.5	7.70	21.39	14.60
25	20	400	1.2	6.40	25.88	21.38
26	18	324	.98	5.20	31.96	32.58
27	16	256	.77	4.10	40.45	52.19
28	14	196	.59	3.10	52.83	89.04
29	13	169	.51	2.70	61.27	119.8
30	12	144	.44	2.30	71.90	165.0
31	10	100	.30	1.60	103.5	342.0
32	9	81	.25	1.30	127.8	521.3
33	8	64	.19	1.02	161.8	835.1
34	7	49	.15	.780	211.3	1,425.
35	5	25	.076	.400	414.2	5,473.
36	4	16	.048	.256	647.1	13,360.

increased its tensile strengh without seriously injuring its conductivity.

The weight per 1,000 feet of a copper wire is given by the formula

$$W = .003027 \times d^2 \qquad (1)$$

in which d = diameter, in mils;
W = weight, in pounds per 1,000 feet.

The resistance per 1,000 feet, in ohms, of a pure copper wire at 75° F. is given by the formula

$$R = \frac{10{,}507.4}{d^2} \qquad (2)$$

in which d = diameter, in mils;
R = resistance per 1,000 feet, in ohms.

EXAMPLE 1.—What is the weight, per 1,000 feet, of a copper wire 80.808 mils in diameter?

SOLUTION.—The weight is

$.003027 \times 80.808^2 = 19.77$ lb. per 1,000 ft. Ans.

EXAMPLE 2.—What is the resistance per 1,000 feet (at 75° F.), of a copper wire 102 mils in diameter?

SOLUTION.—The resistance at 75° F. is

$10{,}507.4 \div 102^2 = 1.0099$ ohms per 1,000 ft. Ans.

3. Strength of Copper Wire.—Good hard-drawn copper wire will support at least three times its own weight in pounds per mile. Thus, a No. 10 B. & S. gauge copper wire weighing 166 pounds per mile will have a breaking strength of $3 \times 166 = 498$. In making specifications for copper line wire, it is customary to require that it shall have a breaking strength equal to at least three times its weight per mile.

Table III gives the tensile strength of the various sizes in the B. & S. gauge of both hard-drawn and annealed copper wire. The breaking strengths of all but the largest sizes in this table were calculated on the basis that soft wire has a tensile strength of 34,000 pounds per square inch and that the hard-drawn wire has a tensile strength of 60,000 pounds per square inch. The tensile strength per square inch is taken at 50,000 pounds for 0000, 000, and 00; 55,000 pounds for 0; and 57,000 pounds for 1. The coefficient of expansion of copper per degree Fahrenheit is .0000093.

4. **Mechanical Properties.**—In purchasing copper wire in large quantities, certain requirements are made as to the strength and other mechanical properties of the wire. The strength of the various sizes of copper wire should be in accordance with Table III. All wire should be fully up to the gauge standard and truly cylindrical. The inspector

TABLE III

TENSILE STRENGTH OF COPPER WIRE

Numbers B. & S. Gauge	Breaking Weight Pounds		Numbers B. & S. Gauge	Breaking Weight Pounds	
	Hard-Drawn	Annealed		Hard-Drawn	Annealed
0000	8,310	5,650	9	617	349
000	6,580	4,480	10	489	277
00	5,226	3,553	11	388	219
0	4,558	2,818	12	307	174
1	3,746	2,234	13	244	138
2	3,127	1,772	14	193	109
3	2,480	1,405	15	153	87
4	1,967	1,114	16	133	69
5	1,559	883	17	97	55
6	1,237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

should test the size and roundness of the wire by measuring each end of each coil, and several intermediate points. A variation of not more than 1½ mils on either side of the specified gauge number should be allowed, and there should not be a variation of more than 1 mil on opposite diameters at the same point. A sample slightly over 12 inches long should be tested for torsion. This test may be made as follows: The wire is gripped by two vises exactly 12 inches

TABLE IV

HARD-DRAWN COPPER WIRE

Number and Gauge	Diameters in Mils			Weights per Mile			Breaking Weights		Weights of Coils		Conductivity		Twist in 6 Inches	Per Cent. Elongation in 5 Feet
	Required	Maximum	Minimum	Required	Maximum	Minimum	Actual Required	Per Square Inch	Maximum	Minimum	Required	Minimum		
8 B. W. G.	165.0	166.0	164.0	436.4	441.7	431.1	1,328	62,108	218	152	97	96	30	1.14
12 N. B. S.*	104.0	104.7	103.3	173.4	175.7	171.1	549	64,600	219	151	97	96	40	1.00
10 B. & S.	101.9	102.8	101.0	165.0	168.0	162.0	540	64,800	218	152	97	96	40	.99
12 B. & S.	80.8	81.3	80.3	104.7	106.0	103.4	336	65,500	72	52	97	96	44	.95
14 B. & S.	64.0	65.0	63.0	65.0	67.5	63.0	220	68,200			97	96	47	.91
16 B. W. G.	65.0	65.5	64.5		68.8	66.7	220	66,200				96		.91
14 N. B. S.	80.0	80.5	79.5		103.9	101.3	330	65,600				96		.94
13 N. B. S.	92.0	92.6	91.4		137.5	133.9	433	65,100				96		.97
10 N. B. S.	128.0	128.8	127.2		265.9	259.4	820	63,700				96		1.06
10 B. W. G.	134.0	134.9	133.1		291.7	284.0	894	63,400				96		1.07

*N. B. S. stands for the New British Standard wire gauge, for which S. W. G. is sometimes used.

apart. One of the vises should then be slowly revolved, and the number of twists before the rupture of the wire takes place should be counted.

Some companies require that hard-drawn copper wire shall conform to the specifications given in Table IV. The sizes given in this table are the ones in general use for line wires.

5. Durability of Copper Wire.—Aside from its superior conductivity, copper wire is practically indestructible under ordinary climatic conditions. When the wire is first put up, a thin oxide or chloride rapidly forms on its surface, after which no change whatever takes place. Except in very unusual conditions, where the atmosphere is filled with particularly destructive gases, copper wire will suffer no chemical change even when exposed to the weather for an indefinite time.

IRON WIRE

6. Iron wire is largely used for telegraph and telephone lines, although it is rapidly being replaced by copper. It weighs 483 pounds per cubic foot and has a specific

TABLE V

IRON AND STEEL WIRE

Name of Wire	Weight per Mile-Ohm	
	Roebling's Sons Co.	Washburn & Moen
Extra Best Best	4,700	5,000
Best Best	5,500	6,200
Best	6,000	
Steel	6,500	6,500

gravity of 7.73. A cubic inch of iron wire weighs about .28 pound. The coefficient of expansion of iron per degree Fahrenheit is .0000068.

7. Grades of Iron Wire.—The various grades of iron wire on the market are termed Extra Best Best, Best Best, and Best. A steel wire is also used, which is cheaper and of higher resistance than iron. It has an advantage, however, of possessing greater tensile strength. It should not be used except on short lines, or in special cases where it is desirable to have great tensile strength.

8. The terms designating the grades are used almost indiscriminately, but among conscientious manufacturers they have approximately the weights per mile-ohm given in Table V.

Extra Best Best (E. B. B.) is the highest grade of iron wire obtainable. As may be seen from the value of the mile-ohm, it stands the highest in conductivity and, besides, is very uniform in quality, being both tough and pliable.

Best Best (B. B.) is less uniform and tough than the Extra Best Best, but is a faily good grade of wire. It is often sold, however, by the less reliable manufacturers, as the finest grade.

Best (B.) is a term applied to the poorest grades of wire. It is harder than the better grades, is much more brittle, and has a lower conductivity.

Steel wire is lower in conductivity than any of the grades of iron wire, but possesses a distinct advantage in point of tensile strength. For a short line where long spans are necessary, this wire is sometimes used in preference to iron wire, as its lack of conductivity may not be a great objection in a short line, while its tensile strength may be a decided advantage.

9. Roebling gives the following formulas from which the resistance per mile may be calculated for E. B. B. and B. B. grades of galvanized-iron and for steel wire:

$$R \text{ for E. B. B.} = \frac{338{,}000}{d^2} \qquad (1)$$

$$R \text{ for B. B.} = \frac{396{,}000}{d^2} \qquad (2)$$

$$R \text{ for steel wire} = \frac{467{,}000}{d^2} \qquad (3)$$

in which d = diameter, in mils

The constants from which the resistances of galvanized-iron and steel wires are calculated vary considerably. Washburn & Moen give for the constants in formulas **1**, **2**, and **3**, for their wire, the values 355,000, 440,000, and 462,000, respectively. For a good quality of iron wire, 360,000 may be used as an average value for the constant.

10. The weight, per mile, of galvanized-iron and steel wire may be calculated from the following formulas:

$$W \text{ for galvanized iron} = d^2 \times .0139 \qquad (1)$$

$$W \text{ for galvanized steel} = d^2 \times .0140 \qquad (2)$$

in which d = diameter, in mils

Washburn & Moen give .01408 for E. B. B., B. B., and steel, for the value of the constant in formulas **1** and **2.**

11. Galvanizing.—Iron, as is well known, is very susceptible to corrosion, due to moisture and other elements in the atmosphere; therefore, to protect iron wires used in outdoor work, they are covered with a thin film of zinc; this process is called **galvanizing.** In order to render the surface of the iron wire perfectly clean, it is drawn through a vat of hydrochloric acid while hot, and immediately afterwards through a vat of molten zinc, the latter being kept at a uniform temperature of 740° F. by a furnace underneath the containing vessel.

The zinc coating, on being exposed to the atmosphere, becomes oxidized; and, as oxide of zinc is not soluble in water, it forms a protection against moisture. However, when the zinc is exposed to the action of sulphur or chlorine from salt spray or the acid gases in smoke, it is converted into zinc chloride or sulphate, which readily dissolves in water. Under especially adverse conditions, it is impossible to make iron wire last more than a few years; and in some cases a few months, and it is therefore desirable to use copper wire in such cases, as this is practically indestructible.

12. Test of Galvanizing.—In view of the fact that the film of zinc is often so thin or so uneven as not to be effective in producing the desired results, it is always an important matter to test the galvanizing before accepting any large quantity of wire. For this purpose the Western Union Telegraph Company requires that several samples of the wire be taken at random and immersed in a saturated solution of copper sulphate for 70 seconds; they are then wiped dry and clean. This operation is repeated three more times. If after the fourth immersion there is no appearance

TABLE VI

IRON WIRE—BIRMINGHAM WIRE GAUGE

Number B. W. G.	Diameter in Mils d	Area in Circular Mils d^2	Weight Pounds		Breaking Strengths Pounds		Resistance per Mile (International Ohms) at 68° F.		
			1,000 Feet	1 Mile	Iron	Steel	E. B. B.	B. B.	Steel
0	340	115,600	304.	1,607	4,821	9,079	2.93	3.42	4.05
1	300	90,000	237.	1,251	3,753	7,068	3.76	4.40	5.20
2	284	80,656	212.	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.	787	2,361	4,449	5.97	6.99	8.26
5	220	48,400	127.	673	2,019	3,801	6.99	8.18	9.66
6	203	41,209	109.	573	1,719	3,237	8.21	9.60	11.35
7	180	32,400	85.0	450	1,350	2,545	10.44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14.53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31.0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	125	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	49.08	57.44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.7
17	58	3,364	8.9	47	141	264	100.5	120.4	139.0
18	49	2,401	6.3	33	99	189	140.8	164.8	194.8

of a copper deposit on the wire, the wire remaining black, as after the first immersion, the sample is well galvanized. If, however, a deposit of copper does appear on the wire, it is a sign that the zinc has been entirely removed, by combining with the sulphuric acid of the solution to form zinc sulphate. In this case, the wire should be rejected, as it shows that the zinc coating is not thick enough.

13. Table VI gives the sizes and principal properties of three grades of galvanized-iron wire. The sizes are according to the Birmingham wire gauge, which is the one most commonly used for iron wire.

14. Table VII contains the results of tests of samples of wire of American manufacture. The column headed Percentage Conductivity gives the percentages that the conductivities of the various samples bear to the conductivity

TABLE VII

Sample Mark and B. W. G.	Mechanical					Electrical	
	Weight per Mile Pounds	Percentage of Elongation	Number of Twists That 6 Inches Will Stand	Actual Breaking Stress Pounds	Relative Breaking Stress	Percentage Conductivity	Resistance per Mile in Ohms, at 60° F.
E. B. B. 12	190.83	11.50	15.00	417.50	11,552.20	14.40	30.50
E. B. B. 8	381.66	17.70	26.50	937.50	12,930.50	17.30	12.67
E. B. B. 11	222.64	17.20	21.50	577.50	13,639.40	15.60	24.20
151 9½	282.80	10.00	26.50	770.00	14,375.90	21.90	16.10
E. B. B. 10	254.44	17.70	28.50	697.50	14,478.10	17.80	18.42
146 9½	287.50	16.00	29.00	832.50	15,288.86	21.90	16.10
E. B. B. 6	508.88	11.40	21.50	1,587.50	16,462.40	17.70	9.21
E. B. B. 9	318.05	19.30	17.50	1,007.50	16,725.10	16.90	15.54
Nashua 8	381.66	15.10	26.50	1,535.00	21,183.00	14.70	15.00
M. S. plain 6	528.00	10.40	19.50	2,137.50	21,375.00	13.50	11.78
443 8	378.10	10.00	31.00	1,635.00	22,301.40	16.50	16.10
A. H. 9½	293.50	16.00	27.50	1,257.50	22,635.00	15.10	22.70

of pure copper. Percentage of Elongation means the percentage of the length a wire will elongate before breaking. The column headed Relative Breaking Stress gives the number of feet of its own length that each sample is able to sustain.

By referring to Tables VI and VII, it will be seen that the wires that bear the greatest tensile strain have the poorest conductivity.

15. Specifications.—Iron wire for use on telegraph and telephone lines should conform to the following specifications of the Western Union Telegraph Company:

1. The wire must be soft and pliable, and capable of elongating 15 per cent., without breaking, after being galvanized.

2. Great tensile strength is not required, but the wire must not break under a less strain than 2½ times its weight, in pounds per mile.

3. Tests for ductility should be made as follows: The piece of wire will be gripped by two vises, 6 inches apart, and twisted; the full number of twists must be distinctly visible on the 6-inch piece between the vises, and the number of twists must not be less than fifteen.

4. The weight per mile for the different gauge wires must be: for No. 4 B. W. G., 730 pounds; No. 6, 540 pounds; No. 8, 380 pounds; No. 9, 320 pounds; No. 10, 250 pounds; or as near these figures as practicable.

5. The electrical resistance of the wire, in ohms per mile, at a temperature of 68° F., must not exceed the quotient arising from dividing the constant number 4,800 by the weight of the wire, in pounds per mile. The coefficient .003 will be allowed for each degree Fahrenheit in reducing to standard temperature.

6. The wire must be well galvanized, and capable of standing the tests given in Art. **12.**

MERITS OF COPPER AND IRON WIRES

16. Iron wire possesses an advantage over copper wire in respect to its first cost, it being much cheaper; but in nearly all other respects, copper is very much superior. In tensile strength, there is little to choose between them, hard-drawn copper being strong enough for all except the most trying conditions.

On a pole line consisting mainly of hard-drawn copper wires, some authorities on line construction advise the use of one or more No. 6 B. W. G. galvanized-iron wires to increase the strength of the system. In durability, copper is far superior; for no matter how well the iron wire is galvanized, the zinc coating will eventually allow the corrosion of the iron itself, after which the destruction of the wire is a matter of but a short time. The greatest points in favor of copper, however, are its electrical properties. It has a conductivity six times greater than the best grades of iron wire, and over seven times greater than the poorer grades.

17. The distance over which transmission can be accomplished depends on the product of the ohmic resistance of the line and the electrostatic capacity. If either or both of these properties are increased, transmission will be correspondingly poorer. If an iron wire of the same size as a copper wire is used, the electrostatic capacity of the circuit will be practically the same, but the resistance will be six or seven times higher, and therefore the product of electrostatic capacity and resistance will be from six to seven times higher. This is a drawback to the use of iron. If an iron wire having the same conductivity as a given copper wire is used, the iron wire must possess six or seven times as great a cross-sectional area as the copper, in which case the electrostatic capacity will be much higher, thus increasing the product of the capacity and resistance.

ALUMINUM WIRE

18. The adaptability of aluminum as a line conductor for telegraph and telephone currents is exciting more and more interest as the price of aluminum is lowered and the price of copper or iron advances, on account of improvements in its methods of production. Table VIII gives some figures regarding the relative merits of aluminum and copper.

19. Table VIII shows that copper has a decided advantage in regard to resistance for equal sizes, but aluminum has a great advantage in the matter of weight, an aluminum wire being less than one-third as heavy as a copper wire of the same size. An aluminum wire possesses less than one-half the weight of a copper wire having the same length and resistance, although, of course, in this case the aluminum wire will be considerably larger than the copper. Pound for pound, aluminum at 29 cents per pound is almost twice as expensive as copper at 16 cents, but for two wires of equal resistance and length, the aluminum wire will be over 13 per cent. cheaper than the copper. For equal resistances, the aluminum wire will have a considerable advantage in point of strength as well as of cost.

TABLE VIII

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM

	Aluminum	Copper
Conductivity, for equal sizes	.54 to .63	1
Weight, for equal sizes	.33	1
Weight, for equal length and resistance	.48	1
Price—Aluminum, 29 cents; copper, 16 cents; bare line wire	1.81	1
Price—Equal resistance and length, bare line wire	.868	1
Temperature coefficient per degree Fahrenheit	.002138	.002155
Resistance of mil-foot, 20° C.	18.73	10.5
Specific gravity	2.5 to 2.68	8.89 to 8.93
Tensile strength of hard-drawn wire per square inch	40,000	60,000
Coefficient of expansion per degree Fahrenheit	.0000231	.0000093

The grades of aluminum wire in Table IX are those manufactured by the Pittsburg Reduction Company.

20. Tying and Joining Aluminum.—In tying aluminum line wires to the insulators, it is best to use an annealed aluminum wire made for this purpose; for, when tied with too hard a wire, the line wires will become indented, and, consequently, will break under a less strain than if the cross-section had been unimpaired. Aluminum cannot be soldered

TABLE IX

RESISTANCE, TENSILE STRENGTH, AND WEIGHT OF ALUMINUM LINE WIRE

Grade	Conductivity Pure Copper = 100	Comparative Section of Equal Conductivity Copper = 100	Comparative Weight of Same Lengths of Equal Conductivity Copper = 100
A 0	62	156.4	47
A 75	58	167.0	50.2
A 2	54	180.0	54

Number B. & S. Gauge	Diameter Mils d	Circular Mils d^2	Area Square Inches $\frac{d^2 \times .7854}{1,000,000}$	Grade A 0		Grade A 75		Grade A 2		Pounds per Mile. Sp. Gr. 2.68 Water 62.355 lb. per Cu. Ft.	Pounds per Mile of Aluminum Having Same Resistance as Copper Wire of Size Given Grade A 75
				Resistance per 1,000 Feet at 75° F.	Tensile Strength Pounds per Square Inch	Resistance per 1,000 Feet at 75° F.	Tensile Strength Pounds per Square Inch	Resistance per 1,000 Feet at 75° F.	Tensile Strength Pounds per Square Inch		
4	204.31	41,742.0	.0327840	.4012	27,000	.4288	33,000	.4605	40,000	200.90	336.0
5	181.94	33,102.0	.0259980	.5058	27,500	.5408	34,000	.5818	42,000	159.30	266.4
6	162.02	26,250.5	.0206170	.6380	28,000	.6820	35,000	.7325	44,000	126.35	211.4
7	144.28	20,816.0	.0163490	.8044	29,000	.8600	36,000	.9235	46,000	100.21	167.6
8	128.49	16,509.0	.0129660	1.6340	30,000	1.1050	37,000	1.1870	48,000	79.46	133.2
9	114.43	13,094.0	.0102840	1.2780	32,000	1.3670	39,000	1.4680	50,000	62.99	105.4
10	101.89	10,381.0	.0081532	1.6130	33,000	1.7240	40,000	1.8520	51,000	48.71	83.6
11	90.74	8,234.0	.0064670	2.0330	35,000	2.1730	41,000	2.3350	53,000	39.63	66.3
12	80.81	6,529.9	.0051286	2.5650	39,000	2.7410	42,000	3.0840	55,000	31.43	52.6
13	71.96	5,178.4	.0040671	3.2330		3.4560		3.7120		24.83	
14	64.08	4,106.8	.0031469	4.1790		4.4670		4.7980		19.76	

readily like copper and iron; furthermore, the soldering of aluminum line wires is not recommended. Those sizes that are used for telegraph and telephone lines can be joined by twisting their ends together, as are copper and iron wires, but sleeve joints are better.

Aluminum sleeve joints, either McIntire tubes or rolled-up sheet sleeves, can now be obtained from the same manufacturers that make similar sleeves for joining copper wire. Joints of this kind are recommended because they are easily and quickly made, and are said to possess both the mechanical strength and the conductivity of the line wire itself.

21. C. T. Child states that the conductivity of aluminum is 63 per cent. that of copper, referring to commercial samples; this would make the diameters of wires for equal conductivity as follows: copper 10, aluminum 12.64. Two wires of equal conductivity would require 1 pound of aluminum and 2.08 pounds of copper.

TABLE X

Price of Copper, per Pound Cents	Equivalent Price of Aluminum, per Pound Cents	Price of Copper, per Pound Cents	Equivalent Price of Aluminum, per Pound Cents
12	25.00	17	35.35
13	27.10	18	37.35
14	29.15	19	39.40
15	31.20	20	41.50
16	33.30		

Based on the weights for equal conductivity (copper 100, aluminum 48), there is an equivalent price of aluminum at which conductors of equal efficiency made from the two metals will be equal in cost. These relative prices are given in Table X in cents per pound.

If two wires of equal length and equal resistance, one of copper and the other of aluminum, be covered with the same thickness of insulating material, the amount required by the

TABLE XI

FACTORS FOR THE DIFFERENT CONDUCTIVITIES OF ALUMINUM

Conductivity of Aluminum	63	62	61	60	59	58	57	56	55	54
Relative cross-section (Copper equals 100)	154.0	156.5	159.0	161.7	164.4	167.3	170.2	173.2	176.3	179.7
Weight of aluminum (weight of copper of equal length and equal resistance equals 100)	46.25	47.00	47.77	48.55	49.38	50.24	51.11	52.02	52.97	53.95
Tensile Strength—Factor by which to multiply tensile strength per square inch of aluminum to obtain tensile strength per square inch required in a copper wire of equal resistance in order to secure same breaking strength	154.0	156.5	159.0	161.7	164.4	167.3	170.2	173.2	176.3	179.7
Price—Factor by which to multiply copper price per pound to obtain equivalent price of aluminum; also factor by which to divide aluminum price per pound to obtain equivalent price of copper	2.160	2.13	2.10	2.060	2.030	1.990	1.960	1.920	1.890	1.850
Price—Factor by which to divide copper price per pound to obtain equivalent price of aluminum; also factor by which to multiply aluminum price to obtain equivalent price of copper	.4625	.47	.4777	.4855	.4938	.5024	.5111	.5202	.5297	.5395

aluminum will be 17½ per cent. more than that required by the copper. The weight of the insulated aluminum, if the ordinary rubber or other good insulating material is used, will still be considerably less than that of the insulated copper wire.

22. Table XI gives some convenient factors for different conductivities of aluminum as compared with 97-per-cent. conductivity copper wire having the same resistance.

Both aluminum and copper are practically indestructible under ordinary atmospheric exposure, and there is probably but little choice between them in this regard. In bare-wire construction, however, the fact that aluminum is somewhat more bulky for a given resistance is of little disadvantage from a mechanical standpoint, except for its greater resistance to the wind, while it possesses an advantage in regard to strength, cost, and weight. From an electrical standpoint, however, there is one disadvantage due to the greater size of aluminum wire; its greater surface for a given conductivity renders its electrical capacity with respect to the earth, or with respect to other conductors, much higher, and thus the product of the electrostatic capacity and the resistance will be greater than for a copper wire of the same resistance. On account of the peculiar nature of aluminum to retain for years some of the grease used in drawing it, the formation on it of any great amount of sleet is said to be prevented, thereby eliminating one cause of breakage.

WIRE MADE OF TWO OR MORE MATERIALS

23. Phono-Electric Wire.—**Phono-electric wire** is a composition, or alloy, wire made by the Bridgeport Brass Company, which claims that it is absolutely homogeneous both in mechanical and molecular structure, and that it does not depend on a hardened skin for its strength. Furthermore, it claims that phono-electric wire has a breaking strain, for the various sizes of wire, from 40 to 45 per cent. greater than that of hard-drawn copper, and that its properties are absolutely permanent. Phono-electric wire seems to have a high elastic limit, which should enable it to endure severe strains without taking a permanent stretch, and thereby weakening the wire for future emergencies.

The company also says that tests have shown that phono-electric wire is exceedingly tough. While a 6-inch piece of No. 8 hard-drawn copper wire broke at 30 turns, a phono-electric wire of the same size and length stood the strain of 50 complete turns. In a smaller-sized wire, the difference was still greater. A 6-inch piece of No. 14 hard-drawn copper wire stood the strain of 47 turns, while a phono-electric wire of the same size and length did not break until 120 turns had been made. Its conductivity is 50 per cent. that of pure copper. All things being considered, it is claimed to be superior to iron, but not to hard-drawn copper, for line wires; it is now used by a few companies for extra long spans where steel wire is not suitable.

24. Bimetallic Wire.—Bimetallic wire, made by Roebling's Sons Company, consists of a steel center with a cover of copper; its conductivity is about 65 per cent. that of pure copper. The percentage of copper and steel may vary a trifle, hence the strength and weight will also vary. According to a table that this company gives, the bimetallic wire (taking No. 9 B. & S.) has a breaking strength about 40 per cent. greater than that of hard-drawn copper. This wire has been used by some telephone companies where an extra strong but fair conductor is required.

25. Silicon- and Aluminum-Bronze Wires.—The high tensile strength of bronze wires and their freedom from corrosion render them especially suitable for guy wires; they resist corrosion fully as well as hard-drawn copper. Some **silicon-bronze wires** have a tensile strength of 80,000 pounds per square inch and are capable of standing eighty twists in a length of 6 inches before breaking. An **aluminum-bronze wire** showed a strength of 110,000 pounds per square inch, but its ductility was less than that of the silicon-bronze wire. The low conductivity of bronze wires (not much over 35 per cent. that of pure copper, and much lower for some of the alloys) excludes them from being used extensively for line wires.

Although bronze wires cost about six times as much as either iron or steel, the saving in the cost for repairs and renewals may make up for their high first cost. It is probably on account of this cost that they are used but very little, if at all, in the United States. On some long lines in Europe, it is quite customary to use bronze wires of some kind.

THE MILE-OHM

26. A convenient standard for expressing the conducting quality of wires of a given metal, regardless of the size of the wires, is what is commonly termed the **mile-ohm,** or, more properly, the **weight per mile-ohm.** When the weight per mile-ohm of a certain quality of metal is referred to, the weight of a circular wire 1 mile long and of such a size as to have a resistance of 1 ohm is meant. Obviously, the better the conducting quality of the metal, the smaller will be the weight per mile-ohm, for a wire 1 mile long having a resistance of 1 ohm will be of smaller diameter if the metal is a good conductor than if it is a poor conductor. The mile-ohm = weight per mile × resistance per mile.

It is not uncommon to say that the weight per mile-ohm of a certain grade of copper wire is, say, 888 pounds at a temperature of 60°, or that the weight per mile-ohm of a certain grade of iron wire is 6,500 pounds. These expressions mean, in the first case, that a wire made of this grade of copper, 1 mile long, having a resistance of 1 ohm, will weigh 888 pounds; and in the second case, that the wire made of that grade of iron, 1 mile long, and having a resistance of 1 ohm, will weigh 6,500 pounds.

27. The weight per mile-ohm of a metal forms a convenient basis for determining the percentage conductivity; for, since the weight of a given wire varies as its cross-section, and since the conductivity varies directly as the cross-section, it follows that the conductivity of two wires will be inversely proportional to their respective weights per mile-ohm. Thus, if we know that the weight per mile-ohm of pure copper at 60° F. is 859 pounds, while the weight per mile-ohm of a sample is 888 pounds, the percentage conductivity x may be found from the following proportion, remembering that the conductivity of pure copper is 100:

$$x : 100 = 859 : 888$$

or $$x = \frac{859}{888} \times 100 = 96.73 \text{ per cent.}$$

in which x = percentage conductivity.

28. If the resistance per mile of a given wire is known and also the weight per mile-ohm of that metal, the weight of the wire per mile may be determined by dividing the weight per mile-ohm by the resistance per mile. On the other hand, if the weight per mile is known, the resistance per mile may be ascertained by dividing the weight per mile-ohm by the weight per mile. Thus, an iron wire weighing 204 pounds per mile, made from metal having a weight per mile-ohm equal to 6,500 pounds, will have a resistance equal to 6,500 ÷ 204 = 31.86 ohms.

EXAMPLE 1.—If the weight per mile-ohm of a pure copper wire is 859 pounds at 60° F., and the weight per mile-ohm of an iron wire is 4,600 pounds, what is the percentage conductivity of the iron wire, pure copper being taken as a standard?

SOLUTION.—Calling x the percentage conductivity of the iron wire

$$x : 100 = 859 : 4{,}600;$$

that is, $$x = \frac{859 \times 100}{4{,}600} = 18.67 \text{ per cent. Ans.}$$

EXAMPLE 2.—A piece of copper wire 1,000 feet long weighs 31.43 pounds and has a resistance of 1.0199 ohms at a temperature of 60°; what is its percentage conductivity, having given that the weight per mile-ohm of pure copper at 60° is 859 pounds?

SOLUTION.—Weight per mile of sample is $\frac{31.43 \times 5{,}280}{1{,}000} = 165.95$ lb.

The resistance per mile of sample is $\frac{1.0199 \times 5{,}280}{1{,}000} = 5.385$.

The weight per mile-ohm of the sample is equal to the weight per mile times the resistance per mile, or $165.95 \times 5.385 = 893.64$ lb. The percentage conductivity of the sample is then equal to

$$\frac{859 \times 100}{893.64} = 96.12 \text{ per cent. Ans.}$$

SIZES OF WIRE FOR VARIOUS PURPOSES

29. No definite rules can be given for the proper size of line wire to be used for overhead lines, but the following wires and sizes will ordinarily answer for the purposes mentioned. In the country and small towns for distances not exceeding 8 miles, No. 14 B. W. G., B. B. galvanized-iron wire may be used; for distances not to exceed 25 miles, No. 12 B. W. G., B. B. galvanized-iron wire may be used; for distances from 25 to 100 miles, No. 10 B. W. G., B. B. galvanized-iron wire may be used; for distances of 100 miles and over, hard-drawn copper wire should be used, not smaller than No. 10 B. & S. for 150 miles and over. The size most generally used on farmers' lines is No. 12 B. B. galvanized-iron wire, weighing about 165 pounds to the mile, although No. 14 will answer up to about 8 miles.

For small city or town lines, No. 14 B. W. G., B. B. galvanized-iron wire is extensively used; although in towns where cable forms part of the line, steel wire may be used. For lines connected with large city exchanges, hard-drawn copper wire (usually No. 12 B. & S.) is most always used.

For toll lines not exceeding 75 miles, B. B. galvanized-iron wire, generally No. 10 B. W. G., but in a few cases No. 8 B. W. G., is used; from 75 to 150 miles, the E. B. B. grade or hard-drawn copper should be used. For good toll lines of any length, the best practice calls for complete metallic circuits of hard-drawn copper, No. 10 B. & S. up to about 500 miles and No. 8 B. & S. up to about 1,000 miles.

For interior wiring, use No. 16 or No. 18 B. & S. copper wire; in dry places, weather-proof office wire; and in damp places, rubber-covered wire.

STRINGING OF WIRES

TOOLS AND METHODS

30. Paying Out.—Where but a single wire is to be strung on poles, the method usually adopted is to secure one end to the cross-arm of the pole at the beginning of the stretch and to unreel the wire from a *pay-out reel* carried along the base of the poles. The wire is drawn up to each cross-arm, and after being pulled up to the proper tension, is tied to the insulators, as will be described later. For paying out the wire, many forms of reels may be procured. A convenient form of reel mounted on a hand barrow is shown

FIG. 1

in Fig. 1. The coil of wire is held in place by the four vertical pins on the reel itself, and as the barrow is carried along by two men, the wire is paid out without any danger of kinking. When it is desired to pay out several wires at once, as described later, a number of reels of the same general form are mounted on a wagon or cart.

31. Wire Wagon.—The **wire wagon** is employed to simultaneously feed out ten wires at once. It consists essentially of a very strong and heavy wagon with five wire reels placed horizontally on a board on each side. A long bar of wood at the back of the wagon has ten catches, through which the wires pass; this bar serves to keep the wires separate and facilitates handling them. When a *run* is to be made, that is, when a section of wires is to be strung, the ends of the wires are first passed through the catches and then hooked to a running board.

32. Running Boards.—When more than a few wires are to be strung, what is termed a **running board** is used. A common form of running board, which is shown in Fig. 2, consists of a triangular piece of iron with a ring and swivel *a* to which the hauling line is attached. This running board has eleven holes in the base to receive the wires. If desired, snaps to hold the wires may be used instead of attaching the wires directly to the base, so that in passing a pole, the five wires on the side of the pole opposite the hauling rope may be quickly placed in their proper places. On new work, however, all wires are generally pulled over the top arm and later dropped to position. The eleventh hole is provided so that an extra wire may be pulled through, by means of which the hauling rope may be pulled back where a number of short pulls are to be made. A piece of rope should be attached to one end of the base to keep that end always down and prevent the triangle from turning over and tangling the wires.

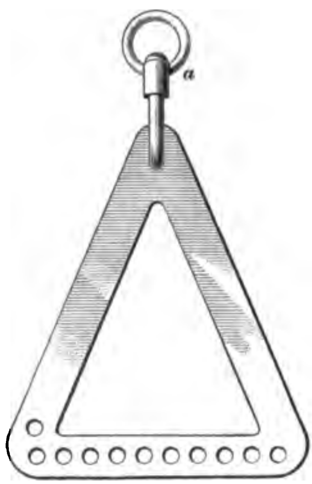


FIG. 2

33. A running board may be made of oak about as long as a cross-arm and having holes for the attachment of wires spaced about the same distance apart as the pins on a cross-arm. A strong rope is attached to the center of the running board, by which it may be drawn over the cross-arms, pulling the wires after it. The rope is first laid over all the cross-arms of the stretch to be strung. The pay-out reels are mounted at the beginning of the stretch, and the wires from them are attached directly to the running board. By means of a team of horses at the other end of the stretch, the running board is then drawn along, being lifted over the pole tops by men stationed on each pole, the wires being separated as soon as the running board passes the pole. In this way, ten wires may be strung at once. When the wires for the lower cross-arms are to be strung, the running board may be made to carry five wires instead of ten, so as to serve for one end of the cross-arm only. Sometimes, however, two of these are used at once, one on each side of the pole, a separate rope being used for each.

34. In Fig. 3 is shown a form of **come-along** that has met with much favor for gripping and pulling hard-drawn copper wire. It has the advantage of having smooth,

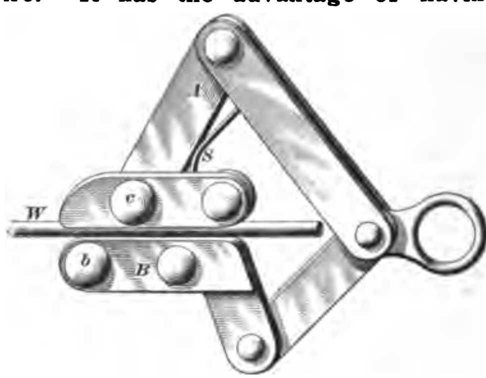


FIG. 3

straight, parallel jaws, thus obtaining a firm grip on the wire without the liability of kinking or nicking it. These clamps are made of steel forgings riveted together, as shown. The member *A* is pivoted to the jaw *B* by the rivet *b*, and to the other jaw by the rivet *c*, so that when the wire *W* is placed between the jaws and tension applied on the eyelet of the come-along, the jaws are forced together, thus gripping the wire and at the same time maintaining the pull in the direction of the wire. The spring *S* serves to open the jaws automatically, thus releasing the wire as soon as the tension is removed. Considerable care must be taken not to nick or kink hard-drawn copper wire. When a kink does occur, it should be cut out and the wire joined.

35. Stretching and Tying.—After ½ mile or so of wire has been looped over the cross-arms, stretching and tying is begun. Starting from the connections of the last fully stretched sections, each wire is taken separately; one end is securely fastened, then stretched to the requisite tightness, and then tied to all the insulators. This is done with the assistance of come-alongs and pulleys. Usually, a span of about five poles is stretched at one time. When the wire reaches the requisite tautness, the man handling the come-alongs throws up his hand, shouting *tie* to the men on the other poles, and the wire is permanently fastened to the

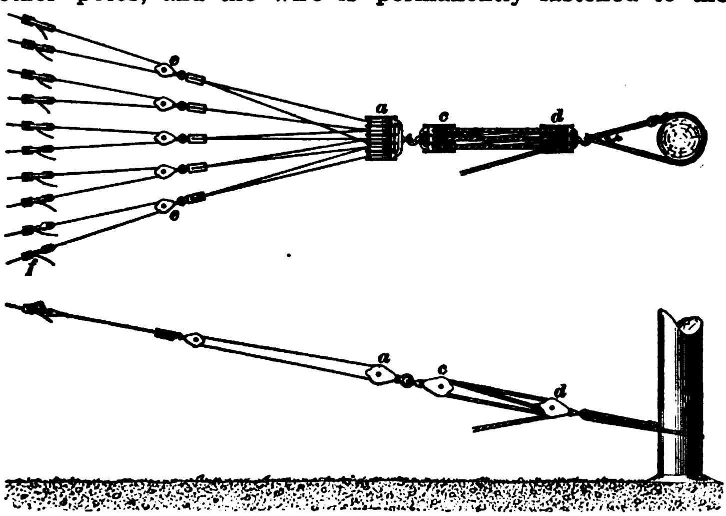


FIG. 4

insulators. Hard-drawn copper wire stretches considerably and allowance should be made for the proper sag in the middle of the loop as given in Table XII or Table XIII. In about 8 months after the line has been finished, the wire will have reached its maximum sag; then, the slack should be taken up. From that time on, there may be a very little sag, but, at the end of 2 years, the wire will have practically ceased stretching, and will require no further attention.

36. Tension of Line Wires.—Obviously, the temperature at the time of stringing plays an important part in the determination of the proper tension, for if strung too tight in hot weather, the wires, in contracting in colder weather, will be likely to snap. Therefore, it is necessary to allow a much greater sag in hot weather than in cold.

Several methods are in vogue for obtaining the proper tension in the line wire. The wire is clamped by means of some form of wire clamp, or come-along, and pulled up either by hand or by means of a block and tackle, the tension being judged either by the amount of sag in the wires or by a line dynamometer, or spring balance, which shows by an indicator the number of pounds of tension in the wire.

Wires of the same size are most readily pulled up by the

TABLE XII

SAG IN LINE WIRES

Temperature Degrees Fahrenheit	Span, in Feet					
	75	100	115	130	150	200
	Sag, in Inches					
−30	1	2	$2\frac{1}{2}$	$3\frac{3}{8}$	$4\frac{1}{2}$	8
−10	$1\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{3}{4}$	5	9
10	$1\frac{1}{2}$	$2\frac{5}{8}$	$3\frac{1}{2}$	$4\frac{3}{8}$	$5\frac{3}{4}$	$10\frac{1}{4}$
30	$1\frac{3}{4}$	3	4	$5\frac{1}{8}$	$6\frac{3}{4}$	12
60	$2\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{2}$	7	9	$15\frac{3}{8}$
80	$3\frac{1}{8}$	$5\frac{3}{8}$	7	$8\frac{5}{8}$	$11\frac{1}{4}$	$18\frac{3}{4}$
100	$4\frac{1}{3}$	7	9	11	14	$22\frac{1}{4}$

arrangement of pulley, or sheave, blocks shown in Fig. 4. For pulling up six wires, use a three-sheave block at *a*; for eight wires, a four-sheave block; for ten wires, a five-sheave block. At *c*, *d*, use three-sheave 6-inch blocks; and at *e*, a single-sheave 4-inch block. At *f* are clips for attaching the wires to the ropes.

37. Table XII, taken from Roebling's handbook on wire, gives the amount of sag, in inches, at the center of the span for different lengths of span at various temperatures. This applies to both iron and copper wire. Some limit this table to Nos. 8 and 12 B. & S. requiring No. 14 B. & S. to have a sag 2 inches greater for the same temperature and span.

Table XIII shows, in inches, the sag between poles of wires at different temperatures as specified by the Postal Telegraph Cable Company.

38. For spans from 400 to 600 feet in length, the sag should be about one-fortieth the length of the span, while

TABLE XIII

SAG IN LINE WIRES

Temperature Degrees Fahrenheit	Span, in Feet				
	75	100	115	130	150
	Sag, in Inches				
0	1	2	2	3	4
20	2½	4	4	5	6
40	4	6	6	7	8
60	5½	8	8	9	10
80	7	10	10	11	12
100	8½	12	12	13	14

for spans of from 600 to 1,000 feet in length, the sag should be about one-thirtieth the span.

As the coefficient of expansion of aluminum is greater than that of copper, it is necessary, in stringing aluminum wires at ordinary temperatures, to allow a little greater sag than for copper wire, otherwise the aluminum wire may break when cold weather comes.

TYING WIRES TO INSULATORS

39. Iron-Wire Tie.—There are several methods of tying line wires to insulators. The most common **iron-wire tie** is shown in Fig. 5. This view shows both plan and side view of the insulator and tie. The tie-wire for an ordinary line insulator is usually made from 14 to 16 inches in length and of the same size as the line wire, or slightly smaller. The line wire is laid in the groove of the insulator, after which the two ends of the tie-wire, after passing half around the insulator, are wrapped in a close spiral about the line wire. Some advocate to start wrapping one end of the tie-wire over and the other end under the line wire.

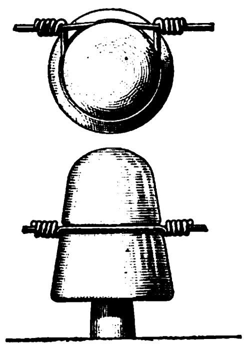


FIG. 5

40. Postal Telegraph Iron-Wire Tie.—For tying iron wire, the Postal Telegraph Cable Company's rules direct that the tie-wire should be No. 8 gauge, 14 inches long, should be placed in the groove of the insulator, with the line wire on top of it, and each end of the tie-wire given four and one-half turns around the line wire in opposite directions.

41. Helvin Tie.—The **Helvin tie**, which has been used quite successfully with hard-drawn copper wire, is shown in Fig. 6. The tie-wire is wound around the insulator and given a twist about itself, and the ends are then wound around the line wire. It is superior, especially for hard-drawn copper wire, to the preceding tie, which has been commonly used with iron wires. Where hard-drawn copper line wires are fastened to insulators, the tie-wire itself should be soft copper.

FIG. 6

42. Tie for Hard-Drawn Copper.—An excellent tie, and one that is largely used in telephone work for hard-drawn copper wire, is shown in Fig. 7. To make this tie, the line wire is laid in the groove of the insulator, and the tie-wire is also laid in the groove and passed once entirely around the insulator. One end of the tie-wire is then brought down over the line wire, while the other end is brought up under it in an opposite direction, the two ends being wound five times around the line wire, as shown in the figure. For line wires .104 inch in diameter, the soft-drawn copper tie-wire should be 19 inches in length, and for line wires .165 inch in diameter, the soft-drawn copper tie-wire should be 24 inches in length.

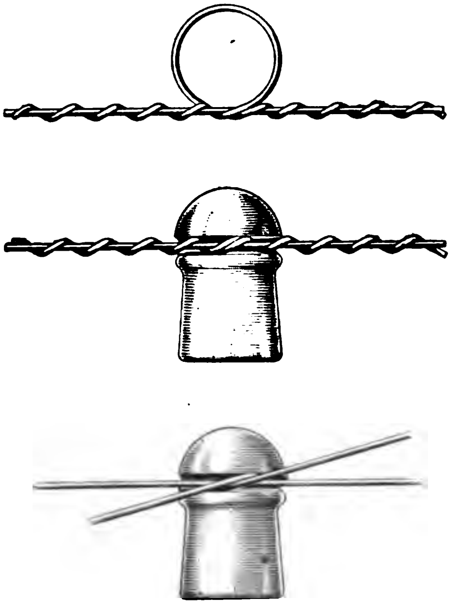


FIG. 7

43. Postal Telegraph Copper-Wire Tie.—For tying copper wire to insulators, the Postal Telegraph Cable Company's rules require the placing of a copper sleeve 7 inches long around the line wire, the center of the sleeve to be placed opposite the center of the insulator, after which a soft copper tie-wire of the same gauge as the line wire, and 28 inches long, should be crossed over the line wire at the center, and each end carried entirely around the insulator in the groove and brought back under the main line and crossed, giving

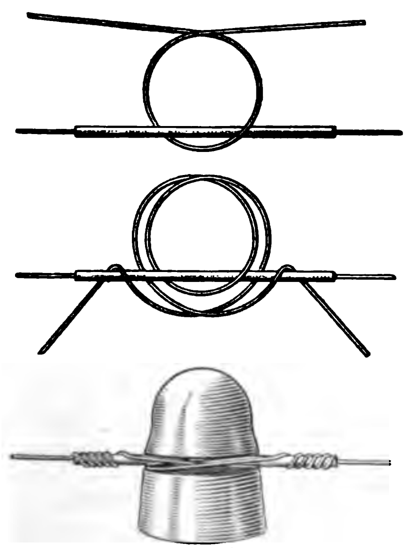


FIG. 8

each end four complete spiral turns in opposite directions. This tie, shown in Fig. 8, is known as the **Postal tie.**

44. Position of Line Wire on Insulator.—On straightaway work, the line wire should always lie on the side of the insulator next to the pole, except the two inner wires, which are placed on the side away from the pole. On curves, however, all the line wires should always lie on the side away from the center of the curve, in order that the strain, due to the bend in the wire, may be taken by the insulator instead of by the tie-wire.

On terminal poles, copper and iron wires should never lie together in the same groove of the insulator, but should be tied around separate grooves on a double-grooved insulator, or else each wire should end on separate insulators. The joint in either case should be thoroughly soldered.

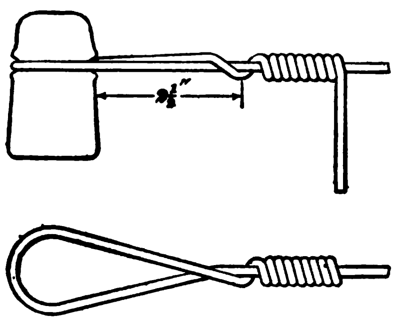


FIG. 9

45. Dead-Ending Wires.—Where a line is terminated at an insulator, or **dead-ended,** as it is called, it is looped around the insulator, as shown in Fig. 9, and the end given about eight close turns around the wire. The wire should be only looped and not wrapped around the insulator, and the twists should begin at a point about 2½ inches from the insulator. If another wire is to be joined to the line at this point, leave projecting enough of the end with which to make the joint, otherwise cut the end off close to the line wire. This is much better than making the joint with the stretched part of the wire. McIntire and rolled-up sheet-metal sleeves, such as will be described presently for making joints in line wires, are often used in making a dead end.

46. Dead-Ending on Double Arms.—Probably the best methods for dead-ending copper line wires on double cross-arms are the two shown in Fig. 10. In Fig. 10 (*a*), the line *E* rests, and some advise tying it, in the upper groove of the transposition insulator *d* and is dead-ended by being passed once around the upper groove of the transposition insulator *c*; a half McIntire sleeve, which should be given 2½ complete turns, being used at *o* to secure it. The line wire *W* rests, and some advise tying it, in the lower groove of *c* and it is dead-ended around the lower groove of *d* by means of a half sleeve. By this method, the pull on the cross-arms is against the pole. In the method shown in Fig. 10 (*b*), standard insulators are used, the wire *E* is dead-ended on the insulator *n* and the wire *W* on the insulator *m*. Although the pull, in this method, is away from the pole, it is usually preferred, as it is neater, cheaper, and less liable to cause crosses. When necessary, the pull on the arms may be compensated for by additional bracing.

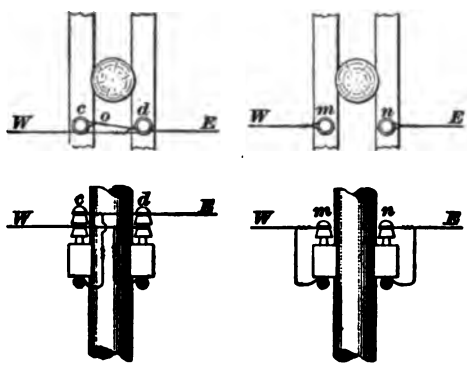


FIG. 10

Where iron wire is employed, and it is desired to dead-end on a double-arm pole, probably the best way is to use double-groove insulators on both pins and wrap the wire from one direction in the upper grooves of the insulators in figure 8 fashion. The wire from the opposite direction should be wrapped around in the lower grooves in the same manner.

47. Dead-ending on a single arm, which is a better method, is done by using one transposition insulator, one wire being dead-ended in the upper and the other in the lower groove. The pulls in opposite directions neutralize each other and, if perfectly done, the pin will only have to sustain the weight of the insulator and wire.

JOINING LINE WIRES

48. Western Union Joint.—Until recent years, all line wires were usually connected by means of the joint, shown in Fig. 11, which is sometimes called the **American**, and sometimes the **Western Union, splice**, or **joint.** In order to make this joint, the wires are first placed side by side, and then each end is wound about the other. Iron-wire joints should always be soldered, to insure the maintenance of good electrical contact and to increase the strength of the joint. In soldering this joint, it is well to apply solder only at its center, for the reason that the heat necessary to cause the solder to flow takes a certain amount of temper from the wire, and therefore is very apt to weaken it. By weakening the center portion only, two strands of the wire are

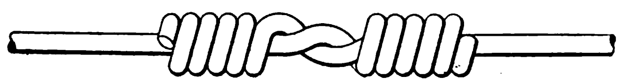


FIG. 11

available to stand the strain, and therefore a rupture is not as likely to occur as if the ends of the splice were heated, for then the strain would be borne by a single strand only.

49. Bare Iron-Wire Splices.—In 1902, a number of tests were made to determine the best way to make a bare iron-wire splice so that the splice would have at least the same tensile strength as the wire of which it was made. It was found that for all sizes of iron wire tested, in order to make a splice of a strength equal to the wire of which it was made, there should be at least five twists in the neck and about five short turns at each end, although joints made with but two or three short turns at the ends often appear to hold as well as those made with more. If the neck is made too short, it will not be possible to make the five turns in it (which, judging from results obtained, are necessary) without either weakening the wire or exercising an unnecessary amount of labor; and if the neck is made too long, wire will be wasted, and after a certain limit the joint will be weakened.

In other words, the proper length of neck is the shortest length that will contain five twists without injuring the wire or making the joint too hard to twist. The lengths used for joints of different-sized wires are shown in Fig. 12. The splices tested were made in the following manner: First, the ends of the wires to be joined were held in the connectors, and with the fingers a length of the wire equal to the length of the neck wanted was given one long twist around the other wire. Second, the loose end was grasped with the pliers and turned around until the number of twists wished

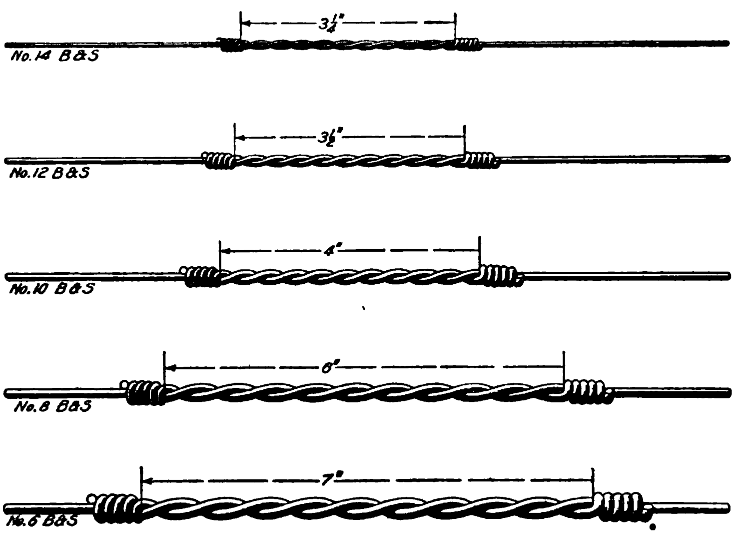


Fig. 12

in the neck were formed. Third, the short turns at each end were made.

In making the specimens, it was found that unless care was taken to twist the two wires composing the neck equally, more strain would come on one wire than the other, and the joint would slip or break; whereas, if the joint had been properly made with an equal twist in the two wires, the wire itself would break before the splice would give.

50. Soldering.—The best way to solder joints is by the use of a dip pot and pouring ladle. By this method, there is less danger of weakening the wire by overheating it than when a gasoline torch is used, or when the joint is dipped into a pot of melted solder.

By careful tests made on a few iron-wire Western Union joints, it has been found that for No. 14 and No. 12 B. & S. wire, even a joint made with one twist in the neck and one

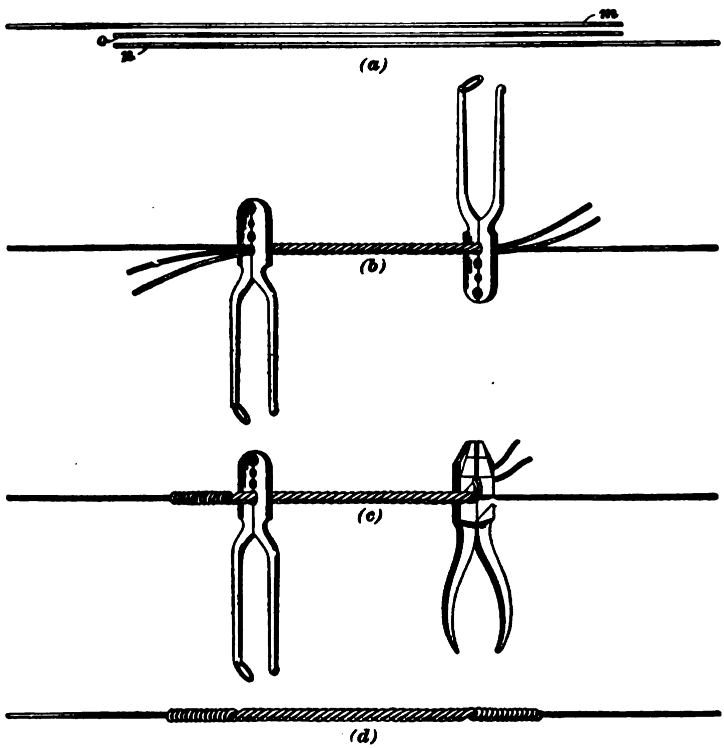


FIG. 13

turn at each end would hold, if soldered, while the wire of which it was made would break. Hence, the proper soldering of an iron-wire joint increases its strength as well as its conductivity.

51. Three-Wire Joint.—The **three-wire joint** is made as shown in Fig. 13. Overlap the ends *m*, *n* 18 inches and lay a third wire *o*, also 18 inches long, alongside *m*, *n* as shown at (*a*). Clamp two pair of connectors, or tie-wrenches over all three wires about 5 inches apart, as shown at (*b*); revolve both wrenches in opposite directions equally and slowly so as to make a smooth joint without straining the wire. When the wires have been twisted fairly tight, remove the wrenches, clamp one pair on the neck to hold joint, and with pliers, as shown in (*c*), give the two wires on each end six or seven turns around the remaining wire. The finished joint is shown at (*d*). This joint is much stronger than the Western Union, especially for hard-drawn copper, as it is not necessary to twist it so tight in the middle, and it is said to have even a lower resistance than the sleeve joint.

52. McIntire Sleeve Joint.—Another joint, which is extensively used, especially for hard-drawn copper and aluminum wires, is the **McIntire sleeve joint.** A variety of sizes of copper, aluminum, and even iron sleeves can now be obtained for this purpose. Since no soldering is required, there is no danger of injuring the strength of the line wire by heating it. The ends of the wire are slipped into a double sleeve of the same material as the wire, as shown in Fig. 14, and the two are then twisted through several turns, making the joint like that shown in Fig. 15. These joints give excellent service, always keeping good electrical contact without the use of solder.

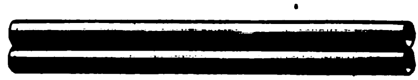


Fig. 14

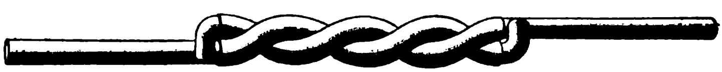


Fig. 15

53. When making a McIntire sleeve joint, pass each end of the wire through the sleeve until it extends $\frac{1}{4}$ inch beyond the end of the sleeve, then place a steel tie-wrench or connector on each end of the sleeve, the outside of the tool to be at least $\frac{1}{4}$ inch from the end of the sleeve, after which three to four and one-half complete turns, depending on the size of the wire, should be made, using great care to keep the sleeve absolutely straight. For No. 8 B. W. G. give four and one-half turns, for sizes more extensively used three turns is usually specified. Sleeves of the proper size to fit the different sizes of wire should be used. Sleeves are made in two lengths, called the full and half sleeves, the former being used for through line joints and the latter for branch joints.

On a telegraph line from Montreal to Vancouver, using 3,000 miles of hard-drawn copper wire, weighing 300 pounds per mile, the McIntire sleeve joints were soldered at the ends. By tests it was found that the breaking strength of the joint was increased by soldering it from 500 to 900 pounds. However, it is not considered necessary to solder sleeve joints and it is very seldom done.

54. Rolled Sleeve Joint.—Instead of the two tubes, of which the McIntire sleeve is made, an oval-shaped sleeve,

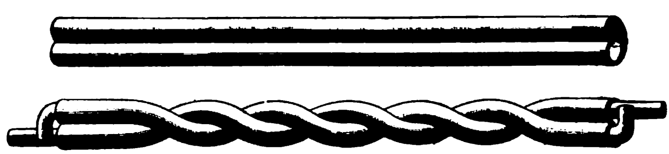


FIG. 16

made out of one piece of rolled-up sheet metal, is now considerably used for both hard-drawn copper and aluminum. Such a sleeve and a completed joint is shown in Fig. 16. The improved Lillie wire type B connectors, made by the Holtzer-Cabot Electric Company, for use on line work when both ends of the wire are available, resembles the sleeve shown in Fig. 16, while the type A, for bridle and branch connections, has one side left open enough to receive the through line wire without cutting it. It is important to make the Lillie sleeve joints as follows: With the open side of the sleeve uppermost and right in front of the workman, the right-hand wire should be put in the groove nearest the workman, the left-hand wire in the other groove, each end being allowed to protrude from $\frac{1}{4}$ to $\frac{1}{2}$ inch, depending on the size of the wire. With the splicing clamps fastened near each end of the joint, the right-hand one should be turned away from the workman, giving two and one-half to three complete twists for a full-length joint and one and one-half turns for a half-length joint, no less nor no more. The protruding ends of the wire should finally be bent back over the joint.

55. Tokay Joint.—Still another method of joining hard-drawn copper line wires, sometimes called the **Tokay sleeve joint,** gave entire satisfaction for at least 2 years while in use by at least one of the Bell telephone companies. It is made in the following manner: The two wires to be joined are slipped into a single round sleeve, snugly fitting the wire, and about 3¾ inches long, until the ends of the wires butt together at the middle of the sleeve. Then, by means of a special compressing tool, the sleeve and wire are compressed or flattened in about five places on each end of the sleeve joint. This prevents the wires from pulling out of the sleeve. It does not seem to be as strong

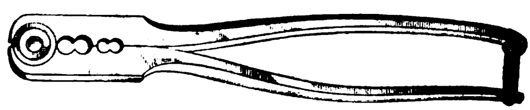


FIG. 17

as the McIntire sleeve joint, and the conductivity is doubtless less, but it is claimed that the line wire will break before the sleeve will allow the wires to pull out. It makes a neater joint than the McIntire sleeve, hardly being noticeable from the ground. Furthermore, in mending a break or joining cut wires, it does not require an extra piece of wire and two sleeve joints, one sleeve joint being all that is required.

56. Tie-Wrenches.—Iron, copper, and aluminum wires should be joined by means of steel **wrenches** or **connectors** instead of pliers. They can be better joined and with less damage to the wire in this way. Twisting clamps or wrenches are also used when joints are made with sleeve connectors. One of these wrenches is shown in Fig. 17. One size of wrench will make joints in wires Nos. 8 to 16; another in wires Nos. 4, 5, and 6. For making the ordinary

Western Union joints, wrenches are used similar to the one illustrated here, except that there is one oval-shaped hole instead of the two nearly complete circular holes shown in this figure.

MISCELLANEOUS DEVICES

57. Test Connectors.—On long toll lines, there should be **test connectors** at convenient places about 5 miles apart where the line can be readily opened without cutting it. The

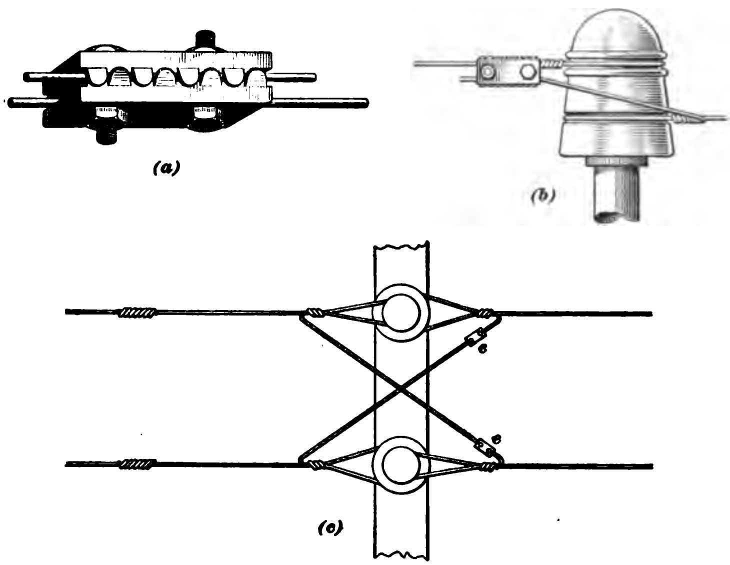


FIG. 18

Cook test connector is shown in Fig. 18 (*a*). A single line wire may have a test connector inserted in it, as shown in Fig. 18 (*b*), a transposition or two-groove insulator being used in place of an ordinary one-groove insulator. A complete metallic circuit may have test connectors inserted at a transposition, as shown at *e*, Fig. 18 (*c*). One end of some forms of connectors may be soldered to the end of one line wire to insure a better contact and the end of the other line wire held by the binding screws.

58. Slack Cutting Appliance.—It is often very desirable to maintain the continuity of a line when it is necessary to cut slack in or out of it. A simple way to do this is to have

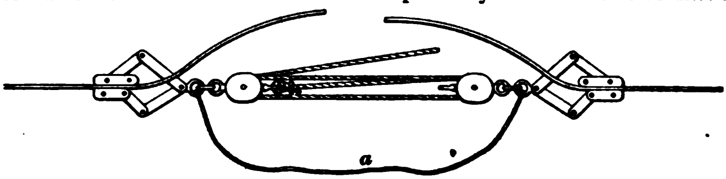


FIG. 19

a length of wire with a clamp of some kind soldered to each end, and when it is desired to open the line the wire is clamped around the point where the cut is to be made. In Fig. 19 is shown another method, in which a piece of flexible lamp cord *a* is soldered to each of the wire grips, thereby giving a circuit around the open point in the line.

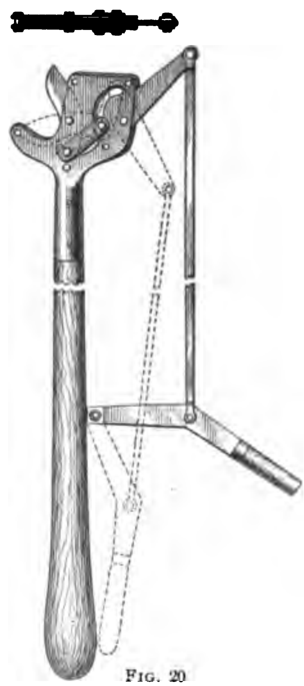


FIG. 20

59. Tree Trimmers.—No branches of trees should be allowed to rest, when either wet or dry, on the line wires. The permission of the owners of shade and ornamental trees should be secured before attempting to trim the trees, which should be trimmed neatly and carefully, and the branches cut off should be taken away. A good pair of tree trimmers, made by the Boyd Manufacturing Company, is shown in Fig. 20. The knife blade moves downwards in cutting the limb, so that the limb being cut does not bind the knife. Its manufacturers claim that it will cut a larger limb and that its leverage exceeds that of any other trimmer. It is stamped from sheet steel, is almost unbreakable, and will stand very rough treatment.

EXTRA STRONG LINES

60. In certain sections of the country, where severe sleet storms break down the poles and wires, causing great interruption to the service and heavy expense for repairs, the following construction has been suggested:

Two poles should be set where now one is used. The poles should be set 6 feet apart at the bottom, brought together and bolted firmly at the top, with a bolt ½ inch in diameter, with the nut on the end screwed up tight. The cross-arms should be fastened to both poles with ½-inch bolts with a nut on the end. One bolt in each cross-arm should be sufficient and no braces will be required. The poles should be further strengthened by braces bolted on diagonally to both poles. On heavy curves, the outside pole should have a guy down to an anchor of the same kind of wood as the pole, so their lives will be the same. The reason for guying the poles on curves to anchors is to prevent the poles from pulling out of the ground, as they frequently do when braced. When two poles are used, they need not be as heavy as when one pole is used. For instance, a single pole 7 inches at the top may be replaced by two poles 5½ inches at the top.

RECONSTRUCTION

61. In reconstructing a line, it is well, where it can be done, to set all new poles and anchors before handling the wires, as it gives the poles time to become settled before they are climbed, and also insures the presence of the foreman with all the men. If the party is divided, the foreman cannot watch both the setting of the poles and the handling of the wires. Where possible to do so, poles should be located so as to give room enough between them and any fence to carry a reel.

62. Pulling Up Poles.—Moving or resetting poles with a number of wires on them can be accomplished without removing the wires by using a roller 8 to 10 inches in diameter (made of a piece of old pole), a chain of $\frac{1}{2}$- or $\frac{5}{8}$-inch round links, and a couple of pulling bars. The chain is fastened around the pole and passed around the roller, which is used as a horizontal capstan. Then, with the bars inserted in holes previously made in the roller, turn the latter, having one man to hold the slack in the chain as it comes to him from the roller. The roller should lie close to the pole and is raised off the ground by placing it on two old cross-arms, or any pieces of timber that will keep it clear so that it can be readily turned by the bars. In this way, a large pole can be lifted with very little digging around it and it is much cheaper than taking the poles down, or attempting to pull them up with bars. It also avoids the damage to poles that the pulling bar causes if the poles are large or carry many wires. This is also a good plan when resetting a line of poles, as all the old stumps can be pulled out and the holes thus utilized at much less expense than digging new holes.

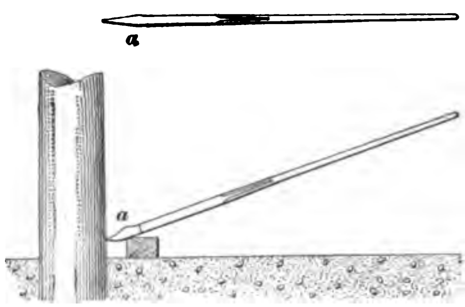


FIG. 21

63. The following method of pulling up poles is said to be superior to any other. Take an ordinary crowbar and have the end drawn out, shaped, and tempered as shown at *a* in Fig. 21. This figure also indicates how the pole is lifted out of the ground. Poles up to 70 feet in length have been pulled out in this way by using three crowbars, and have been moved ahead 15 feet without damaging the line wires.

64. The **handling of wires** on reconstruction has undergone many changes in late years. It is not now considered necessary to restring or pull the slack out of all wires when transferred from old to new poles; as a matter of fact, it is much better for the wires that it should not be done. It has been proved that wires too tightly drawn are a detriment rather than an advantage, and where they are no longer pulled tight, there are many less breaks and joints. The expense of handling wires on reconstruction is said to be reduced one-half where this plan is adopted.

65. Moving Wires Without Interrupting the Service.—When right of way permits, it is a good plan to locate a new line 10 feet away from the old one, as it facilitates the transfer of wires from the old to the new poles, and gives sufficient room to avoid a great amount of trouble with the wires, which is a matter of much importance in these days of busy wires, in both commercial and train service.

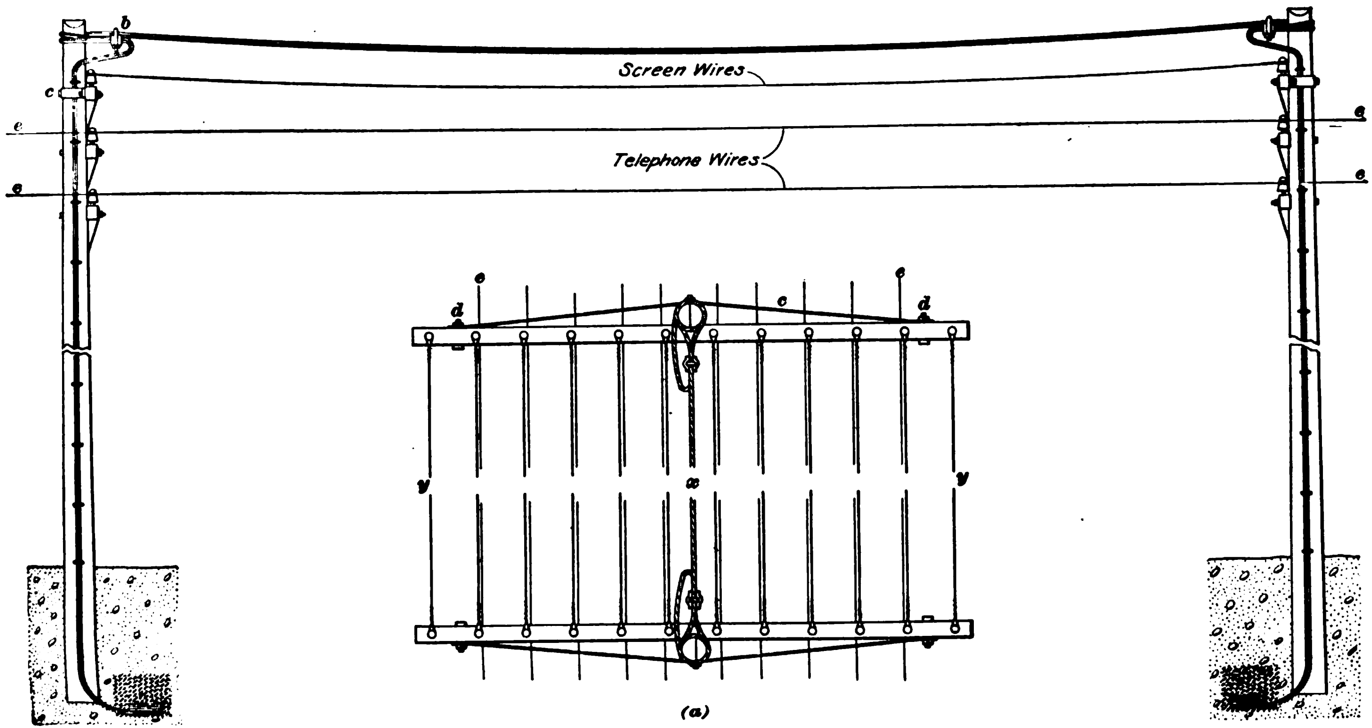
There are many lines where railway right of way is narrow, and two lines of poles must necessarily stand close together and often cross each other. In such cases, it is much better to use a cable, temporarily, and cut the line wires dead. Thus, they can be worked faster and the time gained will offset the labor of handling the cable. In many instances, it is impracticable to handle wires and operate them at the same time.

CROSSING OF HIGH-POTENTIAL AND TELEPHONE LINES

66. Although the running of telephone and electric light or power lines on the same poles should be avoided wherever it is possible, there are instances where such circuits have been carried on the same line of poles for miles, without unreasonable interference. And while it is true that linemen constantly climb among 600-volt wires without experiencing the slightest injury, it is dangerous for them and such construction should be avoided if possible. The crossing of two circuits of widely different character should be so constructed as to minimize the damage that might be caused by an accidental cross between them, and to so arrange the circuits that they will cause the least possible interference with each other. As the number of wires required for electric light or power circuits is usually less than that required for a telephone line and as such wires are always of larger diameter and consequently stronger, it is much preferable to carry them over the telephone lines. This method also secures much greater safety to the lineman, as he does not have to climb through the high-potential light or power circuits in order to repair the telephone lines, while the lineman, who has to repair the high-potential wires, runs practically no risk in climbing through the telephone wires.

67. Where high-potential lines cross telephone lines, both sets of poles should be firmly anchored, and the poles should be placed so close to each other, one pair of poles so much higher than the other, and the lines so arranged that if one of the higher line wires should break, it cannot touch any of the lower line wires as it falls. To provide sufficient strength, insulator pins at such crossings should be of galvanized iron or steel, and, in addition, the higher poles should be supplied with a guard made of a piece of galvanized angle iron, which is secured to the pole directly underneath the high-potential line wires and connected to the ground. The object of this guard is to catch the broken wire as it falls, and ground it before it can become crossed with the lower wires. The guard projects from the pole about 18 inches, being carried on brackets fastened to each side of the pole.

When a high-potential wire touches a grounded wire or guard first, so much current will flow that the circuit-breaker at the power station will probably open the line before any damage can be done to the telephone circuits. If this should fail, the current flowing in the high-potential wire will be so great as to practically lower the voltage of the high-potential circuit sufficiently to cause little or no damage should the wire come in contact with the telephone lines. Furthermore, the large current flowing would probably melt the high-potential wire and burn it off at such a height as to be incapable of touching the telephone line. Such melting usually takes place by the formation of an arc between the fallen high-potential wire and the grounded wire of angle-iron



(a)

Fig. 22

protection employed for that purpose. When a telephone wire falls on a high-potential line, the damage to the former will be much less if it makes a connection with a grounded guard wire before it touches the high-potential circuit.

68. Where the telephone and high-potential circuits must cross without much distance between them, the high-potential wires should cross above the telephone wires and protection afforded the latter by stretching above them, as shown in Fig. 22, a grounded iron or steel rope *x* of such a size as will safely carry at least three or four times the normal current of the high-potential circuit and to place between this grounded rope and the telephone wires, a metallic screen, as shown in the plan view (*a*), built of twelve No. 6 B. W. G. galvanized-iron wires *y*, *y*; this screen should extend 1 foot on each side of the telephone lines *e*, *e*, so that the screen wires will catch the falling wire and also tend to bring it into contact with the grounded iron or steel rope without touching the telephone wires. The twelve screen wires run horizontally and parallel with one another, each wire being dead-ended at each end on cross-arms fastened to the telephone poles, and also grounded at each end. The grounded iron or steel rope is securely fastened at each end by two wraps around the telephone poles above the screen wires and by the use of a standard guy clamp *b*. The value of this protection depends on grounding the steel rope well at each end, and too much care cannot be taken to make a good ground. There should also be a grounded cable below the high-potential wires to hold the taller poles so that all pull will come on this cable instead of on the high-potential wires. To provide a suitable ground, a hole should be excavated at the base of each pole, of sufficient depth to reach a permanently moist stratum of earth. In this hole, 2 or 3 bushels of coke or charcoal should be placed, the ground wire and steel rope being laid in or on this coke or charcoal in a zigzag manner and buried. Sufficient wire or steel rope should be laid in the hole to give a large contact surface, and this wire should never be placed in the ground in the

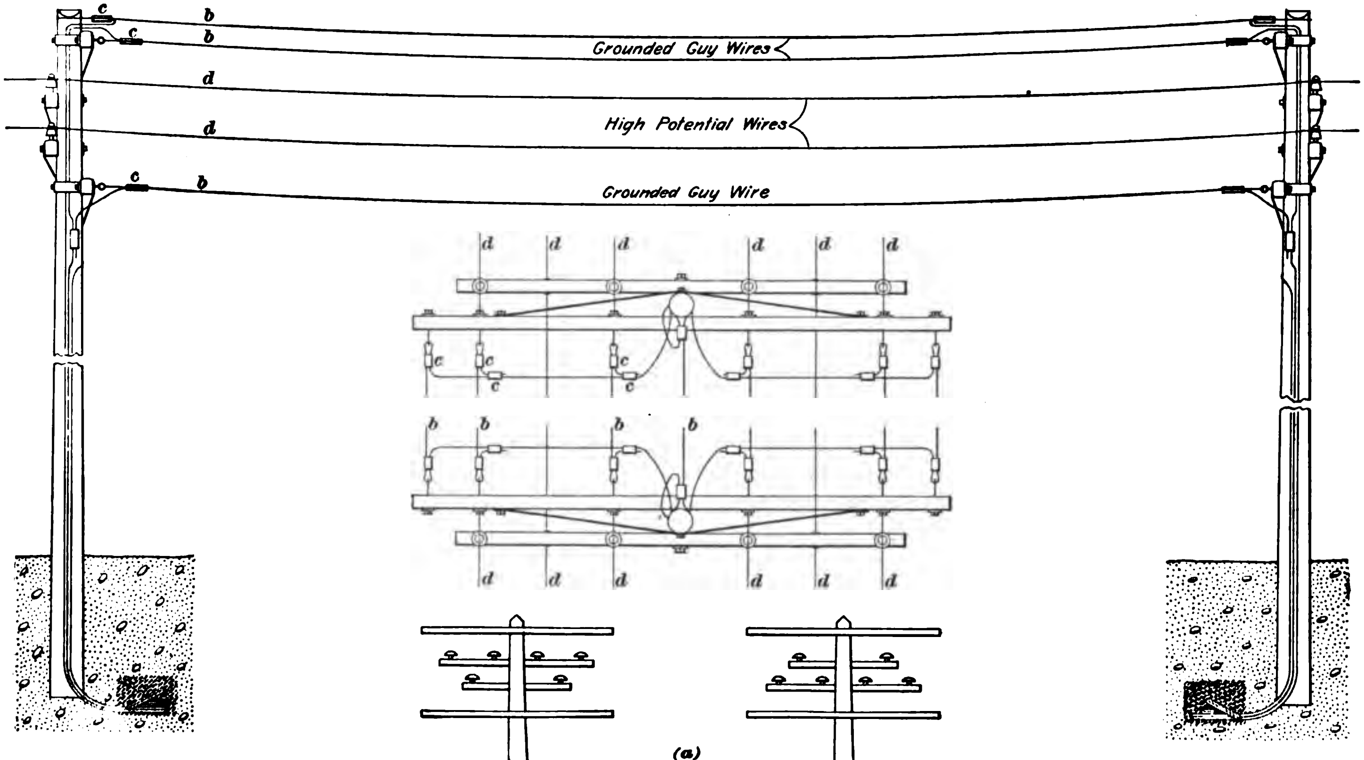

c
b
c
b
Grounded Guy Wires
d
High Potential Wires
d
c
b
Grounded Guy Wire
d
c
b
(a)

FIG. 23

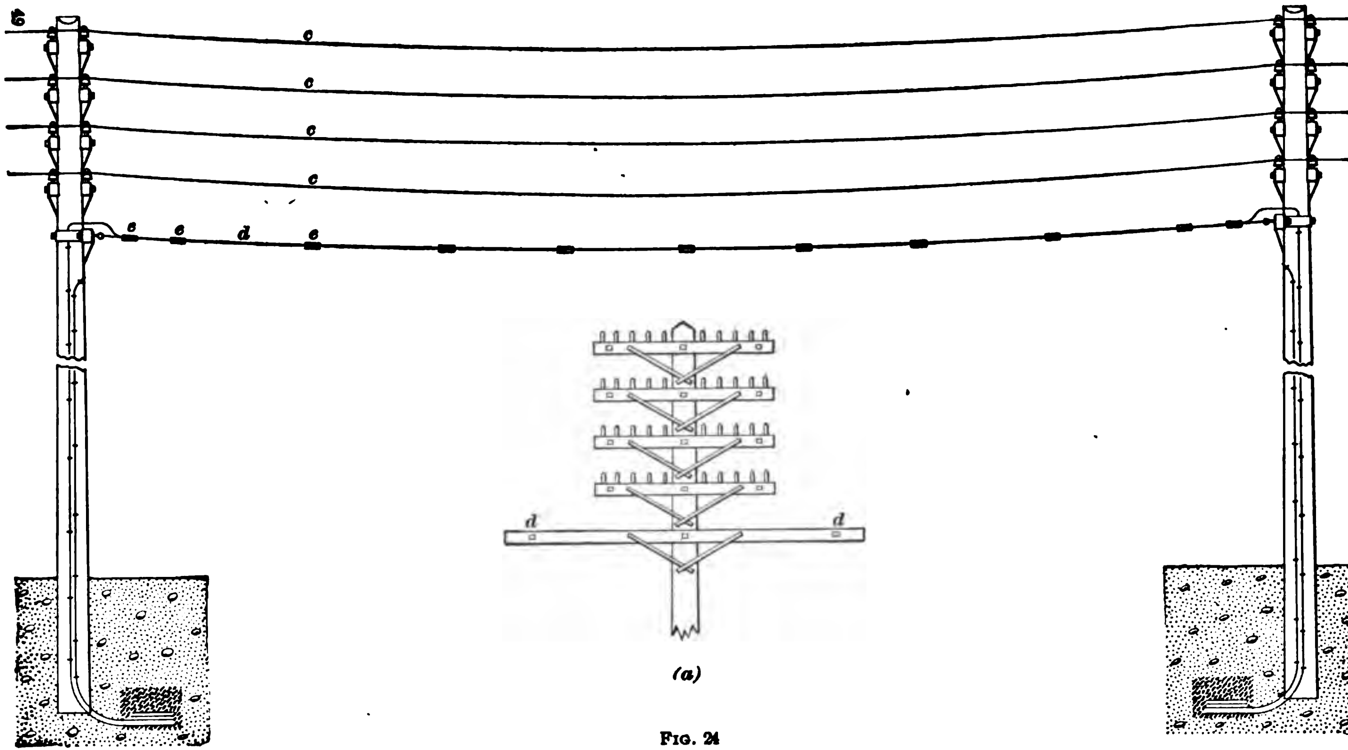


FIG. 24

form of a coil, as this presents considerable impedance, particularly in the case of a lightning discharge.

At the point of crossing, the span should be quite short and the spacing of the pins on the telephone cross-arm may also be reduced with advantage, so that a 6-foot cross-arm may be used for ten wires in place of the usual standard 10-foot arm. The screen-wire cross-arm is braced by a steel back brace *c* that is secured to the arm at *d* by means of a $\frac{5}{8}'' \times 6''$ galvanized, wrought-iron bolt, also a nut, and square washer.

69. In Fig. 23 is shown the arrangement of circuits and ground wires on the high-potential pole lines and in Fig. 24 the arrangement of lines and ground wires on the telephone poles, when the telephone lines must cross above the high-potential circuits. The arrangements shown here are the result of considerable experience and were given in the Electrical World and Engineer by R. A. Chetwood. In Fig. 23, the high-potential wires are shown at *d*, the steel guy ropes, which are grounded at each end, at *b* and the standard guy clamps at *c*. At (*a*) is shown the arrangement of the cross-arms on the high-potential poles.

In Fig. 24, the telephone line wires are shown at *c*. Between the two telephone poles are stretched two steel guy cables *d* grounded at each end. These are secured near the ends of an extra strong cross-arm. At regular intervals along these two guy ropes are placed standard guy clamps *e*, by means of which screen wires, running below and at right angles to the line wires, are secured. These screen wires will catch and ground any broken telephone line before it can come in contact with the high-potential wires that are below these screen wires. At (*a*) is shown the arrangement of the cross-arms on the telephone poles, and also the location of the grounded guy cables *d*.

OVERHEAD CABLE LINES

70. Where there is in a city an average of at least ten circuits on a pole line, it is usually more economical and presents a much better appearance to replace bare or insulated, twisted-pair, overhead, distributing wires with an aerial, lead-covered, dry-core, paper cable. Over two cross-arms or twenty bare wires are not allowed by some cities. The old distributing wires should be taken down and should not be used even to enable the use of fewer cable pole terminals placed farther apart. It is not economical to parallel cables with bare distributing wires strung on cross-arms or brackets. Enough cable terminals should be used to make the subscribers' loops short.

SUSPENSION OF CABLES

71. Messenger Wire.—Overhead cables are supported from a steel wire or rope stretched between the poles. These are termed **messenger, suspension, or carrier, wires,** and usually consist of several strands of steel wire twisted together to form a cable. Table XIV gives the weight per 100 feet and the estimated breaking strength of the various sizes of messenger wire from $\frac{3}{32}$ to $\frac{1}{2}$ inch in diameter.

For supporting heavier cables, containing one hundred wires or more, nothing less than a $\frac{1}{2}$-inch stranded rope should be used. For small cables, the $\frac{3}{8}$-inch or even $\frac{1}{4}$-inch messenger wires will prove sufficient, provided that the lengths of the spans are not excessive.

72. An aerial cable should be accessible throughout its entire length and the easiest way to reach the cable in the span is generally by means of a cable car. Therefore, the suspension, or messenger, wire for any cable should be strong enough to support a man on a car at any point in addition to the weight of the cable. The American Telephone and Telegraph Company requires the use of a $\frac{1}{2}$-inch wire rope, made up of seven strands of galvanized-steel wire, having an estimated breaking strength of 10,000 pounds, as a suspension wire for all lead-covered aerial cables. For, even if small-sized cables are put up, there is always the prob-

TABLE XIV

IRON-WIRE MESSENGER CABLE

Diameter Inches	Weight per 100 Feet Pounds	Estimated Breaking Strength Pounds
$\frac{1}{2}$	51	8,320
$\frac{15}{32}$	48	7,500
$\frac{7}{16}$	37	6,000
$\frac{3}{8}$	30	4,700
$\frac{5}{16}$	21	3,300
$\frac{9}{32}$	18	2,600
$\frac{17}{64}$	15	2,250
$\frac{1}{4}$	$11\frac{1}{2}$	1,750
$\frac{7}{32}$	$8\frac{3}{4}$	1,300
$\frac{3}{16}$	$6\frac{1}{2}$	1,000
$\frac{5}{32}$	$4\frac{1}{2}$	700
$\frac{9}{64}$	$3\frac{1}{2}$	525
$\frac{1}{8}$	$2\frac{1}{4}$	375
$\frac{3}{32}$	2	320

ability that they will be replaced by larger cables in the future, and it is advisable to use the suspension wire already up for the new cable.

FIG. 25

73. Messenger Supports. When but one cable is to occupy the poles and there is every probability that the future will not develop the need for more than two large cables during the life of the poles, the suspension wires should be attached by means of wrought-iron brackets, one type of which is shown in Fig. 25.

74. Cable Arms.—When two or more cables are to be erected, cable arms should be used. Cable arms may be made by bolting a piece of 3-inch angle iron directly to the pole. This may be of any length required, and should project on each side of the pole to a sufficient distance to give room for the desired number of cables. The messenger wire may be supported beneath the angle-iron cross-arm by means of hooks, or it may be passed directly through the cross-arm, slots being cut to the hole in such a manner as to allow the messenger wire to be readily slipped in and at the same time to prevent it from accidentally escaping.

75. The proper place on the poles for attaching a cable will depend on the use to be made of the poles for distributing wires. As a rule, the cable should be attached below the position to be occupied by the lowest cross-arm that may be required for distributing. This will necessitate leaving, in many instances, several unoccupied gains between the cable and the cross-arms placed on the poles at the time. In other cases, the cross-arm space may be limited so that the cable will be beneath the lowest existing cross-arm, and future space for distributing wires obtained by increasing the number of the intermediate terminals of the cable. If necessary, one cross-arm to the pole can be made to serve to distribute a large number of lines within a limited district by terminating a large enough cable a sufficient number of times.

76. Sag of Messenger Wire.—The messenger wire should be drawn up tightly by means of a block and tackle, and firmly anchored at its ends and at frequent intermediate points, so as to prevent any great length of it going down should a fracture occur at any point.

According to some authorities, the amount of sag that should be allowed when the cable is up is about 1 per cent. of the length of the span. That is, in a span of 100 feet, the sag at the center should be 1 foot; in a 150-foot span, 1.5 feet, and so on. In order not to exceed this, the messenger wire should not dip more than 2 or 4 inches before the cable is put up. As the strain on the messenger wire should not exceed 3,000 pounds, it is best to set the poles only 100 or 125 feet apart; then, as the wire and poles will give a little, the final strain will not exceed 2,000 pounds, even with rather heavy cables.

77. Table XV, taken from Roebling's handbook, will give the size of stranded iron-wire cable that should be used to support cables of various weights, per 1,000 feet, for spans of various lengths. In calculating the supporting capacity

TABLE XV

SUPPORTING CAPACITY OF ORDINARY GALVANIZED-IRON-WIRE STRANDED CABLE

Diameter of Stranded Cable Inches	Span, in Feet								
	100	110	120	125	130	140	150	175	200
	Weight, in Pounds, of 1,000 Feet of Cable That the Strands Will Support								
$\frac{1}{2}$	2,818	2,516	2,263	2,152	2,050	1,867	1,709	1,391	1,154
$\frac{15}{32}$	2,520	2,247	2,020	1,920	1,827	1,663	1,520	1,234	1,130
$\frac{7}{16}$	2,030	1,812	1,630	1,550	1,476	1,344	1,230	1,001	900
$\frac{3}{8}$	1,580	1,409	1,266	1,204	1,146	1,043	953	774	640
$\frac{5}{16}$	1,110	899	890	846	805	733	670	544	450
$\frac{9}{32}$	860	765	680	652	620	563	513	414	340
$\frac{1}{4}$	585	521	468	445	423	385	352	285	235
$\frac{7}{32}$	433	385	346	329	313	284	260	210	172
$\frac{3}{16}$	337	300	270	257	245	223	204	165	137

of the iron-wire cable, a dip of 1 per cent. of the length of the span and a factor of safety of 2 have been allowed. By a factor of safety of 2 is meant that the stranded iron cable is assumed to have only one-half the breaking strength given in Table XIV. Since the cables help in a great measure to carry their own weight, the stranded-wire cables will safely carry the loads given for them in the table. The weights of lead-covered and rubber-covered cables per 1,000 feet must be known in order to use this table for determining the size of the messenger wire and the span required for a certain cable.

78. It is seldom necessary to draw up a cable very tightly, thus placing an unnecessary strain on the poles.

TABLE XVI

SAG OF 60-PAIR CABLE AND TOTAL TENSION IN ¼-INCH SUSPENSION WIRE AT DIFFERENT TEMPERATURES

Temperature Degrees Fahrenheit	80-Foot Span		100-Foot Span		120-Foot Span		150-Foot Span		200-Foot Span	
	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds
− 20	6	4,000	9½	4,000	13½	4,000	21	4,000	37	4,000
0	6½	3,650	10	3,700	14½	3,700	22	3,750	39	3,800
20	7	3,300	11	3,400	15½	3,450	23½	3,500	41	3,600
40	8	3,000	12	3,100	16½	3,200	25	3,300	43	3,450
60	8½	2,700	13	2,850	16	2,950	27	3,100	45	3,300
80	9½	2,450	14	2,600	19½	2,750	28½	2,900	47	3,150
100	10½	2,200	15½	2,400	21	2,550	30	2,750	49	3,000

TABLE XVII

SAG OF 120-PAIR CABLE AND TOTAL TENSION IN ¼-INCH SUSPENSION WIRE AT DIFFERENT TEMPERATURES

Temperature	80-Foot Span		100-Foot Span		120-Foot Span		150-Foot Span		200-Foot Span	
Degrees Fahrenheit	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds	Sag Inches	Tension Pounds
− 20	8	4,000	13	4,000	18½	4,000	28½	4,000	51	4,000
0	9	3,700	13½	3,750	19½	3,800	30	3,800	53	3,900
20	9½	3,400	14½	3,500	20½	3,550	31½	3,650	54½	3,750
40	10½	3,150	15½	3,250	22	3,350	33	3,500	56½	3,600
60	11	2,900	16½	3,050	23	3,200	34½	3,300	58½	3,500
80	12	2,700	18	2,850	24½	3,000	36	3,200	60	3,400
100	13	2,500	19	2,700	26	2,850	37½	3,050	62	3,300

The sag given the cable should approximate, according to the directions for cable work of the American Telephone and Telegraph Company, as nearly as possible that given in Tables XVI and XVII, from which it will be seen that an extra amount of sag should be given to long spans. 25-, 30-, and 50-pair cables should have the same sag as a 60-pair cable; 90- and 100-pair, the same as 120-pair; and 150-pair should have 10 per cent. greater sag than 120-pair. The length of cable spans should not vary abruptly unless absolutely necessary.

Short spans with extra sag, as shown in the tables, should, wherever practicable, be made at the ends of the cable lead and at corners. If poles cannot be located to shorten the spans, the sag in the last spans should be increased as much as practicable, up to 80 per cent. greater than given in the tables, and the poles head-guyed.

79. Fastening the Ends of the Messenger Wire. The ends of the messenger wire must be securely fastened around the poles. It should be wrapped around the pole at least twice, and the end securely fastened to the straightaway portion by a clamp similar to that shown in Fig. 26. This

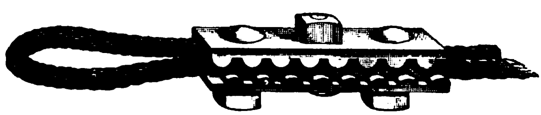


FIG. 26

particular three-bolt wire-cable clamp is made by Frank B. Cook of malleable-iron castings, thoroughly galvanized. In a test, a $\frac{3}{8}$-inch wire cable broke at 5,960 pounds without any slipping of the clamp. These clamps take any size strand from $\frac{3}{16}$ to $\frac{1}{2}$ inch.

As messenger wires and guys are apt to injuriously compress the pole, it is recommended that a heavy sheet of galvanized iron be put around the pole under the wires.

80. Equalizing the Tension.—After a cable has been strung, it is best to loosen the messenger fastenings temporarily along the cable line, in which spans do not vary over

20 or 30 feet, at all poles except at ends and corners and at poles making the end spans in which the sag does not follow that given in Tables XVI and XVII, thereby equalizing the tension along the spans.

81. Anchoring Poles.—In order to hold the messenger wire tight, the end poles must be firmly anchored to the ground. An end guy carried back three or four poles is not a good plan, because all the poles may give sufficient to not only produce slack in the messenger wire, but also in the line wires as well. An anchor log 12 feet long and 1 foot in diameter, buried 10 feet under the surface, has been known to sustain from six to eight cables, producing a strain on the anchor of at least 30,000 pounds. In this case, two anchor rods, $1\frac{1}{2}$ inches in diameter, were used. The anchor may be made still more secure by filling in around the log with concrete.

On intermediate poles, the only strain should be downwards; but they should be reasonably stout in case a pole should give and to withstand the lateral strain caused by storms.

82. End and Corner Poles.—End and corner poles must be held with guys and anchors. If the last span is reduced to 80 feet with the sag remaining at 16 inches, the strain may be reduced to about 2,000 pounds on each end of the span. The last pole of a 100-foot span will, therefore, have an excess strain one way that should be balanced by a head-guy from this pole to the end pole in the 80-foot span. The strain on the head-guy for each cable, if attached 10 feet from the ground, will approximate 1,200 pounds.

83. The guy wires should have double the strength of the messenger wire, in order to prevent the least yielding, and should be securely and permanently pulled up and fastened before the messenger wire is strung. The greater the horizontal distance from the pole to the anchor, the less will be the strain on the anchor and the guy wire. However, in cities, where it is necessary to consider the convenience of pedestrians, the anchor should not be placed very far from the base of the pole. A good way is to carry the messenger wire back to the next pole beyond the cable pole and there fasten it at a height of about 15 feet from the ground. A guy wire stretched between this point and an anchor placed at a horizontal distance of 10 feet from the pole will not be very objectionable. In anchoring poles, they should be given a slight rake toward the anchor, so that when the messenger wires and cables are up, the final strain will pull it up to a perpendicular position.

84. Pole Brace.—Where it is impossible to place an anchor or to use a guy, the pole may be braced as shown in Fig. 27. The brace *b* is set against the pole high enough to meet the dead-ended messenger wire *d*. The brace should be secured to the pole, so that it cannot possibly drift, by at least three lagscrews, and the messenger wire dead-ended below the meeting point, between the pole and the brace. As a further precaution, connect the pole and brace by a stranded or stout wire *c* about 5 feet below the top of the brace. Make sure, by means of lagscrews, staples, or otherwise, that this wire cannot slip on either the pole or the brace. The pole should be set securely in the ground, or there may be a tendency for it to rise.

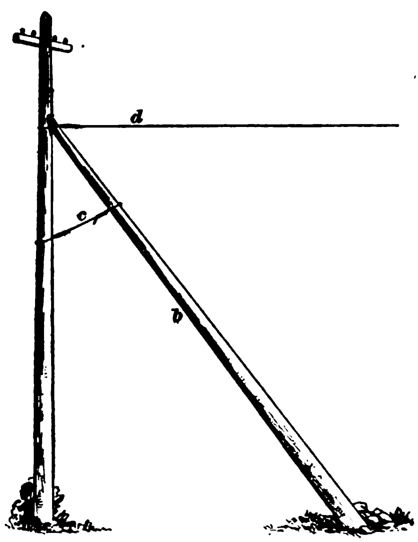


FIG. 27

85. Guy Stubs.—When it is not possible to anchor a rod issuing from the ground at the proper distance from the pole, a **guy stub** should be used, but such guy stub should always be anchored when practicable. The guy stub, being shorter than the pole, can have the anchor placed nearer to it but forming an angle of at least 45°.

Stubs, end poles, and corner poles should be selected from the heaviest and best poles, and may be set in concrete on important work.

86. Iron Poles.—When impracticable to locate a guy rod issuing from the ground, an iron pole of special construction can be set, which will safely hold the strain from four cables, but this must be used only when all efforts to set a rod or rod and guy stub have failed. An iron pole must be set in concrete.

87. Secure Poles Together.—A lead of poles holding the cable should be tied together thoroughly by securing the messenger wire to each pole and by means of guy wires.

88. Head-Guying of Cable Poles.—If a line of poles continues beyond the end of the cable, the strain for a reasonable weight of cables can be taken up by head-guys continuing along the pole lead, practically forming extensions of the messenger wires, provided that such guys extend downwards gradually so as to approximate a straight pull against the end strain of the cables distributed on the several poles. This is based on the fact that the further back from the foot of the pole a guy leading to the ground is secured, the less the extra strain placed on each guy. It is seldom economical, however, to continue head-guys for several cables along a lead for sufficient distance to furnish security; and even when the conditions are favorable for such work, it is generally safer and cheaper to take the head-guys for two or more cables for three or four spans only and secure against the balance of the strain by several auxiliary head-guys, or by anchoring one of the poles. Unusually long cable spans should be head-guyed at both ends.

89. Anchors for Cable Poles.—The best and safest anchor is an iron rod issuing from the ground and attached to a buried framework of sound cedar or oak. Such a rod should be in one piece and should issue from the ground a sufficient distance to allow the attachments of the wire rope to be above the point where damage might occur by persons coming against such attachments in locations where accidents are likely to occur. Turnbuckles or screw connections should not be used as they weaken the rod.

Anchor rods should be placed as far away from the poles they hold as practicable. This distance should always be so far as to form an angle of 45° or more with the pole.

An anchor rod made of $1\frac{1}{2}$-inch round iron should safely hold the strain at the end of a lead of four cables with an 80-foot span with a head-guy in said span. The strain on the anchor rod when placed at an angle of 45° or more will be about 15,000 pounds for four cables and the margin of safety is sufficient to withstand extra strains during construction and the wind pressure.

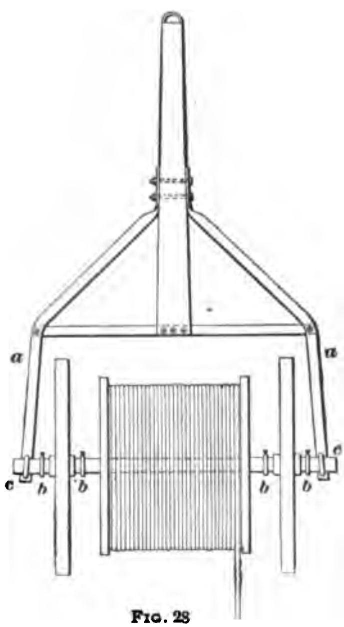


FIG. 28

90. Handling a Cable. It will hardly do to roll a cable reel over the ground to the place where it is needed, and it takes a great deal of muscle as well as time to load it on a truck and to unload it again; therefore, the following method, used by a prominent construction company, is one of the most convenient. The cable reel is supported by an arrangement shown in Fig. 28, which consists primarily of a large pair of wheels, a 2-inch round steel axle, and a frame of strap iron 2 in. × $\frac{1}{2}$ in. *a*, *a* to which a short wagon tongue has been attached. The strap-iron frame is attached to the axle by means of two **U** bolts *c*, *c*. Four collars *b*, *b*, *b*, *b* with set-screws keep the wheels, which work loosely on the axle, in their proper position.

To load the reel, loosen up the **U** bolts *c*, *c* on the end of the axle, and the collars *b*, *b*, *b*, *b*, and remove the wheels. Then slip the axle through the cable reel and run the cable up an incline until it is high enough to allow the wheels to go on again. Put the wheels and collars on the axle, roll it off the incline to the ground, put on the frame, hitch it to a truck, take it to the place where it is needed, and there unhitch it from the truck, block the wheels, and open up the reel.

By many construction engineers, **cable jacks** are much preferred to the wheel arrangement shown in this figure. An axle is passed through the cable reel and with a jack on each side the cable can be easily raised and held off the ground. Jacks can be used in almost any position and the ground need not be level and they can be used to raise any ordinary size reels.

91. Cable Hangers.—Lead-covered cables are sometimes supported from the messenger wire by means of **cable hangers,** secured to the cable usually at intervals of 18 to 24 inches. Although this is not generally considered the best method for supporting cables, it is considerably used. For small light cables, the hooks need not be placed closer together than 30 inches. There are several styles on the market, some of which are made of sheet metal and others of malleable iron. In spite of all precautions, a hanger will sometimes catch, in which case the sheet-metal hangers will generally give way, but the solid hanger has often been known to hold on and seriously injure the cable before the signal to stop could be passed along. For this reason, the malleable or solid iron hangers are not recommended.

92. Malleable-Iron Hangers.—The hanger shown in Fig. 29 is composed of malleable iron, and is readily clamped on the cable by a special tool designed for the purpose. This tool and the method of using it in clamping a hanger to a cable is shown in Fig. 30. The broad band of the hanger is slipped over the cable at the desired point, and the tongs are then applied, as shown, thus squeezing the band of the hanger around the cable until the gap is entirely closed.

It is well, although not strictly necessary, to provide a piece of thin sheet lead about 1½ inches wide and long enough to almost encircle the cable, and to clamp this on under the hanger. This serves as an additional protection

FIG. 29

FIG. 30

to the cable sheath, which is especially desirable where the sheath is extra light.

93. Hold-Fast, or Boston, Cable Clip.—The **hold-fast, or Boston, cable clip,** as it is variously termed, illustrated in Fig. 31, is quickly and easily applied by hand. The metal strap is simply drawn around the cable and passed through the hanger; the part with the hooks is then turned up, as shown in the illustration, which action takes up the slack, binds the strap tightly about the cable, and prevents the latter from slipping. All parts are made of galvanized steel, so that they will not rust. This clip can be removed and used again.

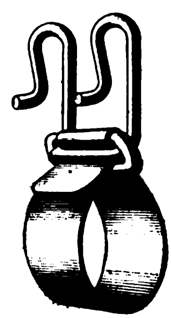


FIG. 31

94. Marline Cable Hanger.—The most common form of **marline cable hanger,** which is considerably used, consists, as shown at *a* in Fig. 32, of a galvanized-iron hook to which the cable is secured by a slip nose made of marline twine. Well-tarred marline will last nearly as long as the cable. There is very little tendency for the marline to slip out of the hook, and the device is one of the cheapest and most quickly applied. Where desirable, it also affords a means of insulating the sheath fairly well from the messenger wire. After the hooks are placed over the messenger wire, they should be closed up with pliers to prevent unhooking.

At *b* is shown the Swisher marline hanger, for which is claimed greater strength, that the hook can not straighten under stress and let the cable down, that the hook cannot

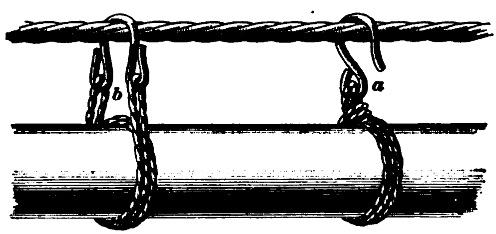


Fig. 32

become detached from the messenger wire, and that in stringing wires above the cable, sagging wires cannot catch under the hook as in form *a*. Marline hangers are usually placed about 18 inches apart.

CABLE STRINGING

95. When the messenger wire is in place and pulled up to the proper tension, a *leading-up wire* of the same material as the messenger wire should be secured to the end of the messenger wire and to a stake or other suitable anchor in the ground, at a distance of 75 or 100 feet from the last pole in the stretch. An anchored guy wire, where there happens to be one, can sometimes be used for this purpose. The reel on which the cable is wound should then be placed a few feet beyond the lower end of the leading-up wire, as shown in Fig. 33, and in such a manner that the cable will unwind from the top side of the reel rather than from the bottom. It is well to use a large wooden pulley at the first pole just below the messenger wire for the cable to run on.

96. For drawing along the cable, a rope is first suspended directly under the cross-arms on the poles for the entire length of the stretch to be strung. A ½-inch hemp rope, or preferably a 1-inch rope, may be used, but a ¼-inch steel-stranded cable will prove more convenient. One end of this rope is attached to a swivel and the swivel to the end of the cable by means of a lash rope; while the other end of the rope is secured to a capstan or windlass at the

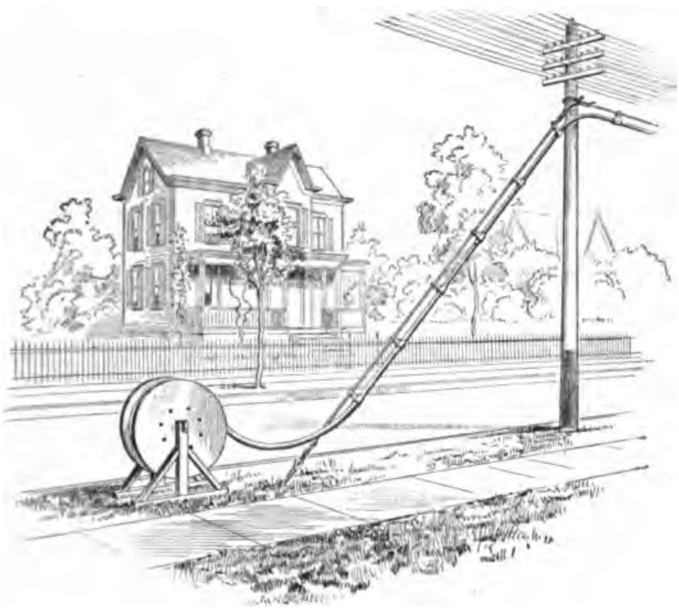


FIG. 38

distant end of the stretch. If no capstan can be obtained, a set of large pulley blocks and a long rope with a horse hitched to it may be used. The cable should not be pulled faster than 10 to 15 feet a minute when hangers are used, for they cannot be attached if the cable travels at a faster rate. To help the rope around a corner, two snatch blocks should be used.

97. Fastening Rope to Cable.—For fastening a rope to a cable, A. E. Dobbs, in the Telephone Magazine, gives the following methods: The end of the rope is frayed out, braided around the cable, the end lashed down with marline twine, and the fastening finished by a series of half-stitches, as shown in Fig. 34. This method generally holds, but, if the pull is a long and hard one, as it is apt to be if an attempt is made to string up 1,000 feet of cable, the lead

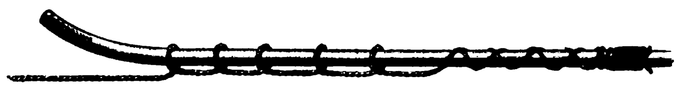


FIG. 34

may creep and break or even pull off altogether. In order to prevent this, the plan shown in Fig. 35 is sometimes used. The end of the cable is bent back and one or more hitches taken at the bend. This method puts the strain on the wires

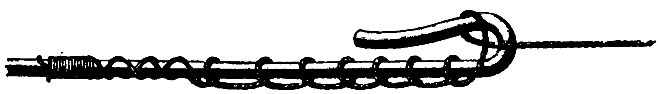


FIG. 35

inside the cable. It is, of course, taken for granted that 3 or 4 feet of the lead at the end of the cable will be thrown away.

Another method, sometimes used on aerial, and more often on underground, cables, is shown in Fig. 36. This

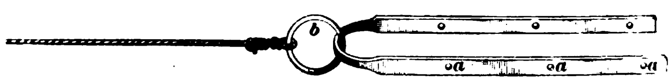


FIG. 36

consists of a concave clamp made to fit over the end of the cable. Through the holes *a*, *a*, *a*, rivets or screws are driven into the cable in order to hold the clamp in place. The cable is pulled along by means of a rope fastened to the ring *b*.

98. Gem Wire Grips.—In Fig. 37 are shown three types of gem wire grips made by C. J. Mullin. The single-eye grip, shown at (*a*), is used to slip over and grip the end of a cable; the double-eye grip, shown at (*b*), slips over and grips a cable at any place along its length; the split grip, shown at (*c*), also grips a cable at any place along its length but is split lengthwise so that it may be placed around a cable at any point and laced tight, as it does not have to be slipped on from one end of the cable, like the one shown at (*b*). These grips are said to be extensively used. The greater the pull on the eye or eyes of the grips the more securely do they grip the cable.

99. One man is needed to turn the reel and mark the cable where the hangers are to be put on. As the cable leaves the reel, the hangers are attached to it by one or two men, the cable being drawn slowly enough to allow this to be properly done. Another man hooks the hangers on the leading-up wire as the cable begins its ascent. Two men at the first pole put the cable on the pulley and unhook and hook on the hangers as they pass the pole to which the messenger wire is fastened. A man stationed on each pole lifts the hangers around the support or cross-arm as the cable proceeds. Usually two men are required to turn the windlass and one man to attend to the rope.

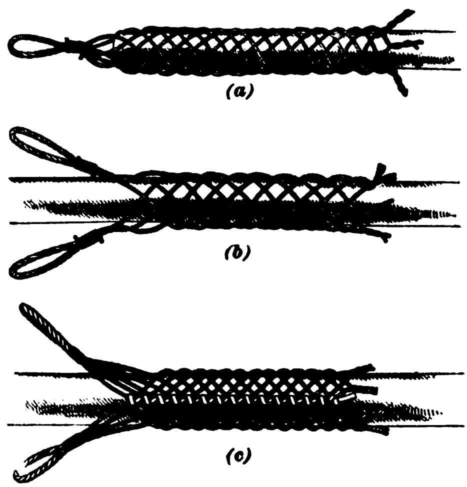


FIG. 37

It is not necessary to attach every hanger to the messenger wire during the process of drawing up, and in order to save labor on the part of the men and facilitate the work, it is well to attach only every fourth or fifth hanger. This method may be followed until the forward end of the cable reaches the last span in the stretch, when a signal should be given for the man on each pole to hook every hanger on the messenger wire as it passes. By this means, the entire cable will be hooked up when it reaches its destination.

Some claim that aerial cables can be put up more quickly and cheaper by the use of snatch or pulley blocks than by sliding the cable along carrier wires by the method just given. Thus the passing of the cable hangers around the pole fastenings of the carrier wire is avoided.

100. An improvement on the method just given of drawing up cables is frequently followed where a large amount of cable is to be erected. This method is used extensively by the Standard Underground Cable Company, by whom it was developed. The hangers are attached to the cable in the usual way, but these are not hooked over the messenger wire during the process of drawing up. Instead of this, the cable rests in carriers, shown in Fig. 38, each consisting of a grooved wheel *A*, pivoted to a supporting stirrup *C*. The grooved wheel rests on the messenger wire, while the cable carrying the hangers is supported in the stirrup beneath. These carriers are applied at intervals of from 10 to 15 feet, and serve to support the cable while it is being drawn over the messenger wire. In order to make it unnecessary to remove the carriers from the messenger wire as they pass a cross-arm or support, switches or side tracks are clamped on the messenger wire at each cross-arm. These serve to engage the wheel of the carriers and guide them down under the cross-arm and again up on the other side and back on to the messenger wire. These switches are so made as to be readily bolted to the messenger wire. When the cable is all pulled up except the last section, men stationed at each pole place the hangers on the wires and remove the carriers as they pass, so that when the last section is pulled into position, all hangers are in place; the switches, or side tracks, are then removed, leaving the cable permanently suspended.

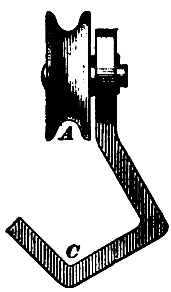


FIG. 38

101. The following method for stringing and holding up an aerial cable is said to be superior to the preceding ones. In this, a special cable carrier [shown at (*b*) in Fig. 39],

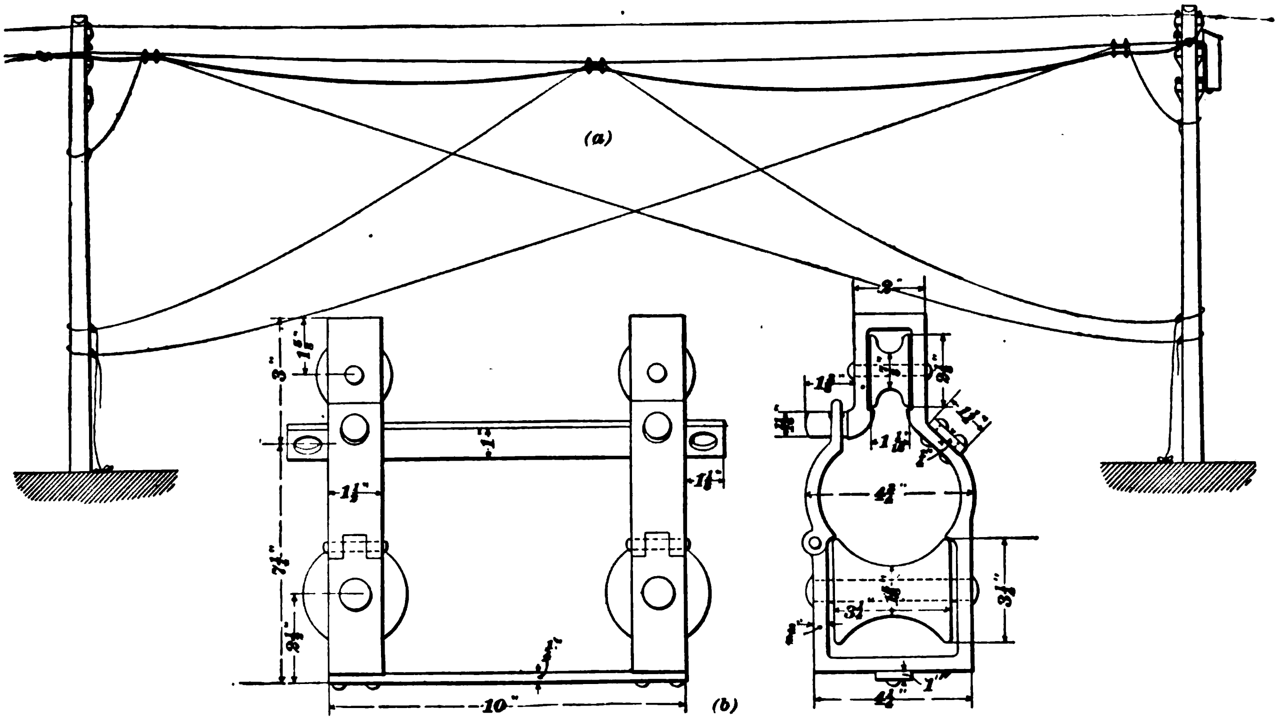


FIG. 39

consisting of four grooved wheels and a wrought-iron framework, is used. Two small wheels, fastened in line with each other, in order that they can either run along or rest on the messenger wire, support both the carrier itself and the cable. Two larger wheels, with grooves larger than the diameter of the largest cable, are in line with each other and directly under the former two. As the cable is drawn along over the two large wheels, the latter revolve. All four wheels are in the same plane and are fixed in position, but revolve freely. These carriers are readily slipped over the wires, but when the two side bars are closed, the cable cannot fall from the carrier nor the carrier from the messenger wire. One carrier is placed on each side of and near to each pole, and one or more between, depending on the length of the span and the weight of the cable. They are held in position by two ropes fastened to the poles, often near to the ground, one on each side of the carrier, so that the carriers will not move when the cable is drawn through them. By placing one on each side of a corner pole, the cable can be pulled around the corner without difficulty. After the cable has been strung and fastened to the messenger wire, the carriers can be drawn to the nearest pole and removed.

102. Chinnock Cable Winder.—Many consider that the best way to support the cable from the messenger wire is by wrapping the cable and messenger wire with strong marline rope or twine, as shown in Fig. 40. The cable is drawn up to the supporting wire and wrapped to it with the marline by means of the **Chinnock cable winder,** commonly called the "spinning-jenny." This device consists of a bobbin, made in halves with a hole through the center large enough to allow the cable and supporting wire to pass through it; (*a*) is a sectional and (*b*) an end view of the winder. The inside of the bobbin is lined with copper, to make it smooth and wear well.

To use the device, place the halves of the bobbin over the cable and supporting wire, fasten them together by the hooks or other means provided, and wrap on enough marline to support the cable between two poles. Fasten one end of the marline at one pole. Then, by pulling the bobbin along by means of a rope *d* attached to the projecting hook *c*, the bobbin draws the cable up close to the wire, pushes before it the slack of the cable, and the marline twine twists itself spirally around the cable and supporting wire. When it reaches a support, the bobbin must be removed, replaced on the other side of the support, and again wound with marline. Sometimes two wrappings of marline are used, in order to make the cable more secure, requiring the process above described to be repeated between supports. It is well to use the best quality of three-ply marline or hambroline, greased with raw tallow before winding it on the jenny.

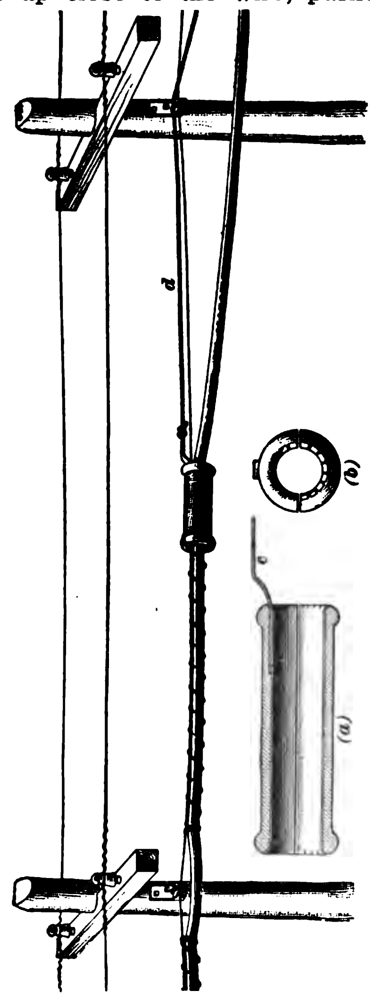


FIG. 40

The spinning of cables holds them up better than the method of hooking them to the carrier wire. The marline when worn out can easily be removed and new marline spun on by men working on the poles, without the use of ladders or a carriage of some sort that will carry a man along the messenger wire, which are necessary when hooks have to be replaced.

103. Cables should be ordered from the factory in certain specified lengths, and these lengths should be so proportioned that the joints will come if possible at the poles and not in the middle of the spans. It is always well to allow a few feet of slack in each section of cable, in order to allow room in the future for making necessary splices as repairs are needed.

104. Fastening Cable Joints to Messenger Wires. All cable joints should be securely fastened to the messenger wire at the middle and on each side of the joint as follows: Wrap the cable and the messenger wire at each point to be fastened with a piece of sheet lead $\frac{3}{32}$ inch thick and 5 or more inches long, and bind around this lead covering tightly and securely No. 12 B. & S., soft-drawn, copper wire. This is to prevent any strain from the movement of poles coming on the joint.

105. Turning a Corner Where There is No Pole. Where it is desirable to turn a cable around a corner where there is no pole, the arrangement indicated in Fig. 41 may be used. The cable is bent to the smallest possible radius and cable clips *d*, *e* are attached as near the bend as possible. At the bend are two three-bolt clamps *c* at right angles to each other and with a 3″ × ½″ bolt passing through the center of both clamps. The ends of the messenger wires *a*, *b* are dead-ended at the next pole.

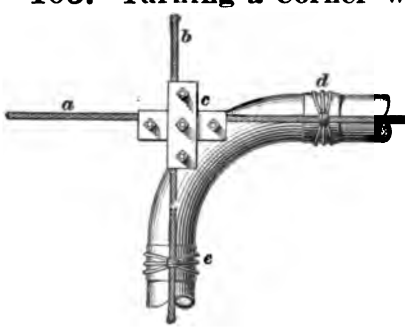


FIG. 41

106. Aerial Conduit.—Where for any reason it does not seem advisable to use underground or overhead lead-covered cables and yet bare-wire construction is objectionable, perhaps on account of numerous trees or for the sake of appearance, the so-called **aerial conduit** is considerably used. As shown in Fig. 42, this system consists of a suitable messenger wire *a* clamped to poles and equipped with metal rings *b*, which are clamped to the messenger wire by means of special pliers. The rings are about $1\frac{3}{4}$ inches in diameter, and are made of corrugated and galvanized steel. This arrangement forms a path or conduit through which insulated twisted pairs of wires may be drawn. Later, a lead-covered cable may be run in place of the insulated pairs, or both a lead-covered cable and a few pairs of insulated wires may be run in the same aerial conduit. At *c* is shown the way to run a twisted pair to a house. Bridle wires may be drawn into the conduit, one or more pairs at a time as needed, and distributed from a pole terminal to any house along the conduit by a direct run without joints.

The rings may be fastened to the messenger wire while on the ground or from a carriage or ladder. The insulated pairs

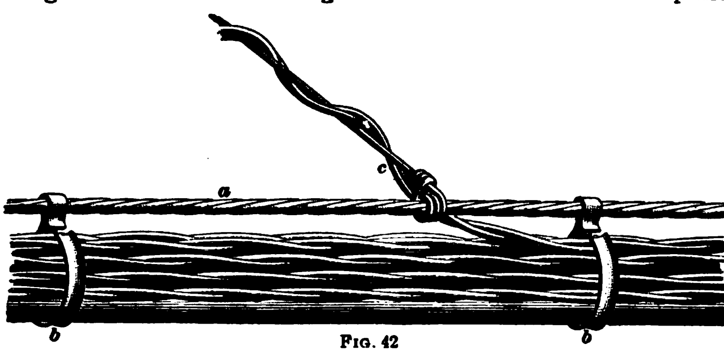


FIG. 42

are run through the rings at any time by a man who rides in a carriage, which is a seat suspended on rollers from the messenger wire. It is also quite common to use a single steel wire of sufficient size in place of the stranded messenger wire shown. With this system, it is claimed that long spans, short poles, and smaller-sized service wires, which are subject to less mechanical stresses, may be used.

It is said to be economical to distribute service wires from cable terminals in this manner to houses within 1,000 feet of aerial-cable routes. Where the distance exceeds 1,000 feet and where there are no obstructions, it is probably more economical to use No. 14 N. B. S. (diameter = 80 mils) bare copper wire placed on cross-arms, the loop to the house being made with insulated twisted pairs.

107. Pole Balconies.—Where an aerial-cable line ends for the purpose of connecting with an underground line or with bare overhead wires or where an underground cable terminates for the purpose of connecting with overhead lines of bare wire, suitable cable terminals should be provided on the pole and enclosed in a waterproof box. In order to facilitate the work of making connections and the subsequent testing out of lines, a balcony should be built below the box containing the terminals. A pole thus equipped is shown in Fig. 43.

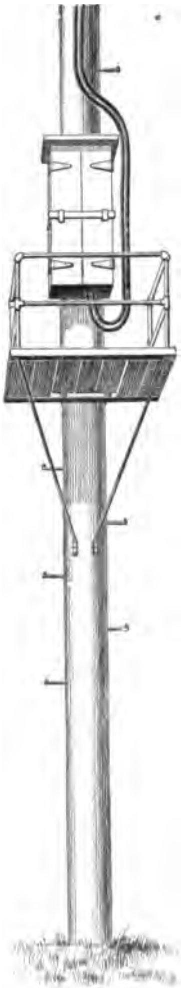


FIG. 43

108. Pole boxes should preferably be made of well-seasoned cypress or long-leaved yellow pine; all joints should be filled with pure white lead before the box is put together; the bottom of the box should be separate, fastened with screws, and rubber weather strips used to make it fit tightly to the box. The outside of the box should be painted with two coats of white paint and the inside with two coats of a fire-proof paint. The box should be fastened to two cross-arms with four machine bolts, about 6 inches long, with round washers under each head and nut. Where there are no cross-arms, the box must be securely fastened to the pole. Holes in a cable box not occupied with cables or wires should be covered with sheet lead tacked on the inside. All cracks and holes should be closed so that the box may be weather proof.

109. To support cables in a vertical shaft, it is only necessary to make a proper bend at the bottom, remove the supports at the top, and allow the cable to settle; it will settle probably 1 inch and then stand on its own end. There is no need of any support to hold the cable up; it should be secured, however, in an approximately vertical position against the wall of the shaft.

110. Carrying a Lead-Covered Cable Over a Bridge.—When a lead-covered cable is run from a messenger wire suspended under or over a bridge, the vibration of the bridge usually causes the lead sheath to break in from $1\frac{1}{2}$ to 2 years. Where the vibrations are severe, the placing of springs between the cable and the point of suspension only puts the trouble off a little longer, and the best plan is to place the cable in a wooden trough on the bridge. For carrying telephone cables across the Brooklyn bridge, the method shown in Fig. 44 was successful, whereas marline hangers previously used caused constant trouble due to cracking of the lead sheaths.

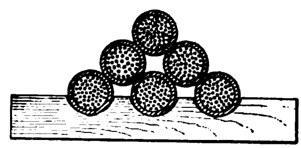


FIG. 44

Some claim that a special hanger with rubber cushions will remedy the trouble, and marline twine hangers are better than hangers made entirely of metal.

TELEPHONE-LINE CONSTRUCTION

(PART 3)

UNDERGROUND CABLE LINES

CONDUITS

KINDS OF DUCTS

1. Underground construction work is becoming of more and more importance, for the increasing number of uses to which electricity is put renders the number of circuits in city streets so numerous as to be a constant menace to both life and property when placed overhead. Besides this, their appearance is, to say the least, unsightly, which is in itself a sufficient reason for the city authorities to demand their being placed underground. Another strong argument in favor of placing wires underground is that they are not liable to injury from storms or fires, and that the cost of maintenance of the plant, when once properly installed, is less than if the wires were placed overhead.

It seems best to limit the number of wires carried on pole lines to about 400 pair; above this limit, the distribution should be made underground. It is, therefore, economical to extend conduit systems, not only throughout the business portion of a city, but also along what may be termed **feeder routes** throughout residence sections. Some companies aim to always use and some telephone companies require the use of aerial or underground cables where more than two cross-arms or about twenty bare wires would otherwise be used on a pole line.

2. It is almost universal practice in the United States to place underground cables in conduits. In some places in Europe, cables have been laid directly in trenches, which are afterwards filled up, thus leaving the cable permanently buried. This practice is followed but little in the United States, it having several disadvantages, chief among which are the difficulty of access to the cable for the purpose of repairing faults, the liability of the cable to injury from chemical action due to moisture and other elements in the soil, and the liability to mechanical injury from the pickaxes of workmen.

3. Open-Box Conduit.—The first conduit used in the United States consisted of a wooden box or trough, made from $1\frac{1}{2}$-inch rough lumber and large enough to contain all the cables needed. After digging the trench, the bottom is approximately leveled to grade, after which the trough, open at the top, is laid, the various sections being butt-ended and held in alinement by a short strip of board nailed along one side and lapping over the joint for a distance of about 1 foot on each side. After the conduit is laid, the reel containing the cable is mounted on wheels and drawn alongside the trench, the cable being unreeled and carefully laid in the bottom of the box as it proceeds. When all the cables have been laid, the box is filled with hot pitch, melted in any convenient manner, preferably in a wagon similar to that used for the same purpose in asphalting streets. The cover of the box is then nailed on and the trench refilled. The highest points in the conduit should be left open for some days, so as to provide means for pouring in additional pitch to make up for the room left by settling.

4. Cables laid in this manner have given very good satisfaction, and the method is, to say the least, an inexpensive one. It is, however, subject to one very serious difficulty, and that is due to the inability to make subsequent extensions and repairs. It is almost impossible to predict, at the beginning of the work, the number of circuits that will be required in a given line of cable; and, moreover, to install as great a number as may be needed in the future involves a greater expense than most companies desire to bear at the outset. Forms of conduit have, therefore, come into general use that allow an extension of the cable system to meet the subsequent growth of the exchange.

5. **Flexible Conduit Systems.**—The conduits may be of either wood, clay, iron, artificial stone, or impregnated paper, and are usually provided with a number of ducts extending as nearly as possible in straight lines between manholes, in such manner as to allow the cable to be drawn in or out, as desired, with but very little trouble. Systems of this kind may be classified under the heading of **flexible conduit systems,** the term referring to the possibility of making changes in the arrangements and numbers of cables rather than to the possibility of actually bending the conduits themselves. Conduits that can be readily built along curves or around obstructions are also said to be flexible; the single short-length ducts are usually the most flexible in this respect also.

6. **Creosoted Wood Conduit.**—A form of conduit largely employed, and one having the advantage of being very cheap to install, is composed of sections of wooden tube, the fiber of the wood being impregnated with creosote, in order to prevent its decay. This form of conduit is commonly known as **pump-log conduit,** on account of the resemblance of the wooden sections to the ordinary form of wooden pump logs. A section of this conduit is shown in Fig. 1, the ends being doweled in order to preserve the proper alinement in joining. These sections are usually 8 feet in length, and have circular holes through their centers from $1\frac{1}{2}$ to 3 inches in diameter, according to

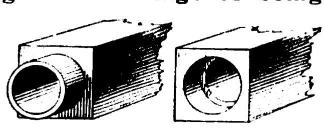


FIG. 1

the size of cable to be drawn in. In the case of a tube having a 3-inch internal diameter the external cross-section is square and $4\frac{1}{2}$ inches on the side. Such a conduit as this, if properly impregnated with creosote, will probably have a life of from 15 to 20 years, and perhaps much longer, this point being one concerning which there is considerable argument, and which probably time alone will decide.

7. In laying a pump-log conduit, a trench is usually dug several inches wider than the number of ducts to be laid side by side require, and after properly grading the bottom of the trench, a 2-inch creosoted plank is laid throughout its length for a foundation. The conduits are then laid in as many

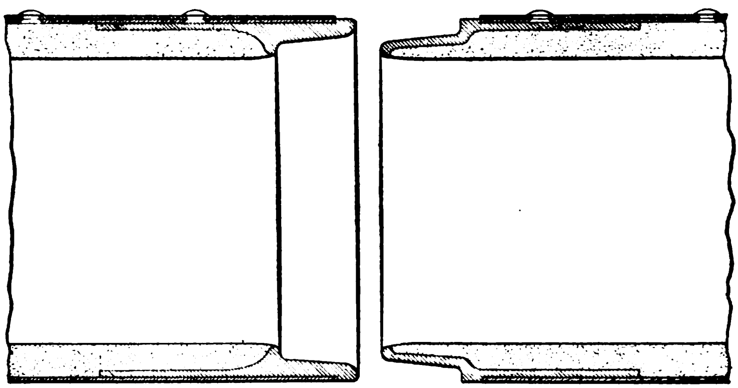


FIG. 2

layers as are required, the ends being merely butted together without further precaution for securing perfect joints. In laying the tubes, however, the joints between the different layers should be broken, that is, overlapped, as much as possible, in order to give greater strength to the structure. The sides of the trench are filled in and thoroughly tamped as the work progresses, and after the required number of ducts are in place, another 2-inch creosoted plank is placed above them, after which the trench is filled in and the pavement relaid.

8. Cement-Lined Pipe Conduit.—The **cement-lined conduit** made by the National Conduit and Cable Company, is shown in Fig. 2. The sections are usually 8 feet long and are made as follows: A tube is made of thin wrought iron, No. 26 B. W. G., .018 inch thick, and securely held by rivets 2 inches apart. The tube is then lined with a wall of Rosendale cement $\frac{5}{8}$ inch thick, the inner surface of which is polished while drying, so as to form a perfectly smooth tube. This comes in three sizes, each having a length of

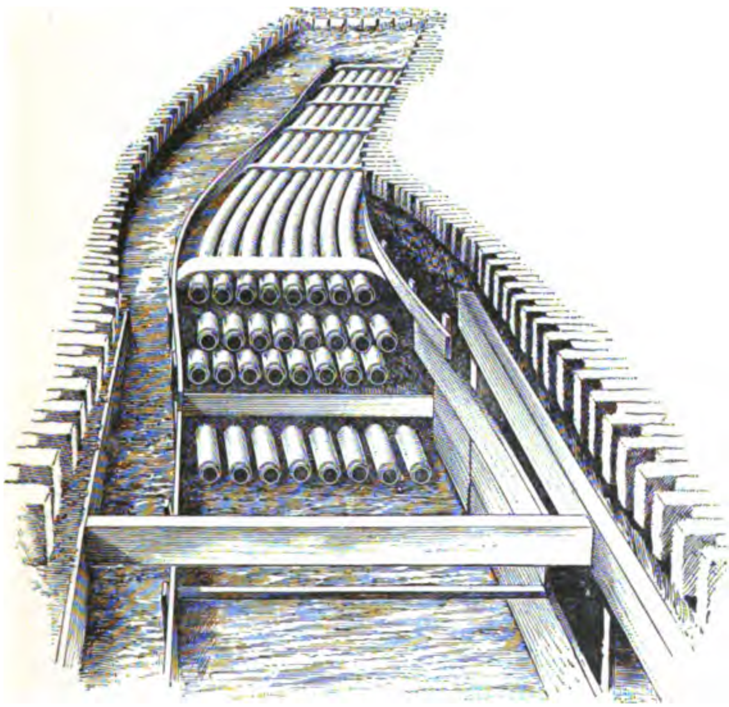


FIG. 3

8 feet and internal diameters of 2, $2\frac{1}{2}$, and 3 inches, the latter being the standard size. Each end is provided with a cast-iron beveled socket joint, by the use of which perfect alinement may be obtained by merely butting the ends together. These beveled socket joints also allow of slight bends being made in the line of conduit as it is being laid.

9. This conduit is laid in a trench, the bottom of which is first properly graded and then filled with a layer of from

4 to 6 inches of concrete composed of broken stone, sand, and cement. The tubes are then laid in layers, until the required number is in place, thoroughly embedded in good cement mortar, and the sides of the hole filled in with concrete as the tubes are laid. On top of the entire structure is placed a layer of from 4 to 6 inches of concrete, after which the trench is entirely filled with earth.

In laying this conduit, special attention should be given to carefully covering the joints with cement mortar, as in this way the conduit may be rendered perfectly water-tight. It is usual to allow about 1 inch of space between the layers of ducts and to make each layer break joints with the preceding one, in order that the whole structure may possess considerable lateral strength. It is frequently advantageous to build in the sides of the trench a wall of rough boards, in order to prevent caving in of the sides and also to confine the cement mortar while setting. A view of a partially completed conduit line constructed with cement-lined pipes is shown in Fig. 3; this line consists of four layers of eight ducts each, making thirty-two ducts in all. This figure also shows how curves may be made in the line when necessary. Such curves should always be made with caution, and it is much better, if possible, to continue the line of conduit in a straight line between the manholes.

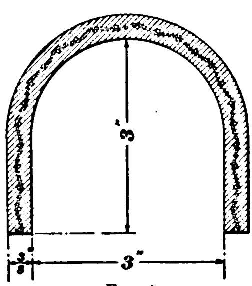


FIG. 4

10. Cement-Arch Conduit.—The **cement-arch conduit** devised by C. H. Sewall, of Chicago, is formed in arches made of cement molded over a network of wire cloth. The cross-section of one of these arches is shown in Fig. 4, the dimensions there given being those of the standard size of conduit. The wire cloth, which gives toughness to the structure is woven from No. 20 B. W. G. iron wire, with a mesh $\frac{3}{8}$ inch square. The cement is made of a mixture of equal parts of Portland cement and sand. The lengths of the section are usually 6 feet, although short sections may be procured, as well as curved sections, where it is necessary to make bends in the line of conduit. This conduit is laid

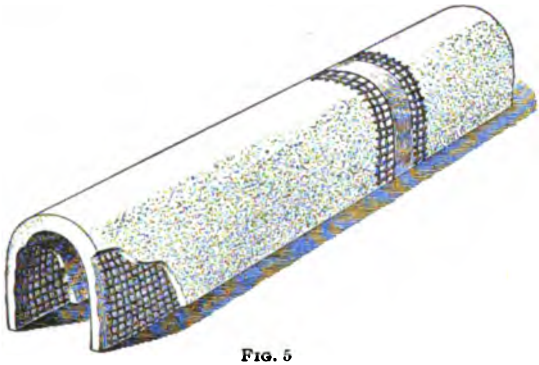


FIG. 5

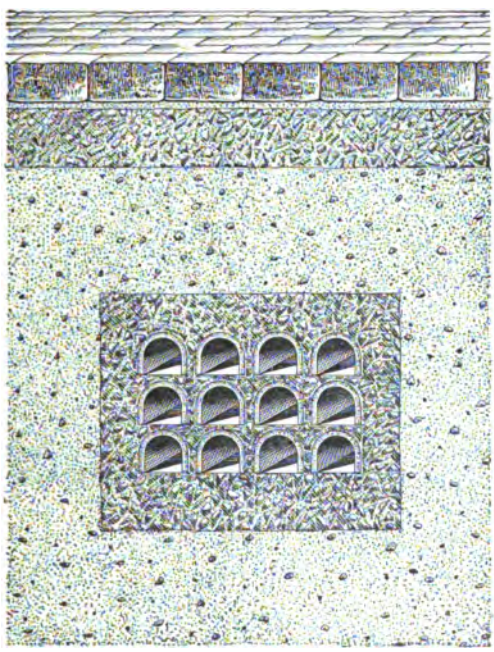


FIG. 6

on a previously prepared cement floor, the joints between the sections being covered with an arch of wire gauze lined with cotton cloth, as shown in Fig. 5.

In laying this conduit, a trench is dug in the usual manner and the bottom filled with a layer of concrete about 4 inches in thickness. This concrete floor is troweled smooth and to an even grade from one manhole to another. The arches are then dipped in water and laid on this floor, a templet being used to secure the proper alinement. As soon as the first tier of arches is in position, it is covered with concrete, which is troweled smooth, forming a second floor, on which the second tier is laid. This work may be done very rapidly, as it is not necessary to wait for the complete setting of the concrete before the second and successive layers are laid. A cross-sectional view of a twelve-duct line of this conduit is shown in Fig. 6.

11. Vitrified-Clay, or Terra-Cotta, Conduit.—A form of conduit that is probably used in good construction work to a greater extent than any other is made of vitrified clay. This material has the advantage of being absolutely proof against all chemical action, and unless destroyed by mechanical means will last for ages. Besides this, its insulating properties are high, and it is comparatively cheap and easily laid.

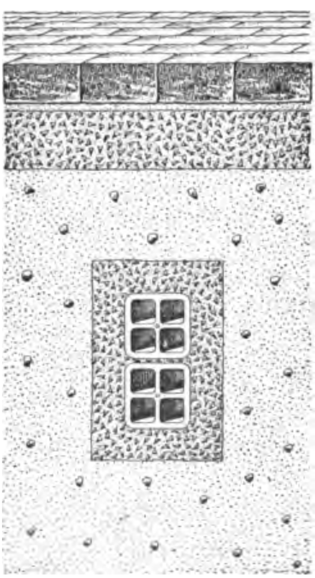


FIG. 7

Vitrified-clay conduits are made with one, two, or more ducts, a common form being the four-duct type, two sections of which are shown in cross-section in Fig. 7. These are made with two, three, four, six, and nine ducts, all in 8-foot lengths. In another form, each section has two ducts only, these ducts being large enough to accommodate several cables. In this form, however, much trouble has been experienced, due to the fact that when several cables are laid in a single duct, it often becomes impossible to withdraw them, owing to the fact that they are much more likely to become wedged than in the forms where one cable only occupies a single duct. It is not good practice to put more than one cable in the same duct and is practically never done now. With multiple-duct clay conduits, dowel-pins are generally used at the joints to connect two sections, thus helping materially in preserving the alinement.

A form of vitrified-clay conduit extensively used is shown in Fig. 8, this being usually made in lengths of 18 inches, having an internal diameter of from 3 to $3\frac{1}{4}$ inches, and being $4\frac{5}{8}$ inches square outside. This duct has an advantage over the multiple-duct sections, due to the greater ease of handling, and also to the fact that it is much less liable to become warped or crooked in the process of burning during its manufacture than the larger and more complicated forms.

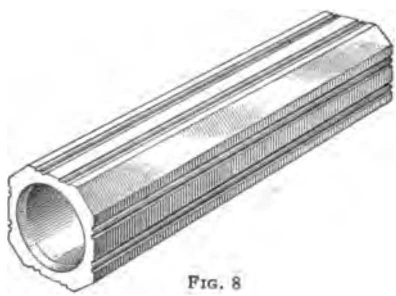


Fig. 8

Like the cement-lined pipe, vitrified-clay ducts are laid on a bed of concrete, cemented together with mortar, and entirely surrounded by concrete. In laying the single-duct type, a *mandrel*, like that shown in Fig. 9, which is of wood,

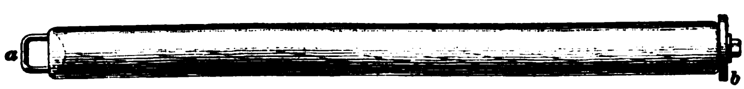


Fig. 9

3 inches in diameter and about 30 inches long, is used. At one end is provided an eye *a*, which may be engaged by a hook in order to draw it through the conduit, while at the other end is secured a rubber gasket *b*, having a diameter slightly larger than that of the interior of the duct. One of these mandrels is placed in each duct when the work of laying is begun. As the work progresses, the mandrel is drawn along through the duct by the workmen by means of an iron

hook at the end of a rod about 3 feet long, the method of doing this being shown in Fig. 10. By this means, the formation of shoulders on the inner walls of the ducts at the joints is prevented, and any dirt that may have dropped into the duct is also removed. The cylindrical part of the mandrel insures good alinement of the ducts, thus securing a perfect tube from manhole to manhole.

12. Fig. 10 illustrates the method of laying this conduit, and shows how the joints should be broken in the various

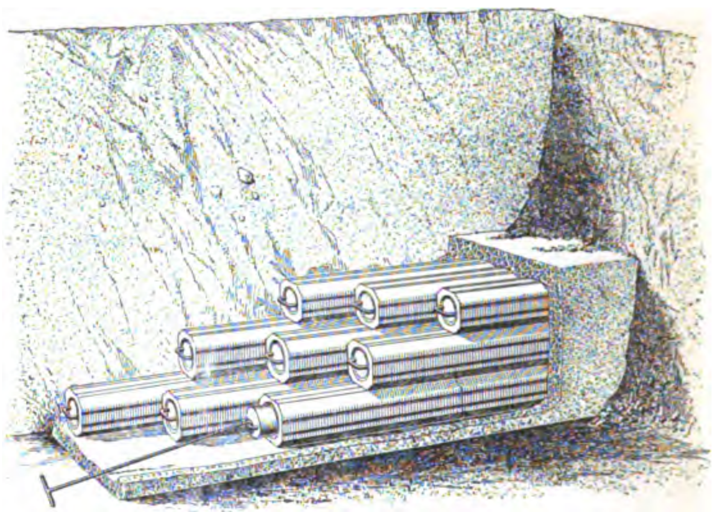


FIG. 10

layers so as to insure a maximum lateral strength to the structure. All conduits should be laid to such grades that there will be no low points or traps in the conduit that will not drain into the manholes, or high points to form pockets in which gas can collect.

A favorable feature of the vitrified-clay single-duct conduit is that in the event of damage to any part of the conduit, the injury can be readily repaired by replacing the damaged piece with horizontally split pieces made for that purpose. This can be done without the removal of the cable.

13. Stone Conduit.—The **stone conduit,** which is shown in Fig. 11, seems to be quite popular. It is made by the American Stone Conduit Company of crushed limestone and the best quality of Portland cement in single-duct, 6-foot lengths, having an outside diameter of $4\frac{1}{2}$ inches and a hole $3\frac{3}{8}$ inches in diameter. By the use of a saw, this conduit can be cut in any desired length. While being made, a pressure of 3,500 pounds per square inch is applied to the inside of the conduit, which makes it very strong and produces a smooth inner surface. On account of the material of which it is made, it adheres very thoroughly to the concrete in which it is laid, making practically a solid structure from one manhole to another with holes through it. It should last indefinitely. Alinement has been secured by the use of rubber mandrels that were drawn through the ducts as they were laid; but a later method consists, as indicated in the figure, in tightly clamping a collar of sheet iron on one end of the conduit and slipping the next piece into this collar.

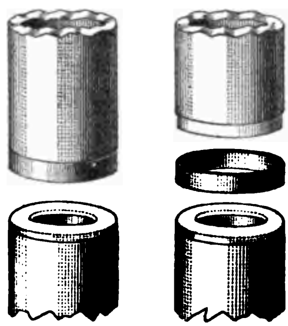


FIG. 11

14. Bituminized-fiber conduit, made by the American Conduit Company and shown in Fig. 12, is increasing in use. Among the advantages claimed for it are that it is electrolysis-

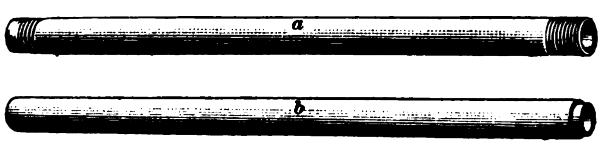


FIG. 12

proof, non-abrasive, moisture-proof, non-corrosive, light, and strong, and also that it can be laid rapidly and cheaply. It is made in 7-foot lengths and can be procured of any diameter, though 3, $3\frac{1}{4}$, and $3\frac{1}{2}$ inches are the standard sizes. To enable the conduit to withstand destructive influences it is thoroughly saturated and coated with a bituminous compound. A permanent alinement is secured by the use of socket joints as shown on the piece *b*; one end of one piece slips inside the adjacent end of another piece. The conduit being neither heavy nor brittle, it is cheap and convenient for shipping and handling and as it is easy to lay, this can be done by unskilled labor.

15. The Fiber Conduit Company makes a similar fiber conduit that has been in use for over 10 years and has given quite general satisfaction. It is made either with screw joints, as shown on the piece *a*, or with socket joints, in 5-foot sections, and of any required diameter up to 4 inches. Fiber conduit, on account of the material of which it is made, reduces to a minimum the possible damage to a cable from chemical or electrolytic action.

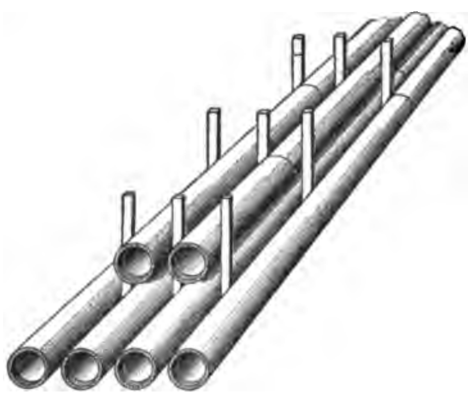


FIG. 13

When laying fiber conduit, spacing stakes of wood, or preferably iron, $\frac{1}{2}$ in. $\times$ $\frac{3}{4}$ in. $\times$ 2 ft. 6 in., are placed vertically, as indicated in Fig. 13, between adjacent ducts so that the concrete can pass between and fill up all spaces. The stakes are placed so as to leave $\frac{3}{4}$ inch between adjacent vertical rows of ducts and are set 5 feet apart before the bottom layer of concrete hardens and removed when all the ducts are laid and used for the next run.

CONDUIT CONSTRUCTION

16. When the trench is excavated for a conduit, it should slant gradually from one manhole to another; it should only slant from a high point between the manholes toward each manhole, when this is the only way it can be drained, for this leaves a pocket in which gas may accumulate. Care must be taken that the bottom is even so that the joints in the conduit will fit together snugly, also to avoid waves in the conduit, which would make it difficult to draw cables in or out and would allow the accumulation of moisture in the low pockets and gas in the high pockets that may be thus formed. If it is not convenient to have a surveyor do this with his leveling instrument, it may be done with a 12- or a 16-foot straightedge and a carpenter's level. By moving along the trench and putting the straightedge on the bottom, every 12 or 16 feet, the level will show the high and low places. One man with a shovel can rapidly take off the high places and fill in the low ones with earth, which should be well tamped down with the back of the shovel.

17. If a small service pipe must be crossed by the conduit, usually no change in depth of trench is required, for part of the conduit can pass under and part over the pipe. This is called splitting the lead. It is well to lay a stick of wood, a trifle thicker than the diameter of the pipe and a trifle longer than the width of the concrete with which the conduit is to be surrounded, on each side of the pipe, so that the pipe may be withdrawn if it should ever be necessary. If the pipe is firmly embedded in the concrete, it is impossible to withdraw or replace it without damage to the conduit. The top of any kind of conduit should never be less than 2 and preferably 2½ feet below the surface of the road. The manholes should be located and dug first, then the connecting trenches.

18. As many men should be used as can be properly watched and directed. Easy digging will of course require less men than hard digging. For ordinary city work, a well-balanced force may consist of one foreman with thirty to thirty-five diggers, one foreman with eight to ten men mixing and wheeling concrete, three conduit layers, five men to refill and tamp, three men to dig manholes, one mason and three men to build manholes, four men and four teams to remove surplus dirt, one water boy, and one night watchman. Additional men will be required where asphalt, granite, or brick pavements must be taken up. The asphalt, granite blocks, brick, and concrete should be saved, piled up separately and free from the dirt. The concrete can be broken up, screened, and used again. A light team will be needed to move the mason's tools, the general tool box, and run errands. It is here assumed that the firms from whom the sand, cement, brick, and perhaps the conduit are purchased will deliver the same where directed along the line of the trench. A crew of this size should lay at least 20,000 duct-feet, including manholes, per week under average conditions.

Ample supplies of conduit, sand, cement, and brick should be delivered along the line of the trench, enough for at least 2 days' work. A permit should be secured from the city to dig up the pavements and for the use of water for making the concrete, and all necessary tools should be on hand in good condition.

19. Concrete for Conduit Work.—In nearly all modern types of conduit, except the creosoted wood, the use of concrete and mortar is required. Concrete forms the foundation for the structure, and is also used in filling in the sides and top of the trench, thus enclosing the entire structure of ducts in a continuous mass of this material. There are various kinds and grades of cement. One part of ordinary artificial Portland cement is equivalent to about two parts of Rosendale or native hydraulic cement. Furthermore, Portland cement is not apt to vary as much in quality as the native cement. As to which is the cheaper will depend on the prices delivered at the place where it is to be used. The sand should be clean, sharp, and free from mud and quicksand. The stone used should pass through a ring 1½ inches in diameter and all dust and pieces passing through a ring ¼ inch in diameter should be rejected. Gravel is usually more expensive than crushed stone for it must usually be washed as well as screened. Good cinders and furnace slag are about as good as stone.

20. Proportions.—Concrete is mixed in various proportions. The following proportions include those generally used:

No. 1: one part of Portland cement, two parts of sand, and four parts of broken stone, or gravel screened to pass through a ring $\frac{3}{4}$ inch in diameter.

No. 2: one part of Portland cement, three parts of sand, and five or six parts of broken stone.

No. 3: native cement, one part; sand, two parts; stone, three parts; or, native cement, twelve sacks; sand, 2 cubic yards; stone, 3 cubic yards.

No. 4: stone, 3 cubic yards; sand, 2 cubic yards; Portland cement, three sacks, or native cement, six sacks.

No. 5: cinders, six wheelbarrow loads; sand, two wheelbarrow loads; Portland cement, two sacks.

No. 6: unscreened gravel, five parts; native cement, one part.

No. 7: unscreened gravel, eight parts; Portland cement, one part.

Formulas 1, 4, 5, and 7 are especially recommended for the best work; however, formula 2 is usually good enough for use around conduits.

Ordinary crushed stone weighs 2,270 pounds per cubic yard; sand weighs, wet, approximately, 3,000 pounds per cubic yard; cement, from 360 to 380 pounds per barrel, which contains, approximately, 4 cubic feet. A convenient way to buy cement is in paper sacks; three sacks being equivalent to one barrel.

21. Mixing.—To get good results, concrete should be mixed as follows: First, mix the sand and cement, turning them together at least three times dry, then add the stone, which should previously have been thoroughly wetted, and turn the mixture at least once over; finally, add enough water to make the concrete tamp nicely, but not so moist as to have water run from it, and turn over at least three times. The water should never be supplied directly from a hose giving a strong stream, because the finely divided cement is very apt to be washed away; either use buckets or a weak stream of water.

22. Mortar is used for binding together the various sections of the ducts in much the same manner as in laying brick, and also to render the joints between the sections of a duct water-tight. It is also used in the construction of brick manholes. A good mortar for conduit work may be made of four parts of sand and two parts of native cement or one part of Portland cement.

The cement and sand should be thoroughly mixed together while dry, after which water should be added to give the mixture the proper consistency for working.

MANHOLES

23. Manholes form a very important part in cable systems, and require careful design to properly adapt them to the particular conditions to be met. They are usually placed about 350 to 400 feet apart, and, if possible, at the intersection of streets. They should be located with a view to making the line of conduit between them as nearly straight as possible. The size of the manhole will depend on the number of ducts that are to be led to it, as well as the number of men that will be required to work in it at one time. Manholes 6 feet square and from 5 to 6 feet high will usually be required for large systems, while for smaller systems, or the outlying portions of large ones, they may be made as small as 4 feet in length in the direction of the conduit, 3 feet wide, and 3 or 4 feet high. They may be round, elliptic, square, or rectangular.

The office manhole, having to accommodate all the cables that may ever lead into the exchange, should be larger and more elaborate than any of the others and, when possible, should communicate direct with the basement of the exchange building by means of a door or other large opening.

Manholes may be built of brick, concrete, or concrete blocks, as preferred. The former is the most commonly used material and in many respects the best, for it is not often that a manhole can be built exactly to the size desired, especially in alleys and streets crowded with pipes and conduits. Brick is the only material by means of which changes can be readily made.

CONSTRUCTION OF MANHOLES

24. Manholes may be constructed of either cement or hard-burned brick laid in Portland-cement mortar, the latter usually being preferable. The foundation should consist of a layer of concrete at least 6 inches thick; the walls, if of brick, should be laid in cement mortar and should also be thoroughly plastered on the outside with the same mortar. All brick should be thoroughly wetted before being used. The walls should never be less than 8 inches thick, and preferably 9 to 13 inches. When adjacent to a trolley line, the walls should not be less than 13 inches thick, and should frequently be made about 16 inches thick where large manholes are being constructed in busy streets. As the brickwork is laid, the iron brackets for supporting the cables around the sides should be built in, although they can be fastened on afterwards. The roof should be of either arched brick or structural iron, supporting some form of cast-iron manhole cover, of which there are several types on the market.

In the round vaults, the brickwork should be corbeled in (that is, successive courses arranged to project beyond those below) at the top, as shown in Fig. 14, to support the manhole cover and its frame. In the square vaults, an iron framework has to be used for the top of the manhole. Angle and T iron, or 60-pound, second-hand, steel rails are used for this work, they are laid close enough together to take the brick between them and a course of brick laid on top. An opening must, of course, be left for the iron cover.

25. Ventilation of Conduits.—It is considered better practice to thoroughly ventilate conduit systems than to attempt to make them gas-tight and water-tight. It seems almost impossible to prevent the accumulation, in conduits, of dangerous and explosive gases; and this being the case, it is necessary to provide means for both drainage and ventilation.

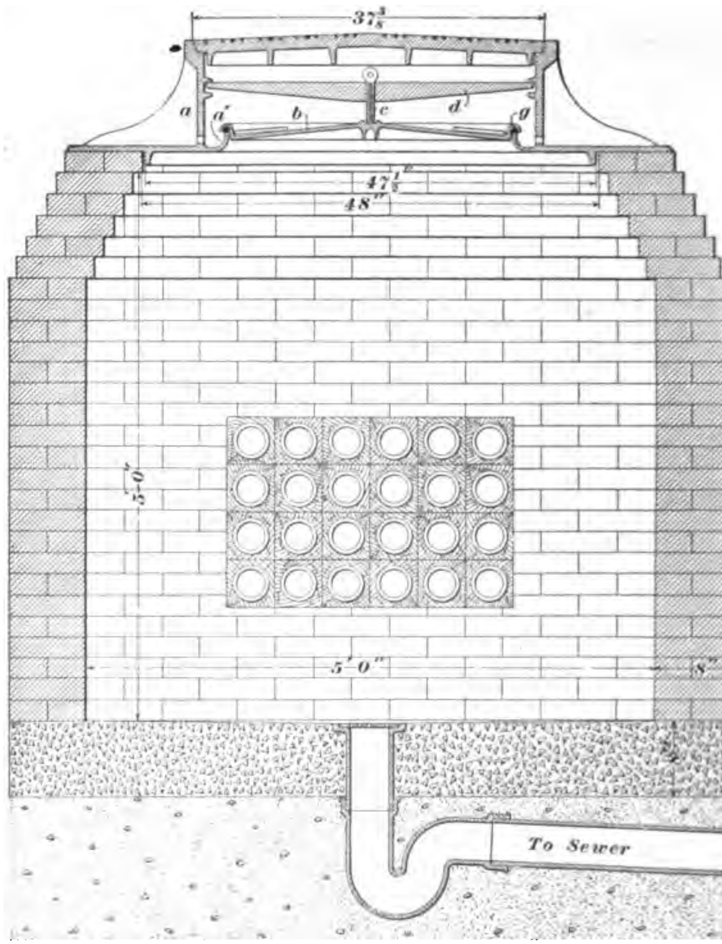


Fig. 14

Whenever work is to be done in a manhole, it is well to remove the cover, not only of this manhole, but of the nearest one in both directions, and allow a few minutes for a fresh current of air to pass through, thus purifying the atmosphere in the subway. This is a little thing to do, and prevents the kind of accidents, which, though rare, are usually serious and costly when they do happen. Where the gases, as is sometimes the case, are so plentiful in the manhole as to render it unsafe for a workman to enter it, the gas is driven out by an ordinary hand blower.

If the subway system is subject to illuminating and sewer gases, it is advisable to seal all the ducts where they enter the manholes with pure clay, plaster of Paris, or other suitable material that will not attack the cables, thus preventing the free circulation of gas from one manhole to another.

26. The entrance of the conduit into the manhole should be deep enough to allow for corbeling over them for the cover, and yet not so close to the bottom as to make the handling of the cable inconvenient. The ends of the ducts should never be brought in flush with the manhole wall, but rather set back a little, forming a pocket. This pocket should be beveled and nicely finished off with mortar. This enables the cable to be bent more gradually and lay close to the walls. The ends of all the ducts should be even, and for this reason they may, in some cases, have to be cut when laying. When built in soil in which the drainage is good, sewer connections from manholes are not necessary. Where such drain pipe is necessary, it should be a 6-inch clay tile provided with a trap to prevent sewer gas entering the manhole.

In excavating for either a round or a square vault, a space should be marked on the pavement slightly larger than the outside dimensions of the completed manhole, and the excavation made to the required depth. In digging round holes in soil inclined to cave in, one should have made a large iron ring—say 6 feet in diameter—of $\frac{1}{2}'' \times 3''$ bar iron; as the hole is lowered, this ring should be let down into it and sheeting driven on the outside close together. This sheeting is driven lower as the excavation proceeds and prevents any caving, the iron ring holding it firmly in place. This ring can be procured for $5 or $6 and is a good investment. In sinking square holes in this same kind of soil, the sheeting is used and is braced by cross-pieces or screw braces across the hole.

27. In Fig. 14 is shown a manhole built of brick, with a cast-iron cover, designed to exclude all moisture. The dimensions of the manhole are shown, the brickwork being corbeled in at the top to support the manhole cover and frame. The particular form of cover shown consists of a heavy frame *a* of cast iron, having an inner and an outer cover. The inner cover *b* rests on an upturned flange *a'* of

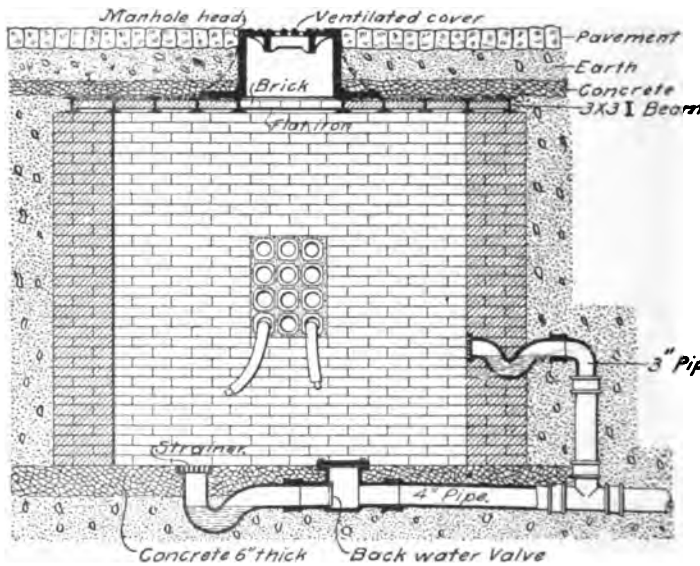


Fig. 15

the frame, the connection between the two being made water-tight by a rubber gasket *g*. This cover is forced down on the gasket by means of the screw *c* passing through a heavy rod or cross-piece *d* secured between flanges in the framework *a*. The outer cover is of cast iron, and made heavy enough to retain its place by gravity alone. The bottom of the manhole is connected by a 6-inch clay tile pipe with the nearest sewer, this drain pipe being provided with a three-fourths **S** iron trap to prevent the entrance of sewer gas into the manhole.

28. Fig. 15 shows a cross-section of an excellent ventilated and drained manhole. This manhole is provided with two sewer connections, so that in case the bottom one gets clogged up, the water will flow through the side connection instead of filling up to the ducts. Both connections are provided with traps to keep out the sewer gas, and the bottom connection is equipped with a back-water valve to keep water from backing into the manhole. A removable cover is provided at the back-water valve, so that any dirt that accumulates may be cleaned out. The roof is made by laying 3″ × 3″ I beams across the top and filling between them with brick, the whole being covered with a layer of mortar.

29. Concrete manholes are made by pouring and tamping concrete in wooden forms, with or without a facing of sheet iron. The least change in the shape or size of the hole requires the making of new forms. Manholes made of concrete blocks are open to the same objection. It is claimed, however, that concrete-block manholes can be put in place more rapidly than the ordinary concrete manhole can be built, because the latter requires the necessity of moving bulky molds from place to place.

The concrete manhole is usually built strictly to the mold, and no slight changes are possible, without a new mold, though they might be advisable or even necessary. In case alterations or additions to the system of ducts are necessary in the future, it is difficult to change the manholes without tearing them down and rebuilding them. The brick manhole has all the advantages that are absent in the concrete vault and can be built almost, if not quite, as quickly and cheaply. Composed of small units, the size and form may be varied, even at the last moment, to conform to any conditions which may arise. The shape may be changed as often as desired, though for all ordinary purposes the round or elliptic vault is better because there is no waste space, as in the corners of square manholes, and it can be built more economically, the brick, mortar, and cover being the only materials required.

30. Concrete blocks, according to H. A. McMann in The American Telephone Journal, may be made in the five shapes shown in Fig. 16. These are formed in molds, one of which is shown in Fig. 17, which are constructed of well-seasoned wood and lined with galvanized sheet iron. The frame of the mold is made to the necessary dimensions. A suitable base is first made of two or three pieces of 1-inch thick wood. It should be well braced on the bottom with cleats. Next, the end pieces are fastened in position; these should be about 3 inches thick. The figure shows, in detail, the construction of such a mold. The front part of the mold

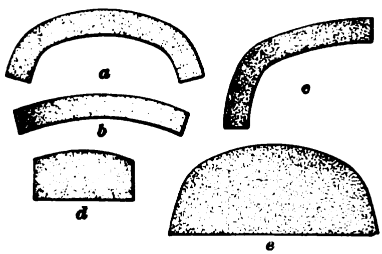


Fig. 16

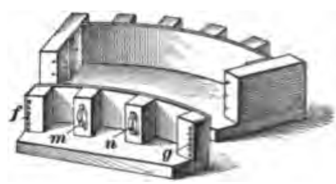
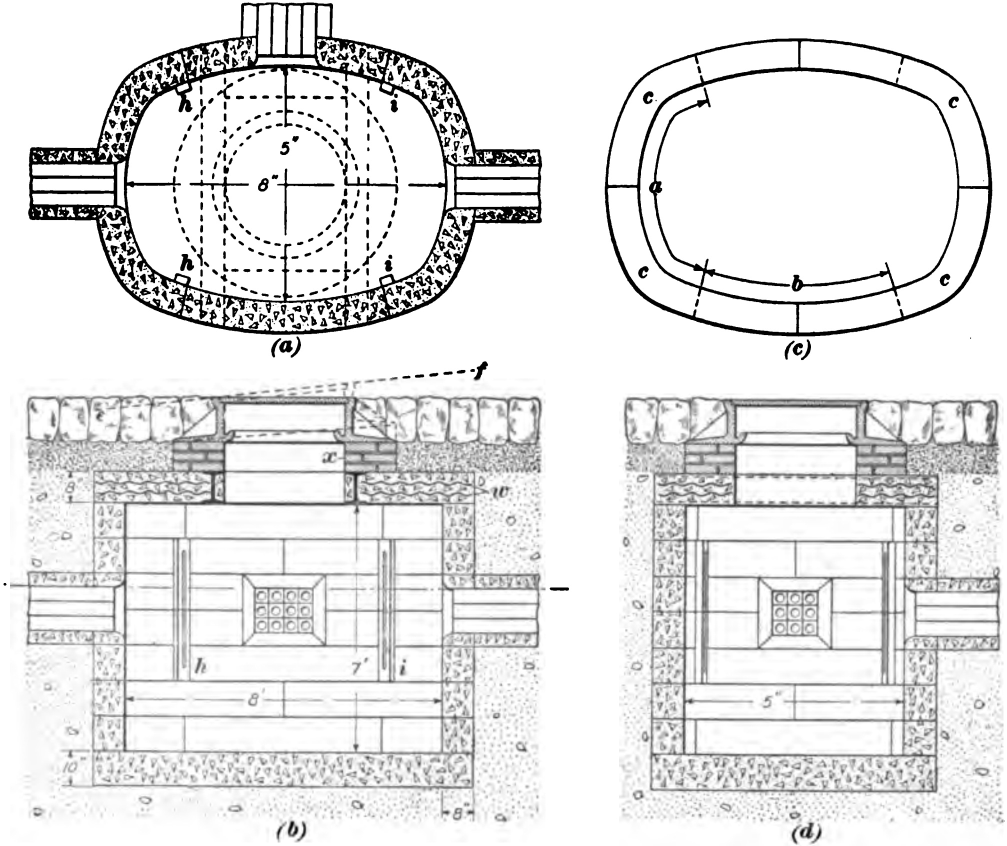


Fig. 17

is made removable, and is built, the same as the backs, of well-seasoned blocks and galvanized sheet iron. The inside of the mold is lined with well-galvanized sheet iron, $\frac{1}{32}$- to $\frac{1}{16}$-inch thick. Hooks *f*, *g* should be put on the ends for keeping the front piece in place while the concrete is setting. Two handles, to be used in moving the front piece when the concrete is set, are arranged as shown at *m*, *n*. All shapes of blocks shown in Fig. 16 are made in the same sort of a mold. These molds can be easily made by the average carpenter.

Concrete for the blocks is made according to formula **1** of Art. **20.** The concrete should be thoroughly rammed into the molds, which should be well greased inside. After the concrete has set for at least 24 hours, it may be removed from the molds, moved away to set, and another batch placed in them. In filling the molds for the top blocks *e*, Fig. 16, two pieces of expanded metal, which is sheet steel cut and expanded by pressure to form a sort of grating, are



Vertical Sections of Manhole and Diagrams Showing Arrangement of Blocks
Fig. 18

inserted about midway between the top and bottom of the mold as shown at *w* in Fig. 18.

31. In constructing the manhole, shown in Fig. 18, the base or bottom layer of concrete should be about 10 inches thick. This is placed on the earth in the manhole excavation and well tamped. Cover this concrete base with a $\frac{1}{4}$-inch layer of mortar and set two pieces shaped like *a*, Fig. 16, on the ends and two pieces shaped like *b* on the sides, as shown in the plan in Fig. 18 (*c*). Fill the joints well with cement. The next course consists of four pieces shaped like *c*, Fig. 16. The third layer is the same as the first, and the fourth the same as the second, and so on to the top of the manhole, the layers alternating. Hence, one joint is never immediately above another. Four iron brackets *h*, *i* should be secured to the walls as they are built for supporting the cables. Two 8-inch **I** beams are now placed across the top of the manhole from side to side as shown in Fig. 18 (*b*). Two blocks shaped like *d*, Fig. 16, are inserted between the **I** beams and well cemented. The blocks *e* are next placed, one at each end of the manhole. Brick is generally used at *x* to bring the top of the manhole casting flush with the surface of the street. If the street is level, the brickwork may be dispensed with and a cast-iron frame simply set on the **I** beams. The inside of the manhole should be coated with a good mortar mixed in the proportion of one part of cement and three parts of good, clean sand. This coating should be a full $\frac{1}{4}$ inch thick. The object of the coating is to make the manhole thoroughly waterproof. At the same time, it adds materially to the appearance of its interior. Where the ducts enter the manhole, it is best to omit a block and fill in around the ducts with concrete. The ends of the ducts may be neatly rounded off with mortar when the inside of the manhole is being coated. Very little has been said in regard to the dimensions of the concrete blocks or the completed manhole, as the only object was to give a general idea of the method. The drawings are dimensioned for a standard intermediate or three-way manhole. For varying conditions, it will be found necessary to alter the dimensions given. The method is said to be readily adapted to any shape manhole now in use.

MANHOLE COVERS

32. Owing to the impossibility of their falling into the manhole through careless handling, a round, rather than a square, cover should be used. The cover and its rim or framework is usually made of cast iron. It is usually not necessary to provide water-tight covers for manholes when a connection is provided from the bottom of the manhole to the sewer. Some consider a water-tight cover an extra frill that adds considerably to the cost. The connection with the sewer should remove all water from the manholes. A good, plain, heavy cover, with perforations in the lid for ventilating purposes, is considered by many the most desirable. It is made in different weights, with a 26-inch opening. The manhole frame and cover, in large cities, where the traffic is heavy, should not weigh less than 1,300 pounds.

The frame and covers of the manhole should rest on the four walls, if possible, and where the manhole is too large for the cover casting to reach over, I beams and arches should be used, the arches not being wider than $2\frac{1}{2}$ feet. Some advise making the top of the cover $\frac{1}{2}$ to $\frac{3}{4}$ inch above the established grade as it will not be noticeable when the pavement is relaid and yet it will keep the water out better.

In many forms of manhole covers, a deep pan is suspended beneath the cover, which serves to catch all moisture and dirt falling through the holes in the cover without interfering with the ventilation. Where no drain pipe is provided for the manhole, however, the water-tight cover is generally considered an absolute necessity. Conduit systems should either be as near gas-tight and water-tight as possible or else well drained and ventilated. In systems not gas-tight and not sufficiently ventilated, gases collect in the conduits and manholes and frequently explode, often doing considerable damage, and even resulting in loss of life.

What is known as the noiseless cover is considered by some as the best form, not only owing to its being noiseless, but because the asphaltum with which the cover is filled acts as a cushion and saves the iron from the blow or impact given by the heavy passing vehicles.

33. Concrete Top. It is frequently necessary, in order to gain room in shallow manholes, to make the roof as flat as possible. According to W. R. Harris in The American Telephone Journal, roofs 5 feet square may be made with two 10-inch **I** beams placed across the top, about 32 inches from center to center, and four 5-inch **I** beams between the 10-inch beams. A form is then placed in position, which

TABLE I

Size of Manhole Feet	Size of I Beams Inches	Weight of I Beams Pounds	Cubic Yards of Concrete
5. × 5.	5 and 10	537	1.15
7. × 7.	7 and 12	760	2.44
7.5 × 9.5	12 and 15	2,724	4.00
8. × 10.7	12 and 15	2,939	5.00
9.2 × 21.3	10 and 12	4,681	11.00
10.5 × 11.8	12 and 15	4,350	6.80

will allow all spaces and 1 inch below and above the beams to be filled with concrete. For a manhole 7 feet square, two 12-inch and four 7-inch **I** beams are used. If the manholes exceed 7 ft. × 7 ft., more and larger beams are used. Table I shows the sizes of some manholes with the quantities of iron and concrete used in the roofs.

34. By using expanded metal, concrete roofs of great strength and durability can be made with a great saving in both **I** beams and concrete. Roofs can be constructed as shown in Fig. 18, omitting the layer of brick x and placing the iron cover directly on the concrete. The **I** beams are used as supports for the manhole casting and also to give additional strength to the concrete. When the walls are brought to the proper height, the I beams should be set in place and a temporary form of smooth matched boards placed in position so as to leave a space of 1 inch between the bottom of I beams and the form. The form should be built so that the beams will be entirely encased in concrete, thus leaving no surface of the steel exposed to the air.

After the form is in position, spread a coat of Portland-cement mortar (using equal proportions of cement and sand) over it to a thickness of about 1 inch, and then add a layer of fine concrete not exceeding 1 inch in thickness. A sheet of expanded metal should now be laid in place and more concrete placed above, to a thickness of about 4 inches. To increase the strength, another sheet of expanded metal may now be laid; in any case, tamp well, add the rest of the concrete necessary to cover the I beams, and tamp it well. Allow the form to remain at least 7 days, and do not pave over the manhole for 3 or 4 days. This form of roof 8 inches thick with one sheet of expanded metal is much stronger than a concrete roof 16 inches thick not reinforced with expanded metal. The expanded metal should be 3-inch mesh No. 10 gauge. Use concrete made according to formula **1**, of Art. **20**.

The coat of cement mortar placed on the form is for the purpose of securing a smooth surface on the under side of the roof. The concrete must be tamped thoroughly and must come in contact with the I beams at every point, leaving no air spaces. Corrosion of iron or steel is avoided by encasing it in concrete, as it is well proved that cement preserves these metals. A manhole casting of any depth can be used to suit varying conditions. Roofs constructed in this manner are comparatively cheap, strong, and durable.

A good manhole 7 feet 6 inches long, 4 feet wide and 6 feet 3 inches deep inside, may be built with brick walls 9 inches thick on a foundation of concrete 6 inches thick. The floor should be given a finishing coat of Portland cement. The concrete roof should be 8 inches thick, with 6-inch 15-pound I beams. The I beams and expanded metal weigh about 223 pounds, and the concrete amounts to $\frac{8}{9}$ cubic yard.

By comparing these figures with those in Table I, the great saving effected by using expanded metal is evident.

35. Length of Cables for Use in Conduits.—When cables are to be installed, care should be taken in specifying the lengths of the cables that they be correct and also plain. It is well to carry all cables supplying aerial leads direct from the exchange to the first cable pole without making any taps in them, leaving the distribution inside the underground district to other cables; these may be designated as trunk and distributing cables. The best way to explain how the length of a cable from one manhole to another is determined, will be to give an example. Suppose that the distance from the center of one manhole cover to the next is 435 feet; that the duct openings in one manhole are set back 2.5 feet from the center, and in the other 3 feet, making 5.5 feet to be deducted from the length, leaving 429.5 feet. To this should be added the distance quarter way around one side of each manhole wall, say 8.6 feet for two round manholes, also 20 inches for the splice. (Twenty inches for splicing may for this purpose be allowed for cables of more than 100 pair, and 18 inches for smaller cables.) This would make 439.8 feet. To this should be added an allowance of ½ per cent. for variation, bends in manhole, etc., or say 2.2 feet, which would make the complete length of the cable 442 feet.

The specifications should designate what duct the cable is to go in. The ducts in a manhole are numbered by turning one's back to the exchange, beginning at the lower left-hand duct and reading from left to right. Thus, in a twenty-four-duct lead, the lower left-hand duct will be No. 1, and the upper right-hand duct No. 24. The lower ducts should be used first, so that in future installations the way will be clear and cables will not have to be run under those already in place.

INTRODUCING CABLES INTO CONDUITS

36. Preparing the Duct.—Assuming that the line of conduit, or **subway,** as it is frequently called, and the manholes are built, the first step before introducing the cables is to make sure that the ducts are all clear. This is usually provided for in the laying of the conduit, especially if a mandrel has been used. The particles of dirt, however, may readily be removed by washing out the duct with a hose carrying a heavy pressure of water. In cases where this is not done, it is well to draw through the duct a mandrel carrying a gasket of leather or rubber, which will push all foreign matter before it.

37. Rodding.—The process called **rodding** is used in order to introduce a wire or rope into the duct for the purpose of drawing in the cable. This process consists of pushing a number of jointed rods into a duct from one manhole until the first rod reaches the other manhole. The rods are joined together by screw connections or by bayonet joints or as shown in Fig. 19, as they are pushed in. The Cope conduit rod illustrated in this figure is made in 3- and 4-foot lengths with steel couplings. When the chain of rods reaches from one to the other manhole, a rope or wire is attached to one end and pulled through, the rods being disjointed one by one as they reach the second manhole or pushed through the next section of ducts.

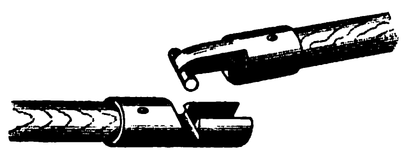


FIG. 19

38. The introduction of a wire into the duct may often be greatly facilitated by using, instead of the rods, a steel wire about $\frac{1}{4}$ inch in diameter and provided with a ball about 1 inch in diameter at its end. This wire may be pushed through a smooth duct without trouble for distances up to 500 feet. If an obstruction is found during the rodding that cannot be removed by means of the rods or by water, the distance to the obstruction can readily be measured on the withdrawal of the rods. This distance can then be measured off along the ground over the subway, thus locating the spot where the obstruction occurs. The conduit should then be opened, the difficulty removed, and the structure repaired. This difficulty, however, should never be met where proper care is taken in laying the conduit.

39. Drawing In the Cable.—One way to **draw in** a cable is illustrated in Fig. 20. The cable reel may be mounted on jacks, so as to be free to revolve in such manner that the cable will unwind from its top. The end of the heavy rope leading through the duct should then be attached to the cable either by grips made especially for the purpose or by binding it with iron wire for a distance of 18 inches or 2 feet from the end. Fig. 20 (*b*) represents a section of a

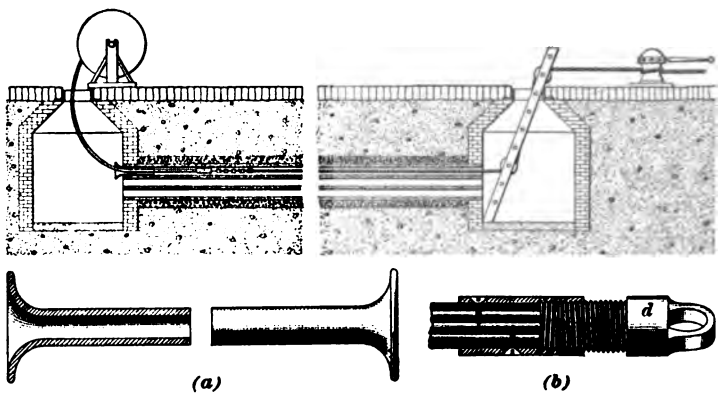


FIG. 20

cable grip of iron pipe made to fit the cable snugly. It is fastened to the cable, as shown, by common wood screws, and the piece *d* to which the *drawing-in rope* is fastened is screwed into the end of the iron pipe. Better forms of cable grip have been illustrated in *Telephone-Line Construction*, Part 2.

The drawing-in rope may also be secured to the cable as follows: Punch two holes by means of a spike through the center of the cable from side to side, the first about 3 inches from the end and the second about 3 inches from the first;

then form a link to connect the cable and the drawing-in rope by passing a No. 10 or a No. 12 steel wire several times through the eye of the rope and the holes in the cable; fasten the ends of the wire so that they will not slip. This is a simple and cheap method, and the means for making it are

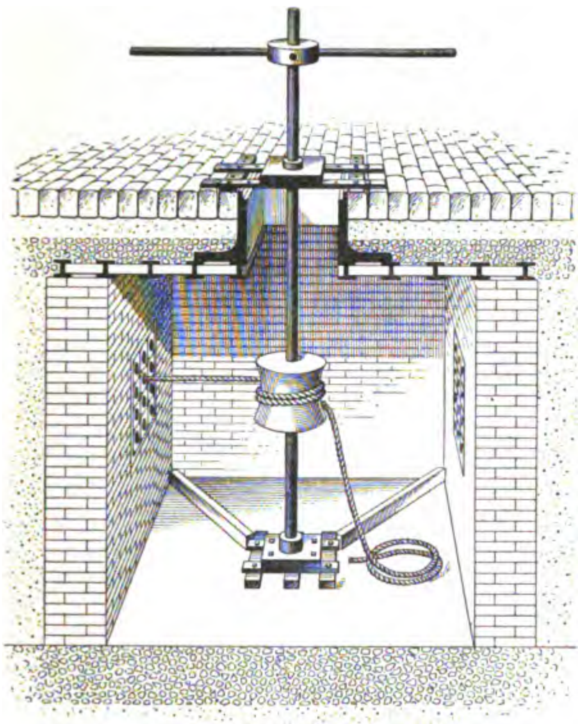


FIG. 21

easily procured. Whenever a hole is made in the end of the cable for fastening the drawing-in rope, the end should be cut off when the cable has been drawn in, to remove all moisture, and then sealed if a joint is not to be made at once. This is a serious objection to this method.

The other end of the rope is passed over the grooved rollers, arranged on heavy planks mounted in the distant manhole, as shown, and is then secured to a capstan or some form of windlass, by which a slow and steady pull may be exerted on it. A man should be stationed in the manhole at which the cable enters, in order to properly guide the cable into the duct, to prevent it from being kinked or unduly strained. It is well to use a special funnel-shaped guide, made of wood or lead, at the entrance of the duct, if the sharp corners have not been eliminated by the proper use of mortar, in order to further insure the cable against injury by the corners of the duct. Such a guide is shown in Fig. 20 (*a*). It is sawed longitudinally into two sections, as shown in the left part of Fig. 20 (*a*), for where the cable is to continue on through a manhole it would be impossible to remove the cylindrical protector if it were one piece.

40. A better and more extensively used arrangement for drawing in a cable is shown in Fig. 21. In this case, the

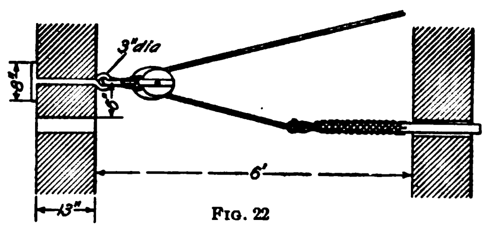


FIG. 22

windlass or winch is placed vertically in the manhole as it is difficult to fasten the winch on the surface of the street as shown in Fig. 20. As these methods do not enable the cable to be pulled farther than the middle of the manhole, it is a good plan to have an iron ring built in the side of the manhole 6 inches above the top ducts, in order that a snatch block may be hooked to it for pulling the cable across the manhole. The ring should be made of ½-inch round iron, have a 3-inch eye, be long enough to go through the manhole wall, and have a **T** with 4-inch ends on the outside of the wall. The arrangement is shown in Fig. 22.

41. Motor Capstan.—One of the best methods for pulling in or erecting cables is probably by the use of a capstan operated by a motor. Fig. 23 gives the general view of such a machine, and Fig. 24 gives the diagram of the motor circuit. The electric motor has several speeds. *M* is an automatic release magnet that allows the starting box lever *l* to return to its off-position when the current through *M* ceases.

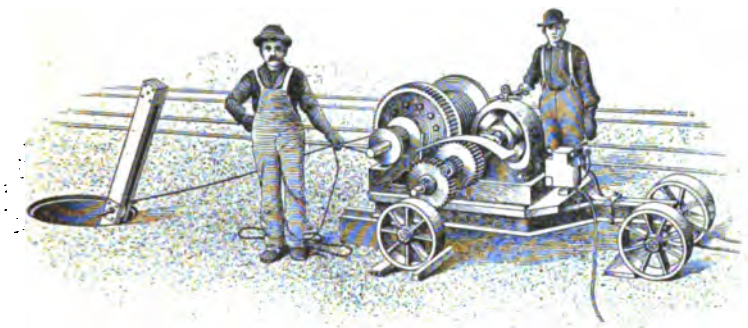


FIG. 23

By opening either *R* or *R'*, or both, the speed of the motor is increased. The cable rope is arranged as shown in the manhole in Fig. 20. There need be no jerk on the cable, as the pulling can be stopped within an inch by allowing the cable rope to slip on the drum about which five turns are taken, the free end being held by one man while another man is required to operate the motor. Usually, power can be obtained for operating the motor from the trolley wire of a street-railway system, in which case one connection is made to the rail, which is grounded. The cost for a month's use, averaging 5,000 feet per working day, is said not to exceed $2, which is a small sum compared with the amount that would be required to pull the

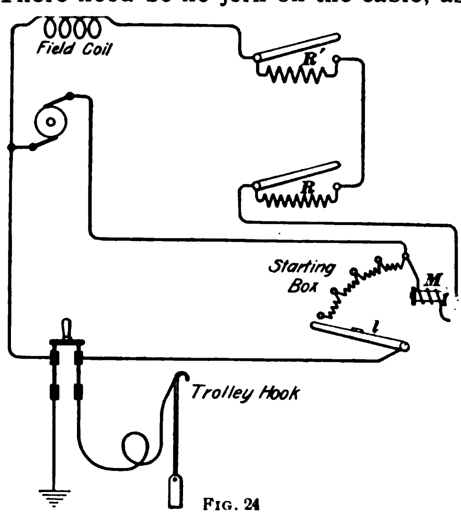


FIG. 24

cable through by manual labor. In the full working day, it is said that 9,000 feet can be pulled with the motor capstan, instead of 1,000 feet by the old hand-capstan method. Six men are necessary for drawing in the cables, one in each manhole, three on the reel, and an extra man for miscellaneous purposes. For pulling in a cable, a $\frac{3}{8}$-inch steel stranded rope with a soft core may be advantageously used.

A similar capstan operated by a gasoline motor, capable of developing 6 horsepower, has been successfully used—2 gallons of gasoline and a little lubricating oil being sufficient for 10 hours' work when pulling cable. It will pull 450 feet of 250-pair cable regularly in 20 minutes and with it, six men and one team have pulled with ease 5,000 feet of cable in a day.

It is not safe to pull cable faster than 30 feet per minute. The motor is connected to the hoisting drum by a friction clutch, by means of which the speed of the drum may be varied and the drum stopped without pulling the cable more than a fraction of an inch and without stopping or interfering with the operation of the engine. The hauling cable in this case was a $\frac{3}{4}$-inch crucible steel rope of six strands of nineteen wires each and a hemp center. The same engine was also used to operate a concrete-mixing machine.

42. Automobile Cable-Pulling Truck.—A device used by the New York Telephone Company for drawing cables in and out of underground conduits consists of a large heavy automobile having at one end an upright device that carries two pulleys for pulling the steel cable and which is let down with one of the pulleys into the manhole when in operation. For this purpose, a special enclosed automobile motor of the series-type made by the General Electric Company is used. It has a normal rating of 2 horsepower, but is designed to operate on a 100-per-cent. overload for 2 hours, and on a 200-per-cent. overload for 20 minutes. The motor drives the drum through double reduction gearing which, with the overload capacity of the motor, gives considerable power. The storage battery, which consists of forty-four cells, operates the truck motors and also furnishes power for the cable-pulling motors. The speed of the cable-pulling motor is controlled by the arrangement of circuits shown in Fig. 25. When the controller arm is in a vertical position, no current flows through the motor. If the main switch is closed and the arm is moved to the right of the center position, the motor will be connected in series with the resistance across the battery. By further turning the arm, resistance is cut out; on the last contact, the motor is connected directly across the battery. By turning the lever to the left, the effect is the same but the flow of current through the motor armature is reversed, causing it to rotate in the opposite direction. The path of the current through the motor is from the battery through the switch and field coil of motor–internal contact ring *e*–contact spring *c*–contact segment *a*–motor armature *f*–contact segment *b*–contact spring *d*–resistance–switch–battery. The motor is adapted to give three pulling speeds, corresponding to 10, 30, and 40 feet per minute, which can pull an average of 6,000 feet of cable in 6 hours. One charge of the storage battery is sufficient to propel the automobile 20 miles and leave enough current to pull cable the remainder of the working day. The cost of a charge per working day with current supplied at 4 cents per kilowatt-hour is $1.07.

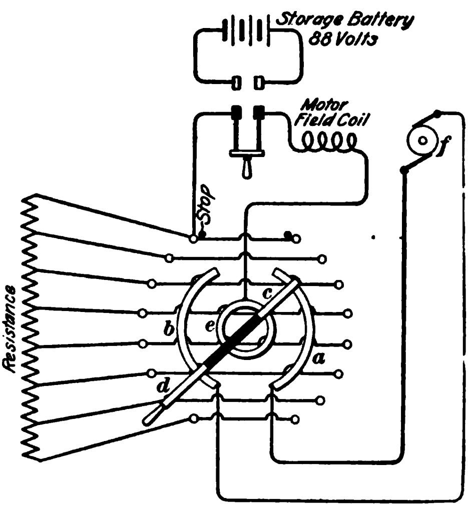


Fig. 25

When no cable is to be pulled in, the automobile may be used as an ordinary truck, usually performing the work of two 2-horse trucks. In this capacity, it is used for conveying the heavy reels from one part of the city to another, the cable-pulling drum being used for loading and unloading the reel. It is also frequently used for the sole purpose of illuminating the interior of a dark manhole when repairs must be made. Special 88-volt incandescent lamps are used for this purpose. They are supplied with long flexible conductors, and protected from breaking by a wire screen, the storage battery supplying the current for the lamps. The automobile is about 16 feet long by 7 feet in width and weighs about 4½ tons, including the battery which alone weighs 2,800 pounds. The truck is guaranteed to carry a weight of 5 tons 15 miles; and on the same charge furnish current for three continuous hours for cable pulling. About the same number of men are required for pulling cables with this apparatus, but they are necessary only for rolling the reels in position, opening the manholes, arranging the pulling connections, and paying out the cable from the reels.

43. Arrangement of Cables in Manholes.—After the cables are drawn in, they are spliced, proper care being taken, of course, to connect no good wires to bad ones. Sufficient slack should be left within the manhole to allow the cable to pass along the sides instead of directly across them, so as to allow plenty of room for the workmen and also to allow a certain amount of slack in case it is needed in making future repairs. It is a good plan to place a piece of sheet lead, heavy felt, or leather under each cable at the point where it emerges from the duct. This greatly reduces the liability to injury of the sheath at that point, due to the weight of the cable in the manhole. If the manhole is large, it is desirable that suitable support shall be arranged on its sides for the systematic support and arrangement of the cables. Racks should be provided on which cast-iron hooks are placed, this arrangement giving excellent satisfaction.

DISTRIBUTING SYSTEMS

44. Designation for Cables.—The Bell companies designate cables in an exchange system as follows: Each main cable leaving an exchange is given a number. If underground cables are continued by aerial cables, both are numbered alike. The first terminal on an underground cable is called A, the second terminal B and so on; and the first aerial cable terminal from the underground terminal A is designated AA, the second from such terminal AB and so on, while the first aerial cable terminal from the underground terminal B is designated BA, the second BB and so on. If no underground cables are used, the double letter is not necessary and the terminals are marked with single letters; for instance, the first terminal on aerial cable No. 3 might be marked 3A, the second terminal 3B, and so on.

45. Numbering of Poles.—Poles are numbered as follows: The poles on each main route from the cable terminal are numbered consecutively, beginning with pole No. 1 as the first pole from the terminal pole. If more than one main route leads from the terminal, each route is distinguished by adding the first letter of the general direction in which the lead extends, as N for north, E for east, etc.

The poles on each branch lead are designated by consecutive numbers, starting with 1 as the first pole from the main lead; and the branch lead is distinguished by the number of the pole on the main route from which it extends. Subbranch leads are numbered likewise from the branch routes and distinguished by the number of the pole of the branch route from which the subbranch extends.

Every pole in the exchange thus has a specific designation, which describes its relative location in the plant; for instance, if a circuit ends at pole 3AB–9W–5S11, it is known that such circuit occupies the following route: In underground cable No. 3 to the first underground terminal A; in aerial cable from this terminal to the second aerial cable terminal B; on nine poles of the main route leading west from terminal 3AB; on five poles of the branch route leading south from main route pole 9W; and on eleven poles of the subbranch route, leaving the branch route pole 5S. This, of course, is an extreme case and designations are unusually less complicated. The pole numbers need only be placed on the map for every fifth or tenth pole and at junction poles.

46. Records.—In Bell exchanges, a complete record of outside lines consists of three parts: (1) a districted map of the exchange; (2) a cable record book; (3) a card-index record of the equipment of each subscriber's circuit.

47. Map.—The **map** should show the following: location and designation of each cable terminal; the outline of the district fed by each cable terminal; the location and number of each pole.

48. Cable-Record Book.—The **cable-record book** should show for each cable the locations of all distributing points, the length of cable conductors from each terminal to the office (direct) not including intermediate branches, the pairs of conductors bridled out at each terminal, the total length of each series of conductors, including intermediate branches, for both underground and aerial cables, and the subscriber's line jack-number corresponding to each pair used.

49. Card-Index Record.—The card-index record consists of a card for each subscriber filed in the order of the subscribers' line jack-numbers, and, when properly kept, furnishes complete data of outside and inside equipment of each subscriber's circuit. On the back of each card is a dead-line record to be used when the subscribers are disconnected from active service, on which the portion of the dead wire shall be noted. The dead-line cards can most conveniently be filed according to the districts in which these lines are located.

CABLE DISTRIBUTING SYSTEMS

DISTRIBUTION FROM UNDERGROUND CABLES

50. It is usually the practice to run the cables that are to serve a certain district to a manhole, located as near as possible to the center of that district, and to distribute from that point by means of overhead construction, although sometimes underground distribution to the points the wires are to serve is required. In this latter case, the service wires are usually led from the manholes in the form of small lead-covered cables enclosing one or more pairs of wires, the service cables being led through iron pipes, if possible, to the basement of the building where the connection is to be made.

Where there are underground conduits, it is to be recommended that direct underground connections be made to various buildings wherever the number of telephones will justify the expense of such a connection. This is usually true of office buildings, apartment houses, large stores, hotels, etc. in large cities.

Where direct communication through a conduit to each building is not economical, the *vault system* may be used. In the **vault system,** a cable is run into one of the basements in a row of houses, and from the terminal there located, distributing wires are carried through the other vaults or cellars to the various telephones. This system is limited in its application because of the irregularities, absence of cellars, and objections of property owners to having the telephone employes frequently passing through their cellars.

51. In passing from an underground to an overhead system, a cable pole is arranged in close proximity to the manhole. A 3-inch iron pipe may be led from the manhole and by a gradual bend upwards along the side of the pole to a point high enough to insure the protection of the cable from injury by passers-by. The cable terminates in a terminal placed in a box through which connection is made with the overhead circuits.

52. In Fig. 26, means are provided for leading a cable from a **handhole** or distributing box to the cable pole. Handholes, such as shown in this figure, are often used where a distribution center occurs between two manholes, and where it is not necessary to provide for access to all the cables. In this case, only those ducts that are to carry cables for this particular section are brought into the handhole, and for this purpose are laid on top of the subway, the through cables being carried in the ducts below, as shown.

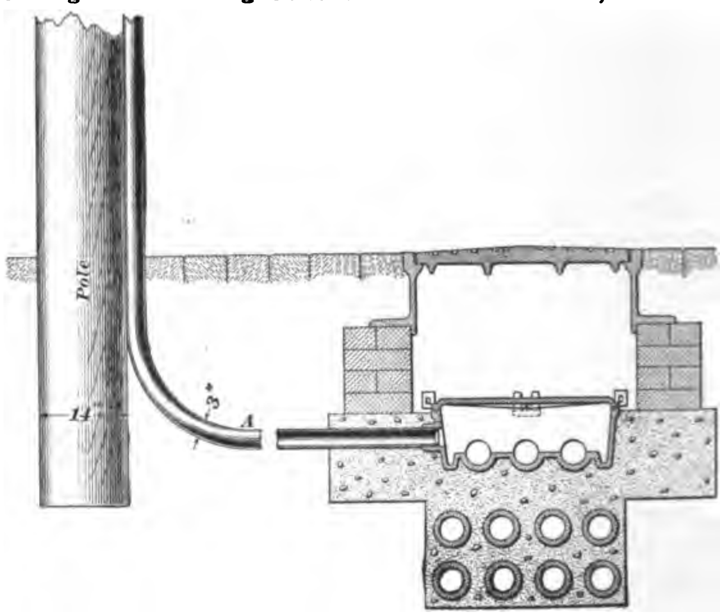


FIG. 26

One or more 3-inch iron pipes *A* lead from the handhole to the pole, to which they are secured by means of wrought-iron straps. The construction of the handhole is shown in this figure. It is a matter of great importance in this kind of work that the handhole shall be free from moisture, for which purpose double water-tight covers are used. The ends of the pipe leading up the pole should be thoroughly sealed, in order to prevent moisture from trickling down the outside of the cable and entering the handhole in this manner.

These pipes may be left open for ventilating purposes, in which case the service box or manhole should be drained, and great care should be taken that there is no low point in the pipe in which water can remain, as it may freeze in winter and crack the lead sheath.

OVERHEAD DISTRIBUTION OF CABLE LINES

53. Interior-Block Distribution.—The **interior-block method** of distributing service wires from a street cable consists in carrying one branch cable from a terminal box or manhole through the basement of one building in each block to the outside rear wall on which a cross-connecting box is placed; from this point, two or more smaller cables run in different directions around the back or interior of the block to feed all the substations in that block. An extra pair of wires should be allowed in each cable for making tests to locate trouble.

The distributing cables are run around the rear of the houses, sometimes on walls and even on fences. The cable may be placed on the side or top of the fence, or attached to the outer wall of a building or wherever convenience suggests. It is usually easy to secure rights for the asking and when refused new places can be secured. This method is said to overcome most of the difficulties of former methods, the great objection to which has been the difficulty of running underground wires from the street terminal to each substation, usually requiring, in the central part of large cities, the frequent digging up of the street and making holes through the walls of each building having a telephone. The character of the street paving and ground under it frequently makes the digging difficult. The greatest expense is the necessity of tearing open the street every time a pair must be run from a conduit.

By the interior-block method, the entrance to all houses, except the one traversed by the cable immediately after it leaves the street terminal, is effected by an aerial line running from one of the distributing points, any desired number of which may be located on the back fences or walls. A large enough cable is originally run to accommodate all the subscribers that the block is likely ever to possess. It is then a simple matter to discontinue service or to instal new telephones up to about the full capacity of the main service cable for this block. After the main service cable is laid, no further digging up of the street is necessary. This system is especially intended for city blocks that are built up solid with houses. This method is said to cost less for wire, rights of way, and construction than the older methods of distributing from either aerial or underground street terminals to each building.

54. Wall-Distributing Arrangement.—In the **wall-distributing arrangement,** a small terminal is fastened on the rear wall of one of the buildings and from it are run, through rings, twisted pairs of No. 18 B. & S. soft-drawn, copper, rubber-covered, and braided wire to the various telephones. This type of connection, a sample of which is shown in Fig. 27, is very neat and economical in first cost and maintenance. It is particularly suited to second-class business districts in the vicinity of underground conduit routes where the buildings are built close enough together to prevent long spans of ring wiring. Where the buildings are very much scattered and the building lines very irregular, some form of distributing pole seems to furnish the best and most economical service until the block is built up closely enough to warrant direct connection through a conduit or by the wall-distributing arrangement.

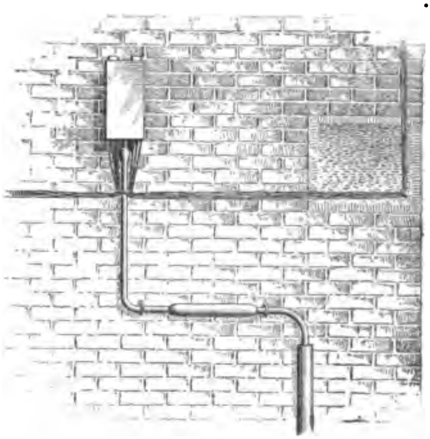


FIG. 27

CABLE TERMINALS

55. Where a cable ends in an office or on a pole, means must be provided for connecting the wires in the cable to the wires leading from it; and in cable terminals located outdoors, it is especially necessary to provide means for excluding all moisture.

56. Various forms of cable terminals are found on the market. These usually consist of a cast-iron or hard fiber box capable of being hermetically sealed to the cable sheath and having within a set of terminals to which the wires of the cable may be fastened. A cast-iron box terminal is shown in Fig. 28. After all the connections within the box have been made, the cover is secured in place, a rubber gasket serving to make the joint tight. The outside wires are then connected to the terminals that project through the sides of the cable head.

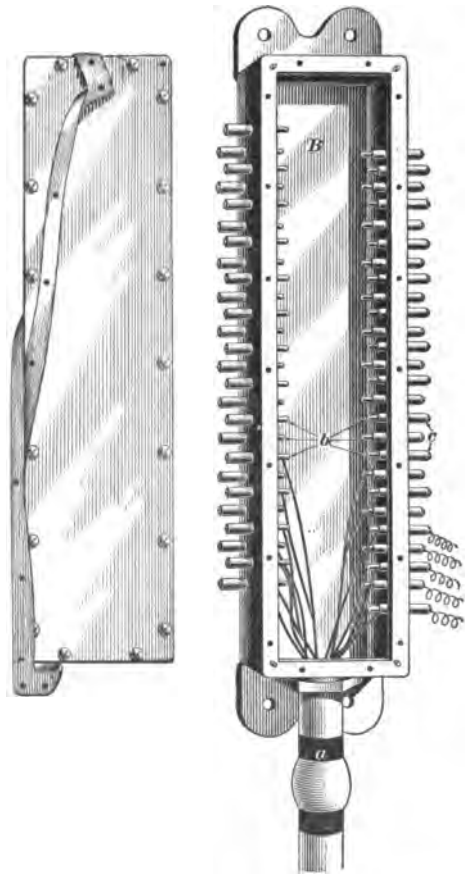


FIG. 28

A brass sleeve *a*, secured to the bottom of the cast-iron box *B*, affords ready means for securing the cable sheath to the box in a water-tight and air-tight manner. The various conductors from a cable are lead up within the box and fastened to the individual terminals *b*, which pass through the

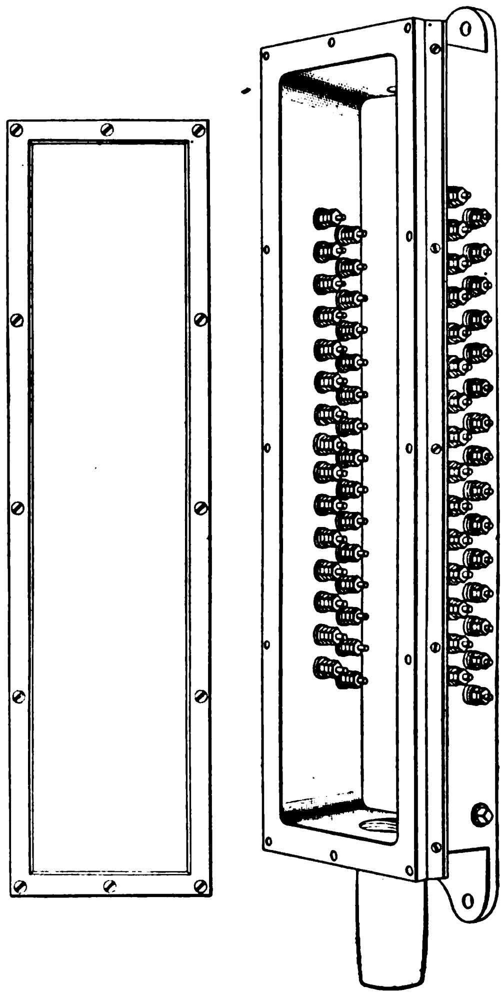


FIG. 29

insulating bushings *c* to the outside of the box. In a cable head of this style, it is necessary to solder the wires to the terminals.

57. A form of cable head more extensively used is shown in Fig. 29. This is a rectangular cast-iron box into which the cable is brought from below, the lead sheath being secured to the sleeve of the cable head projecting downwards by a wiped joint. The cable conductors are securely fastened under washers and nuts on the inside of the head to terminals that project through insulating bushings to the outside of the head, where the outside wires are in turn fastened in like manner.

58. Tubular Terminal Head.—**Tubular terminal heads,** made of hard fiber, are also used. One is shown, both opened and closed, in Fig. 30. The ends of the inside wires are secured under washers and screws, and the ends of the outside wires by strong binding posts, to terminals that extend through the sides of the head.

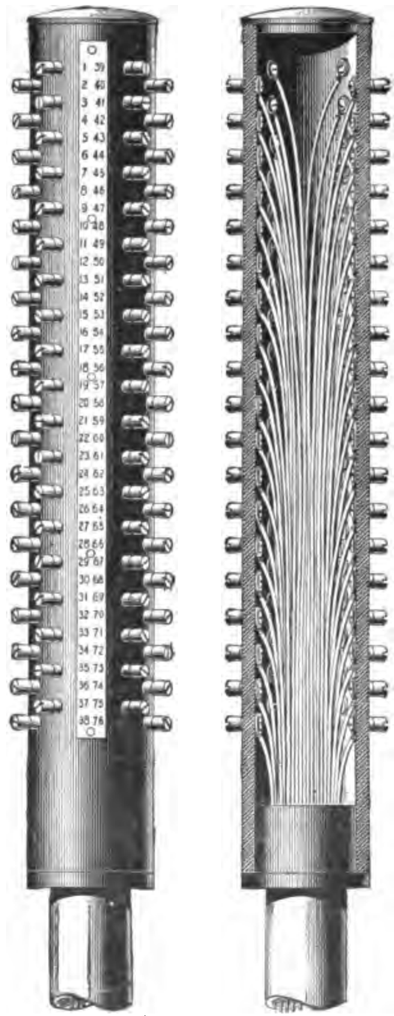


FIG. 30

59. Lightning Arresters.—Lightning arresters and fuses are frequently placed in the pole box near the cable head, in order to prevent injuries to the cable from lightning or by the passage through it of heavy currents, such as might be caused by crosses with power or lighting wires. These protecting devices may be procured in a variety of forms.

A pole box with two tubular cable heads and lightning

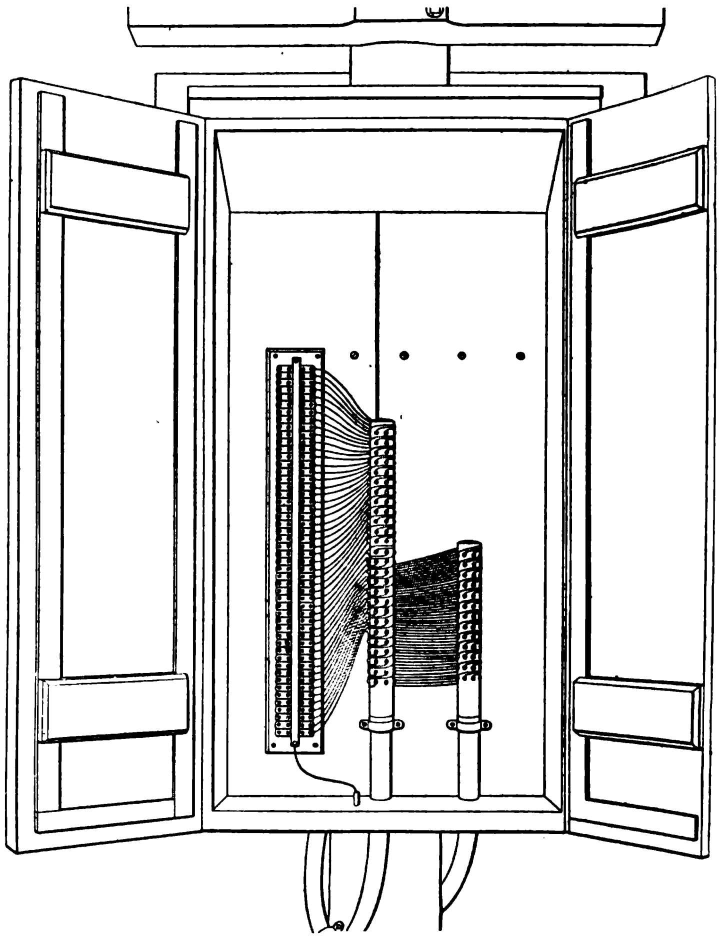


FIG. 31

arresters is shown in Fig. 31. Pole boxes are intended to be waterproof, but sometimes they are not, and, hence, special care should be taken to make the cable heads moisture-proof.

60. Combined Cable Box and Terminal.—Fig. 32 shows the combined cable box and terminal equipped with self-soldering nozzles as made by F. B. Cook. The self-soldering sleeves, which are shown in Fig. 33, are funnel-shaped, made of brass, heavily tinned, and contain a lining of solder. To make a joint, scrape bright the lead sheath of the cable just before soldering, introduce it the proper distance into the sleeve, wrap tape or cloth around the bottom of the nozzle to prevent the solder from running out, and then heat the sleeve with a blow torch until the solder melts and makes a tight joint. A cross-section of the nozzle is shown in Fig. 33 (*a*), while

Fig. 32

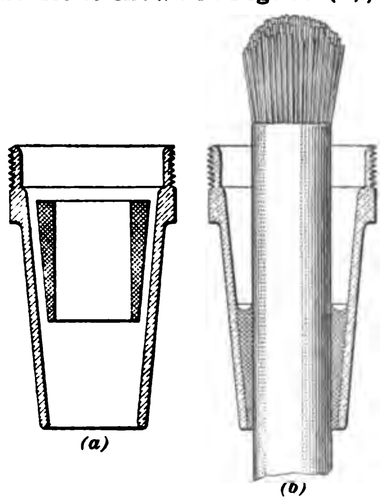


Fig. 33

Fig. 33 (*b*) shows a completed joint. A skilled plumber is not necessary to make this joint; it is therefore especially useful for small companies that do not have enough steady work for a regular cable splicer. The lower part *c* of the combined cable box and terminal shown in Fig. 32 is made separate for use as a junction box only; the upper part constituting the terminal may be added at any time. The galvanized-iron cover, which makes the terminal weather-proof, slides over the top and is automatically locked in either the closed or raised position.

Mr. Cook also makes a terminal like the part *d* that may be fastened in a cable box for the use of those who prefer potheads and cable boxes. The terminal illustrated at *d* is supplied with carbon arresters *e* and long enclosed fuses *m*. Similar terminal heads are made with tubular fuses only and another, for use in small exchanges, having heat coils and carbon arresters.

The American Electric Fuse Company and the Sterling Electric Company make somewhat similar terminals for the same purposes.

61. The **spider** is a term used by linemen to designate the wires that connect the cable-terminal posts to the line wires. Where the pins and posts are numbered alike, as it is best to do, the spider wires are generally lashed together, for there will be no need to disturb them later. For spider wires, use rubber-covered and braided copper wire. The spider can be most conveniently made up in the shop by laying out the same number of arms and in the same position as they are on the pole. Starting from each pin, leave the wires long enough to reach up into the cable box. Lash them together and tag the two ends of each wire alike, thus requiring no testing when they are connected on the pole.

To hold the spider wires in place along the cross-arms, leather strips, $2\frac{1}{2}$ in. × $\frac{1}{2}$ in. × $\frac{1}{8}$ in., are sometimes fastened on the side of the cross-arm on the side next to the pole and opposite each pin, the lower end of the strip being about $2\frac{1}{4}$ inches from the bottom of the arm and to hold the spider wires in place from the cross-arms along the poles to the cable box, leather strips $4\frac{1}{2}$ in. × $1\frac{1}{4}$ in. × $\frac{1}{8}$ in. are fastened to the pole $\frac{1}{2}$ inch below the top of each cross-arm.

For bridle wires, it is customary to use No. 18 B. & S. copper wire twisted in pairs, each wire being sometimes covered with a weather-proof insulation and braid and sometimes with rubber $\frac{1}{16}$ inch thick.

62. The Bell companies require the bridle wires, for which they use No. 18 B. & S. copper wire with okonite insulation, to be formed neatly, the portion going along the pole being wrapped with 2-inch linen tape, and the junctions at the cross-arms with tape so as to leave no opening for water to enter under the tape. After forming and taping, each spider is given two coats of asphaltum paint, carefully applied so as to render the whole impervious to moisture.

Each bridle wire passes through a separate hole bored diagonally through the upper inside corner of the arm and they enter the cable box from the bottom, the hole being packed with oakum. The bared and cleaned ends of the bridle wire are closely wrapped four times around the end of the wire that forms the dead end and soldered.

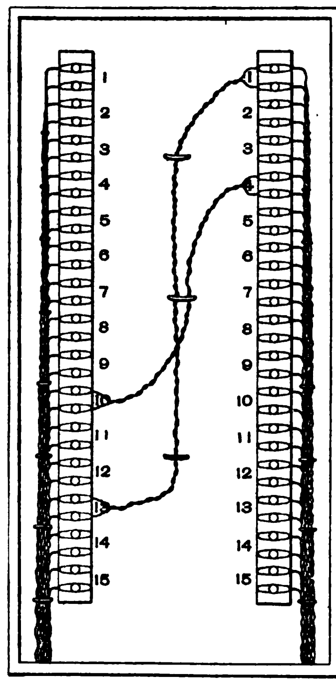


FIG. 34

63. Wiring Cable Boxes. One method of wiring a cable box consists in using what is sometimes known as a straight box, which is intended to be used where underground and aerial lines meet, and where there is no immediate prospect for the need of any branch cables. In the straight box, a standard terminal strip is used, mounted and numbered for 15, 25, or 50 pair, as may be found necessary.

At distributing points a cross-connecting box, as shown in Fig. 34, may be used. The main cable comes in through the bottom on one side and the drop wires on the other side, both being laced and soldered to the terminals in the usual manner. In the center, between the two standard strips, three bridle rings are placed, as shown, and the cross-connections made in the usual manner. This is a very flexible

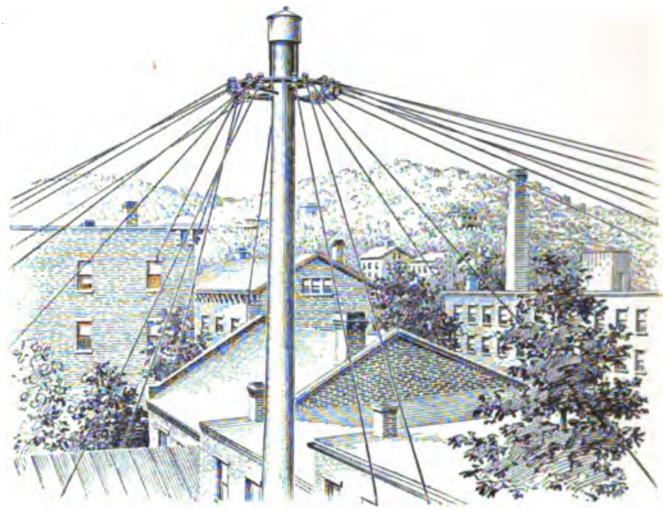


FIG. 35

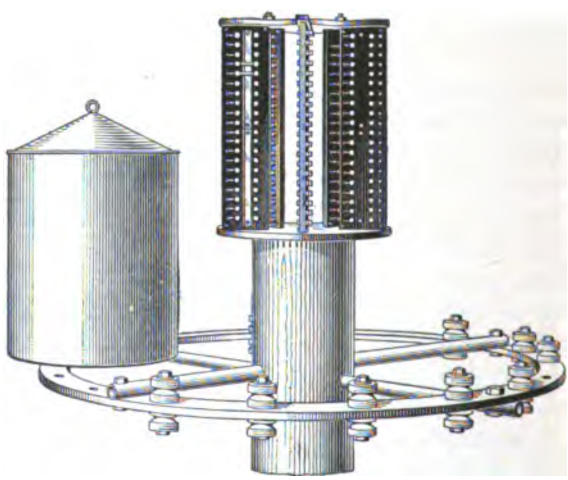


FIG. 36

method, and in many cases accomplishes the same results as are obtained by looping in a cable.

64. Distributing Poles.—A **distributing pole** may be designed with a small circle at the top, which will not be unsightly if the wires are strung from it in a neat manner without attempting to include too much territory. Such a distributing pole is shown in Fig. 35, while in Fig. 36 is shown a pole-top terminal, made by the Mountain State Electric Company, at closer range. 30- to 35-foot poles are frequently used and in some cases 10-pair junction boxes are placed as often as every other pole or even every pole. In such cases, each pair of wires usually appears somewhere along the lead at two or three terminals, so that it may be possible to use any particular pair at different points. Furthermore, the multiple connections are usually so arranged as to permit the economical grouping of party lines.

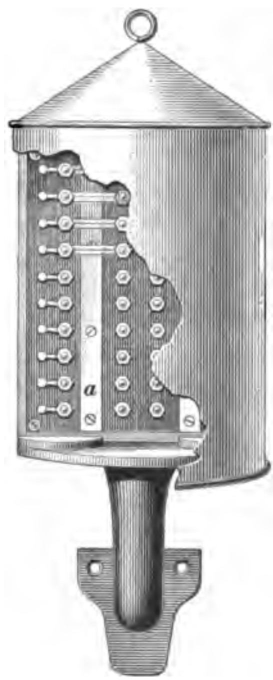


FIG. 37

65. Fig. 37 shows a 10-pair cable box made by the Mountain State Electric Company. It consists of a circular cast-iron base on which is fastened an iron frame holding a 10-pair hard-rubber plate. The 25-pair terminal has a semicircular cast-iron base with five 5-pair hard-rubber plates. These boxes are provided with lightning arresters, which consist of grounded strips *a* of carbon across which the cross-connecting wires or fuses pass, being insulated therefrom by mica strips Galvanized covers *b* are provided that make them water-tight. They are made to be fastened to the sides or tops of poles.

66. Multiple Tap Cable Terminal.—In Fig. 38 is shown a very neat arrangement for carrying 5, 10, or 15 pair of wires from a main cable *a* and a branch cable *b* to a cable terminal *c* and for distributing the drop lines *d* to the subscribers' houses. This terminal contains no fuses or arresters and no cross-arms are used on the pole. The conductors in the branch cable are usually connected in multiple with the conductors in the main cable.

67. The form of terminal used for distributing purposes by the Central District and Pittsburg Telephone Company is shown in Fig. 39. The construction of this terminal is

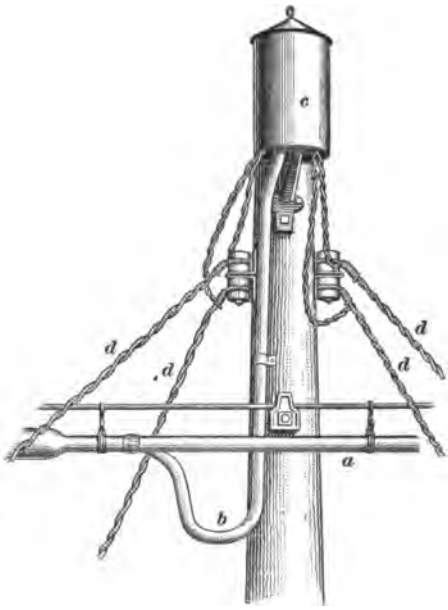


FIG. 38

FIG. 39

better shown in Fig. 40. It consists of a cast-iron box containing a black-glazed porcelain block *c* on which are mounted special terminals *d* made of tinned studs and nuts with $\frac{1}{32}$-inch semihard washers at *n*. The front ends of the studs are burred over so that the nuts, for turning which a special wrench is provided, cannot come off. The cable wires are soldered at *e* to the rear ends of the studs and slack loops are left at *l* to relieve the terminals and wires of any tension; this loop must clear the framework by at least

$\frac{1}{4}$ inch when in place. The space *i* around the cable wires is filled with hot compound through the hole, which is closed by an ordinary cast-iron plug *j*. The joint *f* and the similar one below between the porcelain block and iron frame are made tight with candle wicking. The cable wires are well wrapped at *o* with waxed twine to prevent their falling back into the lead sheath and the cable is secured by a wiped joint to the brass tube *h*, which is 4 inches long and has an outside

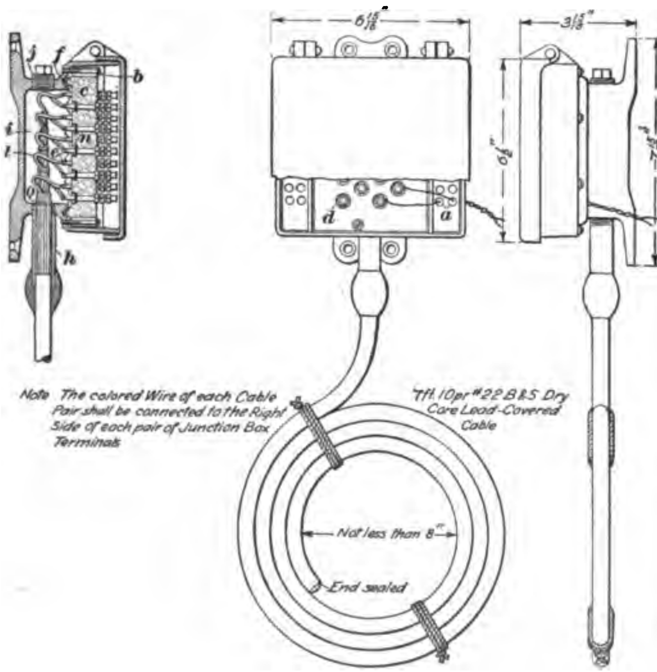


FIG. 40

diameter of .84 inch. All threaded joints are made tight by coating the threads with white lead as they are put together. The brass screws *b* are known as No. 8, 32, $1\frac{1}{4}''$ machine screws and are provided with brass or copper washers.

The holes *a* are filled with a special putty that is broken out when the bridle wires are passed through them. From the locknuts *d*, which are used as binding posts, No. 14 B. & S. copper, rubber-covered and braided, twisted-pair wires are strung direct to the protectors at the subscribers' houses, no cross-arms being used along the lead. On account of the short length of rubber-covered wire used, no protection is provided at the cable terminal. Each line is fused where the aerial cable is connected to the underground cable. This arrangement is very useful for distributing along streets and alleys intersecting the main underground-cable conduits, and also along streets and alleys that will later be provided with underground conduits.

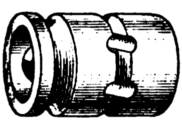
68. On account of the large number required, it is necessary to use an efficient and economical terminal, its first cost, maintenance and life being considered. The terminals shown in Figs. 37 and 39 have both proved satisfactory. The latter is used for vault and wall wiring and on poles in connection with aerial-cable lines. The cost of a 10-pair size is said to be $2.45, placing and splicing to a 50-pair cable $1.70, material used for splicing $1.15, and its life is at least 15 years.

DROP LINES

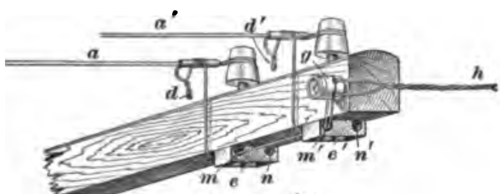
69. Kind of Wire.—The **drop line** means the wires between the line or cable terminal and the subscriber's house. Many companies use for the drop line a rubber-covered and braided copper wire, never smaller than No. 16 B. & S.; however, some recommend a first quality of No. 14 B. & S. hard-drawn copper wire covered with rubber and braid, while others use a similarly insulated No. 14 iron wire on account of its greater strength. All these insulated wires usually come twisted in pairs. Joints in drop lines or interior circuits should always be well made mechanically and soldered.

70. The drop wire should be connected to the terminals of the line wire and brought to the springing off point of the cross-arm in such a manner as not to touch the arm at any point. A good method, which was given in The American Telephone Journal, is shown in Fig. 41. The drop wire is stripped of its insulation for about 6 inches. To insure that the line wire will not touch the cross-arm, two wooden cleats *e*, *e'* are screwed to the under side of the arm in such a manner that the outer surface of it will be directly under the inner edge of each pin. Each cleat has two holes *m*, *n* and *m'*, *n'* bored through it. The pair of wires is threaded through the hole *m'* of the outer cleat, and one conductor is brought up, wound 2½ times around the McIntire sleeve of the line wire *a'*. The skinned end is then wrapped around the free end of the line as shown at *d'* and soldered. The other conductor is brought through the hole *m* of the cleat *e* and secured in the same way to the other wire *a*. The object in wrapping the drop wires around the sleeves is to prevent any accidental pull from coming on the soldered joint.

If the two line wires are dead-ended at the springing off point so that there are free ends, half McIntire sleeves



(b)



(a)

Fig. 41

may be used to make the joints between the free ends and the drop wires. Even if the line wires have no free ends, half Lillie sleeves may be used to make the joint. A split-knob insulator *g* is screwed to the side of the cross-arm as shown, and the conductors are passed through the grooves, which hold them securely in position. From this point, the wires *h* are run to the subscriber's station. If the wires on the next pair of pins end at this pole, the drop wire would be brought through the holes *n* and *n'* and fastened to a split insulator placed on the opposite side of the cross-arm.

Should it become necessary to bring the remaining lines off at this cross-arm, the additional cleats and insulators necessary should be placed on the arm and the drop wires fastened in the same manner. The split insulator is constructed as shown at (*b*), Fig. 41.

71. An excellent way to connect a drop line to a bare overhead line is shown in Fig. 42. At *a*, *b* the line wires are dead-ended, preferably with half sleeves, leaving an end projecting to which the bridle wires are joined by soldering or with half sleeves. The bridle wires are held under the cross-arm with wooden cleats *c*, *d*, *e*, *f*. The drop line is dead-ended by means of sleeves *i*, *j* around the glass insulators on a so-called universal two-insulator iron *h*, which is fastened to the arm with two $\frac{3}{8}$-inch carriage bolts. To the projecting ends *m*, *n* are joined the ends of the bridle wires by soldering or with half sleeves.

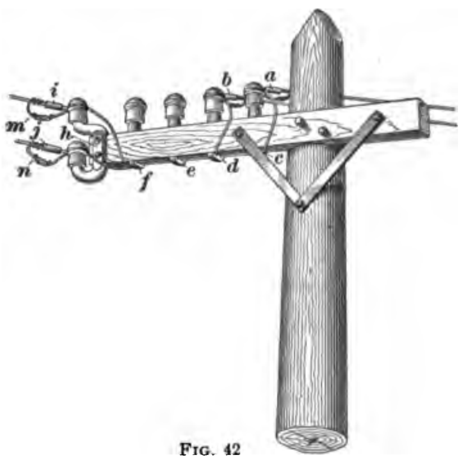


FIG. 42

72. Attaching to Trees.—Where the wires must be fastened to trees, one of the two methods illustrated in Fig. 43 will hold the wire securely and yet allow sufficient play to preserve them from breaking under the strain caused by the swaying of the trees. No wires should be attached to trees unless it cannot be well avoided.

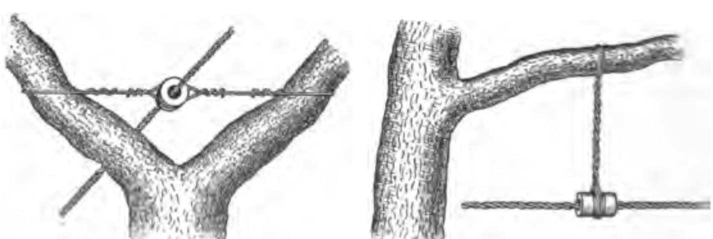

(a) (b)

FIG. 43

73. It is preferable to choose such a path for a drop line that it may be supported every 75 feet. Spans longer than 150 feet should never be employed. The method of attaching to the building depends on the nature of the material to which the attachment is to be made. Where the material is wood, the split insulator may be used. Where brick or masonry walls are to be fastened to, a bracket is the most serviceable. In either case, a small malleable-iron bracket fitted with a double-groove No. 12 insulator, or an iron bracket with two insulators, as shown attached to the cross-arm in Fig. 42, may be used. In most cases, but one attachment is necessary. The wires must be lead inside the building and about a foot left, after forming a drip loop outside.

Where the houses are detached, a good plan is to fasten the drop line under the eaves of the roof. The wire is thus kept out of sight, and is also afforded some protection. Some companies carry the twisted pair-drop wire through $\frac{1}{2}$-inch circular loom, one hole only being used, into the building; the protector being placed immediately outside or inside the hole as seems best in the judgment of the installer, protectors only being used when the drop lines are over 150 feet in length from a cable terminal, or when they pass under or above foreign wires, or when they connect to bare overhead line wires.

The wire should never be allowed to rest on the roof of the building, as it is very apt to be walked on and the heat caused by the direct rays of the sun and the reflected rays from the roof soften the insulation and causes it to deteriorate.

SUMMARY OF DISTRIBUTING SYSTEMS

74. In a paper presented to the American Institute of Electrical Engineers, S. P. Grace, chief engineer for the Central District and Pittsburg Telephone Company, gave the following summary of rules for distributing systems that may be followed with economical results: First, where the number of circuits will exceed 400, underground subways should be built, and the distribution in the immediate vicinity of these feeder routes should be effected by direct connection, vault, wall, or circle pole-top terminals according to local conditions.

Second, where aerial-cable distribution is used, a cable should be placed on short poles, in general not exceeding 35 feet in height, if the number of subscribers will justify the expense of placing the same. This cable is to be provided with 10- or 15-pair terminals, without protecting devices, on alternate poles, from the locknuts of which to the subscribers' premises the connection should be made with twisted-pair, No. 14 B. & S. gauge, hard-drawn, copper wires, insulated with a high grade of rubber compound and protected with heavy braid. Where the distribution is very dense, a tap may be made to the cable on every pole; and in thinly settled districts through which cable may pass, a tap should be placed wherever by so doing 300 feet of twisted-pair cable can be saved.

Third, on side leads intersecting aerial-cable lines, twisted-pair wires strung on brackets should be used for distribution to subscribers located within 1,000 feet of the cable line. If the subscribers are at a greater distance than 1,000 feet, all distribution on these side leads should be effected by means of No. 14 N. B. S. bare copper wire, strung on standard cross-arms, provided that there are no obstacles in the way, such as trees, foreign wires, etc., which would necessitate the use of high poles. If obstacles are met with, a special study should be made to determine which is most economical, the setting of high poles, the use of twisted pairs on low poles, or the use of aerial cable.

Fourth, when the number of circuits on a pole line reaches ten or fifteen, a cable should replace them. This cable should be provided with terminals on alternate poles, so that the bare or covered wire formerly strung along the lead for distributing purposes can be removed and returned to stock.

TELEPHONE CABLES

PROPERTIES AND CONSTRUCTION OF CABLES

INTRODUCTION

1. Where it is necessary to run a greater number of wires than can be accommodated by the bare-wire construction already described, cables become necessary. For both indoor and outdoor work, the use of a cable makes it possible to easily run a large number of wires where the same number by the ordinary construction would be out of the question. Moreover, for the problem of underground and under-water work, where it is impossible to use bare-wire construction, the cable forms the only solution.

Unless certain precautions are taken, the same inductive actions that cause trouble on bare-wire lines will be much more effective in cables, where the wires are so much closer together. The best, and in fact the only practical, remedy in use today to prevent inductive disturbances between neighboring conductors in the same cable consists in using a complete metallic circuit for each line and twisting the two wires forming one line circuit together, thus really transposing the line wires every few inches. Cables having as many as 600 pair are now made with a diameter of about 4 inches and without giving any cross-talk. The latter is due to the twisting together of the two wires forming a pair and the spiraling of alternate layers in opposite directions. Each wire of a pair should never be used for a separate telephone line with the ground as a return, or a third wire, either inside or outside the cable, as a common return. Cross-talk is sure to result from such a use of cable conductors.

2. Satisfactory conversation can be held over a cable 25 miles long and composed of No. 19 B. & S. conductors having an average capacity of .08 microfarad and an average resistance of 94 ohms per circuit mile. Any circuit having a $C \times R$ not exceeding the product of this capacity and resistance should give equally satisfactory service. For short subscribers' lines, cables with smaller conductors and higher capacity may be used; while, for longer toll cables, larger conductors having less resistance and capacity per mile are necessary.

The attenuation constant B where leakage, resistance, inductance, and capacity must all be considered is

$$B = \sqrt{\tfrac{1}{2}\sqrt{(R^2 + p^2 L^2)(S^2 + p^2 C^2)} + \tfrac{1}{2}(RS - p^2 LC)} \quad (1)$$

in which $S = \dfrac{1}{\text{insulation resistance}}$;

R = conductor resistance, in ohms per mile loop (2 miles of conductor);

L = mutual inductance in henrys, per mile loop;

C = mutual capacity in farads, per mile loop.

From the attenuation constant, the actual decrease in the strength of the current between the transmitting and receiving ends and the lengths of lines of different electrical properties that have equivalent transmitting properties can be determined. The so-called **equivalent** of a line is the ratio of the attenuation constant of the line and that of a line considered as a standard. The attenuation constant B of a cable conductor weighing 20 pounds per mile (about No. 19 B. & S.), which may be considered as a standard, is .103. For 100-pound-per-mile cable conductor, the attenuation constant is .0122, so that the equivalent for a 100-pound cable conductor is $\dfrac{.103}{.0122} = 8.45$; which means that 8.45 miles of 100-pound cable conductor will transmit speech as well as one mile of 20-pound cable conductor.

Where inductance and leakage may be neglected, which is usually true for ordinary telephone lines, B. S. Cohen states that the equivalent for any gauge of conductor in the present type of cable, up to conductors weighing 40 pounds per mile, may be determined by the formula:

$$\text{Equivalent} = \frac{2.18}{\sqrt{C\,R}} \qquad (2)$$

in which R = resistance, in ohms per mile loop;

C = mutual capacity, in microfarads per mile loop.

Thus, a cable conductor having a resistance of 84 ohms per mile loop and a mutual capacity of .05 microfarad per mile loop will have an equivalent of $\frac{2.18}{\sqrt{.05 \times 84}} = 1.063$. That is, 1.063 miles of this cable conductor is equivalent to 1 mile of 20-pound cable conductor.

PAPER CABLES

3. Methods of Reducing Capacity.—To reduce the electrostatic capacity of the conductors of a cable, three methods are available: first, the wires may be placed farther apart; second, the wires may be made smaller; and third, an insulating medium having a lower specific inductive capacity may be used.

To place the wires farther apart would be to defeat the principal object for which the cable is employed—that is, compactness. The sizes of the wires may be reduced to a certain limit, but beyond that limit the mechanical strength of the conductor and its ohmic resistance forbid us to go. As a result of this reduction in the size of wires, Nos. 19 to 22 B. & S. gauge are commonly used and No. 24 B. & S. is sometimes used in dry-core telephone cables. In following the third method of reducing the electrostatic capacity, various materials having a lower specific inductive capacity than rubber have been tried, and have been found to give far better results so far as the electrostatic capacity is concerned; and, in fact, in all other respects, when proper care was exercised in their manufacture and maintenance.

DRY-CORE CABLES

4. The telephone cables now most commonly used are made by insulating the various wires with a loose wrapping of very porous dry paper, after which the wires are twisted in pairs and bunched into a cable. A sheath of lead is then placed over the cable, in order to exclude all moisture and also to prevent mechanical injury. The loose wrapping of the paper and its porous nature insure the inclusion in the cable of a great amount of dry air, which possesses the lowest inductivity of any known substance, hydrogen excepted. Two or three feet at each end of the dry-core cable is usually saturated or sealed tight, to exclude moisture, with paraffin; or, better, with some of the special compounds that are made and used by the cable manufacturers. Immediately after testing in the factory, the lead sheath at each end is hermetically sealed by a plumber's wiped joint.

5. The electrostatic capacity of the wires in a toll cable of No. 10 B. & S. built in this manner is often as low as .04 microfarad per mile, and it is customary, in making specifications for telephone cables using No. 19 B. & S. gauge wire, to specify that the electrostatic capacity of each wire shall not exceed .08 microfarad per mile. All cables of this description are made in twisted pairs, the conductors being twisted together so as to give one turn in about 6 inches.

Cables used for trunk lines and composed of 50 and 75 pair of No. 17 B. & S. conductors have a resistance of 59 ohms per circuit mile; while subscriber cables composed of 10 to 120 pair of No. 19 B. & S. and 250 to 400 pair of No. 22 B. & S. conductors, respectively, have a resistance of 94 ohms and 187 ohms per circuit mile, respectively.

The **dry-core cable** represents the highest development in the line of telephone cables. The high insulation obtained by the dry air and paper, the low electrostatic capacity, and the compactness of the cable as a whole render it admirably adapted for both underground and aerial work, but it is not very well suited for long-distance telephone transmission, unless Pupin coils are used. The production of a cable suitable for long-distance transmission is one of the most difficult problems before the telephone engineer.

6. Felten-Guilleaume Cables.—The dry-core cables manufactured by the Felten-Guilleaume Company differ from the construction of the dry-core cables already described only in the method of insulating the two wires of a pair from each other and the pairs from other pairs. The two wires are arranged on each side of a strip of paper, after which the wires are twisted together as shown in Fig. 1. After this, a ribbon of paper is wound about the pair, thus enclosing it in a continuous

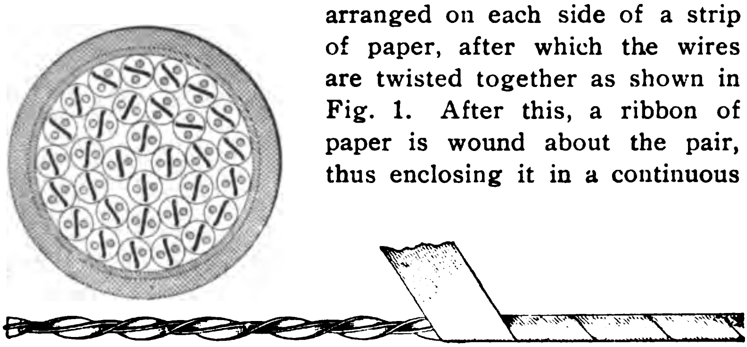


FIG. 1

tube of paper. These tubes are then bunched together and enclosed in a lead sheath, as shown in the upper portion of Fig. 1. Some cables made in this manner have shown an electrostatic capacity as low as .05 microfarad per mile.

7. Objections to Dry-Core Cables.—There is one objection to the dry-core cable, and whether or not this is a serious objection depends on the manner of manufacture and the subsequent care of the cable. A puncture in the sheath allows the entrance of moisture, which, due to capillary attraction, will soon penetrate the entire length of the cable, thus totally ruining the insulation. When moisture first enters, immediate steps must be taken to expel it and to repair the fault, and, if this is not done in an intelligent and prompt manner, the cable will soon be worthless. This point shows the necessity for making frequent insulation tests on cables of the dry-core type, so that if moisture enters, its presence may be detected before it has time to do serious damage.

8. In England and in France, some dry-core cables have been laid with provision for forcing dry air through the cable at a pressure of about 15 pounds per square inch without disturbing the cable at all. Should moisture from any cause get into the cable, it may be expelled by blowing the dry air through it, the looseness with which the insulating material is packed allowing this to be done. The air is thoroughly dried by being passed through a series of **U** tubes containing calcium chloride and is then filtered by being passed through dry cotton wool. The expulsion of the moisture may be aided by warming the cable, if it is known to be wet at any particular place.

9. Lead Sheaths for Cables.—Sometimes the sheaths for cables are made of pure lead, but specifications usually call for a mixture of 3 per cent. of tin with the lead. The reasons for this is that where cables are used for underground work, the lead is more likely to be attacked by chemical action than is the mixture of lead and tin. Considerable difference of opinion exists as to the advisability of making the mixture of lead and tin, some manufacturers claiming that it is impossible to obtain an even mixture of the two, and that the sheath will not be homogeneous, and will therefore contain spots that are more or less brittle, owing to the excess of tin.

The Standard Underground Cable Company, of Pittsburg, Pennsylvania, advocates a sheath of pure lead with an outside coating of tin, claiming that the tin is then in a position to do the most good in preventing chemical action without in any way interfering with the quality of the sheath itself.

10. Outside Braiding of Cables.—The lead sheath of cables is occasionally covered with a braiding of cotton saturated with weather-proof compound. While this undoubtedly protects the sheath from abrasion in both overhead and underground work, it is subject to several disadvantages. Among these is the fact that it renders the location of punctures or injuries in the cable sheath more difficult to locate. It forms a hiding place for bugs, some of which have been known to gnaw their way through the lead sheath. After some years, the braiding rots off and hangs in shreds from the aerial cables, thus presenting an unsightly appearance. In underground cables, the braiding is likely to become disengaged, and bind the cable in the duct in which it lies, thus rendering its subsequent drawing out a very difficult matter. The general opinion now held by many engineers seems to be that, except under certain conditions, the outside braiding on a lead-covered cable is a disadvantage, and, therefore, that its extra expense is worse than useless.

11. Color of Insulated Cable Wires.—The two wires forming a pair in a telephone cable are covered with insulation of different color, usually red and white or red and blue. Among cable men, it is customary to always connect the red wire to the sleeve, ground, or common-return side of the circuit and the other wire, whatever color it may be, to the tip or line side of the circuit. Whatever designation may be used, the cable wires should all be connected in the same manner, otherwise there is almost sure to be trouble from cross-connections. In cable terminals, the top post of each pair should always be connected to the tip or line side and the second post of each pair to the sleeve, ground, or common-return side. Hence, it is well to remember: white to tip, line, or top post; red to sleeve, ground, common-return, or second post.

SPECIFICATIONS FOR DRY-CORE TELEPHONE CABLES

12. The following specifications for underground cables are taken from the printed matter of a prominent manufacturer of cables and the specifications of the American Bell Telephone Company:

13. Conductors.—Each conductor shall be ——— inch in diameter (.03589 inch in diameter for 19 B. & S.) and have a conductivity of 98 per cent. of that of pure soft copper.

Each No. 19 B. & S. conductor shall have a resistance of not more than 47 ohms, at 60° F., for each mile of cable, after the cable is laid, spliced, and connected to the terminals. The maximum conductor resistance of No. 20 B. & S. should be 60 ohms per mile; of No. 16, 23.5 ohms per mile; and of No. 13 B. W. G., 6.2 ohms per mile.

14. Core.—Each wire should be covered with a wrapping of paper, one wire of each pair having the insulation colored; the two wires forming a pair being twisted together, the length of a complete twist not to exceed 3 inches, formed into a core arranged in reverse layers, and covered with a layer of thick, tough paper. At least 2 feet at each end of a cable and at least 2 feet on each side of a joint shall be saturated with an insulating material—in the latter case, of course, after the joint has been made.

15. Sheath.—The core shall be enclosed in a pipe composed of lead and tin; the amount of the tin shall not be less than 3 per cent. The pipe shall be formed around the core, have a thickness of not less than $\frac{1}{8}$ inch for an underground cable, and shall be free from holes or other defects, and of uniform thickness and composition.

16. Electrostatic Capacity.—The average electrostatic capacity of a cable composed of No. 19 B. & S. conductors shall not exceed .08 microfarad per mile, each wire being measured against all the rest and the sheath grounded; the electrostatic capacity of any wires so measured shall not exceed .085 microfarad per mile. These figures apply only to the paper cable, and proper allowance shall be made for the rubber-covered wire used at the terminals.

17. Insulation Resistance.—Each wire shall show an insulation of not less than 500 megohms per mile, at 60° F., when laid, spliced, and connected to terminals ready for use, each wire being measured against all the rest and the sheath grounded.

It is, however, sufficient, when only a few pairs are available, to measure the insulation resistance or capacity of one wire in each of 5 or 10 pair, this wire being tested against its mate, the remaining wires in the 5 or 10 pair tested, and the sheath.

18. Aerial Cables.—The American Telephone and Telegraph Company now specifies No. 22 B. & S. soft-copper wire for aerial cables. The resistance of the conductor must not exceed 90 ohms per mile at 60° F.; and the electrostatic capacity of any one wire must not exceed .1 microfarad and the average of all tested must not exceed .095 microfarad per mile. The sheath must not be less than $\frac{3}{32}$ inch thick. In other respects, the specifications for aerial cables are the same as for underground cables. Where conductors other than Nos. 19 and 22 are specified, the resistance and capacity to be specified will vary accordingly.

19. The foregoing specifications are practically identical with those issued by the Bell companies. The following additional requirements and notes are, however, inserted in some Bell companies' specifications:

The telephone company is to have the right to make such tests of the quality of the materials used and of the electrical properties of the finished cable as it may desire. The inspector of the telephone company is to have the power to reject the cables should the quality of the materials used or the electrical properties of the cables fall below the requirements specified.

The manufacturer shall guarantee that for 1 year from the time the cables are laid, spliced, and connected to terminals, the electrostatic capacity and the resistance of the conductors shall not have increased nor the insulation resistance of the conductors have decreased beyond the limits specified. The manufacturer, however, shall not be responsible for the failure of cables brought about by injuries to the sheath or conductors due to causes beyond his control.

The durability of a cable depends so largely on the character of the joints that it is recommended that the utmost care be exercised in making splices and in drying the core before a joint is sealed. The conductors of a pair in one cable length should be connected to the conductors of a pair in the next cable length; and at each splice the relative position of the pairs in the cable should preferably be changed.

The tests for insulation resistance may be made with an electromotive force not exceeding 550 volts. As a measure of safety, when more than 200 volts is employed in such tests, a resistance of 100,000 ohms should be included in the circuit with the source of the electromotive force and the conductors of the cable.

20. All tests should be made with the cables in place, joined, and terminated, and the results reduced to equivalent values at 60° F. Old cable should not be used again if its insulation resistance is less than 50 megohms per mile. The standard sizes of subscriber cable, that is, cable not used for toll or trunk service, are 30, 60, 90, 120, and 150 pair.

It has been customary to measure the capacity of one wire with all the others grounded to the sheath. A newer method is to measure the capacity between a pair of wires with both wires insulated, but all the other pairs grounded to the sheath. This gives more nearly the mutual capacity of a pair, which is really the quantity desired. The mutual capacity determined in this way is about 33 per cent. less than that determined in the old way. For instance, a pair of No. 19 B. & S. wires in a cable would have a mutual capacity of .054 microfarad per mile instead of .08, as determined in the old way. Similarly, No. 22 wire in a cable would have a mutual capacity of .08 instead of .12 and No. 24 a mutual capacity of .093 instead of .14 microfarad per mile.

TOLL-LINE CABLES

21. The gradual increase in the distance through which telephonic transmission is carried, due to the increase in the size of large cities and the merging into them of suburban points, which results in the replacing of bare overhead lines by cable lines, has caused a corresponding change in the construction of the cable itself. About 1898, when but little toll business was carried through cable conductors, only one style of cable was constructed, namely, that used for subscriber lines. As toll lines were put into the cable, however, it was found—as indeed it was expected—that the transmission was so reduced as to render imperative some change in the construction of cables. The development of the toll-line cable was given an impetus from another direction. The long toll lines of long-distance companies are made up largely of cable, for two reasons: First, where they pass through cities, they take cables in common with the various local companies' lines. Second, they have to cross numerous navigable streams where overhead construction is not permitted, and in such cases are compelled to take submarine cables. In the case of the New York-Chicago line, for instance, the total length of submarine cable included amounts to a considerable item. Two kinds of toll-line cable are, therefore, made use of: the toll-line underground cable and the toll-line submarine cable.

22. The history of the development of the toll-line underground cable consists, first, of a history of the attempt to reduce the static capacity; and, second, that of the attempt to reduce the conductor resistance. While the attempts to reduce capacity have practically resulted in failure, it will be interesting to note their features, as it is impossible to say, but that some slight, though at present unforeseen, change in mechanical construction may result in the accomplishment of the desired result.

The underground cable in use at the time that the attempt to reduce capacity took place consisted of conductors made of No. 19 B. & S. gauge, soft, drawn-copper wire, laid in pairs with Manila-paper insulation. Now, a common substance that above all others possesses the least static capacity is dry air. Next to this is cork. Therefore, a cable was produced in which the conductors were separated from each other by pieces of cork placed between the twists. An experimental cable constructed along these lines gave excellent results so far as capacity was concerned. The mechanical weakness, however, of such a cable was soon made apparent, as the cork pieces slipped out of place on its being pulled through the duct, or handled roughly. The cost of construction, also, was excessive.

The next step in this direction was to replace the pieces of cork by powdered cork spread uniformly over the surface of the insulation. This scheme failed from the fact that the cork, not being adhesive, did not stick to the surface of the paper, but collected in heaps here and there throughout the length of the cable. The idea of further reducing the capacity by using insulating material other than paper was abandoned, and attention was turned in the direction of reducing the conductor resistance by increasing the size of the wire. Cables were made, having conductors of No. 18 B. & S. gauge wire, next No. 16 B. & S. gauge; and finally of No. 13 and No. 10 B. & S. gauge wire. No. 18 wire is used for trunks, and cables made of it are called *trunk cables.* Those made of Nos. 16, 13, and 10 gauge wire are called *toll cables;* the smaller size is used for short toll lines—those up to a length of 10 miles—while the larger sizes are used for greater distances. The make-up of the cable is exactly the same as that of the standard cable used on subscriber lines and already described. The trunk cable is made up in 100 pair, while the two toll cables are made up in 60 and 35 pair, respectively. An attempt has been made to construct a cable of No. 8 B. W. G. wire, but so far it has proved a failure owing to the difficulty of twisting together such large-sized conductors.

SUMMARY

23. The specifications of a large company require cables to at least fulfil the conditions given in Tables I and II, probably at a temperature of 60° F. Table III gives the size and capacity of conductors and the number of pairs used in various kinds of cables.

TABLE I

DRY-CORE TELEPHONE CABLES

Gauge Number B. & S.	Diameter of Conductor, in Mils, Not Less Than	Resistance of Single Conductor, in Ohms per Mile, Not Less Than	Weight of Single Conductor, in Pounds, Not Less Than
10	101.89	5.2773	165.98
14	64.084	13.34	65.658
17	45.257	26.789	32.786
18	40.303	33.729	25.970
19	35.890	42.533	20.594
20	31.961	53.636	16.331
22	25.347	85.274	10.272

TABLE II

DRY-CORE TELEPHONE CABLES

Number of Pairs	Thickness of Sheath, in Inches		Diameter of Cable, in Inches, Not Greater Than	Approximate Weight of Cable, in Pounds, per 1,000 Feet
	Aerial Not Less Than	Underground Not Less Than		
5	3/64	1/16	5/8	747
10	3/64	1/16	13/16	1,214
25	3/64	3/32	1 5/16	2,332
50	7/64	7/64	1 3/4	3,678
100		1/8	2	5,505
120		1/8	2 1/8	
150		1/8	2 1/4	
200		1/8	2 3/8	
250		9/64	2 1/2	
300		5/32	2 5/8	
400		5/32	2 3/4	

TABLE III

DRY-CORE TELEPHONE CABLES

Number of Pairs	Kind of Cable	Size of Conductor B. & S. Gauge	Capacity Microfarads per Mile
10	Subscriber	19	.080
10	Subscriber	20	.085
10	Toll	10	.040
20	Toll	14	.050
25	Subscriber	19	.080
25	Subscriber	20	.085
30	Subscriber	19	.080
30	Subscriber	20	.085
50	Subscriber	19	.080
50	Subscriber	20	.085
50	Trunk	17	.065
50	Toll	14	.050
75	Trunk	17	.065
100	Trunk	18	.075
100	Subscriber	19	.080
100	Subscriber	20	.085
150	Subscriber	19	.080
150	Subscriber	20	.085
200	Subscriber	19	.110
200	Subscriber	20	.110
250	Subscriber	19	.110
250	Subscriber	20	.110
250	Subscriber	22	.120
300	Subscriber	20	.115
300	Subscriber	22	.120
350	Subscriber	20	.115
350	Subscriber	22	.120
400	Subscriber	20	.118
400	Subscriber	22	.120
600	Subscriber	24	.140

SATURATED-CORE CABLES

24. Paper-insulated cables are sometimes saturated with certain insulating compounds, in order to maintain the insulation even if the sheath is punctured. These cables are commonly termed **saturated-core cables**, in order to distinguish them from dry-core cables. For short lengths in small exchanges, where the requisite means for testing out and repairing cables are not at hand, the saturated-core cable may be used. It should, however, never be used on long-distance work or on circuits that are likely to be connected with very long lines. Never more than 2,000 feet of paper or cotton saturated with paraffin, or ozite, or any other compound should be used in one circuit.

SPLICING DRY-CORE PAPER CABLES

PRELIMINARY PREPARATIONS

25. The **splicing** together of two dry-core paper cables is a matter involving considerable care and skill; it should never be left in the hands of irresponsible persons. If the cable is already on poles, it will be necessary to erect a platform, if one is not already provided, on the pole where the splice is to be made; or, if in the middle of a span, a traveling platform suspended beneath the cable from the messenger wire on which the cable is supported must be used, provided, of course, that arrangements cannot be made to make the splice on the ground.

26. Slack in Cable.—The two cables on which the splice is to be made are drawn together until their ends overlap from 2 to 4 feet, according to conditions. When splices have to be made in manholes, the cables should bend around the side of the hole and be supported on the walls by suitable supports. The cable ends should be made to overlap as much as 4 feet, in order to give sufficient slack when the splicing is done. Great care must be taken to avoid kinking the cable at the ducts. When cables are suspended from poles, however, no slack is needed, as the sag is not increased at the point of splicing, so that the ends are made to overlap only enough to allow of the performance of the work in the proper manner.

27. Testing for Moisture.—Careful tests should be made to determine whether or not moisture has entered the insulation of the cable from the exposed end. If the cable is new, its end will be sealed and probably will be free from moisture; but if the splice is necessary on account of having to cut away an injured portion of the cable, there are many chances that moisture will be present in the insulation. A short piece of the injured cable should be cut off and dipped in paraffin heated above 212° F. The rising of bubbles through the liquid is a sure sign of moisture, but if no bubbles arise, it is safe to say that the cable is dry. If moisture is found in small quantities, it may sometimes be expelled by heating the cable sheaths with a torch for a considerable distance back of where the splices are to be made and gradually working toward the end. Great care must be taken, however, in doing this not to melt the lead and thus destroy the sheath. The cable should not be spliced until all moisture is expelled; and if this cannot be done by ordinary methods, a section of it should be cut away and the end so exposed again tested for moisture.

28. Enough paraffin should be used to nearly fill a 2-gallon granite coffee pot in which it is melted. A ladle may be used to pour the paraffin over the splice, the drippings being caught in the pot; a better way seems to be to use a pan under the splice in which to catch the drippings, the paraffin being poured over the splice directly from the melting pot.

Paraffin, if too hot, will ignite spontaneously when lowered into a moist manhole. Hence, it should be tested by waving the open kettle in the air before it is lowered into the manhole. In the latter case, it will burst into flame, if too hot. The melting point of paraffin is 123° to 125°.

29. Chipping Knife.—The lead sheath is cut away from both cable ends for a short distance, and the conductors and their paper insulation exposed. It is very important, in order that the conductors may not be injured, that the sheath should be removed in the proper manner. The tool used for this work is called a **chipping knife,** and is shown in Fig. 2, omitting the wooden handle that is frequently provided. It has a heavy broad-backed blade *a* having a stout edge *c* and a handle *d*. It is made of tool steel. In Figs. 3 and 4 is shown the proper method of removing the lead sheath. In Fig. 3, at a point about 2 feet from the cable end, a circular groove is cut at *B* in the sheath *a*. In doing this the chipping knife *C* is held in the position shown, while blows are struck with a hammer on the head *D*, in the direction indicated by the

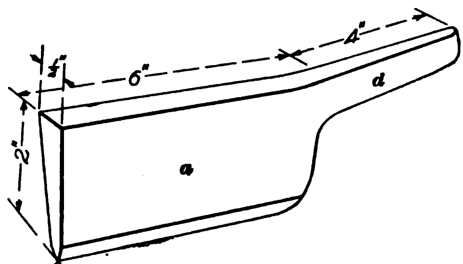


FIG. 2

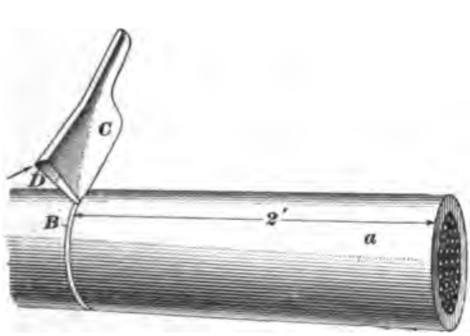


FIG. 3

FIG. 4

arrow, so as to give it a tangential motion. In this way, the sheath is cut without the knife being allowed to cut into the conductors. This groove having been cut, a longitudinal incision is made from it to the cable end. The method of holding the knife for this work is shown in Fig. 4. As before, the blows are struck at the point *f*, and the knife is thus given a backward and tangential motion combined, which rips off the sheath, as shown at *c*, without the possibility of injuring the conductors.

30. When all is ready, place the cable in the approximate position it is to permanently occupy, the ends overlapping the proper distance, and cut away the lead sheath from

TABLE IV

FOR STRAIGHT SPLICES

Pairs in Cable	For No. 22 B. & S.		For No. 19 B. & S.	
	Diameter of Sleeve Inches	Length of Sleeve Inches	Diameter of Sleeve Inches	Length of Sleeve Inches
15	1½	18	2	20
20	1½	18	2	20
25	2	20	2	20
30	2	20	2	20
50	2	20	2	20
60	2¼	20	2¼	20
90	2½	24	2½	20
100	2½	24	2½	20
120	2½	28	3	20
150	3	28	3	20
200	3	28	3½	20
300	3½	28	4	24
400	4	28	4	28

the end of each section in the manner already explained for a distance of one-half the length of the sleeve given in Table IV or Table V for various-sized cables. Table IV gives the dimensions of sleeves used by some companies, while Table V gives the dimensions of sleeves generally used by Bell companies. For a Y or loop splice, use a sleeve one size larger than that given for straight splices on the same sized cable.

31. The condition of the cable after the ends of the conductors have been stripped of their insulation to a point 4 inches from the end would then be represented by Fig. 5. The core, that is, the insulated wires at the ends of each cable, should be bound tightly with cotton twine or wicking, packing the latter close up to the lead. Each end, including the cotton binding, is then entirely immersed in hot paraffin

TABLE V

LEAD SLEEVES

Pairs in Cable	For Straight Splices		
	Diameter Inches	Length Inches	Thickness Inch
10	1	20	$\frac{3}{32}$
15	1	24	$\frac{3}{32}$
25	$1\frac{1}{2}$ to 2	25 to 28	$\frac{3}{32}$
30	$1\frac{1}{2}$ to 2	26 to 28	$\frac{3}{32}$
50	2	28	$\frac{3}{32}$
60	$2\frac{1}{4}$	28	$\frac{3}{32}$
90	$2\frac{1}{2}$	28	$\frac{3}{32}$
100	$2\frac{1}{2}$	28	$\frac{1}{8}$
120	$2\frac{3}{4}$	28	$\frac{1}{8}$
150	3	30	$\frac{1}{8}$
200	$3\frac{1}{4}$	32	$\frac{1}{8}$
250	$3\frac{3}{8}$	34	$\frac{3}{16}$
300	$3\frac{1}{2}$	36	$\frac{3}{16}$
350	4	38	$\frac{3}{16}$
400	4	40	$\frac{3}{16}$

(heated above 212° F.) until all bubbling ceases and then drained. This is to expel all moisture from the core ends and to coat them with paraffin to prevent moisture getting into the cable while splicing. The ends of the conductors should now be stripped of their insulation for a distance of 4 inches, care being taken not to nick the wires, and careful tests should be made for grounded, crossed, or open wires in a cable, for to connect a good wire in one section of the cable to a defective wire in another section means the loss of both the good and the bad wire. Then a lead sleeve is slipped over one end of the cable and back several feet out of the way of the workman.

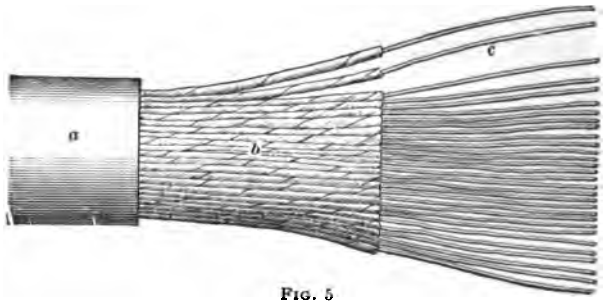


FIG. 5

32. Lead Sleeves.—The length and diameter of the **lead sleeve** will, of course, depend on the size of the cable. The size of the lead sleeves for cables should be about $\frac{3}{4}$ inch larger than the cable sheath, from $\frac{1}{32}$ to $\frac{3}{16}$ inch in thickness, at least as thick as the lead sheath of the cable, and long enough to allow the joining of all conductors without bunching the joints so much as to prevent the entrance of the joint into the sleeve, and also long enough to lap over each cable sheath at least $1\frac{1}{2}$ inches and preferably 2 inches; thus making the sleeve from 3 to 4 inches longer than the distance between the ends of the two cable sheaths after the splice has been made.

33. Separate each layer of wires in each end into halves, bend back each half, and bind them loosely, in bunches, to the cable. Paper sleeves, about 6 inches long, which have been previously boiled in paraffin, should be slipped over every other wire in the end of one cable, and over every other wire in the end of the other cable. The pairs in paper-covered cables are usually colored red and white, and as a matter of convenience the paper sleeve should be slid over the red wire on one end of the cable, and the white wire on the other.

JOINING THE CONDUCTORS

34. After securely setting the ends of the cable sheaths the proper distance apart, which may be determined by the aid of Table IV or Table V, take a pair of wires from each bunch, stretch them straight, and give the pairs one-half turn around each other. This will mark the point from which to strip the insulation from the ends of the wire. The joint is made by taking one wire from each end, overlapping them 4 inches, and stripping the insulation off about $1\frac{1}{8}$ inches for No. 22 B. & S. wires, about 2 inches for No. 19 B. & S. wire, and corresponding distances for other sizes; then twist the ends together as shown at *c*, Fig. 6; cut off the extra ends

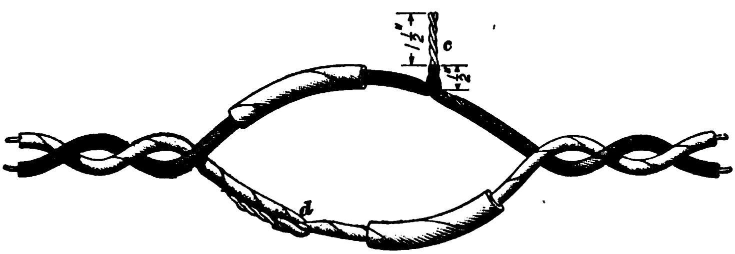


FIG. 6

not twisted together. For No. 22 B. & S. wire, the finished joint should include $\frac{1}{2}$ inch of the insulated wires and 1 inch of the bared and brightened wire.

The joint is then bent away from the paper sleeve and parallel with the conductor, as shown at *d*, Fig. 6. Twist wires of like color together. Wire joints are not soldered in lead-covered dry-core paper telephone cables.

After making the joints, the paper sleeve should be slid over them, leaving the finished splice as shown in Fig. 7.

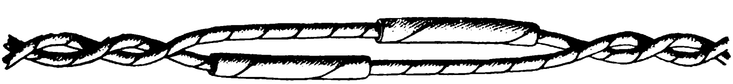


FIG. 7

The joints should be staggered as much as possible throughout the entire length of a splice, in order that an undue bulge may not occur at any one place in the splice. When all the wires are spliced and smoothed down, the appearance of the splice will be somewhat as represented by Fig. 8.

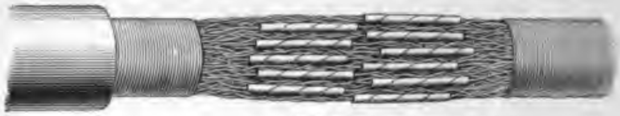


FIG. 8

35. Boiling Out.—The next process is termed **boiling out,** and on it depends in a great measure the success of the splice. A dripping pan should be placed directly under the splice, and as close to it as possible. Paraffin, heated above 212° F. in a 2-gallon granite coffee pot, is then poured over the splice, beginning at the ends and working toward the middle, until every trace of moisture has been removed. The paraffin is allowed to drip back into the pan. This process should be repeated until no bubbles appear in the hot liquid, the presence of bubbles always indicating that a certain amount of moisture is left in the cable. After the splice is boiled out, bind the wires with a strip of cheese cloth previously boiled in paraffin, pulling the wires together fairly tight; the joint should now appear as shown in Fig. 9.

FIG. 9

36. The lead sleeve should then be slipped over the splice, while it is still hot, to the proper place, which should previously be marked on the cable sheath, lapping the sleeve 2 inches over each end of the lead sheath. Dress down the ends of the sleeve to make a close fit with the sheath and make a carefully wiped joint at each end.

A **Y** splice is made in a similar manner, except that three wires will be twisted together when the conductors are legged off instead of two wires.

WIPING A LEAD-COVERED CABLE JOINT

37. The following tools are generally used in making lead-covered cable joints: A gasoline furnace and solder pot in which to melt the solder and an iron ladle to mix and pour it; a shaving hook, such as shown in Fig. 10, to scrape or shave the surface of the lead where the joint is to be made; a mallet or a hammer, and a pad to hold in the lower hand under the joint. This pad may be made of four or five thicknesses of ticking, about 3½ by 4 inches, one surface of the pad being well rubbed with tallow, or with chalk and tallow, to prevent melted solder from sticking to it. A small hand glass or mirror is useful for examining the under side of the joint, and a pair of dividers, or compasses, to make a mark around the cable.

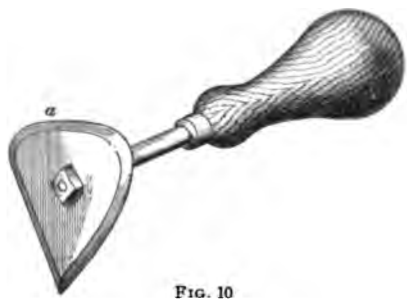


FIG. 10

38. The following materials will also be required: Lead pipe for sleeves, wiping solder, paper pasters, and tallow candle. One large cable company specifies the National Lead Company's extra wiping solder, which is a 40-60 lead solder, that is, solder containing 40 per cent. tin and 60 per cent. lead, and in place of mutton tallow, which is often used as a flux, the stearic-acid candles made by Proctor & Gamble Company. However, half-and-half solder (50 per cent. lead and 50 per cent. tin) or 43-per-cent. tin solder is more generally specified, enough to keep the melting pot full. Another material required is gummed paper, frequently called paper pasters, 2½ inches wide, or plumbers' soil or plumbers' paste. A piece of chalk is also convenient to have. All these things—except, perhaps, the gummed paper—may be obtained from a dealer in plumbing supplies. The gummed paper comes in rolls and may be obtained from almost any printing establishment.

39. Plumbers' soil is made by dissolving two tablespoonfuls of glue in 1 quart of boiling water or stale beer. Beat into the mixture 1 pound of lampblack and a tablespoonful of powdered chalk. Heat the soil each time it is used.

40. Plumbers' paste is made by mixing flour and water quite thin, beating out all lumps. By adding a little pulverized alum, the paste may be preserved a month or more. Thicken by heating it slowly over a fire.

41. Suppose that the conductors are all spliced, thoroughly dried out by the use of hot paraffin, and that the lead sleeve has been slipped over the joint. The lead sleeve should lap over the lead sheath of the cable at least $1\frac{1}{2}$ inches at each end. The ends of the lead sleeve should be dressed down with a wooden mallet, that is, hammered down so that the lead sleeve will fit tightly over the lead sheath of the cable.

42. Paper Pasters.—Instead of plumbers' soil or paste, as used by most plumbers in a manner that will be explained, most cable splicers now use **paper pasters,** first scraping with the shaving hook the portion where the joint is to be made and placing one strip of gummed paper around the sheath and another piece around the sleeve, leaving the lead exposed for a distance of about $1\frac{1}{2}$ inches on each side of the joint, or a distance of about 3 inches between the adjacent edges of the paper pasters, as shown at *a* in Fig. 11. This brightened and exposed lead should be covered with candle grease or tallow to prevent it from oxidizing. Do this at one joint only, leaving the other joint until ready to wipe it.

Plumbers generally cover the joint for a distance of about 3 or 4 inches on each side of where the sleeve and sheathing come together, first with chalk to counteract any grease that may be present, then with plumbers' soil or plumbers' paste. After this is dry, make marks around the cable and sheath at a distance of $1\frac{1}{2}$ to 2 inches on each side of the joint, using for this purpose the compasses, with their points set this distance apart. Of course, the mark may be made with a knife, but not as conveniently. With the shaving hook, shave or scrape the lead bright and clean

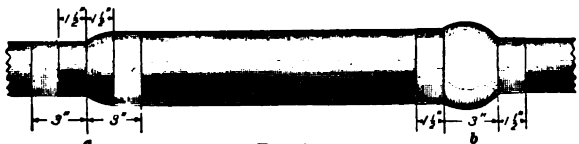


FIG. 11

for the distance of 1½ inches each side of the joint, as indicated at the end *a* in Fig. 11, immediately covering the bright portion with mutton tallow or candle grease.

43. It is very important to fix the joint firmly in some position so that the parts cannot move while the joint is being wiped. This may be done by resting the cable on bricks with bricks or other weights resting on the cable, as shown in Fig. 12. There should be a space of at least

FIG. 12

4 inches below and on both sides of the joint to provide room for the movement of the hand and cloth.

Melt the necessary amount of solder, which will depend on the diameter of the cable, in the pot and heat it to the proper temperature. The solder should not be any hotter than really necessary to make it flow. It should not be hot enough when in the pot to ignite a pine stick when thrust into it, or just hot enough to char paper when thrust into it. When learning to wipe a joint, care must be taken not to have the solder too hot, or to pour too much of it at one place, otherwise there is danger of melting the lead sheath. Place a piece of clean paper or a clean board under the joint to catch and keep clean whatever solder may fall on it.

Warm the wiping cloth until it becomes pliable, and hold it in the left hand, steadying it with the thumb. The cloth should form a hollow, resembling a saucer, so that it will receive and retain the solder that falls from the joint, in order to heat the under side of the joint. The solder should be thoroughly stirred with the ladle so as to mix the ingredients, tin and lead, together. The first object in making a joint is to tin the entire portion that has been scraped bright and covered with tallow, and the second object is to get on enough solder to make a tight and strong joint.

44. The solder is then slowly poured over the joint, the surplus solder being caught in the cloth under the joint, as shown in Fig. 12, taking care to heat the parts uniformly all around. When a quantity of solder has been caught in the cloth, it should be worked around on to the top, then more solder poured on this, the surplus being caught in the cloth, as before, heating the under side of the joint with it and again working it to the top of the joint. When the solder on the joint has become so hot as to be plastic, and is inclined to slide or drop off, and if it is certain that the surfaces are thoroughly tinned, and that the sleeve and sheath are sufficiently hot to maintain the solder in a plastic condition long enough to perform the necessary work, and also that there is enough plastic solder to make a good joint, pouring should be stopped and the wiping begun. The colder pieces of solder that have set, or are beginning to set, are first thrown off the joint with the cloth, then the edges of the cleaned or shaved parts are located, and the solder is formed into the shape desired, as shown finished at *b* in Fig. 11, by hollowing the cloth for that purpose.

45. At the time of forming the joint, all the superfluous solder should be thrown off. The joint should then be finished by working the cloth around from bottom to top, on both sides, as shown in Fig. 13, and finally drawing the cloth lightly across the top, as shown in Fig. 14.

FIG. 13

This movement frequently leaves some solder projecting over on the paper pasters or soiling. This should be broken off as soon as it forms, by lifting it with a knife blade. The hand glass may be used to see whether the under side of the joint is properly made. When the joint is made, it is well to spray a little water over it, or to fan it, in order to make it set rapidly, thus preventing the separation of the tin and lead in the solder, which may happen if it cools too slowly.

46. Wiping an Upright Joint.—To wipe a joint on an upright cable, secure the parts firmly in position, apply

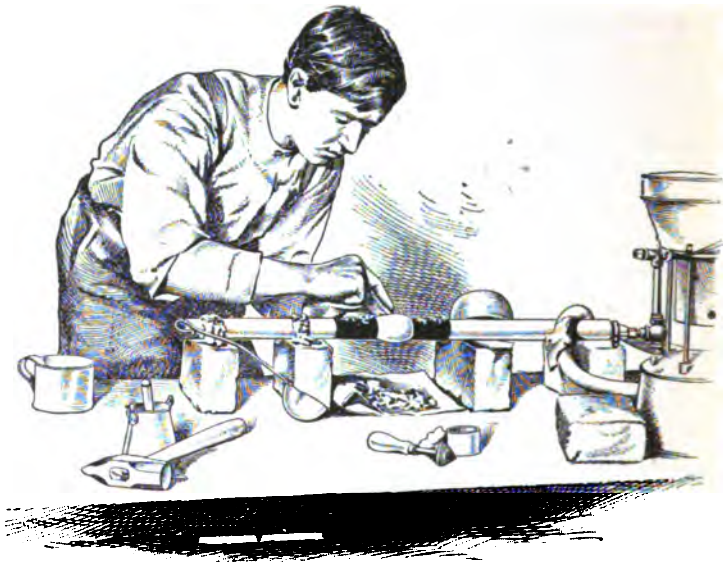


FIG. 14

the plumbers' soil, paste, or gummed paper and shave the joint and put on the tallow as already explained. A collar

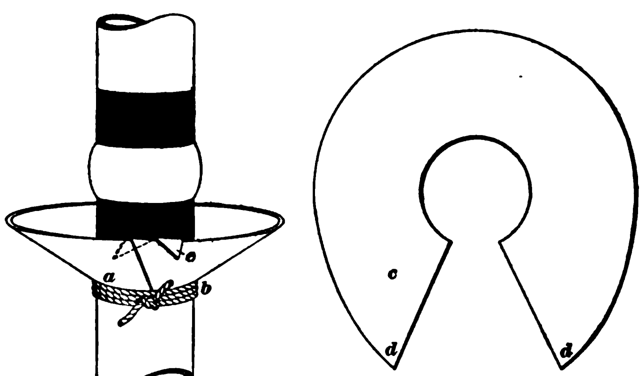


FIG. 15

should then be attached temporarily to the cable directly under the joint so as to catch the solder and raise the temperature of that part of the sheath. In Fig. 15 is shown a piece of lead pipe with a collar *a* in position, the collar being supported by a chord *b* tied around the pipe. The collar should be cut to a pattern similar to *c*, so that when it is formed around the sheath, the points *d*, *d* can be doubled over and locked together, as at *e*, to prevent its spreading apart when the solder falls into it. These collars are best made of sheet lead, as this metal is very pliable and free from spring. The inner surface of the collar should be coated with soil or paste each time it is used to prevent solder adhering it. Paper collars are sometimes used, but they are not so satisfactory.

47. The heat may be applied to the joint by a gasoline torch. The solder is splashed on the joint from the ladle, using if necessary or convenient a flattened stick for this purpose. It is splashed on gently and in small quantities at first to avoid burning a hole in the sheath. The speed and quantity is increased, however, until a body of solder is piled up against the scraped portion of the joint. The splashing is continued or metal may now be thrown on the joint from the ladle direct until the joint is thoroughly and uniformly heated and the mass of solder is so soft that it cannot stay up, but slides down into the collar. As the sheath conducts the heat away, it is necessary to lift the plastic solder to the top of the joint, which cools first, in order to keep that part hot. When the solder persists in sliding down into the collar and when there is considerably more solder than necessary to finish the joint, the wiping cloth is used to wipe the solder into the proper form.

48. Joint Between Lead and Brass or Iron.—When a wiped joint is to be made between a lead cable and a brass or iron sleeve or pipe, it is necessary to first tin the brass or iron sleeve thoroughly. To do this, the sleeve must be scraped clean and bright and resin or soldering fluid used as a flux to make the solder adhere to the brass or iron. The use of soldering fluid, such as zinc dissolved in muriatic acid, enables brass, and especially iron, to be more easily tinned, but the latter is very corrosive and must be thoroughly wiped off, both outside and inside the sleeve, before the cable is brought near it. With patience, either brass or iron can be tinned, using resin or some other non-corrosive soldering preparation as a flux, and by its use there is no danger of injuring the conductors or the insulation. A tight fit should be made between the lead sheath of the cable and the brass or iron pipe; in most cases, the lead sheath can be inserted ¼ inch or more inside the brass or iron pipe. The lead sheath is then prepared for a joint, which may be made in the usual manner.

49. To make a good wiped joint will be very difficult for a time and will require considerable practice, for which purpose scrap pieces of cable had better be used. By the application of the principles explained and by sufficient practice, almost any kind of a cable joint may be made. A joint should not be left until it is perfectly made, thus furnishing as good a protection to the conductors within as the sheath of the cable itself.

50. As there are very few cable splices that do not have to be opened sometime or other, experienced cable men prefer to use, the first time a splice is made, as short a sleeve as possible and having a rather large diameter so that a short splice may be made; when the splice is made the second time, the cutting in of a new piece of cable may then be frequently saved by using a longer sleeve.

After making a splice, the conductors should be tested out for crosses and continuity. If it can be avoided, a cable should never be opened during rainy or foggy weather, as enough moisture will enter the cable to cause considerable injury. If a cable must be opened in a case of emergency during wet weather, the cable ends should be thoroughly protected by means of canvas sheets. If caught in a shower while making a splice, great care must be taken to protect the cable ends from moisture by thoroughly soaking them in hot insulating compound and wrapping them with canvas. If the end of a cable must be left unconnected for a considerable time, the sheath should be sealed with a lead cap by a plumber's wiped joint.

51. Filling Sleeve Joints.—Where saturated-core cables are used and wool-insulated cables are joined to dry-core cables, the sleeve is generally filled by pouring hot insulating compound through two holes cut in the lead sleeve for this purpose. These holes are made about one-third the distance from the ends and the hot insulation is poured into them alternately until the sleeve is filled. Sufficient time should be given the compound to permeate the cable and drive off any moisture that may be present. The expulsion of all moisture is important. Should there be any indication of moisture in the cable when the insulating compound is being poured into the sleeve, one end should be elevated, in order that, as the compound is being poured into one hole, it will run out at the other, carrying with it all moisture. The amount of overflow should at least equal that required to fill the sleeve. This overflow may be caught in a vessel and used for other joints. When the sleeve has been completely filled, the holes are closed by carefully soldering sheet-lead caps over them.

RUBBER-COVERED CABLES

52. Cables composed of rubber-covered wire without a lead cover, are used in special cases although the paper-insulated cable is much more desirable. A good rubber-covered cable is made as follows: The wires are of copper No. 14, 16, or 18 B. & S. gauge, having a conductivity of 98 per cent. that of pure copper. The wire, having been thoroughly tinned, is given a double coating of rubber insulation and then taped. After the requisite number of conductors are bunched, the cable is double-taped and covered with tarred jute, over which is placed a heavy braid of cotton saturated with weather-proof compound, which serves not only to protect the rubber from the action of the air, but to protect the entire cable from mechanical injury. The manufacturer claims that these rubber-covered wire cables are waterproof and can be used under water where there is no danger of mechanical injury. The sizes and weights of cables made in this manner are given in Table VI, which is taken from Roebling's handbook.

TABLE VI

AERIAL CABLES WITH RUBBER-COVERED WIRES

Number of Conductors	14 B. & S. Insulated to $\frac{6}{32}$ Inch		16 B. & S. Insulated to $\frac{5}{32}$ Inch		18 B. & S. Insulated to $\frac{4}{32}$ Inch	
	Outside Diameters Inches	Weight per 1,000 Feet Pounds	Outside Diameters Inches	Weight per 1,000 Feet Pounds	Outside Diameters Inches	Weight per 1,000 Feet Pounds
2	$\frac{3}{8}$	102	$\frac{3}{8}$	92	$\frac{3}{8}$	82
3	$\frac{1}{2}$	149	$\frac{7}{16}$	126	$\frac{13}{32}$	104
4	$\frac{9}{16}$	183	$\frac{1}{2}$	155	$\frac{7}{16}$	127
5	$\frac{11}{16}$	226	$\frac{5}{8}$	193	$\frac{1}{2}$	151
6	$\frac{3}{4}$	260	$\frac{11}{16}$	222	$\frac{9}{16}$	175
7	$\frac{13}{16}$	297	$\frac{3}{4}$	251	$\frac{5}{8}$	200
10	$\frac{15}{16}$	401	$\frac{7}{8}$	335	$\frac{11}{16}$	256
12	1	465	$\frac{15}{16}$	393	$\frac{3}{4}$	296
15	$1\frac{1}{8}$	563	1	468	$\frac{13}{16}$	355
18	$1\frac{3}{16}$	651	$1\frac{1}{16}$	541	$\frac{7}{8}$	413
20	$1\frac{1}{4}$	714	$1\frac{1}{8}$	593	$\frac{29}{32}$	452
25	$1\frac{3}{8}$	863	$1\frac{3}{16}$	708	$\frac{15}{16}$	541
30	$1\frac{7}{16}$	1,008	$1\frac{1}{4}$	824	1	633
35	$1\frac{1}{2}$	1,147	$1\frac{5}{16}$	938	$1\frac{1}{16}$	723
40	$1\frac{9}{16}$	1,268	$1\frac{3}{8}$	1,053	$1\frac{1}{8}$	813
45	$1\frac{5}{8}$	1,431	$1\frac{1}{2}$	1,182	$1\frac{3}{16}$	903
50	$1\frac{3}{4}$	1,577	$1\frac{5}{8}$	1,311	$1\frac{1}{4}$	994

53. Tape-covered cable, especially if put up on a slant, should have the joint in the tape on the under side of the cable to prevent water or moisture from working into the cable. The cable should be retaped when the outside cover begins to disintegrate or fray out. For, if left until the covering of tape begins to separate, the insulation over the individual conductors will crack and the cable will soon be damaged beyond repair.

54. The insulation resistance of wires in this cable will, if the cable is in good condition and the proper materials are used, vary from 300 to 500 megohms per mile, at a temperature of 60° F., after the cable has been immersed in water for 24 hours. This cable is, therefore, well adapted for underwater work where it is not subject to mechanical injury. For use in mines, or where it is necessary to pass a large number of wires on poles through the foliage of trees, this cable should give good results. One objection to cables of this kind is the high electrostatic capacity of the conductors. Rubber is an excellent insulator, but has a very high specific inductive capacity, thus greatly increasing the electrostatic capacity of the wires that it serves to insulate.

SPLICING A RUBBER-COVERED CABLE

55. Insulating a Joint on a Rubber Cable.—On rubber-insulated cables, the copper conductors are joined as described in connection with cables insulated with fiber or paper. The wire splice is then covered by a thin layer of pure unvulcanized rubber tape, $\frac{1}{64}$ to $\frac{1}{32}$ inch in thickness, wrapped spirally around the splice, and this layer is covered with tapes until the insulation is as thick as on the main conductor. The tapes contain less and less rubber until the outer layer is reached, which is usually a first-class adhesive cotton or linen tape. When the cables are lead-covered, the rubber tapes do not require vulcanization, as the lead cover is air-tight; but on aerial or other non-leaded cables, the rubber should be carefully vulcanized by means of heat, applied by a spirit lamp or other suitable device, and then covered with linen or cotton tape, as a mechanical protection. The vulcanizing of non-leaded rubber cables is a very important feature, and should be entrusted only to an expert if satisfactory results are to be obtained and the cable is to last any length of time.

56. Rubber cables are also spliced in the following manner, although it does not make as thorough and lasting a joint as the method just given: The wires in the rubber cables having been spliced, each joint is wrapped with a piece of approved waterproof tape of sufficient length to make three layers. After this has been done, the wires at the splice are wrapped with several layers of heavy tarred tape, of sufficient length to render this section of the same thickness as the cable. This wrapping should cover the braid on the cable for a distance of 3 inches from the points where it is cut.

CABLE DISTRIBUTING SYSTEMS

BRANCH SPLICING

57. Cable Branches.—In order to solve the problem of telephone distribution in the most economical manner, it is necessary to provide cables with branches, which are usually run at right angles to the main cable, to districts on both sides of the general line of distribution. Suppose, for the purpose of explanation, that it is necessary to provide 200 additional pair of conductors in a central office on account of probable growth. Obviously, these 200 pair may be placed in one cable, two cables of 100 pair each, four cables of 50 pair each, or eight cables of 25 pair each. At first sight, it might appear that if a large district is to be covered, the best plan will be to install eight cables of 25 pair each, cut the district up into eight sections, and run one to the center of each section. The most serious obstacle to this method is the inability of predetermining the number of new subscribers to be found in each section. For example, in one section so many subscribers might be found that additional cable would have to be run to give them service, while in other sections many and perhaps all the conductors would remain idle. This would mean the loading down of the central-office terminal equipment with cables that were not earning money, in addition to the cost of buying and laying the cables themselves.

58. Split and Multiple Branches.—To overcome this difficulty, the cables are branched in two ways: First, a number of conductors are turned aside from the main cable and run out in the branch, while the remainder continue to the terminal of the main cable. For example, a 100-pair cable is run to the point where the first branch is to be made, and the first 25 pair turned aside and run to the branch terminal. The remaining 75 pair are carried through the main cable to its terminal. Sometimes, several branches are made in this manner. A cable branched in this way is called a **split cable,** from the fact that at each branch a certain number of pairs are split away from the main cable. Second, instead of turning aside the requisite number of conductors at each branching point, all are carried through to the terminal of the main cable, and at each branching point the conductors in the branch cables are connected to the proper ones in the main cable. In this manner, all conductors appearing in the branch-cable terminals appear also in the main-cable terminal. Cables branched in this manner are termed **bridging cables,** from the fact that the conductors of the branch cable are bridged to those of the main cable. When branch cables are bridged or connected in multiple with a main cable, so that each pair or certain pairs in the main cable appear at several or all terminals along the route, in order that these pairs may be available at any one or several of the terminals, it is called **multiple distribution,** and the splices are termed **multiple-branch splices.**

59. Advantages of Multiple Distribution.—When cables are terminated at one point only by means of split branches, it is necessary to allow a much greater margin for an increase or change in the number of subscribers than when the multiple method of distribution is employed. If a margin of 10 pair is allowed at each point and one cable is split up so that one-fourth of its pairs terminate at one point only, 40 extra pair must be provided for fluctuations in the number of subscribers. However, if 10 pair are distributed in multiple so as to terminate at each one of the four terminals, the 10 pair will practically suffice for the same length of time. Small groups of subscribers show a much larger percentage fluctuation in number than larger groups, on which fact depends the economy of the multiple distribution.

Data from a large exchange shows that while the increase in small groups (ten lines) may be 24½ per cent.; in large groups (eighty-seven lines), it is only 3½ per cent.; and while the temporary variation from a uniform increase or decrease in small groups is 26 per cent., in large groups it is only 5 per cent.

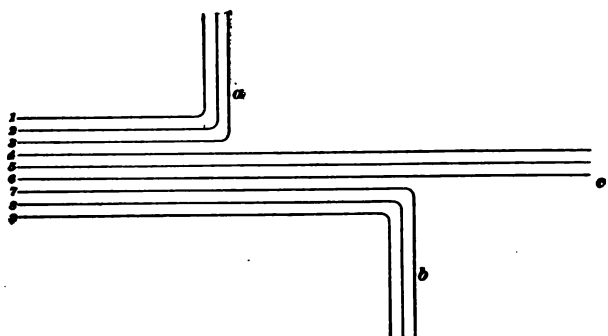


FIG. 16

It is therefore necessary to provide a larger proportional margin for small groups of subscribers for increase and changes than for larger groups. As the total increase in a number of small groups will, however, closely correspond to the increase in a large group of the same total number, the changes in the small groups can be most economically met by making the same cable conductors available for use at several distributing points. Again, it is economical to have a larger allowance for increase in small cables on account of the cost of relief and rearrangement when the capacity is exhausted, being greater on the average than the small difference in cost between the small and larger cables when first installed. For all new work in cities, it is therefore usually advisable to use the multiple system of distribution.

60. Split-Cable Branches.—The method of making split-cable branches is indicated in Fig. 16. Let *1*, *2*, *3*, *4*, etc. represent pairs in a cable, *a* the first branching point, where pairs *1–3* are carried to the left end, *b* a second branching point, where pairs *7–9* are carried to the right. Pairs *4–6* are carried through the main cable to its terminal at *c*. In Fig. 17 is shown the method of bridging cables. Here, as before, let *1*, *2*, *3*, *4*, etc. represent pairs in a cable. At *a*, the first branching point, pairs *1–4* are bridged; at the second branching point *b* the remaining pairs are bridged, while all the pairs in the main cable appear at its terminal at *c*. Except in the poorest class of construction, these branch or

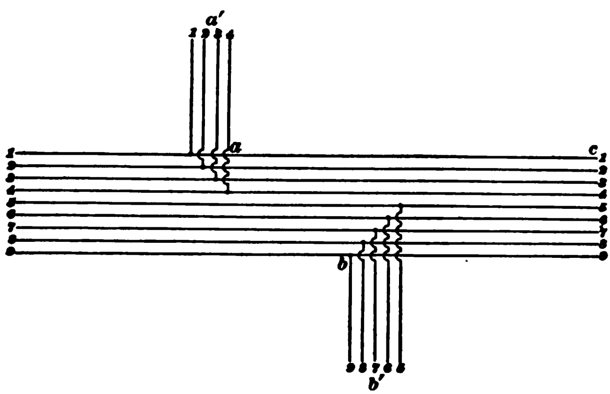


Fig. 17

Y splices are never made in rubber cables, because they are not made large enough to warrant such treatment, and because their nature of construction is such that weather-tight splices of this sort could not be made. This practice is resorted to only in the case of lead-covered cables.

61. The distinctive feature of a Y splice is the method of preparing and adjusting the lead sleeve; however, there are a few details about connecting the conductors in a split branch that deserve special mention. It should be remembered at the outset that such splices are made only at the end of a section when new cable is so treated. Split branches are never made on cable previously laid, but bridging branches often are; and, when this is done, the splice is often made in the middle of a section. The two cases require separate treatment.

In Fig. 18, let *a*, *b* represent the exposed conductors of the two adjacent sections of main cable and *c* a branch cable, the sheaths on each end having been removed in the proper way. Those conductors that are to be split are separated

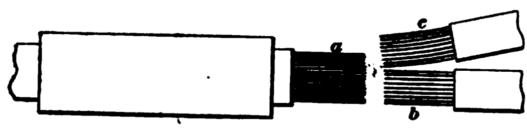


FIG. 18

from the others and spliced to the proper conductors of the branch cable *c* in the ordinary manner, while the remaining conductors are spliced to those of the other section of main cable *b*. The splice is then boiled out and the branch cable *c* is laid flat against the section *b* of the main cable, as in Fig. 19, where the conductors are shown spliced and bunched. The sleeve is shown at *d* over the cable *a*. The sleeve must be selected of sufficient size to enable it, when placed in position for wiping to pass over both branch-cable sheaths. The splice having been made and boiled out, the sleeve is slid

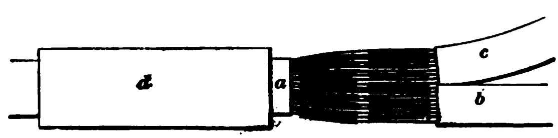


FIG. 19

to its proper position and the end covering *a* treated in the ordinary manner. The end covering the cables *c* and *b* is hammered so as to close up the cavity between these two as much as possible. The ends of the sleeve are secured to the cable sheaths in the same manner as for a bridging splice, all the details of which are shown in Fig. 20. The gusset used at *b* is cut, in the shape shown in the right-hand view at (*e*), out of sheet lead. It is inserted at *b* and the ends bent, as shown in the left-hand view at (*e*), with the fingers to fit closely against the sheaths. A section through

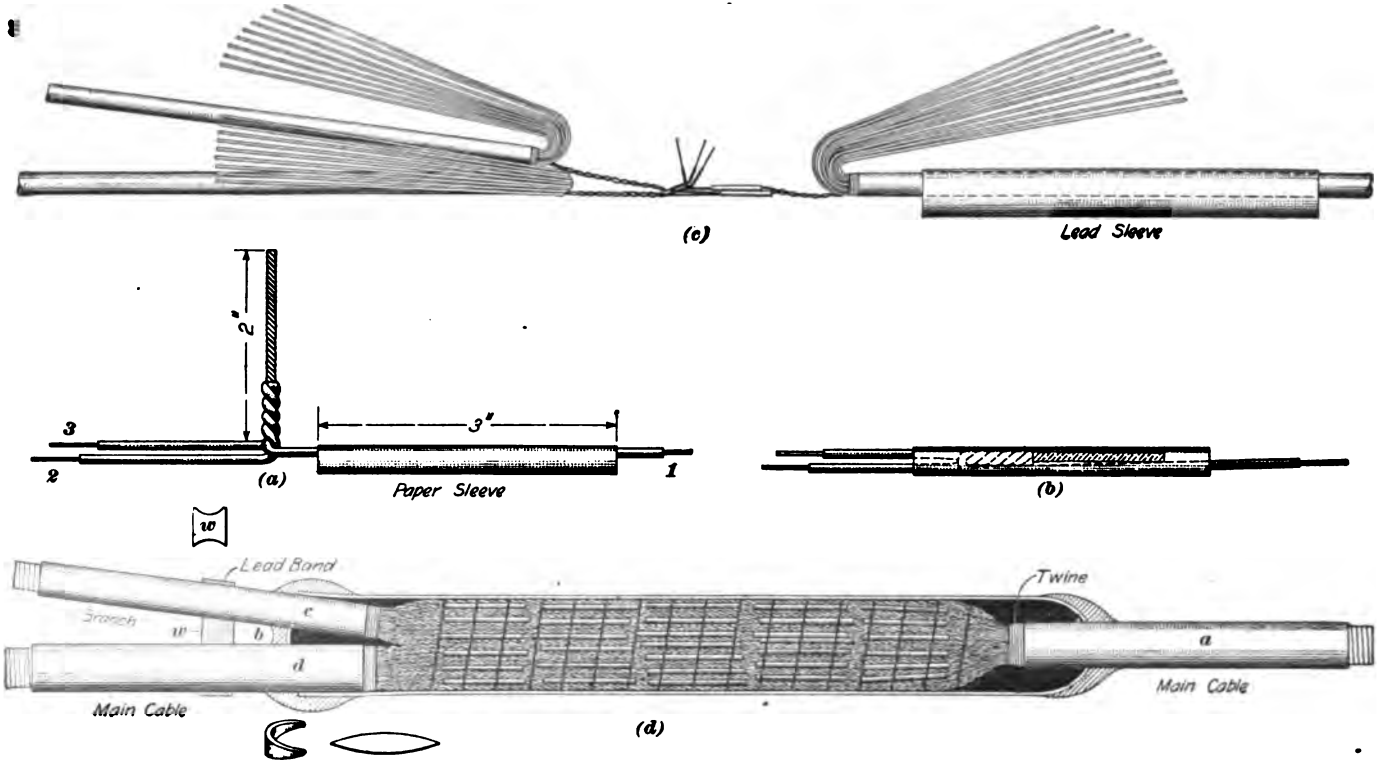

(c)
Lead Sleeve
3
2
2"
3"
(a)
Paper Sleeve
1
(b)
w
Lead Band
Twine
c
b
w
d
a
Main Cable
Main Cable
(d)
(e)

FIG. 20

the finished splice is shown at (*d*). When this work has been done, it appears as shown in Fig. 21, the space at *e* being covered by hammering down the edge of the sleeve at this point against the gusset. The joint is then wiped in the usual way.

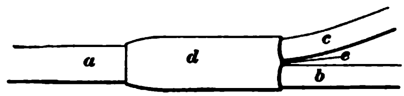


FIG. 21

62. Bridging Branches.—The method of making a bridging splice, which is shown fully in Fig. 20, differs only in the manner in which the conductors are joined. When made at the end of a piece of the main cable, the conductors are bared in the usual way, and three of them—one from each section of main cable and one from the branch—are twisted together. This is shown in Fig. 22, where conductors *1*, *2*, and *3* from cable ends *a*, *b*, and *c*, respectively, should be twisted together as shown in Fig. 20 at (*a*) and covered with a paper sleeve as shown at (*b*). This process is carried on until all the conductors to be bridged have been spliced, when the remaining conductors are spliced through in the usual manner. The lead sleeve is placed and wiped in exactly the same manner as that described for split branches.

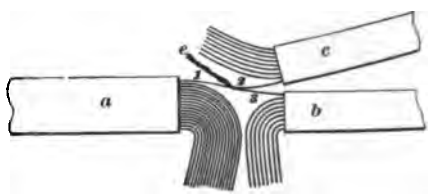


FIG. 22

63. When bridging splices are to be made in the middle of a section, the sheath is removed from the cable for a distance equal to one-half the length of the sleeves specified for the next larger size cable in Table IV or V, and the conductors to be bridged are cut, one at a time, and spliced in the manner shown in Fig. 20. The sleeve is split longitudinally, opened up, and placed over the splice. The joint is wiped in the usual manner, and the longitudinal split is soldered tightly. In general, it might be said that in making splices on working cables, one conductor should be cut at a time, so as to interfere with the service as little as possible.

64. Loop splicing, which has been confined mostly to aerial cables, requires a piece of cable with twice the number of conductors that are to be left at a distribution point; that is, for a 30-pair loop splice, it requires a 60-pair piece of cable. But as it is generally a short piece, the difference in the cost is small. In a multiple splice, where a wire is branched out at several points along a route, the wire is liable to get in trouble in a cable box where it is not in use, and the cable may get in trouble beyond the point where the wires are in use. But in loop work, when a pair of wires is

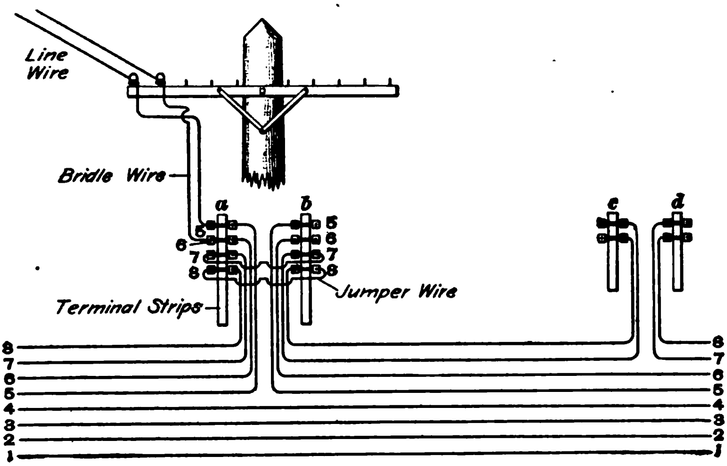


FIG. 23

in use at a certain point, the wires can be opened beyond it. A loop running to a cable box is shown in Fig. 23. The left-hand strip *a* should correspond with the office end of the cable and the right-hand strip *b* with the left-hand strip *c* in the next box. Wires *5* and *6* are shown connected through bridle wires with the line wires on the pole. By means of jumpers, wires *7* and *8* are connected through to some point beyond. It is best to put a jumper across each wire when the cable is installed, and when a pair is connected through bridle wires to the overhead, bare line wires, cut the jumper wires off that pair.

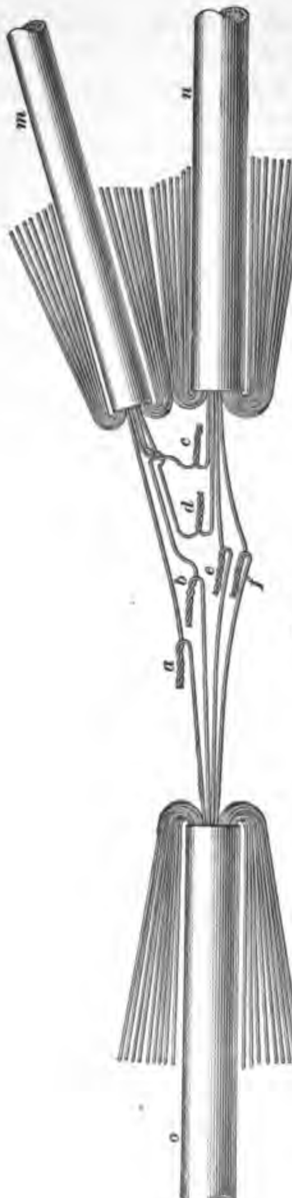


Fig. 24

65. Making and Testing a Loop Splice.—The construction of a loop splice is indicated at *a*, *b*, *c*, *d*, in Fig. 24. To make it, follow the directions given for making straight and **Y** splices, except in testing. Suppose that there was a 120-pair cable *o*, and a 30-pair (wires 1 to 60) loop splice was to be made. The splicer would first bunch wires 1 to 60 at the office end of the cable *o* and then pick out these wires where the splice was to be made, say near a cable box. Thirty pair of wires from a 60-pair cable would then be spliced as at *a*, *b* near the cable box to the 30 pair selected and running toward the office end *o*. This would leave 90 pair running unbranched to the office *o* and 30 pair, like *a*, *b*, looped to the cable box. From the 120 pair in the cable *n* pick out 30 pair at random and splice them to the remaining 30 pair in the cable *m* running to the cable box. The remaining 90 pair in the cables *n*, *o*, are then spliced together as indicated at *e*, *f*.

Now test out the wires 1 to 60 at the end of loop *m* and connect them to the left-hand strip in the cable box; then connect the remaining 30 pair at random on the right-hand side and put a jumper across each wire, that is, from wire 1 on the left-hand side to wire 1 on the right-hand side and so on, which closes the wires through for the next splice.

66. Branch Cable Joints.—In making T, Y, and four-way joints, split sleeves are occasionally used. A split T sleeve is shown in Fig. 25. The split sleeve is slipped over the branch end of the joint and after the splice is made it is drawn back in place and secured by a plumber's wiped joint to the lead sheaths of the cable ends. The edges of the sleeve that are to be wiped or soldered together are trimmed so that they touch only on the inside and widen gradually toward the outside, as at *a* in Fig. 26. The space *a* is filled with solder, thus making a good tight joint. When centered over the splice, each end should overlap the lead sheath of the cable ends at least ½ inch, though a distance of 4 inches is preferred. Split sleeves for joints can be obtained from cable manufacturers, but unsplit ones may be purchased at plumbers' supply stores, in which case it is necessary to split them. The separate branches of a T, Y, or four-way joint should be from 13 to 16 inches long for a 150-conductor cable.

FIG. 25

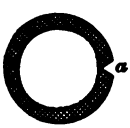


FIG. 26

67. Repairs.—When a cable sheath is found to be perforated, make repairs promptly as follows: Remove the lead sheath for at least 6 inches on each side of the point of injury, and also any material wrapped around the wire core. Separate the wires of the exposed core. Pour paraffin, heated to over 212° F., over the core, beginning at the sides and including several inches of the lead sheath, and working toward the middle. If moisture is shown by bubbling, remove the lead sheath until a part of the core is uncovered that gives no evidences of moisture. Prepare a lead sleeve of proper dimension for the cable and 4 inches longer than the exposed core by splitting down one side and cutting the slit to form a V-shaped groove. Place the split sleeve around the core, overlapping the sheath 2 inches at each end. Close the groove with solder run from a hot soldering copper and make wiped joints at each end. Great care must be exercised in using the split sleeve and a thorough examination should be made before the joint is left to see that it is thoroughly sealed with solder. Under no circumstances must the lead sheath remain unsoldered over night, either at the end of a cable or at a splice.

CABLE TERMINALS

68. There are three ways in which lead-covered cables may be terminated. A convenient method consists in the use of a box terminal of iron or other material in which cable conductors are hermetically sealed. They have been found to be bulky and expensive, but possess the advantage of allowing access to the wires for alterations or rearrangement in the case of failure of any wires, and for extending branches if they should be found necessary.

A widely used method is the **pothead terminal.** A **pothead** consists of an auxiliary cable, usually a short one, made of rubber-insulated wire spliced to the paper cable, the joint being covered with a lead sleeve that is fastened with a plumber's wiped joint to the lead sheath of the paper cable, and filled with some insulating compound such as ozite or Chatterton's. The advantages of this method are its compactness, lower cost than the previous method, and its complete sealing of the core of the cable against the entrance of moisture. The latter is true only when the work has been thoroughly well done, and for that reason extreme care must be exercised, particularly when potheads are made under unfavorable conditions out-of-doors. When properly made, however, they are thoroughly reliable. The disadvantage of the pothead is inaccessibility of wires after a splice has been made, and the occasional failure of the seal due to accident or careless making. Novelty potheads made by the New

Haven Novelty Machine Company are now being used to some extent. These potheads are made with brass splicing sleeves that do not require the customary wiped lead joint.

The third method, suitable for use in a dry building, especially in exchanges, consists in splicing to the end of the paper-insulated cable, another cable made of wire insulated with wool instead of with paper. The splice is made in the usual manner, being filled with paraffin or cable sealing compound. Wires covered with wool maintain a relatively high insulation even when exposed to the air, but such insulation will not withstand very damp air, so that the method is distinctly more suitable for the office ends of cables than for terminals, distributing poles, or in manholes. This method is now extensively used.

POTHEAD TERMINALS

69. Materials Required.—The directions about as issued by the Bell Company, for making pothead terminals on aerial cables, are as follows: The terminal wires should be No. 19 B. & S., okonite insulation $\frac{3}{32}$ inch thick, with no braid or outside covering, colored red and black and twisted in pairs. Sleeves should not be less than $\frac{1}{8}$ inch thick, of pure lead, and of dimensions given in Table VII. Use $\frac{3}{4}$ inch wide okonite tape and tinned brass tubing $\frac{1}{2}$ inch in diameter, length $2\frac{1}{2}$ inches less than that of the lead sleeve. All moisture should be driven from the paper sleeves by dry heat before they are used. Heavy cotton twine or wicking, 43-per-cent. tin solder, and sealing compound as furnished by the Company will also be required. Ozite or paraffin should not be used nor should different compounds be mixed together or with other materials. Potheads require from $3\frac{1}{2}$ to $6\frac{1}{2}$ pounds of sealing compound, $\frac{1}{2}$ to $1\frac{1}{2}$ pounds of solder, and one-half to one roll of tape, depending on the size of the cable, 25 to 150 pair, inclusive.

70. Construction.—Remove the cable sheath for about 15 inches and 17 inches for 15- and 150-pair cable, respectively, and corresponding lengths for intermediate sizes.

Thoroughly dry out the cable end; slip the lead sleeve over the cable end; splice the cable wires to the okonite wires in the usual manner, joining the colored wire of the cable to the red okonite wire of each pair; cover each splice with a sleeve; keep the splices within a limit of 13 inches from the end of the cable sheath, except for a 150-pair cable on which the limit can be 15 inches. Remove all pieces of paper or other débris; bind the cable wires close to the sheath with

TABLE VII

LEAD SLEEVES FOR POTHEADS

Pairs in Cable	Sleeve		Brass Tubing	
	Diameter Inches	Length Inches	Diameter Inches	Length Inches
15	2	20		
20	2	20		
25	2	20	$\frac{1}{2}$	17
30	2	20	$\frac{1}{2}$	17
50	$2\frac{1}{2}$	20	$\frac{1}{2}$	17
60	$2\frac{1}{2}$	22	$\frac{1}{2}$	19
90	3	24	$\frac{1}{2}$	21
100	3	24	$\frac{1}{2}$	21
120	$3\frac{1}{4}$	24	$\frac{1}{2}$	21
150	$3\frac{1}{2}$ to 4	26 to 28	$\frac{1}{2}$	23

several layers of twine, to prevent the compound entering the cable; tape all the okonite wires together for 3 inches in such a manner that $\frac{1}{2}$ inch of the taping will be below the surface of the compound; separate the spliced wires, if possible, to allow a little free space between them; bind the brass tube with twine alongside the wires with the lower end even with the end of the sheath of the cable, binding no higher than the wire splices; draw up the lead sleeve until it laps over the cable sheath $1\frac{1}{2}$ inches, and wipe it to the sheath. Secure the whole in an upright position; heat the lead sleeve until it can hardly be touched with the hand; place a funnel in the brass tube and pour in the sealing compound, which has previously been heated to 350° F., slowly and cautiously through the funnel, until it fills the sleeve to within ½ inch of the top; remove the funnel and allow the compound to settle and cool.

A good way to test whether or not the compound is too hot, is to dip a piece of okonite wire into it for 2 minutes just before using the compound. If, on withdrawal, the okonite insulation on the wire is softened so as to readily peel off, the compound is too hot. If, however, the insulation remains firm, the compound is not too hot. Cover the upper end of the wires issuing from the compound so as to protect them from the weather. The next day fill with hot compound to make up for settlement. Three days later, or each day for several days, do the same, if necessary. After it has ceased to settle and when thoroughly cold, dress the top of the lead sleeve into contact with the okonite-tape wrapping, thus giving a rather finished appearance to the work and making a tight joint. At this point, the tape wrapping should consist of three or four layers. Place a cross-mark on the outside of the lead sleeve opposite the top end of the brass tube so that it may be readily found when needed.

71. The reason for using the brass tube instead of pouring the insulated compound directly in the top of the lead sleeve is that by so doing the mixture is forced to the bottom of the joint, from which it proceeds slowly upwards, thus expelling all the air. The insulating compound may be purchased from various cable manufacturers and wire dealers, and in ordering it care should always be taken to specify the purpose for which it is to be used. It should contain no paraffin whatever, as the latter will injure okonite insulation. Do not boil out the cable with paraffin or ever use it on the okonite ends. Drive out all moisture in the cable or in materials by means of dry heat. If the cable end is damp, the pothead must not be made until all moisture is driven

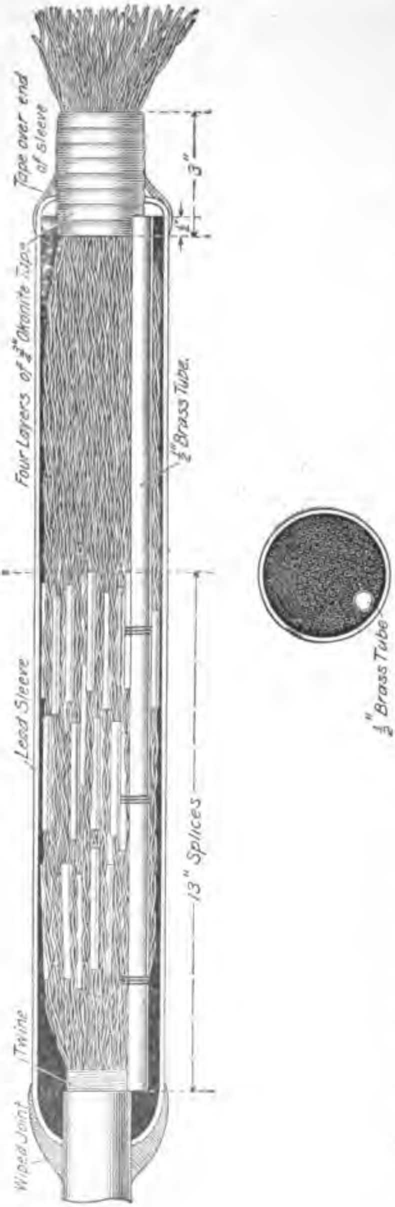


Fig. 27

out or the damp portion cut off.

When a cable is tested from the office to the poles, as is usually the case, the pothead wires should be cut off just long enough to reach the terminal posts. Economy in okonite wire is necessary, hence the ends cut off should be saved and used in making smaller potheads and for such other work as the length will prove suitable.

72. Fig. 27 shows the construction of a pothead for a 100-pair aerial cable made according to the directions of the Central Union Telephone Company.

Fig. 28 (*a*) shows the arrangement of a pothead, cable box, and **Y** joint on an aerial cable. The method of securing the lead cable tightly to the messenger wire is shown at the joint *m* and on each side of it at *n* and *o* to prevent any stain on the joint. At (*c*) is shown a section through *n* and at (*d*) a section through *m*. The support at *o* is made in the same manner.

In order that there may be no strain on the pothead, aerial cables should make a downward loop of about 12 inches as shown at *a* just before entering the pothead. The pothead may be made in the shop on a piece of dry-core cable about

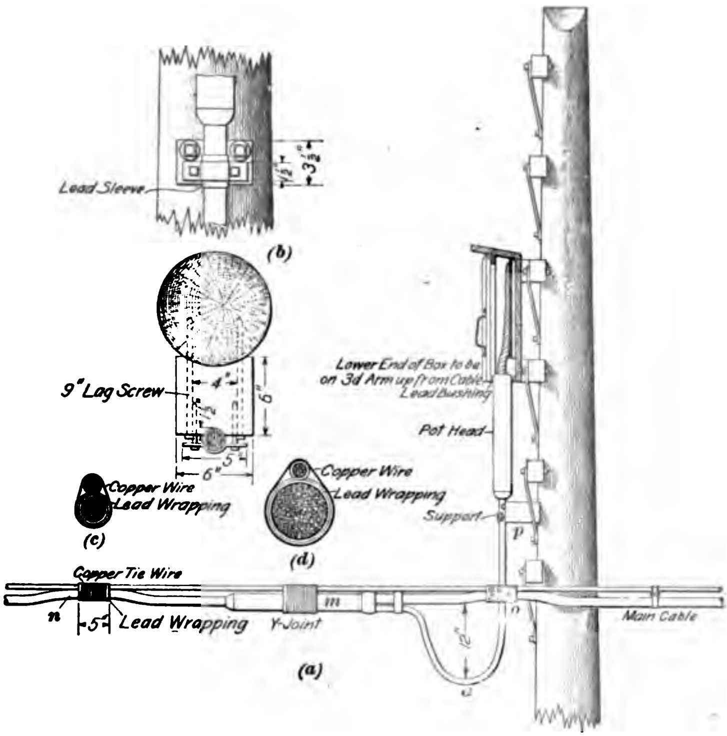


FIG. 28

9 feet long and then spliced to the main cable by a **Y** joint. The pothead should be securely fastened to the pole at *p*, which is just below the wiped joint, by means of wooden blocks and iron straps, the cable being protected where the strap presses on it by a piece of sheet lead wrapped around the cable to form a sleeve. At (*b*) are shown two views on a larger scale of the details of the cable support at *p*.

Where the pothead enters the cable box, a lead bushing should be soldered to the pothead inside the box and tacked down to the bottom of the box. The lead sleeve of the pothead should project at least 1 inch inside the box. Pothead terminals should always be placed in a vertical position with the end from which the okonite wires issue upwards.

INSIDE OFFICE TERMINALS

73. In the smaller Bell exchanges, the office terminals are distinct from the distributing board and are connected to the protective devices. In larger Bell exchanges, the cables terminate under the horizontal runs of the distributing frame. In order to have the distributing frame as free as possible from imflammable material, wool-insulated wire is used because it is nearly non-imflammable and non-hygroscopic. It is therefore preferable to okonite or rubber-covered wire for this purpose, but is not sufficiently non-hygroscopic to be used for potheads in outdoor cable boxes.

In all, except the smaller, Bell exchanges, wool-insulated cables covered with lead are used to connect the dry-core paper cables to the terminals on the main distributing frame or on the protective apparatus. Such a joint is superior in a dry terminal room to an ordinary pothead made with rubber-covered wires, because the compound in potheads expands in warm weather and oozes out among the wires. Furthermore, if potheads are placed in a horizontal position on distributing racks, the compound drops on the cross-connecting wires, which makes it very hard to change the cross-connections. The wool cables are made with tinned copper wire covered with a double wrap of wool for insulation and lead covered.

JOINING WOOL CABLES TO PAPER CABLES

74. Wool-insulated lead-covered cables should be joined to other cables where the splices can be conveniently laid in a horizontal position. When connected to underground cables, the best place is generally the office manhole or the basement run; when connected to aerial cables, the best place is usually the horizontal run of cable after entering the building. The length of wool cable for each incoming cable should not be less than 15 feet; but not too long, because this cable is more expensive than dry-core paper cables.

Wool cables are joined to other cables in the same manner as two dry-core paper cables, except that the splice should be filled with hot paraffin, which should be tested with a piece of the wool insulation, as it will char the wool if too hot. After the splice is made, cut a hole in each end of the lead sleeve 1 inch from the wiped joint and pour the hot paraffin in one hole, the other hole serving as a vent. This prevents moisture getting into the paper cable even if it should get into the wool cable. The same compound used for potheads may be used instead of paraffin. When completely filled, cover the holes with lead caps and solder them tight.

Remove the lead sheath on the wool cable the proper length for forming the end to correspond with the terminals where they end. Boil out these ends by dipping them into a hot mixture of equal parts of paraffin and pure beeswax. Then form the end. All twine used for binding should be waxed. The formed end should be again boiled out in the same mixture. After it is cold, bind the end where the wires leave the lead sheath with rubber tape. A little gasoline applied to the lead will make the tape stick. When placed in position and connected to the terminals, the wool wires should be varnished with a very thick solution of white shellac in pure grain alcohol; a second coat being given when the first is dry. This closes all the pores and gives the formed end a neat appearance.

75. When a dry-core or wool cable runs into an iron terminal head, the cable sheath must be thoroughly sealed to the terminal by a wiped joint, the wires soldered to the terminals unless screw connections or binding posts are provided, and the core bound with cotton twine or wicking and paraffin poured into the end of the cable until the neck is filled flush with the bottom of the terminal.

NOVELTY SLEEVES AND POTHEADS

76. To eliminate the services of an expert plumber or cable splicer in making cable joints of various kinds, the so-called **novelty sleeves** and **potheads** have been developed. They are made of brass containing solder that has only to be melted to make a tight joint.

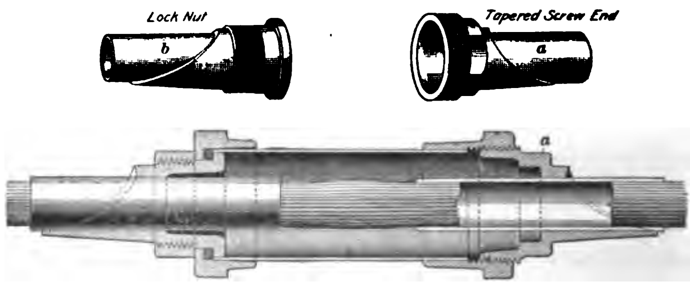


FIG. 29

Fig. 29 shows the novelty slidable sleeves that are used for making an ordinary straight joint between two cables. It consists of a brass shell with hubs *a*, *b* tinned ready for soldering, and screwed on each end. To make a joint, unscrew the tapered screwed end *a*, pass it over the cable, and slip the rest of the sleeve on the opposite end of the cable.

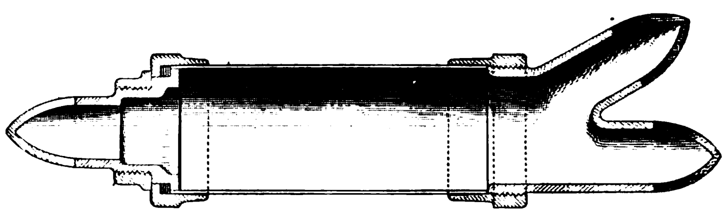


FIG. 30

Splice the wires as usual, screw the tapered end *a* into the sleeve using plumbago mixed with cylinder oil to a paste on the screw, as this will not set like red lead and hold the joint when it is necessary at some future time to unscrew it. Place the sleeves central on the cable so that the spliced wires will be in the center thereof. Then solder the joints to the lead sheaths by heating them with a blow torch or a hot iron. This is said to make the joint air- and water-tight. These brass tubes forming part of the sleeves are made from 1½ to 4 inches inside diameter and 8 to 20 inches in length.

77. Fig. 30 shows a novelty sleeve for a Y branch, which is made in the same sizes as straight sleeves. Fig. 31 shows a novelty pothead, which consists of two pieces, the brass sleeve *a* and the end *b*. To make the joint, unscrew the end *b* from the sleeve *a*, pass it over and solder it to the cable sheath with a hot iron or blow torch. Pass the sleeve *a* over the rubber-covered wires and, after splicing the wires, screw the sleeve up tight on the soldered end *b* and fill with hot compound. As the sleeve is made of brass, it may be heated

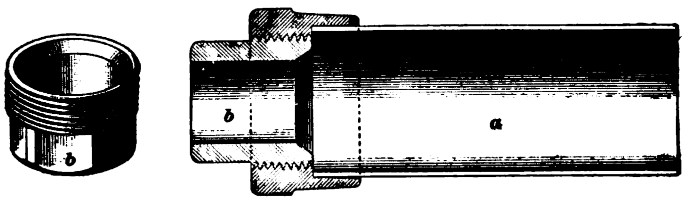


Fig. 31

with a blow torch to make the compound flow in freely in cold weather when it is apt to harden, which cannot safely be done with lead sleeves. These potheads are made with brass tubes having inside diameters from 1¼ to 4 inches and from 10 to 17 inches in length.

It is claimed that skilled plumbers are not required, that 1½ to 2 inches is saved on the end of each cable, that the time and cost of making joints, especially Y and three-way joints, is much less when the novelty devices are used, and that the joints are moisture-proof. For inspection, these devices may be readily opened at any time with a wrench.

78. Prevention of Damage to Cables.—Cables should be kept as clear as possible from trees, especially the large branches, as the constant rubbing will in time wear a hole in the lead sheath or crack it. No undue stress should be brought on a wiped joint, especially if of the Y type. Cables should never be bent on a radius of less than 12 inches and a larger bend than this is always desirable.

They should never be struck with sharp tools, nor dragged over pavements, nor allowed to rest on or against cross-arms or poles, nor lie on buildings or against chimneys, nor carried over a chimney; nor must wire or rope be dragged over a cable, nor allowed to rest permanently on it; nor must the cable be allowed to remain within 2 feet of any electric light or power circuits, nor in such proximity to a guy or line wire as to allow the same to sway against the cable, or if broken to come in contact with the cable. Men must not, under any circumstances, stand on or lean against a cable.

INJURY TO CABLES DUE TO FREEZING

79. In some cases, cables have been damaged due to the fact that they were placed in iron pipes in which water collected and froze. The first indication of trouble, due to the freezing and compression of the ice around the lead cable, is the short-circuiting of one pair of conductors, followed by the short-circuiting of other pairs. This is caused by the expansion of the water as it freezes thereby crushing the lead-covered cable, which forces the conductors through the soft paper insulation into contact with one another. In some cases, it has been customary, in leading a lead cable from a regular line of conduit to a pole, to use sewer tile to within about 15 feet of the pole where a 3-inch iron pipe was joined to the sewer tile, the pipe having been bent so as to lead up the pole, the bend in the pipe having a radius of about 3 feet. To the end of this piece of pipe, which extended about 2 feet above the ground, was connected another length running up the pole. Due to accident or ignorant construction, the bend in this iron pipe would frequently be lower at the pole than at the tile connection and, consequently, any water that got into the pipe would remain there. Where there was trouble from freezing, with such constructions as here outlined, it always occurred where the cable lay in the iron pipe. Although the iron pipe and the tile might be flooded with water and frozen solid, there was no trouble where the cable lay in the tile.

To avoid this trouble, due to freezing, laterals should be constructed about as follows: Sewer tile should be used in preference to iron pipe to make all bends used in bringing the cable up to the pole. An iron pipe may be used on the pole itself, but it should be made water-tight, so as to prevent water, as far as possible, from running down the outside of the cable into the pipe. Drip bends should be put on the cables at the top of the pipe.

SUBAQUEOUS CABLE

CONSTRUCTION

80. It is frequently necessary to extend telephone lines under water, either in crossing rivers, bays, or lakes, or in extending lines from the main land to neighboring islands. For short lengths of cable across rivers or bays having smooth bottoms and slow currents, and where no boat anchors are liable to injure them, cables of the ordinary lead-covered type, having rubber or gutta-percha insulation, are sometimes

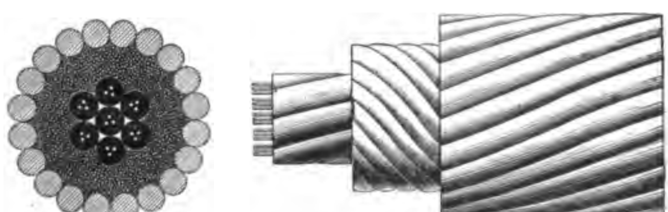


FIG. 32

used, no special armor for the mechanical protection of the cable being necessary. It is well in such cases to order an extra heavy lead sheath, and also to cover the lead sheath with a heavy braiding of fibrous material saturated with waterproof compound.

In order to meet more severe conditions, special armored cables are required, the whole bunch of insulated conductors being covered with rubber or cotton insulation or a heavy wrapping of jute, which is afterwards served with an armor composed of iron wire of about No. 10 B. & S. gauge, affording a continuous mechanical protection for the wires and insulation within. This construction is shown in Fig. 32.

81. For long under-water cables, where it is necessary to reduce the electrostatic capacity of the conductors to as great an extent as possible, a special paper insulation is sometimes used between the conductors. The Felten-Guilleaume Company manufactures an excellent type of cable for this purpose. In Fig. 33 is shown a cross-section of a four-wire cable. The four conductors *a*, *a*, *b*, *b* are insulated from one another by a cross-shaped paper diaphragm *c*. The group is then wrapped by a spiral paper tube *d*. This tube is then covered with a lead sheath *e*, after which a double coating *f* of gutta-percha insulation is applied. The iron armor consists of spiral wrappings of iron wire *w*, of the peculiar cross-section shown, this cross-section being adapted to cause an interlocking between the adjacent wires in such manner as to form an arch that will resist a large amount of compressive strain, besides giving the cable the requisite tensile strength. Over the iron armor is placed a heavy braiding of fibrous material saturated with waterproof compound. Cables built on this general plan are now being used successfully for telephonic transmission across the English Channel.

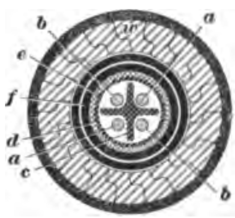


Fig. 33

82. A radical change has been made in the construction of the submarine cables used by the American Telephone and Telegraph Company. The rubber insulation formerly used was replaced by paper. The cable was then filled with asphalt to prevent the introduction of moisture. The capacity was thereby reduced to .09 microfarad

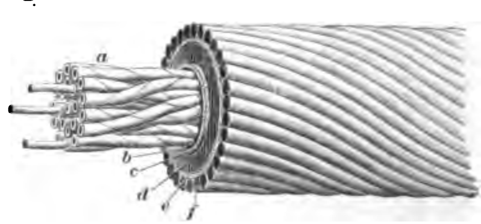


Fig. 34

per mile. The size of the conductors was also increased, as in the case of the underground toll cable. In Fig. 34 is shown an asphalt-filled submarine cable of 11 pairs used in connection with long-distance circuits. *a* represents the paper insulation over each conductor; *b*, a filling of asphalt; *c*, a wrapping of cotton; *d*, a lead sheath; *e*, a wrapping of marline, over which is placed an armor of steel wire *f*.

LAYING SUBAQUEOUS CABLES

83. The means to be adopted for laying cables under water must be decided on for each particular case. Of course, in laying comparatively long lines, the same methods that are followed in the laying of submarine telegraph cables should be adopted, the cable being coiled in tanks on a steamer and paid out over the stern by special apparatus as the vessel proceeds. In laying a cable across a comparatively narrow river, the reel on which the cable is wound should be mounted in the bow of the boat, so as to unreel over the stern of the boat, the cable passing from the under side of the reel. One end of the cable is secured to the shore at or near the point where it is to terminate permanently, after which the boat proceeds across the river, paying out the cable as it goes. Men should be stationed at the reel in order to regulate the tension of the cable as it unwinds, thus preventing too much slack. After reaching the opposite shore, the end is secured and permanent connections with the overhead or underground circuits are made. The shore ends of the cable, extending as far into the deep water as possible, should be buried, in order to protect them from mechanical injury.

84. A method of propelling a boat across a river in a very nearly straight line, which may often be successfully used, is as follows: A rope is first stretched across the river between the points near where the cable is to terminate. This rope may engage running blocks on the bow and stern of the boat, thus serving to guide it across the river. The boat may be propelled by pulling it along the rope by hand, or, where the water is not too deep, by poling it.

SUBMARINE CABLES

85. Limitations of Submarine Telephony.—It has already been shown that telephone transmission through cables is very difficult on account of the high electrostatic capacity of the conductors. This difficulty is made greater in under-water work because the electrostatic capacity is rendered still higher by the presence of the armor and of the water outside of the cable, and sometimes by the use of insulating material having a high specific inductive capacity.

86. Even if transoceanic telephony could be accomplished, with our present knowledge of the subject it is doubtful if it could be made a paying investment. Many efforts have been made to accomplish this by means of improvements in telephone transmitters and receivers, but it is ratner the transmission circuit and not the telephone instruments that are at fault. Professor Pupin claims that a submarine cable of almost any length could be made, by the use of his coils, to transmit articulate speech successfully. At present no submarine telephone cables exceeding about 60 miles are in use.

87. A Long Submarine Telephone Cable.—Up to 1904, the longest submarine telephone cable was 54 miles in length, and was laid between St. Margaret's Bay to La Panna through the English Channel. The cable contains four cores giving two telephone circuits. Each core consists of a strand of seven copper wires weighing about 141 pounds per mile, (39.7 kilograms per kilometer) equivalent to a copper wire of about .095 inch in diameter. Each conductor is covered with three layers of gutta percha, the weight of the insulating covering being 300 pounds per nautical mile, making the total weight of each core 460 pounds per nautical mile. One nautical mile equals 1.151 statute miles. The four cores, together with strands of tarred hemp, are wound helically around a central strand of tarred hemp; this is covered with a stout tape and a brass ribbon, which forms a continuous metal envelope to protect the gutta percha from the attacks of the Teredo worm. Over a cushion of Russian-hemp covering the brass envelope, fourteen galvanized-iron wires are laid, each .28 inch in diameter, forming the outer protection of the cable. The total diameter of the cable is nearly 2¼ inches, and the weight 13.288 tons per nautical mile, or nearly 5 pounds per foot. Tests made after the cable was laid showed the resistance to be 7.09 ohms per nautical mile; the electrostatic capacity, .266 microfarad per nautical mile; and the insulation resistance, over 1,000 megohms per nautical mile. The total resistance of each conductor in the completed cable was found to be 331.3 ohms, and the total capacity 12.6 microfarads. The cost of the cable was about $2,900 per mile, and the total cost, including the work of laying, which required two ships for 25 days, amounted to $148,445. The total length of the London-Brussels line, which includes this cable, is 238 miles, and the charge for communication is $2 for 3 minutes.

POWER EQUIPMENT

(PART 1)

DYNAMOS

INTRODUCTION

1. Modern telephone practice involves the use of electric currents in so many ways and in such considerable quantities that quite an elaborate power plant is now necessary for the successful operation of a telephone system. While the individual units are usually not large, they must be of considerable number to furnish the different kinds of currents required.

In central-energy systems, electric current is used for two purposes; namely, to supply the talking circuits and to perform the function of signaling. For energizing the transmitters, direct current is invariably used, it being taken usually from storage batteries, which have been found to be the most satisfactory source of current not only for all the transmitters but also for the operation of relays, magnets, and miniature lamps used as signals. Storage batteries have been fully considered elsewhere. For ringing the subscribers' bells, some form of alternating or interrupted current is generally used.

2. A **dynamo** is a machine for converting the mechanical energy furnished by a steam engine, waterwheel, or other prime mover into electrical energy by electromagnetic induction. Dynamos may be divided into two general types, depending on the character of their currents. These two types are:

1. *Continuous-current* or *direct-current dynamos*, in which the current through the external circuit flows continuously in the same direction.

2. *Alternating-current dynamos*, the current from which periodically alternates or reverses in direction and usually with great rapidity. A common frequency for alternating-current dynamos used for incandescent lighting is 60 cycles per second, but they may be designed to give almost any desired frequency.

3. Advantages of Dynamos.—Dynamos and storage batteries are rapidly replacing primary batteries, because they are generally more economical. It is generally most economical to use dynamos as a source of current supply; next in order of economy come rotary converters or dynamotors, motor-dynamos, and then storage batteries, and, finally, primary cells. Mr. Preece, when head of the telegraph and telephone systems of the British Government, stated that, for telegraph and telephone purposes, electricity produced by primary batteries cost $1.50 per kilowatt-hour, as against 2 cents by the system in which dynamos and storage cells are used. The relative cost is doubtless as much in favor of the dynamo and storage battery in other countries as in England. Furthermore, primary cells must be periodically replenished or renewed and require continual inspection and attention in order that they may be kept in good condition and their electromotive force even approximately constant.

4. Essential Parts of a Dynamo or Motor.—The parts of an ordinary dynamo or motor may be summarized as follows: (1) As complete a circuit of iron as possible. Such a circuit is composed of the cores of an electromagnet, usually an iron yoke or base connecting the cores, and the cylindrical or ring-shaped core of an armature that revolves between the magnet ends or poles, which are shaped so as to partly embrace the armature. This iron circuit is shown in Fig. 1. *C*, *C* are the iron cores, *A* the iron part of the armature, and *M* the iron yoke. (2) Coils of insulated wire *W* wound around the field-magnet cores *C*, *C*. When a current flows through these coils, magnetic lines of force are set up through the iron circuit. The dotted lines represent the path and the arrows represent the direction of the magnetic lines, or *flux*, as they are called. (3) Coils of insulated wire, wound on the iron armature core but carefully insulated from it. When the armature core and coils are rotated between the pole pieces *S* and *N*, the coils cut the magnetic lines of force and develop an electromotive force. (4) A collecting mechanism, called the *commutator* in a direct-current machine and *collector rings* in an alternating-current machine. The commutator or collector rings are attached to, but insulated from, the armature shaft and rotate with it. The collecting mechanism consists of these rings or segments of rings, to which the wire coils of the armature are connected and on which press copper or carbon pieces called *brushes*.

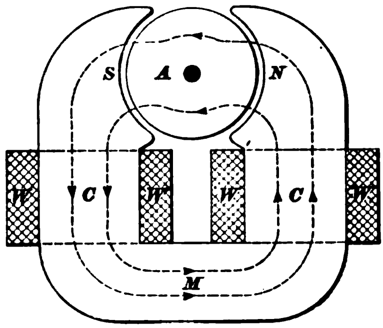


FIG. 1

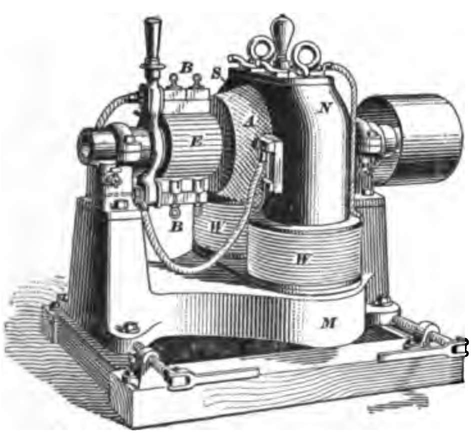


FIG. 2

5. In Fig. 2, *E* represents the commutator and *B*, *B* the brushes of a direct-current dynamo or motor. This is rather an old type but is used here as it shows the various parts better than a more modern enclosed type of machine, which will be illustrated presently. When used as a dynamo, the electromotive force developed by the cutting of the magnetic lines of force by the wires on the armature shows itself as a difference of potential between the brushes. This difference of potential at the brushes or at the terminals of the machine, to which the brushes are directly connected, usually by short heavy wires or bars, is called the **voltage** of the dynamo, because it is measured in volts.

If the two brushes B, B on opposite sides of the commutator E are connected with some circuit external to the machine, the potential difference will cause a current to flow in that circuit. By using enough coils on the armature and properly divided and connected segments on the commutator, the current may be made to flow always in one direction, giving a practically continuous current; such a machine is called a **direct-current dynamo.** If only two collecting rings are used, the current flows first in one direction and then in the opposite direction; such a machine is called an **alternating-current dynamo.**

6. The potential difference at the brushes of a dynamo depends on the speed at which the armature rotates, on the strength of the magnetic flux passing through the armature, and on the number of turns of wire on the armature. Consequently, with a given machine in which the number of turns on the armature is fixed, the voltage will remain uniform, provided that both the speed and the magnetic flux remain constant. The speed is usually constant within about 2 per cent. By regulating the current in the field coils, the magnetic flux may be varied, and, consequently, the voltage can be regulated.

7. Methods of Exciting the Field.—The requisite number of ampere-turns for exciting the field of a dynamo-electric machine may be obtained in a variety of ways. In the first place, the current that flows through the magnetizing coils may come either from some separate external source, the machine being then said to be *separately excited*, or it may be furnished by the armature of the machine itself, it being then said to be *self-excited*. In some cases, a combination of these two methods may be used.

DIRECT-CURRENT DYNAMOS

SEPARATELY EXCITED DYNAMOS

8. A **separately excited dynamo** is so named from the fact that its field magnets are excited or magnetized by a current from some external source, as, for instance, a voltaic battery or another continuous-current dynamo. The connections of a separately excited dynamo are represented in Fig. 3. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery *B*. The exciting current flows from the battery around the cores of the field magnet in such a direction as to set up lines of force through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo, when the armature is rotated at a uniform speed, remains constant as long as the external circuit is open; but when the external circuit is closed, the difference of potential gradually diminishes as the strength of the current increases, owing to the internal resistance of the armature conductors and the reactions of

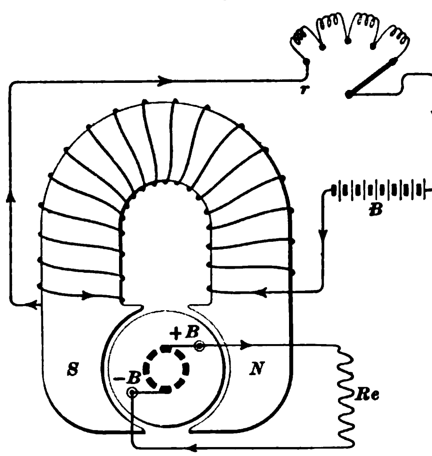


Fig. 3

the armature current on the field. An explanation of this can be found in a treatise on the theory of dynamos, but it would require more space than is advisable to devote to it here.

SELF-EXCITED DYNAMOS

9. A **self-excited dynamo** is so named from the fact that the exciting current for the field magnet is furnished by the dynamo itself. There are three methods of self-exciting a dynamo.

1. The field coils may be connected across the brushes in shunt with the external circuit; such a machine is called a *shunt dynamo.*

2. The field coils may be connected in series with the external circuit and the armature; this is called a *series-dynamo.*

3. The field may have two distinct windings on it, one of which is connected across the terminals or brushes and in shunt with the external circuit, and the other in series with the external circuit and the armature; this is called a *compound*, or a *shunt-and-series dynamo.*

10. Shunt Dynamo.—In Fig. 4 is shown a **shunt dynamo.** One terminal of the magnetizing coil is connected to the positive brush and the other to a terminal mounted on the field rheostat *r*; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen that the total difference of potential exists between the terminals of the magnetizing coils when the dynamo is generating its maximum electromotive force. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential between the field terminals. In well-designed dynamos, the resistance of the shunt coil is large enough to allow not more than about 5 per cent. of the total current of the dynamo to pass through the field coils. According to Ohm's law, the strength of current, in amperes, circulating around the field coils is equal to the difference of potential, in volts, between the brushes, divided by the sum of the resistances, in ohms, in the field coil and in the rheostat *r*. Since the total resistance in the field circuit is large compared with the voltage between the

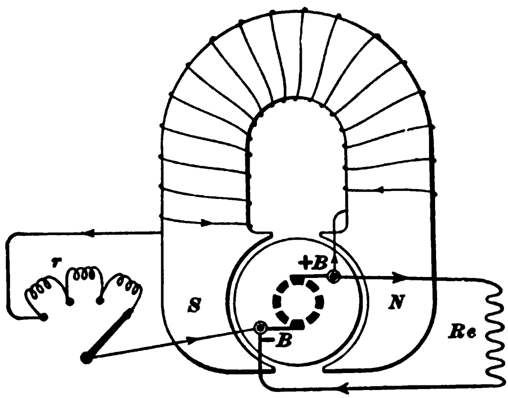


FIG. 4

brushes $+B$ and $-B$, the current in the field coils will be relatively very small compared to the total current as just stated.

11. Regulation of a Shunt Dynamo.—The difference of potential between the brushes of a shunt dynamo gradually decreases as the current from the armature becomes stronger, on account of the internal resistance of the armature conductors and the reactions of the current on the field. Any decrease in the difference of potential between the brushes causes a corresponding decrease in potential at the field terminals, thereby weakening the current in the magnetizing coils. In order to compensate for the decrease in the difference of potential at the brushes, a field rheostat *r* of comparatively high resistance is connected in the field circuit, and is so adjusted that when no current is flowing in the external circuit, only enough current flows through the field to produce the normal difference of potential between the brushes. This normal difference of potential between the brushes is kept constant, as the load increases, by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

As the resistance in the rheostat is decreased, more current flows through the field coils, thus increasing the flux or strength of the field; this, in turn, causes an increase in the electromotive force generated in the armature, provided, of course, that the speed remains the same. If there is an appreciable change in the voltage at the terminals of the dynamo when running, it is the dynamo attendant's business to keep this voltage constant within prescribed limits by properly adjusting the field rheostat.

12. The shunt dynamo is very extensively used. Fig. 2 shows an old type of shunt dynamo mounted on sliding rails, which are attached to a wooden bedplate. Two adjusting screws, one on each side of the machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt, as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole pieces; from the terminals, the current divides, a small portion passing through the field coils and the rheostat, which is not shown in this figure, and the rest through the external circuit.

An incandescent lamp is often connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal electromotive force. A lamp used for this purpose is often called a **pilot lamp.**

13. Series-Dynamo.—Fig. 5 shows a **series-dynamo.** The magnetizing coils of a series-dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a series-dynamo are shown in the figure. The current starts from the positive brush $+B$, circulates around the external circuit Re, thence through the magnetizing coils back to the negative brush $-B$. The action of a series-dynamo differs widely from that of a shunt dynamo. The difference of potential between the brushes depends on the strength of the current flowing from the armature, but it is not necessarily directly proportional to the strength of the current. Compared with the coils on a shunt dynamo, the magnetizing coils of a series-dynamo are made of a few turns of a large conductor. This is necessary, because the coils are usually required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are necessary to secure the proper magnetizing force.

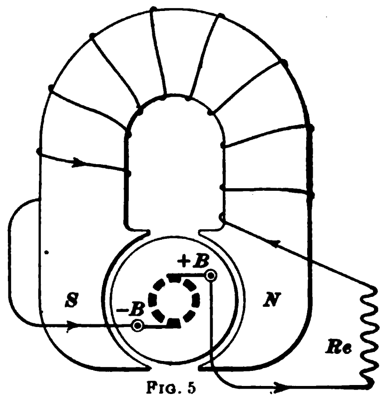


FIG. 5

14. Compound Dynamo.—In the shunt dynamo previously described, the regulation of the difference of potential at the terminals of the machine is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement of the rheostat arm is sometimes imparted automatically by a magnet controlled by the current in the external circuit. But, more often, when a very constant potential is desired, it is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils; such machines are termed **compound dynamos.**

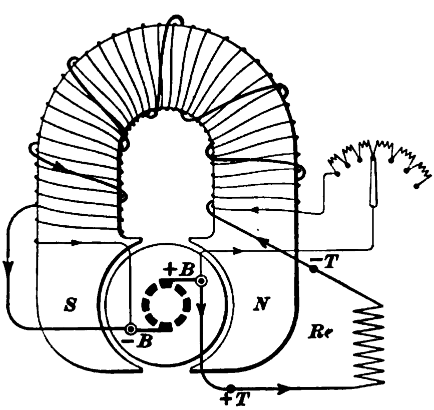


FIG. 6

In Fig. 6, the shunt coils consist of a large number of turns of fine insulated wire wound on the core of the magnet. The series-coils, consisting of a few turns of large insulated wire, are wound over or alongside the shunt coils. The main part of the current from the armature flows from the positive brush $+B$ through the external circuit Re, thence through the series-coils to the negative brush $-B$. The shunt coils and an adjustable resistance are connected to the two brushes $+B$ and $-B$. But the series and shunt coils are so wound that the currents in both will circulate around the core of the magnet in the same direction when they are connected as shown in the diagram. The action of both currents, therefore, is to produce the same polarity in the magnet, the shunt current being reenforced by the series-current. When the dynamo is not loaded, that is, when no current is flowing in the external circuit and the armature is rotated at normal speed, the normal electromotive force is generated in the armature due to the magnetic field produced by the shunt coils alone. On closing the external circuit, however, the difference of potential between the brushes tends to decrease, and it would continue to decrease, as previously described in a simple shunt machine, if the series-coils were neglected. The current circulating through these, however, reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for nearly all changes of load in the external circuit. This method of regulating the difference of potential at the terminals of a dynamo is called **compounding.**

15. The **terminals** of a dynamo are the binding posts to which the external circuit is connected. In a series, or compound, dynamo, one terminal is attached to the outside end of the series-coils, as $-T$ in Fig. 6, and the other terminal $+T$ is connected directly to the brush $+B$. In a compound dynamo, the shunt field and adjustable resistance are usually connected directly across the brushes.

16. Direct-current dynamos may be subdivided into two classes, as follows:

1. *Constant-potential dynamos*, in which the difference of potential at the terminals of the machine remains constant and the strength of current changes with the load or external resistance. The word *load* is a common expression for current in dynamos generating a constant potential. Strictly speaking, however, the load means the product of the current and the voltage, but the voltage is considered constant and, therefore, the load is directly proportional to the current. That is, if the current in the external circuit is doubled, the load is doubled.

Constant-potential dynamos should be started and brought up to full speed and normal voltage with the main switch connecting the external circuit open, that is, before any load is put on the machine. It is preferable to apply the load gradually and not all at once.

2. *Constant-current dynamos*, in which the strength of current (continuous, pulsating, or alternating) remains constant and the difference of potential at the terminals of the machine changes with the load.

Compound, separately excited, and shunt dynamos are included under the first head, and rank in their ability to maintain a constant potential in the order named and for reasons already explained.

Constant-current dynamos have usually a series-field, and at present are used almost exclusively for operating continuous- or direct-current arc lamps.

17. Currents furnished by dynamos for charging storage batteries in telephone exchanges should preferably be as smooth and continuous as possible, that is, they should closely resemble the continuous non-pulsatory current obtained from batteries. In order to obtain such smooth currents from dynamo-electric machines, it is best to have a smooth, iron, armature body on which to wind the wire and a commutator with a large number of segments (at least 48). The revolving armature and commutator should run at a fairly high speed. Armatures with the wires wound in slots produce a current more pulsatory in character, and are sometimes very troublesome to grounded telephone systems, whose wires run near and parallel, even for a short distance, to other wires that are supplied with currents from such armatures.

ALTERNATING-CURRENT DYNAMOS

18. Alternating-current dynamos are used for generating ordinary ringing currents. The fields of alternating-current dynamos are usually separately excited, either from a direct-current dynamo or from storage batteries. A large alternating dynamo usually has a small direct-current machine

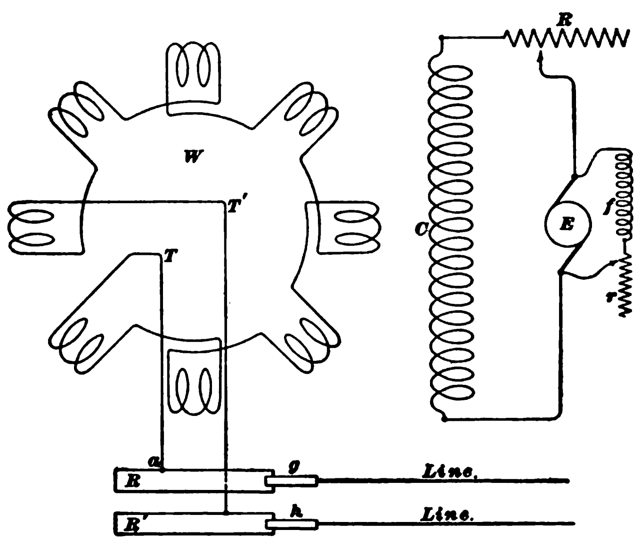


FIG. 7

associated with it for exciting its field. In Fig. 7 is shown a diagram of connections of a simple alternating-current dynamo with a much smaller direct-current machine for exciting the alternator fields. *W* represents the armature winding of the alternator, the terminals *T*, *T'* of which are connected to the collecting rings *R*, *R′*, which make contact with the line wires by means of the brushes *g*, *h*. The field is excited by a set of coils on the pole pieces represented by *C*, and the current is supplied to these from a small direct-current dynamo, or exciter, *E*. This is a small shunt-wound machine with an adjustable field rheostat *r* in series with its shunt field *f*. An adjustable rheostat *R* is also placed in the alternator field circuit. When the voltage drops or rises, the fields may be strengthened or weakened by adjusting the resistances *R* and *r*; thus, the voltage may be kept right.

By means of a commutator mounted on the shaft of the alternator alongside the slip rings some of the current generated in the armature may be rectified, that is, converted into a direct current, and passed through a series-winding on the field. The arrangement accomplishes about the same purpose as the compound winding of a direct-current dynamo, that is, the alternating-current voltage increases with the load enough to keep the voltage at some point on the line constant or nearly so.

SELECTION AND INSTALLATION

SELECTION

19. A few general principles in regard to the selection of dynamos and motors apply to almost all cases. The construction of the machine should be first class in every respect. There should be evident solidity, each part being amply large to insure durability and as simple as possible; complicated parts are almost sure to cause trouble and expense. Machines in which careless workmanship, defective material, or poor finish are evident should be avoided. If there is danger of mechanical injury from foreign substances falling against the rotating parts, the machines should be provided with perforated doors or covers so arranged as to furnish the necessary mechanical protection and at the same time allow all possible ventilation. Electric machines for use in a damp atmosphere or one filled with dust or small flying particles of any kind should be entirely enclosed, dust- and moisture-proof, with suitable doors, or covers, for inspecting the working parts. This class includes motors for installation in mines, rolling mills, forge rooms, carbon works, cement works, etc.

The machine selected should be of ample size for the work required and its construction, both mechanically and electrically, should be such as to require the least possible care and attention. The first cost of such a machine is not often of so great importance as is the cost of care and insurance against breakdowns and repair bills.

20. The losses occurring in electrical machinery are mostly converted into heat, which raises the temperature of the surrounding parts. In the purchase of such machinery, it is important that the temperature rise, as well as the sparking and overload conditions, be fully specified. It is not best to specify to manufacturers of electrical machinery many of the details of construction; the conditions to be met should be clearly stated and the specifications strictly enforced.

Finally, it is best always to deal with manufacturers of established reputation and to purchase machines so well standardized that duplicate repair parts can be quickly and easily obtained. Moreover, such concerns always keep in their employ competent engineers who will give valuable advice as to an installation on which they are permitted to bid.

INSTALLATION

21. Location.—The machine should be located in a clean, dry, cool place, protected from the dropping of water from steam and water pipes or from the roof. A space surrounding the machine, especially around the commutator and brushes, should be clean and free from all obstructions. If the machine is controlled from a switchboard, the operator should be able to reach the board without going through a belt or over other obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation of electrical machines, but dust from a coal pile or any kind of grinding or turning machine is even more so because it is often more adhesive, or sharper and more gritty.

22. Foundations.—Every machine of 25 horsepower, or more, should be provided with a substantial foundation. In order to avoid communicating to the building the vibrations incidental to the running of the machine, this foundation should, if possible, be independent of the floor and walls of the building in which it is installed. If several machines are to be installed in the same room, it will be best to have the whole floor space concreted and covered with a layer of cement or a wooden floor; but for a single machine or a group of small machines, it will be sufficient to make the foundation slightly larger than the floor area. In any case, stonework, solid brickwork, or concrete is the best foundation; but where these are impracticable, a substantial wooden frame construction can be used. When a concrete or brick foundation is used, it is customary to cap this with a hardwood frame, coated with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts to cushion the blows and lessen the vibration due to the machine.

Insurance underwriters have established certain rules, known as the **National Code Rules**, for installing electrical machinery, wires, etc. to which all such installations must conform before the buildings containing them are insurable against loss by fire.

If the machine is belt-driven, means should be provided for tightening or slacking the belt. This is usually accomplished by mounting the machine on rails or on a subbase and moving it by means of a ratchet lever and screw. The foundation should in every case be so disposed that the distance between the centers of the driving and driven shafts will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley. The loose side of the belt should be on top and the driving side below, as this will increase the arc of contact and the driving power of the belt.

23. Erection.—Small machines are usually shipped complete and ready to run, so that it is only necessary to set them in place and make the necessary connections. Large machines cannot be shipped, with safety, in an assembled condition, and are, therefore, dismounted and the parts marked and packed in separate parcels. The assembling of the parts should not be undertaken by one wholly unfamiliar with such work, and even an expert must follow closely the blueprints and the marks on the parts.

Too much caution cannot be used when handling such machinery, to see that it is not injured. A slight bruise or scratch on a journal or bearing or a bruised oil ring may result in much annoyance and, possibly, expense. Especial care is needed when handling the field coils and the armature; it is imperative that these be not bruised or the insulation abraded in any way. The commutator is very sensitive to pressure or blows and should be shielded from them in every way possible.

OPERATION OF DIRECT-CURRENT DYNAMOS

24. Dynamo-electric machines and all devices connected with their operation or regulation should be kept scrupulously clean. No copper or carbon dust, dirt, grease, or oil should be allowed to remain on any part of the machine. If available, a jet of compressed air should frequently be used to blow all loose dust out of the commutators, armatures, field coils, etc. If this cannot be done, a good hand bellows should be used. Not only the machines themselves but all their surroundings should be kept perfectly clean and free from rubbish or litter. The appearance of the dynamo room, as well as that of the machines, indicates the alertness of the attendants and the probable attention given the whole plant. Continual watchfulness is necessary to discover any possible defect before it has developed sufficiently to cause serious trouble. It is well to follow a definite system of inspecting and caring for electrical machinery. Each part should be systematically examined, and cleaned or repaired if necessary, at regular intervals. If this is done, there will be less chance of overlooking or forgetting anything, and expensive delays or repairs may be avoided.

25. Starting a Dynamo.—Care must be taken to have the machine in perfect order mechancially before starting it. Turn the armature slowly by hand to see that it does not rub nor bind at any point. Put on the belt, with the minimum distance between pulleys. See that all loose articles are removed from the machine. A good rule is never to allow a loose article of any kind to be placed on any portion of a dynamo. Start the machine slowly and see that the oil rings rotate. When everything seems to be running smoothly and easily and without undue noise or vibration, gradually bring the machine up to speed and allow it to develop its normal electromotive force. If a belt is used, tighten it until it runs steadily and without flopping and allow the machine to run several hours without load. If the windings have been exposed to dampness, it might be well to run at slow speed and a reduced voltage for a time, thus allowing the passage of sufficient current to dry out the moisture. After everything is in perfect order and the windings are thoroughly dried, the speed and the load may be gradually increased until the desired capacity is reached.

26. Field rheostats consist of a resistance so arranged that it can be cut in or out of a circuit by steps. The resistance material may consist of German silver, iron, or other material, or sometimes of cast-iron grids. Wire or strip resistance is usually wound or assembled on an insulating support of some kind and afterwards covered with an insulating and heat-conducting material. The total resistance should be about the same as that of the field to be controlled and of sufficient current capacity to carry the largest field current indefinitely without overheating.

27. Knife switches should be substantially constructed, with blades preferably of drawn copper and the clips stiff enough to give good firm contact when fully closed; they should have ample current-carrying capacity, so as not to overheat, and be capable of breaking the largest current through the circuit without destructive burning or arcing. Plain knife switches are generally used for pressures up to 1,000 volts; above that and even above 500 volts, it is better to use some kind of a quick-break switch. Switches on a vertical surface should be mounted with the handles up when the switch is closed, so that, when open, the switch will not tend to fall closed.

INDIVIDUAL PARTS OF MACHINES—THEIR DEFECTS AND REMEDIES

BRUSHES AND BRUSH HOLDERS

28. On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine. Brushes are of two kinds: *radial* and *tangential*. **Radial brushes**, Fig. 8 (*a*), point straight toward the center of the commutator. **Tangential brushes**, Fig. 8 (*b*), frequently made of copper, are found, as a rule, only on low-voltage high-current machines. Radial brushes are nearly always made of carbon and are always used on machines designed to rotate in either direction. The brushes should be so placed that with a slight end play of the armature the whole commutator surface will be utilized.

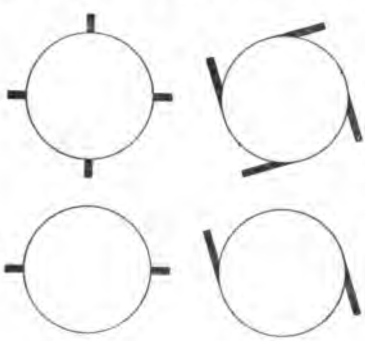

(*a*) (*b*)

FIG. 8

The pressure with which a brush should bear on the commutator depends on the material and condition of the commutator and the material of the brush itself. A copper brush does not, as a rule, require as much pressure as a carbon brush, and soft carbon will run with less pressure than hard carbon. Good practice is from 1½ to 2 pounds per square inch. Pressures greater than 2 pounds per square inch are seldom necessary except where there is excessive vibration, as on railway motors. Increasing the pressure beyond what is necessary to maintain good contact, only results in increasing the friction, with consequent heating and wear.

29. Carbon brushes are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. High-voltage machines usually require harder carbons than low-voltage machines. There are so many conditions affecting commutators that it is extremely difficult to specify the grade of carbon most suitable for a particular machine. The carbon must not be so hard as to scratch the commutator nor so soft as to cover it with smut. Harder carbons are generally used on electric-locomotive and electric-car motors than for stationary work.

Carbon brushes may be given a good bearing surface on the commutator by sliding a piece of fine sandpaper back and forth between the brush and the commutator, with the rough side next to the brush. Do not use emery paper on the brushes or the commutator, as emery is a conductor and may cause short circuits between adjacent commutator bars. Moreover, particles of emery sticking to the face of the brush, being more gritty than sand, will scratch the commutator.

30. Examine the brushes frequently to see that they have full bearing surface and that the surface is smooth and glossy. If it is raw, grayish in color, rough, and gritty, or if it is covered with particles or streaks of copper, something is wrong. Sometimes conditions can be improved by changing the brush lead, that is, shifting the brushes, and often considerable relief can be had by boiling the brushes in vaseline. To do this place the brushes in a vessel with sufficient melted vaseline to cover them and boil for about 1 hour, after which remove the brushes and wipe them dry. If there is time, let them stand in an oven or other warm place for a few hours and wipe off all surplus grease before replacing them in the holders.

31. Metallic brushes are made of strips of copper, bundles of copper wires, or, more frequently, copper gauze folded into shape and stitched. Those made of strips or wires are very liable to have the edges or ends of the laminæ fused together by sparking, forming hard points that cut the commutator. Whenever this occurs, they should be taken out and the ends trimmed off. To get them to the proper level, so that they will rest evenly on the commutator at the proper angle, it is customary to use a filing jig, as shown in Fig. 9. This consists of a block of steel with a hole through it the size of the brush, and with one end beveled off to the proper angle and hardened. The brush is placed in the jig with the end projecting a little from the beveled face, and clamped in position. The end of the brush may then be filed or ground down flush with the face of the jig, thus giving it the correct bevel.

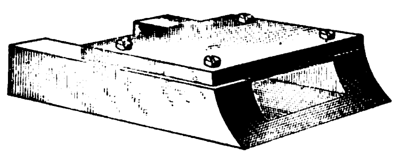


FIG. 9

Metallic brushes should not be allowed to become filled with oil or dirt; if they get in this condition, they may be readily cleaned with benzine or kerosene.

32. Brush Holders.—The moving parts of the brush holders should be as light as is consistent with strength and there should be no stiffness or rigidity to prevent the brush from closely following any unevenness in the commutator. If carbon brushes are used, the brush, as it wears off, should move toward the center of the commutator and the pressure of the brush spring should remain practically constant until the brush is worn out. To prevent a tendency to chatter, or jump from the commutator, the brush holders should be set as near the commutator as possible. These points regarding brush holders are determined by the manufacturer, but will guide in selecting a machine.

THE COMMUTATOR

33. The **commutator** is the most sensitive part of a machine, and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it assumes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Oil should be used very sparingly, if at all, on a commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what oil goes through the pores. Too much oil or grease will cause arcing or flashing at the brushes and black rings will form around the commutator. These should be wiped off with clean cloth. Never use waste to wipe the commutator or brushes and the cloth used should be as free as possible from lint.

34. Roughness of the commutator may be due to overloads, to improper setting of the brushes, to poor workmanship or material, or to defective design. For occasional slight roughness due to either of the first two causes, sandpaper may be used; but if the condition keeps recurring and seems to be due to either of the last two causes or to some other cause not readily ascertained, some more permanent remedy must be used.

Before using sandpaper remove the brushes or fasten them back where they will be out of the way. Hold the sandpaper on the rotating commutator with a segment of wood having the same radius as the commutator. Use No. 2 sandpaper at first and finish with No. 0. For a final polish reverse the paper and hold the smooth side next the commutator for a moment. Blow all dust out of the machine as soon as the operation is completed.

35. Stoning.—Frequently, a commutator that appears very rough may be placed in a satisfactory condition by a process called **stoning.** A block of sandstone 4 inches square and 8 inches long can be placed in a wooden holder of convenient shape and size and one of the long surfaces made to fit the curvature of the commutator. Grinding a commutator with a stone made in this way is preferable to using sandpaper, for the stone will not dip into low places but will grind the high bars only. If the stone is coarse, it may be desirable to finish the commutator with fine sandpaper. The stone will not reduce the diameter of the commutator, or the radial wearing depth of the bars as much as a turning tool.

36. Eccentricity.—If a commutator is not properly baked during construction or is not screwed down after it is baked, it is liable to bulge out in the course of time under the action of the heat due to its normal load and the action of centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good. The best thing to do with such a commutator is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary unevenness of surface of large commutators due to wear, it is customary to set up a tool post and a slide rest on the bedplate of the machine itself and turn off the commutator while in position. Commutator turning tools that may be readily attached to almost any large dynamo or motor are supplied by many leading manufacturers of electrical machinery.

37. High or Low Bars.—If, when a commutator is rotated slowly, a sharp metallic click is heard as many times per revolution as there are brush holders and a slight jumping of a brush is noticed every time the click is heard, there is probably one or more high or low bars. If it is a high bar and if it is tight in the commutator, the material in the bar is probably too hard; the bar may be dressed down with a file while the armature is standing still. A low bar may be due to soft material, to bad sparking caused by a defect in the armature winding, to a careless blow, or the bar may be loose. If due to any of the first three causes, the armature surface should be turned down in a lathe or with a commutator turning tool to the level of the low bar. If due to the second cause, the defect in the winding should also be found and removed. A loose bar, either high or low, will necessitate a thorough repair job. After turning a commutator always finish with No. 0 sandpaper as directed in Art. **34.** Inspect the surface closely to see that no burrs bridging across the mica have been left by the tool.

38. The most serious condition is to have an armature or a commutator that is defective in design or that contains defective material or workmanship. If the design is poor, it may be very difficult or even impossible to keep the commutator in good condition. If the mica is too soft, it will pit out between the bars leaving a trough to fill up with carbon dust and thus short-circuit the neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and require frequent turning down.

THE ARMATURE

39. Heating.—An armature should run without excessive heating; if it heats so as to smoke or give off an odor, the machine should be shut down at once and the cause of the heating should be located and removed. The odor of overheated insulation is very peculiar and easily recognized, especially after having once experienced it. The heating may be caused by damp insulation—a condition that, as a rule, is shown by steaming, but which can be better determined by measuring the insulation to the shaft with a voltmeter. If low insulation is indicated, the armature should be baked, either in an oven or by means of a current passed through it in series with a lamp bank or water resistance, or as directed in Art. **25.** The baking current should not exceed the full-load current of the machine. If, while the machine is at rest, a current for baking purposes be sent through the armature from an external source, be sure that the series-field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor.

40. Short Circuits.—If, instead of the whole armature running hot, the heat is confined to one or two coils, there is probably a short circuit either in a coil or between the two commutator bars to which the ends of the coil connect. If a short-circuited coil is run in a full-excited field, it will soon burn out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife up to the head of the armature while it is running in a field. Any existing short circuits in the coils or commutator will cause the piece of iron to vibrate very perceptibly; each time the defect passes underneath. If the trouble is confined to one or two coils, it can frequently be located by stopping the machine after running a few moments and feeling the armature all over for the hot coil.

If one or more coil connections are reversed on one side of a dynamo armature, that side will generate less electromotive force than the other, and hence, will receive current from the other side; that is, a current will flow through the armature coils that does not flow through the external circuit. This current is useless and heats the machine unnecessarily. If the same mistake is made in connecting a motor armature, the side having the reversed connections will generate less counter electromotive force than the other side and will therefore receive more than its share of the current flowing through the motor, making this side overheat.

41. A **flying cross** in an armature is a defect caused by a loose or broken wire with poor insulation; when the armature is standing still or even when it is rotating much below its standard speed, the wire may remain so nearly in place that the defect cannot be noticed; but when full speed is attained, centrifugal force throws the wire out of place and into contact with other wires or with the core or framework of the machine causing sometimes severe sparking or flashing. Such a defect is often very hard to find; some of the tests given in Art. 40 may assist in locating it, or it may be necessary to give the whole armature winding a minute inspection.

42. **Overloaded Armatures.**—One of the most common causes of general trouble and heating in an armature is **overload;** this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing much more than the work for which it was designed. By adding lamps, one or two at a time, it is an easy matter to unwittingly overload a dynamo. Or in the case of a motor, small devices may be added, one at a time, until an overload is the result. Ammeters sometimes get out of order, read incorrectly, or stick, and thus do not indicate the full load of the machine.

FIELD-COIL DEFECTS

43. **Open Circuits.**—Among **field-coil defects** are *open circuits*, *short circuits*, *grounds*, and *wrong connections*.

An **open circuit,** or a break, occurring in the field circuit of a dynamo or a motor when the machine is idle, will usually be discovered on attempting to start up, before any further injury has resulted. If the break occurs while the machine is in service, the field magnetism will be lost with results more or less disastrous, depending on the style of winding, the work the machine is doing, and whether it is operating alone or with other machines. For example, if the break occurs in the shunt-field winding of a shunt- or a compound-wound dynamo, operating alone, the machine will merely cease to generate; if operating in parallel with other dynamos, the other machines will be short-circuited through its armature with the possible burning out of some or all of the dynamo armatures on the circuit. A shunt motor will cease to generate counter electromotive force, and its armature will become a short circuit across the line and will be **burned out** unless the armature circuit is opened almost immediately. Application of the principles governing the generation of an electromotive force will enable one to determine the result of a break in the field circuit under conditions other than those given.

44. Short Circuits.—The effect of a short circuit in a field coil depends on the kind of machine and the method of field connection. If the defect occurs in a shunt field, there will be an increased field current and but very little change in the speed of a motor or in the electromotive force of a dynamo. If a series-field is short-circuited, the effect in a dynamo is to reduce the electromotive force and in a motor to increase the speed; hence, if the electromotive force of a dynamo becomes too low or the speed of a series- or a compound-wound dynamo becomes too high and the change cannot be otherwise accounted for, it is probable that the series-field has become short-circuited.

Short circuits may be caused by carelessness in winding or in handling, by defective insulation, or by moisture. By far the larger part of such defects are probably due to moisture absorbed by the insulating materials when the machines are idle for some time, especially if they are in a damp place. This moisture should be baked out either in an oven or by allowing a small current to flow through the coils for some time, increasing gradually to the normal current as the coils become dried. If very moist, the coils should be baked in an oven before a current is sent through them.

45. Grounds, or Connections Between Windings and the Field Frame.—In circuits, neither side of which is permanently grounded, an accidental grounding of the windings will produce no further immediate injury to the machine, provided that the ground be removed at once; but if it be allowed to remain until a second one occurs, the two may have the effect of a short circuit. On electric-railway circuits, however, where one terminal of the dynamo is permanently grounded to the rails, a single ground on the windings will usually have the effect of a short circuit.

46. Wrong Connections.—One or more field coils may be connected so that the current flows through them in the wrong direction, or the series and shunt coils of a compound-wound machine may be connected **differentially**, that is, so that they oppose each other in effect, when they were intended to be connected **cumulatively**, that is, so that they would assist each other in magnetizing the fields. It is a good plan, when connecting up a machine, to try the poles with a compass when the fields are excited, to see that the north and south poles alternate and the series and shunt fields, if both are used, are connected in the right direction with respect to each other.

REASONS FOR A DIRECT-CURRENT DYNAMO FAILING TO GENERATE

47. Among the causes for a dynamo failing to generate may be given, loss of residual magnetism; wrong connections of field or armature; open circuits or poor connections; short circuits; low speed; magnetic-circuit defects, which may consist of bad flaws or blowholes in the field casting or poor magnetic joints; wrong position of the brushes, etc. Some of these causes may result in a decreased voltage instead of a complete failure to generate.

48. Loss of Residual Magnetism.—Of all the causes that may make a dynamo fail to generate, the loss of residual magnetism, or **charge**, is one of the most troublesome. As a rule, dynamos leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it. Some dynamos never lose their charge, while others are continually doing so.

49. When a dynamo has lost its charge, the pole pieces have little or no attraction for a piece of soft iron. Series-dynamos seldom lose their charge so entirely that they fail to pick up a field when short-circuited. When a compound-wound dynamo refuses to generate its normal electromotive force with its shunt winding, it can often be made to pick up by disconnecting the shunt coils and short-circuiting the machine through a small fuse. Machines can in some cases be made to pick up a field by simply rocking the brushes back from their neutral position.

50. If these expedients fail to produce the desired result, the fields must be recharged from an outside source. If the dynamo runs in multiple with other dynamos, it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. If the dynamo does not run in multiple with another and there is a dynamo or storage battery within wiring distance, disconnect the shunt field of the dead dynamo and connect it to the live circuit. If there are absolutely no other means available for charging, several ordinary battery cells may be used. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate.

Sometimes a dynamo, instead of losing its residual magnetism, will acquire one of a reversed polarity, for which it is difficult to give a cause that will be generally applicable. In this case, the dynamo will build up with the polarity of the brushes reversed. In some cases, this would do no harm; but in most cases, it is essential that the brush polarity be always the same; and if the dynamo begins to build up wrongly, it is best to stop it at once and ascertain the cause. If it be found that the residual magnetism is reversed, an external electromotive force should be applied, to restore the fields to their proper direction.

51. Wrong Connection of Field or Armature.—In the process of building up the field of a dynamo, it is essential that the very slight electromotive force due to the armature conductors cutting the residual magnetism shall send current around the field coils in such a direction as to add to the residual magnetism. If the reverse were true, all the magnetism would be killed and the dynamo would fail to generate. It follows then that, after a dynamo has been left charged in one direction, if its field or armature leads are reversed, the machine will not pick up; and, if it be run long with these wrong connections, the residual magnetism will be completely lost and the machine will fail to pick up, even when the connections are made right again, until the fields have been recharged.

52. Again, one or more field coils may be incorrectly put on, or connected so that they oppose each other. On a compound-wound dynamo, the reversal of a shunt-field coil will generally keep the dynamo from picking up on open circuit, unless the dynamo has more than four coils; the more coils it has, the less effect will the reversal of a single coil have. The reversal of a series-coil is not felt until an attempt is made to load the machine; the voltage will not come up to where it should for a given load, and the brushes are apt to spark on account of the weakened field.

53. Open Circuits or Poor Connections.—A shunt or compound-wound dynamo will not pick up if the shunt-field circuit is open; the open circuit may be in the field itself, in the field rheostat, or in some of the wires or connections in the circuit. A careful inspection will generally disclose any fault that may exist in a wire or connection. To find out if the rheostat is at fault, short-circuit it with a piece of copper wire; if the dynamo generates with the rheostat cut out, the fault is in the rheostat. A field circuit is sometimes held open by a defective field switch that is apparently all right; repeated burning may have oxidized the tip of the switch blade and formed on it a non-conducting blister, which prevents the jaws of the switch from coming into electrical contact with the blades. Another trivial but common cause of open circuits is the blowing of fuses.

An open circuit in an armature will interfere with the proper generation of electromotive force, but such a fault, as a rule, announces its own occurrence and location in a very emphatic manner: there will be severe sparking and the commutator bars to which the open coil is connected will be badly burned in a short time.

Before attributing the failure to generate to any of the foregoing open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out. The electromotive force generated when a machine is first started is very small, because the residual magnetism is weak. It may not require a complete open circuit in a field to prevent a machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage may be sufficient to prevent its picking up when first started. A loose shunt wire in a binding post or a dirty commutator may introduce sufficient resistance to prevent the machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, clean the commutator thoroughly, wipe the ends of the brushes with benzine, and see that they make a good contact with the commutator surface.

54. Short Circuits.—A short circuit occurring on the main line of a shunt dynamo while the machine is running will cause it to lose its field; therefore, the machine will not pick up if its line is short-circuited. A short circuit on the line of a series-wound or a compound-wound dynamo increases its ability to pick up, because the fault is in series with the series-coils and a large current passes through them. A series-dynamo cannot pick up with its external circuit open because no current can flow through its field coils. Either a series or a shunt dynamo may not pick up if its field is short-circuited. A compound-wound dynamo may not pick up on open circuit if the shunt field is short-circuited; if the series-coils only are short-circuited, the machine will pick up with the main circuit open, but will not hold its voltage when the current begins to flow. In some cases, a shunt dynamo will not develop its normal electromotive force on full load, as this approaches too nearly the condition of a short circuit; so that to be on the safe side, it is best to let the machine build up its field before closing the line switch.

Short circuits within the dynamo itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the dynamo or out on the line; if the machine picks up its field when the line switch is opened, but fails to do so when it is closed, the trouble is on the line.

55. Low Speed.—A dynamo will not pick up its field when running below a certain speed, but with the field once established, the machine will hold it at a much lower speed than that required to pick it up. The speed at which a series-dynamo will pick up depends on the resistance of the external circuit.

SPARKING AT THE COMMUTATOR

56. Probably the most troublesome and annoying feature in the operation of direct-current dynamos and motors is **sparking at the commutator.** The cause is not always apparent, but it may usually be found among the following: Too much load; brushes improperly set; commutator rough or eccentric; high or low bars; sprung armature shaft; brushes making poor contact; dirty brushes or commutator; too high speed; low bearings; worn commutator; short-circuited or reversed armature coil; open-circuited armature; vibration; belt slipping; weak field; grounds.

57. An **overloaded armature** heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a dynamo and back on a motor. If the machine is a motor, the speed will be low; if a dynamo, the voltage will be below the normal amount, unless the machine is heavily overcompounded.

58. Brushes may be improperly set in either of two ways: They may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but the spacing between adjacent holder studs be wrong; count the commutator bars between adjacent sets of brush holders and adjust the spacing until the number of bars between each pair is the same.

59. Poor Contact.—The brushes may make poor contact due to a brush being stuck in a holder so that the spring does not force it down on to the commutator; to the temper being out of the spring; to the pressure of the spring not being brought to bear directly on the brush; to the brush not fitting the commutator surface, etc.

Dirty brushes or commutator may cause the brushes to make poor contact. Some carbon brushes contain paraffin placed in them for lubricating purposes. When the brushes are hot, the paraffin may run out too rapidly and cover the commutator with a greasy smut, which insulates it in spots. Copper brushes sometimes get clogged with oil, dust, and bits of lint or waste. Dirty commutators are usually the result of using too soft brushes, or too much oil, or frayed cloths or waste in cleaning.

60. Too high speed is apt to make a machine spark, because it increases the voltage induced in the armature coils as each coil is momentarily short-circuited by a brush. **Worn bearings** sometimes throw the armature far enough out of the center to distort the field and cause sparking. A **badly worn commutator,** even if otherwise in good condition, seems inclined to spark in spite of everything that can be done—it may be because, as the bars grow shorter by wearing away, they become thinner and the brushes then span too many bars, in which case a thinner brush may give relief; or it may be because the error in the angle of the holder increases with the distance from the commutator.

61. Either a short-circuited or a reversed armature coil will cause a local current that will increase the power required to run either a dynamo or a motor, even without any load. A motor will run with a jerky motion, especially noticeable at low speeds, and a dynamo will cause the needle of the voltmeter connected to its terminals to fluctuate. In either case, unless the cross that causes the trouble is removed, the coil will burn out.

By an **open-circuited armature** is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load, or perhaps less, burns it off. A commutator may become loose and break off one or more leads. Sometimes, on account of excessive heating, the armature throws solder and all the commutator connections become impaired; in such a case, while there may be no actual open circuits, there are poor contacts that result in making the commutator rough and black.

62. **Vibration** of a dynamo or a motor will cause constant sparking even at very light loads. The vibration may be due to a poor foundation or to a poorly balanced armature; the remedy is to place the machine on a firmer foundation or to properly balance the armature. A **slipping belt** will sometimes cause intermittent sparking because it subjects the machine to unusual variations in speed.

63. Causes for **weak fields** have already been mentioned; viz., poor joints, either magnetic or electric, wrong connections, short circuits in series-fields, etc. A weak field is easily distorted by armature reaction until it may become impossible to shift the brushes to a point of sparkless commutation.

As in the case of field coils, a single ground on the armature windings of a railway generator, or any machine working on a permanently grounded circuit, will have the effect of a short circuit and will cause sparking and heating. When all wires connected to a dynamo are insulated, two grounds on the dynamo armature windings will cause more or less of a short circuit.

64. The causes of sparking thus far mentioned are such as may be due to improper treatment or abuse after a machine has left the factory, and not necessarily the result of faulty design or construction. It sometimes happens, however, that notwithstanding a dynamo or motor receives only the best of care, it persists in sparking badly at full load or even less. This may be due to poor design, mechanically or electrically, something for which the attendant is not responsible, except possibly as the machine may be one of his selection.

65. A moderate amount of sparking at the commutator is not very objectionable, but, if it becomes sufficient in amount or in duration to blacken or roughen the commutator bars, the cause should be located and removed if possible. Numerous small white sparks, evenly distributed along the edge of the brush and producing no distinguishable noise, usually work little injury. Larger sparks, appearing at irregular intervals along the edge of the brush, usually with a greenish hue and accompanied by a hissing sound, are more serious. Such sparks usually cling tenaciously to one point on the brush edge, and they are due to small particles of copper, torn loose from the commutator by excessive local heat and which cling to the brush surface. On stopping the machine after running a few hours with this kind of sparking, a furrow, or strip, will be found cut into the commutator all around the circumference under the spot where the spark appeared. A well-designed, modern, direct-current dynamo or motor, with the brushes in one position, should be sparkless from no load to full load and possibly to 25 per cent. overload. There should be no injurious sparking at 50 per cent. overload and many manufacturers guarantee their machines to stand even 100 per cent. overload, momentarily, without injury.

TESTING FOR FAULTS

66. Many of the defects that are liable to develop in dynamo-electric machines are apparent from a mere inspection. Other defects, such as short-circuited or open-circuited field coils or armature coils, must be located by making tests. For tests of this kind, the Weston or similar instruments are most convenient if they have the proper range for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a current measured by an ammeter through the resistance and measuring the drop of potential by a voltmeter or millivoltmeter between the terminals of the resistance; from the two readings the resistance is calculated. For measuring a very low resistance as, for example, that of an armature coil, the voltmeter must be capable of reading low, say to thousandths of a volt. A millivoltmeter will be best suited to this work.

67. Open-Circuited Field Coils.—If a dynamo fails to pick up and a voltmeter, connected across the brushes, shows a small deflection when the machine is running at full speed, the failure cannot be due to loss of residual magnetism. A careful examination will reveal any defective or loose connections between the coils. Quite frequently, the wire becomes broken at the point where the leads leave the spool, while the insulation remains intact, so that the break does not show. This may be detected by bending the leads to and fro.

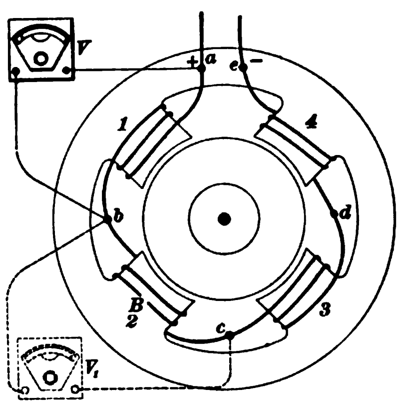


FIG. 10

If the break, however, is inside the winding of one of the coils, it can be detected only by testing each coil separately to see whether its circuit is complete. To do this, connect the field directly across the circuit of another dynamo, if one is available, as in Fig. 10, where the field terminals are connected at *a*, *e* to wires coming from another machine in operation or from a storage battery. If the field coils *1*, *2*, *3*, *4* are all perfect, a current will flow through them; but if one of them has a break in it, as at *B*, no current can flow.

To locate the defective coil, the terminals of a voltmeter are touched to the terminals of the different coils until the defective one is indicated by a deflection of the voltmeter needle. The needle will in each case indicate drop of potential. When the terminals are touched to terminals *a*, *b* of coil *1*, there will be no deflection of the needle because no current is flowing through coil *1*, hence there is no drop of potential in the coil. When the voltmeter terminals are touched to terminals *b*, *c* of the defective coil, as indicated by dotted lines, it is connected through coil *1* to the positive side of the circuit and through coils *3* and *4* to the negative side; hence, it will measure the full pressure of the circuit connected to *a*, *e*.

If a dynamo or storage battery is not available for making the test, a common battery and a bell in series, or a magneto-generator and bell may be substituted for the voltmeter. It is evident that if connections are made at the terminals *a*, *b* of coil *1*, or those of any other perfect coil, the bell will ring but, if made at *b*, *c*, or at the terminals of any other coil containing a break, there will be no ring.

68. Short-Circuited Field Coil.—If the windings of a field coil become short-circuited, either by its wires coming in contact with each other or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across each of the various field coils should be about the same, so that if one coil shows a much lower drop than the others, it indicates a short circuit of some kind. The short-circuited coil will usually run cooler and all the others warmer than normal.

69. Grounds Between Winding and Frame.—After a machine has thoroughly warmed up for the first time after being installed, and at frequent intervals thereafter, it should be tested for grounds. This may best be done with a good high-resistance voltmeter, as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo and the other terminal of the voltmeter to the frame of the machine, as shown in Fig. 11, where

T and T_1 are the terminals of the dynamo and V and V_1 two positions of the voltmeter, connected as described.

If, in either position, the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the other terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the terminal T_1, and vice versa. If the needle shows a deflection in both positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If, in either case, the deflection does not amount to more than about one-twentieth the total electromotive force of the machine, the ground is not serious; but if the deflection is much more

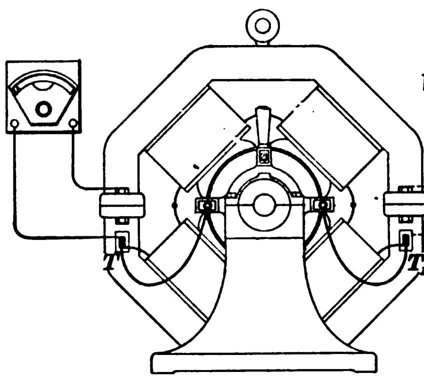


Fig. 11

than this, the windings should be examined separately, the ground located, and, if possible, removed. Before making this ground test on a railway or other permanently grounded dynamo, the grounded terminal should be disconnected from the circuit.

70. Locating a Ground.—Fig. 12 illustrates a method of testing to locate a ground. The machine is shut down and the electric circuit broken into as many distinct portions as possible; that is, each field coil is disconnected from its neighbors and the dynamo terminals T, T_1 are disconnected from the external circuit. C, C_1 are terminals of a live circuit of about the same difference of potential as the normal voltage of the defective dynamo when running. One terminal C of the live circuit is connected to some bright surface on the frame (a bolt head in this case) where good contact can be had, and the other to a voltmeter V of sufficient capacity to measure the full electromotive force of circuit $C C_1$. The other voltmeter terminal is connected to successive field terminals t, t_1, etc. and, if need be, to the machine terminals T, T_1 or to the commutator. In each case, little or no deflection will be shown until connection is made to the defective portion of the circuit. In the figure, if the coil with terminal t_1 were grounded, the voltmeter would show a deflection. If the ground were complete, that is, a *dead ground*, the deflection would show the full voltage of the circuit $C C_1$.

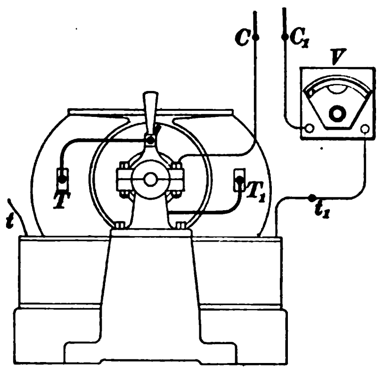


FIG. 12

71. Defects in the Armature.—Faults in the armature may best be located by what is known as the **bar-to-bar test,** connections for which are shown in Fig. 13. A current from an external circuit E is led through the armature by way of contacts A, B, which may be clamped to the commutator. A variable resistance, represented by the lamp bank $L B$, should be used to regulate the strength of this current. A millivoltmeter G is connected, through the commutator bars *1*, *2*, *3*, etc., successively, to the individual coils N, W, K, etc., by means of a contact maker, or crab, C, which is provided with two properly spaced contact pieces. Suppose, in this case, that the dynamo has three defects, which are as follows: (1) There is a break in coil T, which prevents any current flowing through the bottom coils between the contacts A, B, but all the current passes through the top coils; (2) there is a short circuit in coil N; (3) the commutator leads of coils S, K, W are mixed. All these defects are indicated in the figure.

72. The test is carried out as follows: Adjust the lamp bank until the voltmeter gives a good readable deflection when *C* is in contact with what are supposed to be good coils. The amount of current required in the main circuit will depend on the resistance of the armature under test. If the armature is of high resistance, a comparatively small current will give sufficient drop between the bars; if of low resistance, a large current will be necessary. With the contact maker *C*, the operator runs over several bars to obtain what is called the standard deflection with which to compare all the other deflections. The damaged part will often show a wide difference in deflection from the good coils. The deflection of the voltmeter will depend on the difference of potential between the bars. If everything is all right, the difference of potential between each pair of consecutive bars will be practically the same.

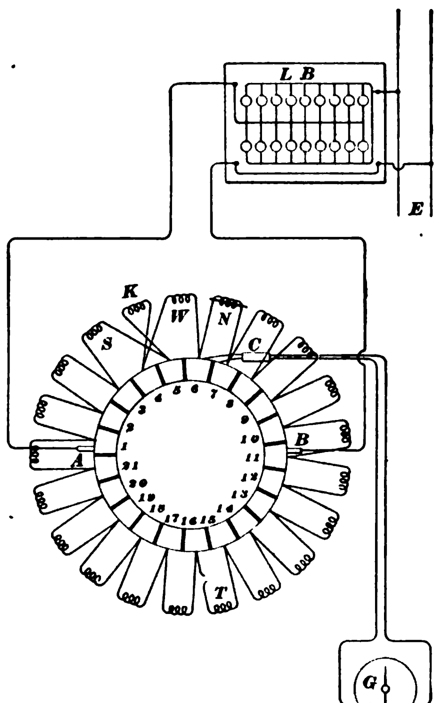


Fig. 13

No deflection will be obtained on the lower side, except when bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. The break is thus located in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected together by a jumper or piece of short wire. The defective coil *T* should, however, be repaired as soon as possible.

When the contact rests on bars *3* and *4*, a deflection about double the standard will be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection will reverse, because the leads from *K*, *S* and *K*, *W* are crossed; but it will not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* as large a deflection will be obtained as between *3* and *4* and for the same reason. Between *6* and *7* little or no deflection will be obtained, because coil *N* is short-circuited, and hence there will be in it little or no drop.

If a coil has poor or loose connections with the commutator bars, the effect will be the same as if the coil had a higher resistance than it should, and hence the deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

REPAIRS

73. Field Coils.—In case of accidents to parts of the machinery, it is sometimes very convenient to make repairs on the spot, saving the time lost in sending the injured apparatus to the makers. There is usually no difficulty in rewinding field coils in a lathe. First weigh the old coil and, when removing the wire, note carefully the method of connecting, the size, and the insulation of the wire, and the insulation on the spool. When rewinding the coil, use exactly duplicate features, as nearly as possible, unless it be plainly evident that the conditions can be improved.

If necessary to make a joint in the wire, the ends of the wires should be rubbed bright with fine sandpaper, twisted firmly together, and soldered with a hot iron, using only resin as a flux. Only solder enough should be left on the joint to make the connection between the wires solid. Remove all projecting ends or bits of solder, leaving a perfectly smooth joint and one occupying as little space as possible. The joint should then be well insulated with silk, cotton, paper, or adhesive tape.

74. Armatures.—To rewind an armature, in whole or in part, is usually a much more difficult task; and if the job be of much importance, the advice or assistance of an experienced man should be obtained. If such work be attempted, proceed slowly, carefully noting connections, insulations, etc. in removing the old portion and duplicate all these features, as nearly as possible, in the new winding. When complete, the binding wires should be replaced, and the winding tested for grounds, before connecting it to the commutator. It will be well, while replacing the winding, to make frequent tests for grounds or short circuits.

When being replaced, binding wires should be subjected to a considerable tension, so that when they expand as the armature heats up they will not become loose. They should be soldered together quickly with a very hot iron, using, as before, only resin as a flux.

75. Balancing an Armature.—Many makers balance armatures by means of small masses of solder secured to the binding wires. If these binding wires are replaced, the armature must be rebalanced in order that it may run without excessive vibration. For this purpose, two iron or steel straightedges or ways, as shown in Fig. 14, should be provided. These should be from $\frac{1}{8}$ to $\frac{3}{8}$ inch wide on the upper edge and from 12 to 18 inches long, depending on the weight and size of the armature to be balanced. They should be set level and parallel, and at such a distance apart that the journals of the armature shaft will rest on them.

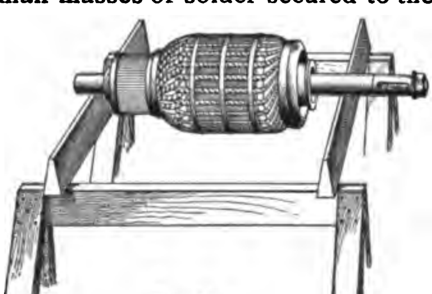


FIG. 14

To balance the armature, place it on the ways, when it will turn over until the heavy side is beneath. A small weight, as a piece of solder, is then temporarily fixed to the upper part of the armature, which is then given a slight motion by the hand. It will settle in a new position, when another weight may be temporarily affixed to the armature, or a little of the other weight removed, according to the judgment of the workman. This operation should be continued until the armature shows no decided tendency to remain in any one position; the weights may then be permanently fastened in place.

The method of repairing broken leads, connections, and the like may be readily seen from the nature of the fault. In any kind of repair, the object in view should be to replace the defective part so that it will be exactly as it was before being damaged, unless, as before stated, the conditions can be improved.

MOTORS

76. Reversibility of Dynamo-Electric Machines. If, instead of forcibly revolving the armature of a dynamo and thereby generating an electric current, we supply the machine with current at the proper voltage, the armature will be revolved with sufficient force to do mechanical work. An electric machine used in this manner is called a **motor.** Combinations of dynamos and motors are extensively used in telephony.

OPERATION OF DIRECT-CURRENT MOTORS

STARTING AND REGULATING DEVICES

77. The preceding discussion regarding the selection, installation, and care of electrical machinery applies with equal force to both dynamos and motors. Each may develop faults in insulation, open circuits, short circuits, etc. and each may cause trouble by sparking. The tests and the remedies in each case are practically the same. In the operation of motors, however, there are some features requiring special mention. Auxiliary apparatus is usually necessary with motors and a brief description of some of the most commonly used *starting rheostats* and *speed controllers* will be given.

78. When motors are operated on constant-potential direct-current circuits, it is necessary to insert a resistance in series with the armature when starting the motor. In the case of a series motor, this starting resistance is also in series with the field. The resistance of a motor armature is very small, and that of a series-field is also small, so that if the machine were connected directly across the circuit while standing still, there would be an enormous rush of current, because the motor would be generating no counter electromotive force. For example, if a shunt motor of which the armature resistance is .1 ohm, were connected across a 110-volt circuit while the motor was at a standstill, the current that would flow momentarily would be $110 \div .1 = 1{,}100$ amperes, the amount being limited only by the resistance and self-induction of the armature. The rush of current through a series motor would not be quite so bad, as the field winding, owing both to its resistance and its inductance, would help to choke the current back.

Small motors, especially if series-wound, may be started by switching them directly on to the circuit. The ability to do this successfully depends on the style of winding, the voltage, and the load the motor is required to start. Before attempting to start a motor in this way, the manufacturers of the motor should be consulted and their advice should be followed.

Fig. 15

79. Starting Rheostats. The **starting rheostat**, or **starting box**, as it is often called, is simply a resistance divided into a number of sections and connected to a switch arm, by means of which these sections can be cut out as the motor comes up to full speed. When the motor is running at full speed, this resistance is completely cut out, so that no energy is lost in it.

Fig. 15 shows a simple form of starting box, the resistance wire being embedded in enamel on the back of an iron plate, while the iron ribs *r* on the front are intended to present a large radiating surface that may be cooled by the air. The handle *h* of the rheostat shown is provided with a spiral spring *s* tending to hold it against the stop *a*, which makes it impossible to leave the contact arm *h* on any of the intermediate points. On the last point, a clip *c* is placed to hold the arm of the rheostat. When the arm is in this clip, all the resistance is cut out. Starting rheostats are not designed to carry current continuously and should therefore never be used for regulating the speed of the motor. The resistance wire is made of such a size as to be capable of carrying the current for a short time only, usually 15 to 30 seconds, and if the current is left on continuously, the rheostat will be burned out.

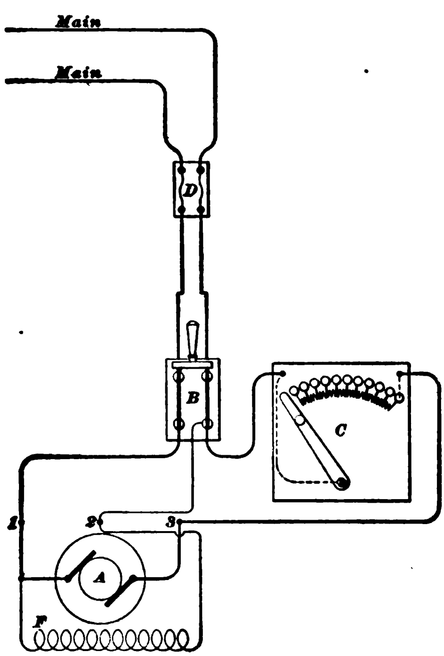


Fig. 16

Starting rheostats are made in a great variety of forms and sizes, but the object is the same in all of them, that is, to provide a resistance that may be inserted when the motor is at rest and gradually cut out as the motor comes up to speed.

SHUNT-MOTOR CONNECTIONS

80. One method of connecting a shunt motor to constant-potential mains is shown in Fig. 16. The lines leading to the motor are connected to the mains through a fuse block *D*, from which they are led to a double-pole knife switch *B*. One end of the shunt field *F* and one brush are connected to terminal *1* of the motor; the other field terminal is connected to terminal *2*, and the other brush to terminal *3*, which is connected to one rheostat terminal. One side of the main switch connects to terminal *1*; the other side connects to terminal *2* and also through the starting rheostat *C*, to terminal *3*. As soon as the main switch is closed, current will flow through the field *F*. When the rheostat arm is moved to the first contact button, current will flow through the starting resistance and the armature *A* and the motor will start; as the handle is moved over slowly to the last point, the motor gradually attains its full speed.

81. Fig. 16 shows connections for a motor having a three-point terminal-block, one point for each line wire and a point for one field terminal, the other field terminal being brought directly to a brush. Modern motors are usually provided with a separate terminal point for each field and armature lead; that is, a four-point block for a shunt motor. With such a block, the direction of current through either the field or armature can be reversed independently of the other, making it easy to reverse the direction of rotation of the armature. Where desired, such reversals are usually provided for in a controller so that a movement of the controller handle will reverse the direction of rotation.

82. Methods of Connecting.—Fig. 17 shows three methods of connecting a shunt motor. The switches are shown as single pole for the sake of clearness in the diagram. In Fig. 17 (*a*), the shunt field is excited as soon as the switches are thrown; this is the method used in Fig. 16, except there is no release magnet in Fig. 16. In Fig. 17 (*b*), the shunt field is not excited until the rheostat lever is thrown to the first button, and when the lever is moved over to its full-on position the field current must flow back through the starting resistance; this is objectionable, but as the resistance is usually low and the field current small, little harm results. On some rheostats, an auxiliary contact and path is provided, as shown by *a* and the dotted line, to lead the field current around the armature resistance when the lever is in the full-on position. A wrong connection frequently made is shown in Fig. 17 (*c*). The shunt field, instead of being connected across the line, is connected directly across the armature terminals when the lever is on any of the contacts and hence receives only the voltage applied to the armature.

83. Automatic, No-Voltage, Release, Starting Rheostat.—In Fig. 16, the simplest type of rheostat was

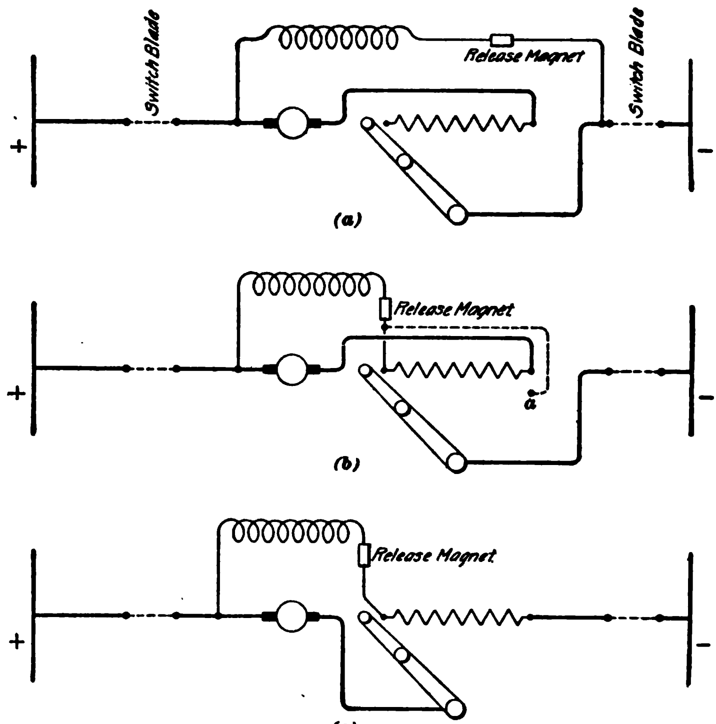


FIG. 17

shown in order to make the connections as clear as possible; but such rheostats are now used but little for the following reasons: Suppose that a motor is shut down by opening the main switch and the attendant forgets to move the rheostat arm back to the off-position. When the motor is started up again, the chances are that it will not be noticed that the rheostat arm is at the on-position, and when the main switch is closed a rush of current that may damage the motor takes place. Again, the motor may be running and the current in the supply circuit may, for some reason, cease long enough to allow the motor to slow down or stop, and when the voltage again starts suddenly to increase, the rheostat is at the on-position, thereby allowing a large rush of current to flow through the motor. For these reasons, it is customary to arrange on almost every starting rheostat what is called an **automatic,**

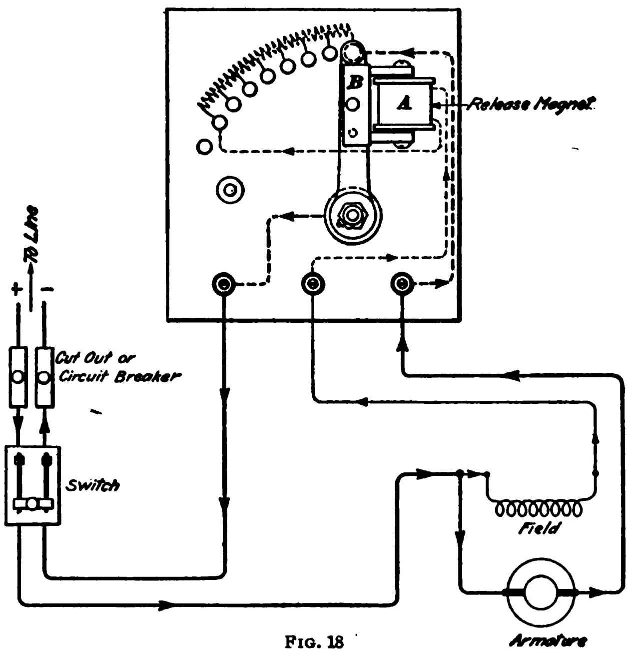


FIG. 18

no-voltage, release mechanism so that the rheostat handle will fly to the off-position whenever the power is cut off from the motor.

84. Fig. 18 shows a simple form of automatic rheostat made by the General Electric Company and its connection to a motor. The automatic feature consists of an electromagnet *A* in series with the motor field. The lever is moved over against the action of a coiled spring, and is held at the full-on position by the attraction of magnet *A* for the armature *B*. If the current supply be interrupted, the current in coil *A* gradually decreases as the motor slows up and the pull of the magnet becomes weaker, until finally the armature *B* is released, and the arm flies back to the off-position. With such a rheostat, the proper way to stop the motor is to open the main switch and let the rheostat take care of itself. The release magnet is connected in the field circuit because it then protects the machine in case only the field circuit is broken.

The automatic release magnet, instead of being connected in series with the shunt-field circuit, is sometimes connected, with or without a resistance in series, directly across the main circuit so that the release coil is excited independently of the shunt-field current. This is nearly always the case with rheostats for series-wound motors and some manufacturers adopt this plan for all their no-voltage magnets.

85. Cutler-Hammer Rheostat.—Fig. 19 shows a Cutler-Hammer Manufacturing Company's automatic, no-voltage, release, starting rheostat with connections made according to their usual plan for shunt- and compound-wound starters, as indicated in Fig. 17 (*b*). The wrong connections shown in Fig. 17 (*c*), are made by interchanging the wires coming to the two binding posts on the rheostat marked *Line* and *Arm*. This is frequently done by careless workmen and the result is that the motor will not start until the lever has been moved over several contacts and then, if the machine starts at all, it is with a sudden jerk, and a very high speed is attained almost at once.

An advantage claimed for the connections shown in Fig. 17 (*a*) is that the field is fully excited before any current flows through the armature and that a better torque is thereby obtained when the lever is moved to the first contact than if the field magnetism must build up after the first contact is made, as is the case with the connections shown in Fig. 17 (*b*). But the time required for the magnetism of small motors to reach a maximum is so short that the advantage claimed for the connections shown in Fig. 17 (*b*) is of little importance. With large motors, the claim is probably justifiable and the advantage of considerable importance.

On the other hand, with the method of connecting shown in Fig. 17 (*b*), it is impossible to open the field circuit, as it is always closed through the armature and the rheostat resistance. With the connections shown in Fig. 17 (*a*), the field circuit may be broken after the main switch is opened, by

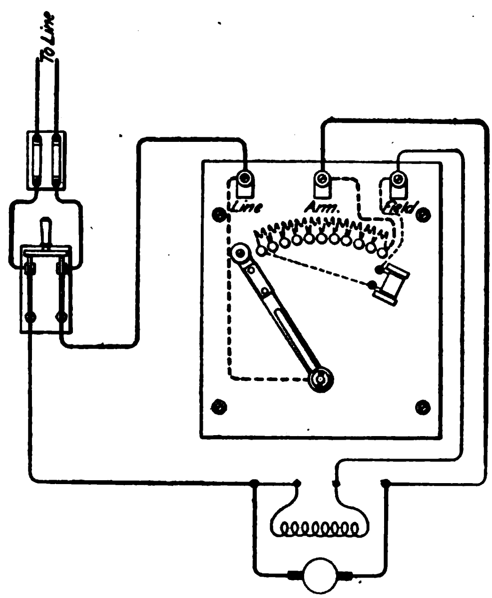


FIG. 19

the rheostat arm opening the circuit consisting of the armature and field before the counter electromotive force, which tends to maintain the field current, ceases. On any but very small machines, it is not good practice to suddenly break a shunt-field circuit in which current is flowing because the sudden interruption of the flow of current will induce in the coil itself a voltage that may be high enough to puncture the insulation. For this reason, when the connections shown in Fig. 17 (*a*) are used on large machines, a by-pass or high-resistance path is sometimes so arranged that it will be connected across the field terminals just before the field circuit is broken. The field discharge then passes harmlessly through the by-pass, which is finally opened.

86. Automatic No-Voltage and Overload-Release Starting Rheostat. Fig. 20 (*a*) shows the front of a Ward Leonard Electric Company's SKE type motor starter and Fig. 20 (*b*) shows the diagram of connections. An automatic, no-voltage, release magnet *m* is connected with a resistance in series across the circuit independent of the shunt field; and an overload-release magnet *m'* is connected in

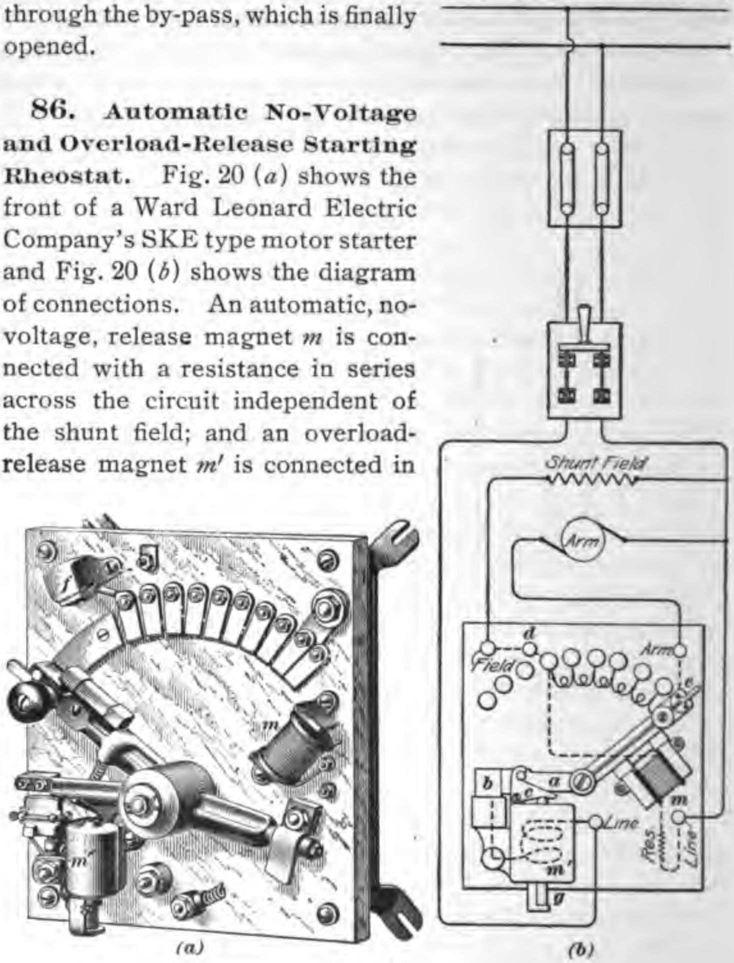


Fig. 20

series with one line so that all current to the motor must flow through magnet *m'*, blades *b*, arm *a*, the rheostat handle, and the starting resistance, to the armature as well as to the shunt field and the no-voltage release magnet. If the motor is so overloaded that the current required exceeds a predetermined amount, the core *g* of magnet *m'* is drawn up, turning catch *c* on a pivot so that arm *a*, which is held closed by the catch against the action of a spring, flies upwards, opening the circuit, thus demagnetizing magnet *m* and releasing the rheostat handle, which returns to the off-position. The arrangement on this rheostat is such that arm *a* cannot be closed until the rheostat handle has returned to the off-position. The overload feature just described is properly called a circuit-breaker. On the end of the rheostat handle is a small pivoted tongue *e* held in a central position by a spring. This arrangement, known as a *flipper switch*, catches an auxiliary button or projection *d* when the arm is returning to the off-position and maintains contact with it until the arm has left the first resistance contact, after which the flipper snaps back into its normal position, quickly breaking the arc and thus protecting the main contacts from being burned. On sizes above 10 horsepower, a magnet *f*, shown only in Fig. 20 (*a*), which is a 15-horsepower size, is also arranged to blow out the arc.

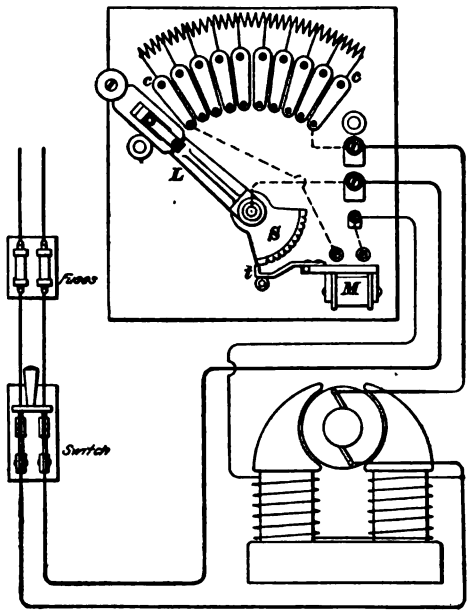


FIG. 21

In another type of overload release rheostat much used, the action of the overload-release magnet closes a short-circuit around the no-voltage magnet, thus releasing the rheostat arm, which flies back to the off-position.

87. Speed Regulating Rheostats.—**Speed regulating rheostats,** often called **speed regulators,** are very similar in construction, in appearance, and in connections to starting rheostats except that regulators, owing to their greatly increased carrying capacity, are much the larger. The chief difference between the two, however, is that while a starting rheostat has resistance so proportioned as to carry the starting current required by the motor armature for only a few seconds, usually not over 15, a speed regulator has resistance designed to carry the armature current continuously. The starting-rheostat lever should, therefore, never be held longer than 2 or 3 seconds on any step except the last, on which the resistance is all cut out. The speed-regulator lever is usually arranged to be held automatically on any desired step. Fig. 21 shows the connections of an

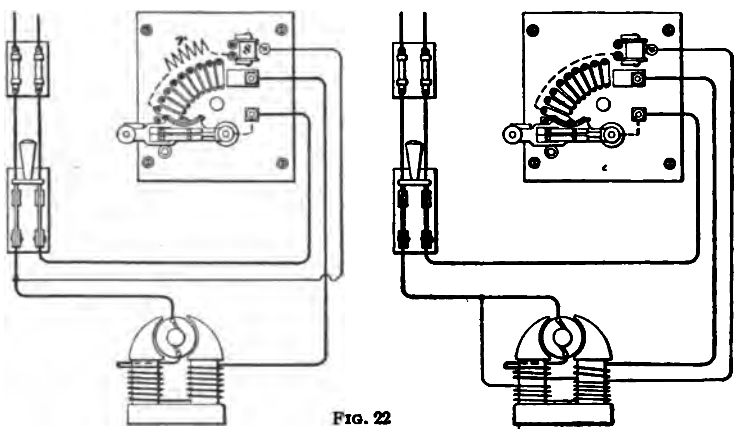


FIG. 22

automatic speed regulator. The segment *S* is rigidly fastened to the lever *L* and turns with it. A pawl or catch *t* is held in the notches in *S* by the action of the magnet *M*. The notches are so distributed that each will hold the lever squarely over one of the contact segments *c*, *c*. If the voltage of the circuit fails or if the switch is opened, the magnet *m* releases the pawl *t* and the lever flies back to its initial position. In this regulator, the contact segments *c*, *c* are renewable and may be easily replaced when worn or burned.

SERIES- AND COMPOUND-MOTOR CONNECTIONS

88. Connections for shunt motors have been discussed first because they are the most complicated and the most common. If these are fully understood, the methods of connecting the other field windings will then be easily derived. Fig. 22 shows simple diagrams of connections for series- and compound-wound motor starters with automatic underload release. The release spool *s* of a series-motor starter is usually connected directly across the circuit with a resistance *r* in series unless the voltage of the circuit is very low, in which case the resistance is omitted.

Since its field helps to choke back the starting current, a series motor does not require as large a starting resistance as a shunt motor.

INSTALLING A DIRECT-CURRENT MOTOR

89. When installing a motor in an isolated place where a voltmeter is not available, it is well to permanently connect an incandescent lamp across the circuit near the motor so as to supply a ready means of ascertaining whether power is on the line at any time. By using a key socket, or receptacle, the lamp may be switched off when not needed.

Before attempting to start the motor see if there is power on the line and then close the main switch; this may or may not allow a current to flow through the motor fields, according to the kind of winding and the method of connecting. Move the lever of the starting rheostat quickly and squarely to the first contact segment and let it stay there for 2 or 3 seconds. The motor should start at once and begin to increase in speed. Move the lever from segment to segment, stopping on each but 2 or 3 seconds, until the full-on, or short-circuit, position is reached, where the lever should be firmly held by the retaining magnet. During this process, the motor speed should have gradually increased to full speed, the total time required to accelerate to full speed being usually about 15 seconds. Do not hold the lever longer than indicated on any contact, unless the starting resistance be intended also for speed control. If the motor does not start when the lever is on the first contact move quickly to the second. If still no start is made move to the third; if the machine then fails to start, immediately open the main-line switch and look for the cause of the failure.

90. The failure may result from any one or more of several causes, namely:

1. *Wrong connections*, of the field coils among themselves or with other parts of the circuit. Make sure that the shunt field obtains the full voltage when the lever is on the first step, and that the poles are magnetized.

2. An *overload* on the motor; when a motor is first installed, the current required to start its load, as well as the running current after obtaining full speed, should be ascertained. An ordinary motor intended for continuous service should not be expected to start a load requiring more than double its rating, in amperes. This rating is usually stamped on the name plate. Motors intended for intermittent service, such as railway and hoisting work, are designed to start with almost any load up to what will actually stall the armature.

3. An *open circuit* due, possibly, to a defective switch, a broken wire or poor connection in the starting box, or the brush not making good contact with the commutator, or an open circuit within the motor itself.

4. A *short circuit* will nearly always make its presence and possibly its location known. Among the more common sources of short-circuiting are: short-circuited armature coils; short-circuited commutator; short-circuited field coils; brushes in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a series-field coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed. A wrong position of the brushes will usually be indicated by violent sparking. The correct position may be found by trial if it is not marked on the frame.

REVERSING THE DIRECTION OF ROTATION

91. If the current in either the field or the armature of a motor is reversed, the direction of rotation will be reversed; but if the current in both the field and armature be reversed, the direction of motion will remain unchanged. A series motor will, therefore, run in the same direction, whatever the direction of the current through the machine as a whole. Reversing the line connections to the motor terminals simply reverses the current through both armature and field and does not change the direction of rotation. In order to reverse a series motor, either the armature terminals must be interchanged, so as to reverse the current through the armature only, or the field terminals must be interchanged so as to reverse the current through the field only.

POWER EQUIPMENT

(PART 2)

DYNAMO-ELECTRIC MACHINES

ALTERNATING-CURRENT MOTORS

1. Motors designed for use in connection with alternating currents may be divided into two classes: (1) *Synchronous motors;* (2) *induction motors.* Both kinds are in common use, and by far the larger part of all the motors operated in connection with alternating current belong to one of these classes. There are a few other motors used to some extent, but their number is insignificant compared with those of these two classes.

It will be well to explain, before going further, a few terms commonly used in connection with alternating-current machines and circuits.

2. Single-Phase and Polyphase Currents.—Two alternating currents are said to be in phase when they pass through corresponding values in the same direction in their cycles at the same instant. To be, or at least to continue, in phase, the two currents must have the same frequency.

A single alternating current flowing in a system of conductors is called a **single-phase current.** Two alternating currents in a system, differing from each other in phase by one-fourth a cycle, or 90°, make a **two-phase,** or **quarter-phase, system.** Three alternating currents in a system, differing in phase from one another by one-third a cycle, or 120°, make a **three-phase system.** Alternating-current systems through which flow more than a single alternating current, are called **polyphase systems.**

Coils possessing inductance are called **choke, impedance,** or **reactance coils.**

3. Power Factor.—If a circuit possesses inductance, the current lags behind the electromotive force; and if it possesses capacity, the current leads the electromotive force. When the circuit possesses only a non-inductive resistance, the current and electromotive force are in phase. Consequently the product of the reading of an ammeter and the reading of a voltmeter in an alternating-current circuit gives the true power, in watts, expended in the circuit only when the circuit consists of a non-inductive resistance or occasionally when the inductance balances the capacity, leaving as before only the non-inductive resistance to be considered. In all other cases, the true power, in watts, is obtained by multiplying the product of the volts and amperes by a quantity that may be different for every circuit or even for the same circuit under different conditions. This quantity is called the *power factor* of the circuit or system. The product of a voltmeter reading and an ammeter reading taken simultaneously on the same circuit is called the **apparent watts.** The **true watts** are given by the reading of a wattmeter, which, in its action, allows for the difference in phase between the electromotive force and current. The power factor of a system may then be defined as that quantity by which the apparent watts expended in the system must be multiplied to give the true watts. The power factor is equivalent to the cosine of the phase angle between the current and electromotive force. The power of a circuit containing only incandescent lamps, which are non-inductive resistances, is very nearly 1; that is, the true watts are nearly equivalent to the apparent watts.

4. Transformers.—An ordinary **transformer** is essentially an induction coil having usually a closed magnetic circuit of iron, a primary coil, and a secondary coil. The primary coil is usually wound with many turns of fine wire and the secondary with fewer turns of larger wire. The coils and core are usually enclosed in an iron case. Transformers are used on alternating-current circuits to transform a small current at a high voltage to a larger current at a lower voltage, or vice versa.

An **autotransformer** is a transformer having but one winding, which serves both for the primary and secondary coils. Fig. 1 shows the general arrangement; A represents the laminated iron core on which are wound two coils t, t' connected in series so that they practically form one coil. The primary line wires are connected to the terminals a, b and the secondary line wires to c, a. The ratio of the secondary potential E_s to the primary potential E_p depends on the ratio of the number of turns t' to the total number of turns between a and b. For example, if t' is one-third the total number of turns, the voltage E_s will be about one-third the line voltage and the current taken from the secondary will be about three times that drawn from the line wires. The secondary terminals may be connected to points anywhere along the coil.

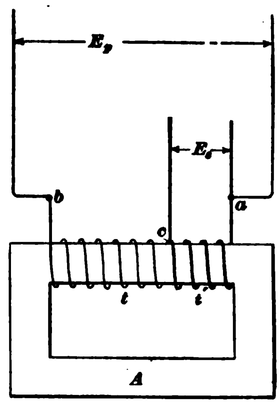


FIG. 1

SYNCHRONOUS MOTORS

5. Synchronous motors are made to operate either on single-phase or polyphase systems, and are so called because they always run in synchronism with, or at the same frequency as, the alternator driving them. In construction, they are almost identical with the corresponding alternator, and always consist of the two essential parts—field and armature—either of which may revolve. The field of such motors must be excited from a separate continuous-current machine in the same way as an alternator.

6. **Single-Phase Synchronous Motors.**—If a single-phase alternator is connected to a similar machine, the latter will not start up and run as a motor, because the current is rapidly reversing in its armature, thus tending to make it turn first in one direction and then in the other. The consequence is that the armature does not get started from rest. If, however, the second machine is first run up to a speed such that the frequency of its alternations is the same as that of the alternator, and then connected in circuit, the impulses of current will tend to keep it rotating and the machine will continue running as a motor. The motor must be run up to synchronism by means of some outside source of power, usually by means of a small self-starting motor. After the large motor has been brought up to synchronism, the small starting motor is disconnected by means of a clutch, and is then shut down. Since **single-phase synchronous motors** will not start of their own accord, they are seldom used.

7. **Polyphase Synchronous Motors.**—Synchronous motors operated from two- and three-phase alternating-current circuits are called **polyphase synchronous motors.** They will start from rest and run up to synchronism when their armature windings are supplied with current, although in doing so they take a large current from the line; and if the motor is a large one, it is better to bring it up to speed by means of some outside source of power, such as an auxiliary motor. After the machine has come up to synchronism, its fields are excited by an exciter in the same way as a single-phase motor or alternator.

8. Synchronous motors behave differently in some repects from direct-current machines. If the field of a direct-current motor is weakened, the motor will speed up. If the field strength of a synchronous motor is changed, the speed cannot change, because the motor must keep in step with the alternator. Such a motor adjusts itself to changes of load and field strength by the changing of the phase difference between the current and electromotive force. Synchronous

motors are used mostly for work where the motor is not started and stopped frequently, and where it is not started under load. They are used mostly in the larger sizes. For ordinary work, involving frequent starting and stopping under load, induction motors are preferable.

9. Speed and Direction of Rotation.—The speed at which a synchronous motor will run when connected to an alternator of frequency n is

$$s = \frac{2n}{p}$$

in which s = speed, in revolutions per second;
p = number of poles on the motor.

For example, if a ten-pole motor is run from a 25-cycle alternator, the speed of the motor will be

$$s = \frac{2 \times 25}{10} = 5 \text{ revolutions per second}$$

or 300 revolutions per minute. The speed of an induction motor when not loaded is found in the same manner.

A synchronous motor will run in either direction, depending on the direction it is revolved when started up by its auxiliary motor. If, however, it is started by simply allowing current to flow through the armature, its direction of rotation will depend on the way in which the armature terminals are connected to the line. Interchanging any two of the leads of a three-phase motor will reverse the direction of rotation, while interchanging the two wires of either phase of a two-phase motor will accomplish the same result.

INDUCTION MOTORS

10. In a great many cases, it is necessary to have an alternating-current motor that will not only start up of its own accord, but one that will start with a strong torque. This is a necessity in all cases where the motor must start up under load. It is also often necessary that the motor be such that it may be started and stopped frequently, and in general be used in the same way as a direct-current motor. These requirements are fulfilled by *induction motors*.

11. Induction motors are usually made for operation on two- or three-phase circuits, although they are sometimes operated on single-phase circuits, as explained later. They always consist of two essential parts, namely, the *primary*, or field, to which the line is connected, and the *secondary*, or armature, in which currents are induced by the action of the primary. Either of these parts may be the revolving member, but we will suppose that the field is stationary and the armature revolving, as this is the usual arrangement. In a synchronous or a direct-current motor, the current is led into the armature from the line, and these currents, reacting on a fixed field provided by the stationary field magnet, produce the motion. In the induction motor, however, two or more currents differing in phase are led into the field, thus producing a magnetic field that is constantly changing and inducing currents in the armature coils, which form closed circuits. These induced currents produce a field of their own, which react on the motor field and produce the motion of the armature. It is on account of this action that these machines are called induction motors.

12. Reversing Direction of Rotation.—In order to reverse the direction of rotation of an induction motor, it is necessary to reverse the rotation of the revolving magnetism set up by the field windings. In a two-phase motor, this can be done by reversing the current in either of the phases; i. e., by interchanging the connections of the wires leading from one pair of supply mains to their terminals on the motor. A three-phase motor can be reversed by interchanging the connections of any two of the line wires with the motor terminals.

13. Slip.—If the armature is held from turning in a revolving field, the coils on the armature will act like the secondary of an ordinary transformer, and heavy currents will be set up in them. However, as the armature comes up to speed, the relative motion between the revolving field and armature becomes less, and the induced electromotive forces and currents become smaller, because the secondary turns do not cut as many lines of force per second as before. If the armature is running exactly in synchronism with the field, there will be no cutting of lines whatever, no currents will be induced, and the motor will exert no torque. Therefore, in order to have any induced currents, there must be a difference in speed between the armature and the revolving field, and the greater the current and consequent torque or effort, the greater must be this difference. When the load is very light, the motor runs very nearly in synchronism, but the speed drops off as the load is increased. This difference between the speed of the armature and that of the field for any given load is called the **slip.** The slip in well-designed motors does not need to be very great, because the armatures are made of such low resistance that a small secondary electromotive force causes the necessary current to flow. In well-designed machines, it varies from 2 to 5 per cent. of the synchronous speed, depending on the size. A 20-horsepower motor at full load might drop about 5 per cent. in speed, while a 75-horsepower motor might fall off about 2½ per cent. For example, if an eight-pole motor, which has four pair of poles, is supplied with current at a frequency of 60, its field will make $60 \div 4 = 15$ revolutions per second, or 900 revolutions per minute, and its no-load speed will be very nearly 900. At full load, the slip might be 5 per cent., so that the speed will then be 855 revolutions per minute. It is thus seen that as far as speed regulation goes, induction motors are fully equal to direct-current machines.

If S' represents the speed of the armature and S the speed of the revolving field in revolutions per second, then the

$$\text{slip} = S - S' \qquad (1)$$

or expressed as a percentage of the speed that the armature will run at if it is in synchronism with the field,

$$\text{slip (per cent.)} = \frac{(S - S')\,100}{S} \qquad (2)$$

POLYPHASE INDUCTION MOTORS

14. **A polyphase induction motor** may be started by connecting its field directly to the line, but this allows a large rush of current, which may be sufficient to disturb other parts of the system and is, therefore, objectionable. This method of starting is not practicable with any but small motors. In order to start large motors smoothly, and thus avoid a rush of current, either of two methods may be adopted: The voltage applied to the primary may be reduced either by inserting a resistance or by the use of an autotransformer; or a resistance may be inserted in the secondary at starting, and cut out when the motor comes up to speed.

15. **Starting Compensator, or Autotransformer.** Where a motor is provided with a so-called *squirrel-cage*, or

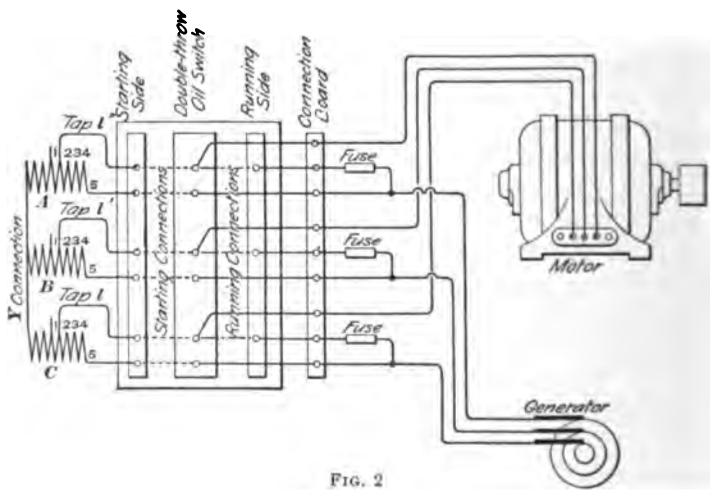


FIG. 2

short-circuited, winding, it is generally started by cutting down the voltage applied to the primary. This is usually done by means of an autotransformer inserted between the line and the motor field, the transformer being provided with a double-throw switch, so that it can be cut out when the motor has come up to speed.

Fig. 2 shows the connections for starting a three-phase induction motor by means of an autotransformer. *A*, *B*, *C* are the coils of the autotransformer, each coil being provided with a number of taps *1*, *2*, *3*, *4*. When the switch is thrown to the left, as indicated by the dotted lines where it says "Starting Connections," coils *A*, *B*, *C* are connected in circuit with the supply generator or mains. The motor windings are, however, connected only across that portion of each coil that lies between the points *1* and *5*; consequently, the voltage applied to the motor is decreased and the current is correspondingly increased. The voltage applied to the motor at starting can be adjusted by using the taps *1*, *2*, *3*, *4*, so that the starting current can be varied to suit the conditions under which the motor is used. A simple arrangement is provided so that leads *l*, *l'*, *l''* can be connected to points *1*, *2*, *3*, or *4*, as desired. If connected to points *4*, the maximum starting effort is obtained with a correspondingly large current taken from the line. The two-phase starter has two coils but its principle of operation is the same.

16. The motor is started by throwing the switch from the off-position to the starting position. After the motor has come up to speed, the switch is thrown over to the right or running position, as indicated by the dotted lines where it says "Running Connections," thus cutting the autotransformers out of circuit. When starting motors with such devices, time should be allowed after the switch is placed in the starting position for the motor to come up to nearly full speed before turning the switch to the running position, otherwise the fuses in the supply leads are very apt to be blown.

17. In some cases, a low starting voltage can be obtained without the use of a compensator. For example, the step-down transformers that supply the motor can have taps brought out from the middle point of their windings and connected to a double-throw switch, so that in one position of the switch the motor gets only one-half the normal voltage, while for the running position of the switch it is connected across the secondaries in the usual manner and gets the full voltage.

Some induction motors are started with a resistance mounted in the armature. When the machine reaches full speed, this resistance is cut out by pushing in a handle projecting from one end of the hollow armature shaft. This eliminates the use of collector rings.

An induction motor, if overloaded excessively, will stop and will soon overheat unless the current is cut off. In order to protect these motors, either fuses or circuit-breakers may be used, though sometimes they are installed without any protective device. The fact that the motor stops if loaded excessively is often depended on to serve as an indication of overload, but this method cannot be recommended, and it is better to have some form of protective device.

SINGLE-PHASE INDUCTION MOTORS

18. If a motor constructed on the same lines as an induction motor, but provided with only a single winding on the field, instead of two or more sets of windings, as in the polyphase induction motors that have just been considered, is connected to single-phase mains, it will not start up of its own accord. If it is given a start by pulling on the belt, it will gradually come up to speed in whichever direction it is started, provided that no load is applied. The motor will exert very little torque, but it will gradually increase in speed until it attains a speed nearly in synchronism with the generator. After the motor has been started, the load may be applied and the motor will behave in the same way as one operated on a polyphase system.

In order to make a single-phase motor start from rest and give a good starting torque, it is necessary to provide a rotating field at starting. This can be done by using regular two-phase or three-phase windings on the motor and supplying these windings with displaced electromotive forces obtained by *splitting the phase*, as it is called. Many methods for phase splitting are in use.

19. In Fig. 3, the motor is provided with a two-phase winding, and in series with winding A, a non-inductive resistance R is connected. An inductance L is connected in series with B, and the two windings are connected in parallel across the same line wire. The current in B will lag behind that in A, and if the resistance and inductance are correctly proportioned the currents can be made to differ enough in phase to produce an imperfect form of rotating field sufficient to start the motor. The windings are frequently so designed that the necessary phase displacement is caused by the windings themselves, and outside resistance and inductance are rendered unnecessary. In some cases, one of the windings is a main, or working, winding, and the other is used only at starting, being cut out by open-circuiting it by means of a switch after the motor has attained its speed.

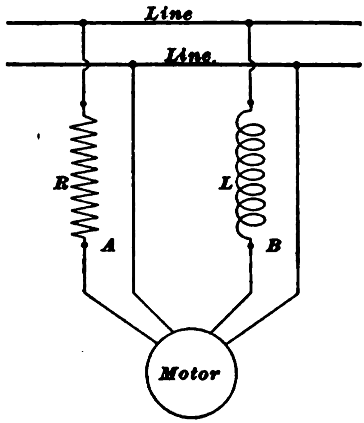


FIG. 3

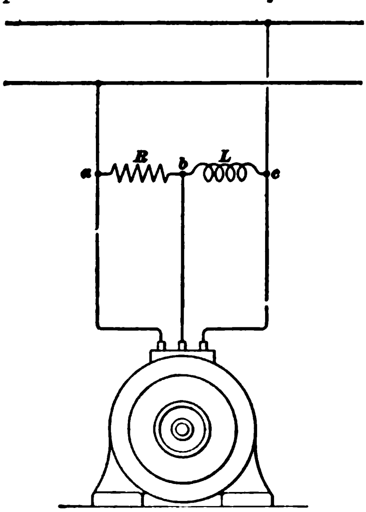


FIG. 4

20. Fig. 4 shows another scheme for starting a motor on single-phase mains. Two of the terminals are connected to the mains, and the third terminal is connected to the point b between the resistance R and inductance L. The electromotive force between a and b differs in phase from that between b and c, so that the different windings of the motor are supplied with displaced electromotive forces suitable for starting. A switch can easily be arranged to disconnect *R* and *L* after the motor has come up to speed, thus running it on the two outside lines only.

21. Fig. 5 shows a starting arrangement similar to Fig. 4, except that a condenser *C* is used instead of the inductance *L*. Sometimes, where this combination is used, *R* and *C* are not cut out after the motor has attained speed, because the condenser *C* counteracts the self-induction of the motor and thus raises its power factor to such an extent that the small amount of loss in *R* is more than made up.

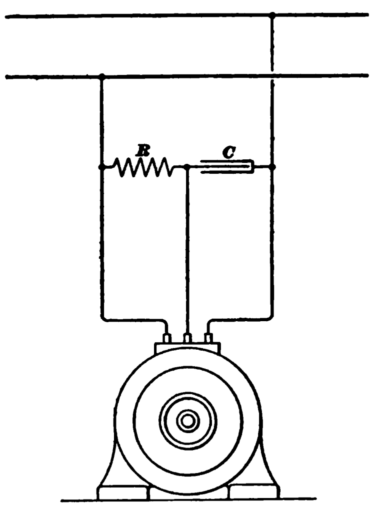


FIG. 5

22. Speed Regulation of Induction Motors.—The induction motor tends to run nearly in synchronism with the alternator that supplies it with current. Its speed can never quite reach synchronism, because it always takes some power to make up for the friction losses, etc., even if the motor is unloaded. It is also evident that the speed cannot rise above that of synchronism, and that with the exception of the slight variations in speed, due to the changes in load and corresponding change in the slip, the speed of the motor remains practically constant as long as the speed of the alternator and voltage on the line remains constant. Generally speaking, the induction motor is not as well adapted for variable speed as the direct-current motor, although its speed can be varied through a considerable range by variable resistances connected through slip rings with each winding on the armature.

SERIES MOTOR ON ALTERNATING CURRENT

23. If a motor constructed in every way like a series-wound direct-current machine is provided with laminated fields and supplied with current from alternating-current mains, it will start with a good torque and run up to speed under load, thus making a single-phase alternating-current motor. Since the field is in series with the armature, it follows that the current in each reverses at the same instant. If the currents in both field and armature of direct-current motors are reversed, the direction of rotation remains unchanged. Series-wound motors with laminated fields have been used to a limited extent with alternating current, but so far without success except, perhaps, in motors of small size. The chief trouble has been to design motors of considerable output that will operate without vicious sparking at the commutator.

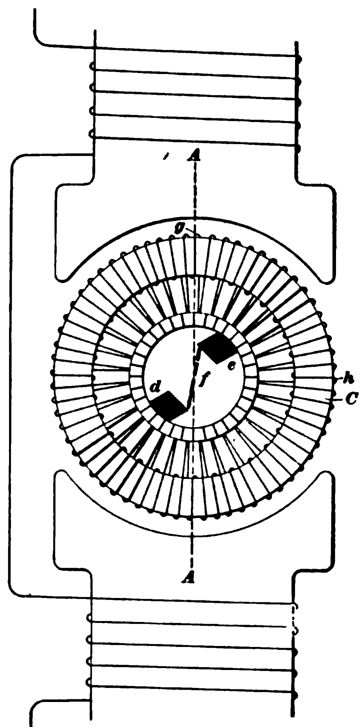


FIG. 6

REPULSION MOTOR

24. Fig. 6 illustrates the principle of a type of single-phase alternating-current motor known as a **repulsion motor**. The laminated field *A A* is excited by single-phase alternating current. *C* is an armature provided with an ordinary direct-current winding connected to a commutator; *d* and *e* are thick brushes with their center line at an angle of about 45° with the center line of the poles.

Suppose, for the present, that the brushes are not in contact with the commutator. When the field is excited, opposing electromotive forces will be induced in the two sides of the ring-wound armature, like in a direct-current armature, and no current will be set up in the windings; no turning effort will be exerted, and the armature will not start. If a coil at *g* is short-circuited by means of a brush, no current will be set up in it because the plane of this coil is in the same plane as that of the field; consequently, no torque will be exerted on the coil. If coil *h* is short-circuited, a heavy current will be set up in it because the alternating flux threads through it. However, there is no field, from the pole pieces, at *h* to react on the induced current; hence, no torque will be produced. On the coils located between *h* and *g*, a varying torque will be exerted, the maximum occurring in those coils situated about half way between the extremes. If, therefore, two thick brushes *d*, *e* are arranged so as to short-circuit a number of the coils lying in this region, a replusive force will be exerted on the coils so short-circuited and the armature will revolve. The short-circuited coils are shown by the heavy lines. It will be noted that only those coils that are short-circuited by the brush are effective in producing rotation, so that comparatively few of the armature coils are utilized. More coils can be utilized and the repulsive effect made stronger by connecting the brushes together, as shown by the heavy dotted connection *f*.

When the motor has attained full speed, the commutator is short-circuited by means of a ring that automatically connects all the segments together and at the same time the brushes are lifted from the commutator, thus preventing brush friction and wear except during the time that the commutator is actually in use.

COMBINATIONS OF DYNAMOS AND MOTORS

MOTOR GENERATORS

25. The term **motor generator,** or **motor-dynamo,** is used to designate the combination of a motor and a dynamo mounted on one base, with their shafts rigidly coupled together, the armature windings being distinct on each shaft, and each armature having its own independent field. The motor is designed to be operated at any required voltage from a power or light circuit, and is started and regulated like any similar but detached motor. The dynamo is operated like any similar dynamo that is driven in any other manner. The voltage of the direct-current dynamo part of the machine may be regulated by adjusting the strength of either the dynamo or motor-field current by means of an adjustable resistance in either field circuit. A rheostat in the field circuit of the dynamo is the more common method, however. The motor may be any kind of direct- or alternating-current motor, and the dynamo may be designed to furnish direct or alternating currents at almost any desirable voltage. Motor generators for charging storage batteries are usually shunt-wound direct-current machines. Later types of direct-current motor generators have the generator fields excited from the direct-current street mains that supply the motor with current; this increases the efficiency.

26. The motor of a motor-generator set, if supplied with current from alternating-current mains, may be a synchronous motor or an induction motor. The field of a synchronous motor must be separately excited with direct current; and, unless provided with some special arrangement for the purpose, the motor will not start itself. As the motor parts of motor generators, dynamotors, and rotary converters are started in practically the same manner as similar motors, the explanations for starting simple motors will also apply to the former machines.

So many varieties of satisfactory alternating-current motor generators are now on the market that no general description that will apply to all can be given. Any reliable manufacturing company, if the voltage, the kind of circuit (whether a single-, two-, or three-phase circuit), the normal load that the motor will have to carry, and the purpose for which the motor is to be used are sent to them by a prospective purchaser, will give all the necessary directions for connecting and operating the machine of their make that is best adapted to the purpose.

27. There are several firms manufacturing motor generators especially for telephone exchanges, in which the

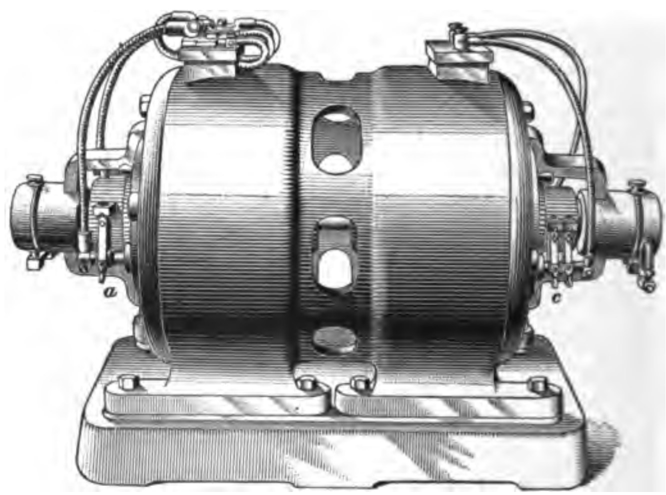


Fig. 7

motor and generator are twin sets mounted on a common base and directly connected by means of a flexible insulating coupling keyed to the shaft. The machines are also insulated from the base, thus preventing any electrical connection between them. The bearings of the machine should be supported in such a manner as to leave the space about the commutator open and easy to get at for inspection and cleaning.

The general appearance of a motor generator, made by the Holtzer-Cabot Electric Company and others, and extensively used by telephone companies, is shown in Fig. 7. The two armature cores are carried by one long shaft supported by the outer bearings only, no intermediate bearing being used. The principal advantage of this form of construction is its compactness. At *a* is shown the direct-current motor commutator and at *c* the direct-current dynamo commutator. The two sets of field coils and the two armatures are enclosed by a mild-steel casing that forms the yoke of the fields. The holes in the casing affords sufficient ventilation to prevent the armatures and fields from becoming overheated.

DYNAMOTORS

28. A **dynamotor** is a machine for transforming current from one voltage to another. It has one magnetic field and usually only one armature, which, however, contains two windings, one winding being connected to a commutator on one side of the armature and the other winding to a commutator on the other side. Sometimes, however, there are two armatures.

Dynamotors may be used to change from a direct current at one voltage to a direct current at another voltage, or from direct current to alternating current or vice versa. A dynamotor differs from a rotary converter in having two distinct armature windings.

On account of the equalizing action of the motor-armature and dynamo-armature windings, no shifting of the brushes of a dynamotor is required with a change of load. These machines are more efficient than motor generators, as there is but one field winding to consume energy; but they cannot be compound wound to insure a steady voltage at the dynamo side, as the effect of such compounding would be to correspondingly alter the motor speed. For the same reason, it is not possible to regulate the voltage on the dynamo side of dynamotors by regulating the current in the field coils, as any change in the strength of the field will change the speed of the motor. The only way to regulate the voltage of a dynamotor is to insert resistance in the main supply circuit, which is very wasteful. Where voltage regulation is desirable, motor generators should be used.

ROTARY CONVERTERS

29. It is often necessary to change direct current to alternating, and vice versa; for this purpose, **rotary converters** are generally used in large power plants and frequently in telephone exchanges. A rotary converter is a

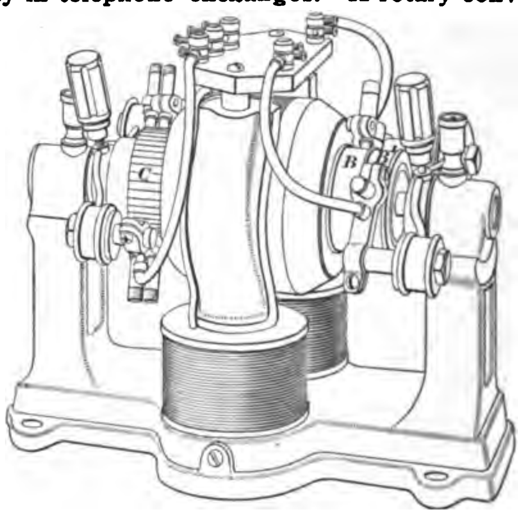


FIG. 8

rotary dynamo-electric machine that transforms from alternating to direct current or vice versa and has one armature winding, one field frame, one commutator, and one set of slip rings. Rotary converters are frequently called *synchronous converters*.

30. A rather old type of rotary converter is illustrated in Fig. 8, as it shows the various parts better than the more modern enclosed machine, which will be shown in connection with ringing machines. At the left-hand end of the armature shaft, associated with the motor side of the machine, is placed the commutator *C*, to the brushes of which are led the wires from the lighting or power mains, the current from which is to operate the machine. On the other end of the armature shaft are mounted two separate collecting rings B, B' for the generator windings of the machine, from which is taken an alternating current. By connecting the collecting rings to an alternating-current circuit, the alternating-current side is used as a motor and a direct current may be taken from the commutator, now the dynamo side of the machine. Rotary converters are manufactured by several dynamo builders and may be wound for any standard voltage on the motor side.

Synchronous converters must have their fields excited from the direct-current side of the machine. Some manufacturers arrange their synchronous converters so that they are started by connecting a part of the whole field coil temporarily in series with the motor side of the armature. A rotary converter, run from alternating-current mains, operates as a synchronous motor and hence runs at a constant speed. Unless overloaded so much as to put it out of phase with the alternator and thus cause it to stop, the speed of a synchronous converter will not vary, no matter what load may be taken from the direct-current side, provided that the speed of the alternator that supplies the current is maintained at a constant value.

31. Starting Rotary Converters.—Converters are started in the same manner as motors; that is, the motor side of the machine is connected to the circuit and operated precisely like the corresponding kind of motor.

For instance, a rotary converter supplied with direct current is started with a resistance in series with the motor armature. The resistance of the armature is so small that if the machine is connected directly across the supply circuit while standing still, there will be an enormous rush of current.

32. Voltage Regulation of Rotary Converters. When the motor side of a rotary converter is supplied with alternating current, it operates as a synchronous motor and the ratio of the alternating voltage to that on the direct-current side is a fixed quantity. For example, suppose that it is desired to transform alternating current at 2,000 volts to direct current at 500 volts. We will suppose that a three-phase rotary converter is employed. Then it follows that the alternating current must be supplied to the rotary converter by the transformer at a pressure of

$$E = .612\ V = .612 \times 500 = 306 \text{ volts}$$

The alternating current will, therefore, be first sent through static transformers wound so as to reduce the pressure from 2,000 to 306 volts, and the secondary coils of these transformers will be connected to the alternating-current side of the converter. For a single-phase or two-phase rotary converter the voltage on the alternating-current side is

$$E = .707\ V$$

in which E = voltage between two wires of single-phase circuit or between any two wires constituting one phase of two-phase circuit;
V = direct-current voltage.

If it is necessary to vary the direct electromotive force on the dynamo side through any considerable range, it is necessary to vary the alternating electromotive force applied to the motor side. This is frequently accomplished by using transformers provided with a number of taps from the secondary windings, so that the turns can be cut in or out, thus varying the alternating electromotive force applied to the rotary converter. Another plan is to insert special transformers, called **potential regulators,** between the secondary of the transformers or supply mains and the collector rings of the rotary.

33. Operation From Direct-Current Side.—When a rotary is supplied with direct current, it runs as a direct-current motor and its behavior is quite different from that when it is operated from the alternating-current side. Weakening the field will cause the armature to speed up, and strengthening the field will slow it down as with any direct-current motor. Altering the field strength will not change the alternating electromotive force because every change in field strength is accompanied by a change in speed, and the alternating electromotive force that is generated in the conductors remains the same. In order to vary the alternating electromotive force delivered by the alternating-current dynamo side, it is necessary to vary the electromotive force applied to the motor armature by the use of an adjustable resistance in series with the armature only, or else regulate the potential in the circuit leading from the alternating-current side.

34. Converter and Supply-Circuit Connections. One method of connecting a converter to constant-potential

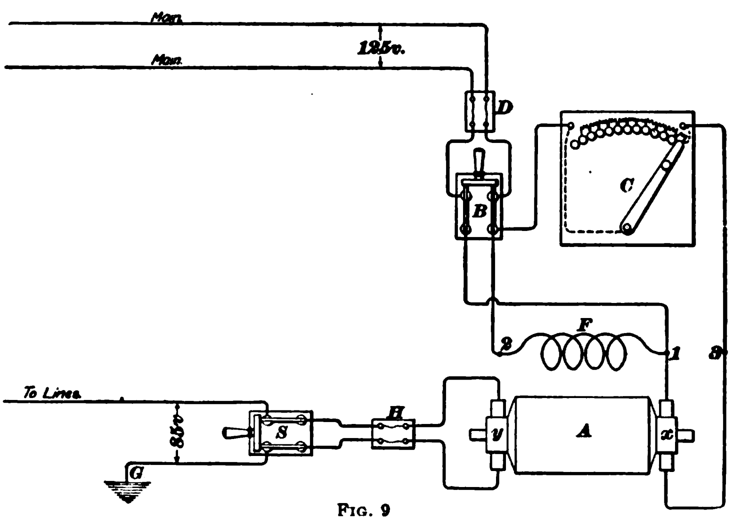


FIG. 9

mains is shown in Fig. 9. The wires from the mains leading to the converter are connected through a fuse block *D* to a double-pole knife switch *B*. One end of the shunt field *F* is connected to terminal *1* of the converter, to which is also connected one brush on the *x* commutator. The other field terminal is connected to the converter terminal *2*. The other brush on the *x* commutator leads to the terminal *3*. It will be seen from the figure that as soon as the main switch is closed, a current will flow through the field *F*, and thus magnetize it before any current flows through the armature *A* (the first contact at the left on the rheostat being a dead point). When the rheostat arm is moved toward the right, a current flows through the armature and a strong starting effort is produced, because the field is already magnetized. The handle is then moved slowly and left on the last point on the right when the converter has attained its full speed. The switch *S* and the fuse *H* are on the side of the converter that supplies the desired current. The switch *S* should not be closed until the machine is running at its usual rate.

35. The voltage between the two brushes on the *y* commutator side of the converter may be controlled by an adjustable resistance in the supply mains. Such a resistance or rheostat must be made of wire large enough to carry the whole current for an indefinite length of time without undue heating, and it will take the place of the starting rheostat or box *C*. Starting rheostats for motors are not designed to carry the current continuously and are not suitable, therefore, for regulating the voltage of a converter.

DOUBLE-CURRENT GENERATORS

36. If a machine constructed in the same way as a rotary converter is driven by another motor or engine by means of pulleys and a belt, it will deliver direct current from the commutator end and alternating current from the collector rings. A machine so operated is called a **double-current generator.** The full output of the machine may be delivered as direct current, as alternating current, or partly as one and partly as the other, provided, of course, that the combined output on the two sides does not exceed the capacity of the machine.

RINGING MACHINES

ALTERNATING-CURRENT GENERATORS

37. There are three types of **ringing machines** to be considered. The motor generator, the dynamotor, and the belt-driven generator, all of which answer the same purpose; that is, the generation of alternating and other signaling currents for actuating the telephone bells at the subscribers'

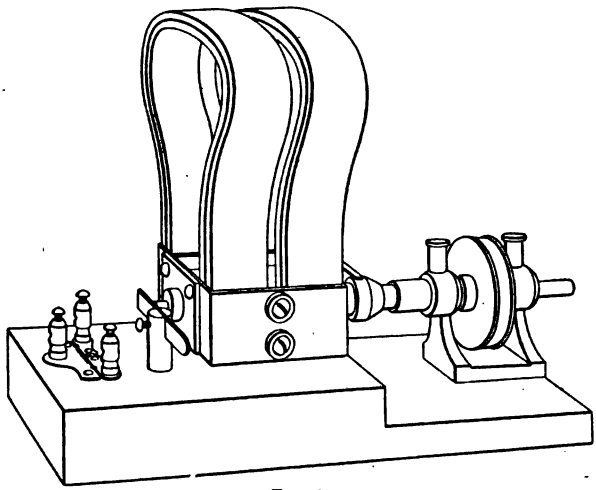


FIG. 10

substations. The only essential difference in the types is in the application of the driving power. The frequency of the machine must be that best suited to the natural vibration frequency of the ringers used in the telephone instruments, the most common frequency being in the neighborhood of 20 cycles per second, corresponding to from 2,200 to 2,400 alternations per minute.

38. Magneto-Generators.—In very small exchanges, the calling is usually done by hand, a small **magneto-generator** being supplied for that purpose, which the operator turns by hand whenever she desires to transmit a signal to the line of any subscriber. For larger exchanges, the duty imposed on the operator of turning a crank every time she desires to transmit a call becomes excessive, and in order to obviate it, constantly driven generators are employed, which may be switched into circuit by the pressure of a ringing key, or by the other methods already discussed. These power generators frequently consist of ordinary magneto-generators mounted on a base and provided with a grooved pulley, by which it may be belted to a source of power. Such a generator is shown in Fig. 10. In this figure, the armature and pole pieces of the generator are the same as those of the ordinary hand generator, but the permanent horseshoe magnets are somewhat larger, in order to give a stronger field. The generator shaft is prolonged and carries a grooved pulley mounted between two bearings, as shown. This machine is mounted on a slate base provided with suitable terminals in the form of binding posts, and also with an old-style saw-tooth lightning arrester shown at the left side.

39. Electric-Motor-Driven Generator.—The means for driving generators of this general description are varied.

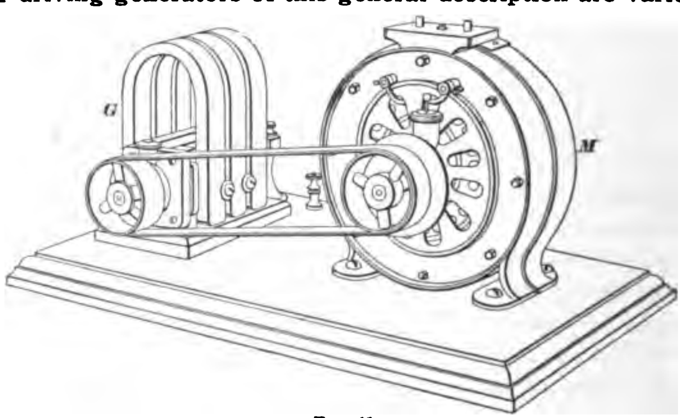


FIG. 11

Where electrical power is available, the best method is to use a small electric motor, preferably mounted on the same base. These motors may be procured for any standard voltages, and for either direct- or alternating-current work.

In Fig. 11 is shown a combination of a small direct-current motor *M* belted to a magneto-generator *G*, mounted on the same base. For large exchanges, the most desirable machine for generating ringing current is the motor generator.

40. Water Motors.—Where electric power is not available, water-power may be resorted to for driving a small dynamo where a sufficient water pressure can be obtained. **Water motors** of the type shown in Fig. 12 are obtainable for this purpose, and will operate satisfactorily in driving very small generators where a pressure of 40 pounds per square inch can be obtained in the city mains or elsewhere. In Fig. 12, *S* is the supply pipe leading to the motor and *O* the outlet pipe for carrying away the water after its use. This latter pipe should be perfectly straight for a distance of at least 20 feet from the motor. These motors operate by a jet of water flowing through a small nozzle and impinging against buckets on a wheel within the casing. The bore of the nozzle is usually about $\frac{1}{16}$ inch in diameter on the small sizes of machine, but if sufficient power is not obtained with this size, the nozzle may be drilled to a larger size by an ordinary twist drill.

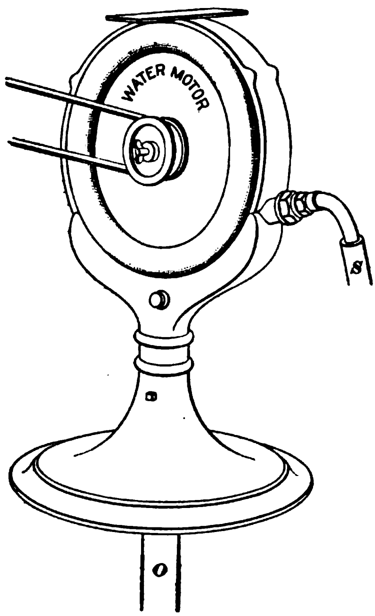


FIG. 12

41. Another way of driving a small generator is to place it in a factory where there is machinery in constant operation. The generator may be belted directly to some shaft, and the current from it carried to the office by one or two copper wires. This method is sometimes convenient in places where there may be a shop of some kind near at hand, but no lighting or power plant. Hand generators must be used, however, during the night and on Sundays when the shop is shut down.

42. Quantity of Energy Required for Ringing Circuits.—It is difficult to give any rule for determining the size of the ringing machines to be used in an exchange. For a large exchange, it is usual to estimate that one operator can handle sixty to one hundred lines, also that the ordinary telephone bell will require about $1\frac{1}{2}$ watts and 80 volts. The size of ringing machine to be used, then, will be determined by the number of operators who will draw current at the same time, allowing each operator about $1\frac{1}{2}$ or 2 watts.

For an exchange of from 500 to 1,000 subscribers, the generator should deliver about 1 ampere of current at 95 to 100 volts when required, which would ring about fifty telephones at one time, if necessary, although it probably would not be called on very often to take such a load as this, but as a short-circuit on the line takes rather more current, it is well to have plenty to fall back on. On open current, the voltage may be 110 volts or even higher. A generator of this size, at 60-per-cent. efficiency, will require nearly $1\frac{1}{4}$ horsepower to drive it at full load. It is said that a good ringing generator of $\frac{1}{7}$ horsepower will ring simultaneously fifteen 1,000-ohm bells, each bell being connected in series with a 2-microfarad condenser, a $\frac{1}{6}$-horsepower generator will ring thirty such bells, and a $\frac{1}{4}$-horsepower generator will ring seventy-five such bells.

43. All telephone plants of any size usually have duplicate sets of charging and ringing machines and usually two sources of power available for running the machines. This is of the utmost importance, as in the central-energy system the failure of the current supplying the power board will tie up the whole system. One ringing machine should be run by a motor supplied with current from the storage battery to provide for failure of the current from the street mains, or accident to the main motor-generator set. The low voltage used in the armature of a ringing dynamotor or converter makes this arrangement free from the danger of high voltage crosses, which might develop in a machine of the same type run from the higher voltage street mains.

SELECTIVE RINGING MACHINES

44. Where selective ringing is required, provision must be made for obtaining selective currents from the ringing machines. The two most popular schemes for selective ringing are: First, the application of positive and negative pulsating currents to either side of the line, in connection with biased ringers, two being connected between each side of the line and ground, which ringers respond only to current in one direction, giving four parties; and, second, the employment of widely different frequencies in connection with telephone ringers having either tuned hammers, which respond only to frequencies within certain limits, as in the Dean and Kellogg systems; or an arrangement of induction coils and condensers as in the Leich system. The practical limit of the latter two systems is usually four parties.

The majority of selective party-line systems use bells that require delicate adjustment, and for this reason it is necessary that the fluctuations in the speed of the ringing machine be limited to very small variation either above or below the rated speed of the machine. Motor generators run from street mains supplied by a comparatively small station generator and on the circuit with elevator motors that constantly change the load are subject to more or less variation of speed. For this reason, it is sometimes necessary to do all the ringing from a dynamotor or rotary converter operated with current from the exchange storage battery, thereby giving a more nearly constant speed. While the batteries are charging, however, their voltage gradually rises to about 23 per cent. above normal; and to keep the speed of the machine constant small compensating batteries or polarization cells are sometimes installed, which automatically take care of any voltage variation. Polarization cells may be made of lead plates immersed in dilute sulphuric acid, the same as used in storage batteries.

45. Special signaling tones may be obtained on lines and circuits by the use of currents that will give musical tones when passed through a telephone receiver. By differences in pitch, by combinations of different pitches, and by interruptions of different durations of the tones themselves, a great variety of distinct audible signals may be procured. Generally, these currents are obtained by interrupting a battery current by means of a rotating circuit-breaker, or *commutator* as it is also called, thereby producing signals according to a prearranged code. In many cases, the transforming action of a repeating coil is also added to vary the tone or signal. Diagrams of such arrangements have been shown in connection with central-energy systems. As examples may be mentioned the howler, busy tone, don't-answer tone, out-of-order tone, etc.

For this purpose, it is usual to provide ringing generators with special attachments. One furnishes current for the *busy signal*, and consists of a commutator or toothed wheel, the spaces between the flat-topped teeth being filled with fiber, as a means for rapidly interrupting a direct current, usually supplied by the battery, at intervals, which, when heard in the receivers, resembles the buzz of a large insect repeated at regular intervals and signifies that the line desired is busy. The *howler* is a similar device, but interrupts the flow of current at a much higher rate and continuously, and is used when a subscriber neglects to hang up his receiver when leaving the instrument. When applied to a line, it causes the receiver to emit a sort of whistling howl, which very soon attracts attention and on account of its weird, disagreeable note accomplishes the desired purpose.

46. Pulsating-Current Attachment.—A Holtzer-Cabot ringing machine equipped with pulsating-current, busy-back, howler, and tone-test attachments is shown in Fig. 13. This machine is a very complete ringing generator. It will run as a motor and deliver alternating and pulsating current, as well as drive the busy-back attachment shown at the left of the figure, thus producing a great variety of signals.

Outside the regular collecting rings *a b*, from which the regular alternating ringing current is obtained, is a split ring *r*, each half of which is so connected to the armature winding that either half of each current wave may be used as required. Thus the operator is able to secure from the dynamo a uniform succession of electrical waves that are

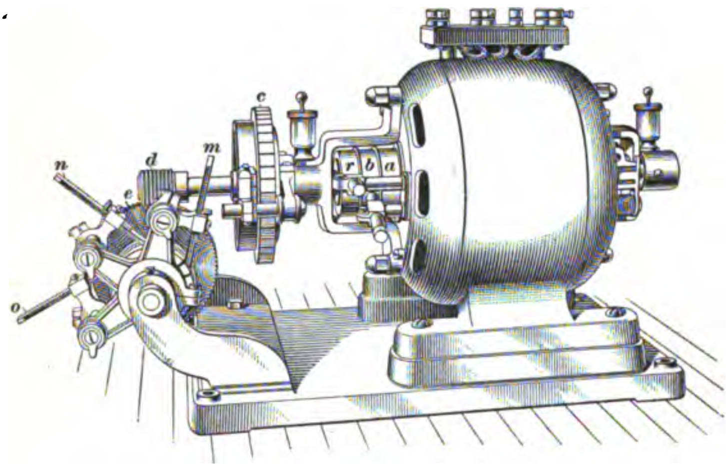


FIG. 13

disconnected, but uni-directional and either plus or minus as desired.

47. Busy-Back Attachment.—A very complete **busy-back, or tone-test, attachment** is shown at the left of this figure. The worm-gear *d* drives the gear-wheel *e* and the three commutators mounted on the same shaft at a very much slower speed than the speed of the armature. By means of the commutator *c*, a direct current from the battery, or other source of direct current, is interrupted at a frequency that produces a musical tone in a receiver. This may be used for a howler circuit. The commutators on which rest the brushes *m*, *n*, *o* are used to again interrupt the interrupted battery current at suitable periods for two different signals.

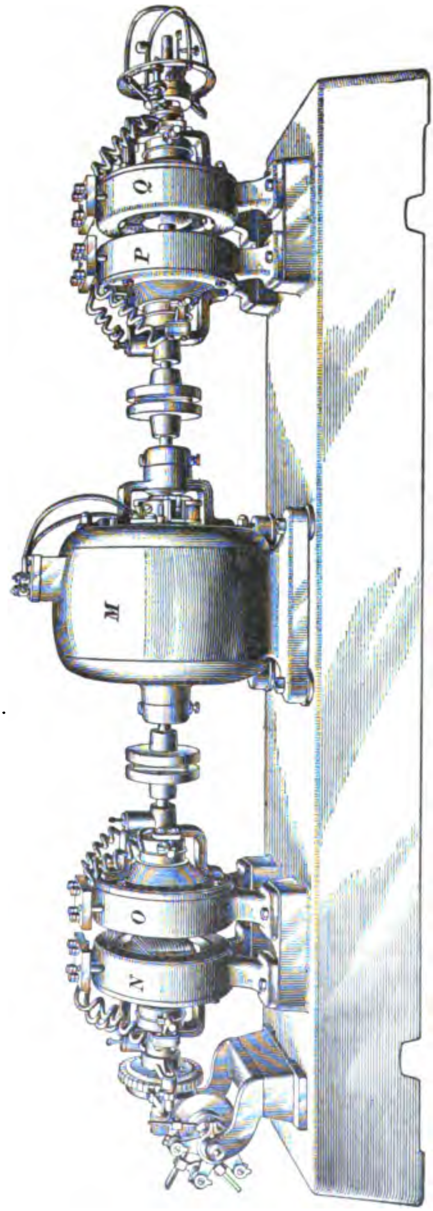


Fig. 14

Thus one commutator and brush may produce a musical tone for 8 seconds followed by silence for 4 seconds; another may give equal intervals of sound and silence, while the third, or middle, brush and slip ring are used to supply current to the commutators and brushes on each side of it.

48. The Dean and Kellogg party-line systems employ, in large exchanges, motor generators delivering current at different frequencies. One of these machines is shown in Fig. 14. This set consists of a motor *M* driving generators *N*, *O*, *P*, *Q* of two, four, six, and eight poles, thus giving current of four frequencies. A speed governor is shown at the left whose purpose is to hold the speed of the combination constant by cutting resistance in and out of the motor field. This particular machine is made by the Holtzer-Cabot Electric Company and is used in connection with the Kellogg system of party-line signaling. The tone-test arrangement is shown at the left of this multicycle set.

49. Dynamotor Connections.—In Fig. 15 is shown the connection of a Holtzer-Cabot dynamotor with a howler, busy-back, and don't-answer attachment mounted on the shaft on the alternating ringing-current side of the machine. A starting box with a release coil is connected as shown, in

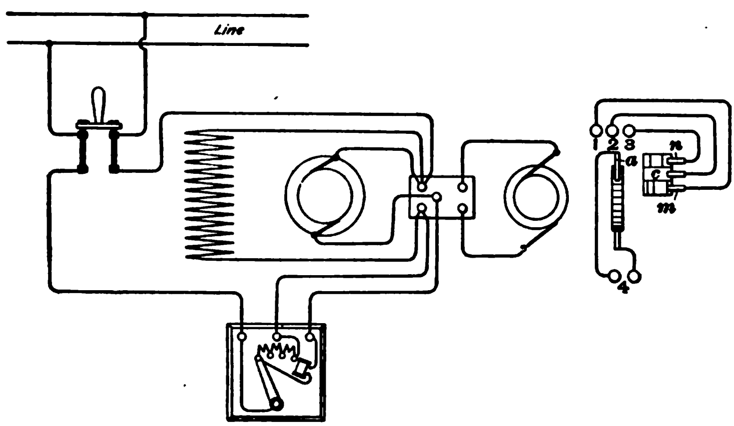


Fig. 15

the circuit of the direct-current shunt-motor part of the machine.

The don't-answer, busy-back, and howler attachment is connected in a manner to suit the telephone system and about as shown in other figures. From binding post *1* is supplied the don't-answer tone, from *3* the busy-back tone, while brush *a* or other source of rather high-frequency, interrupted or alternating current, is connected through binding post *2* to the slip ring *c*, from which the current is supplied to the interrupting commutators and brushes *n*, *m*. The two binding posts *4* are the howler-circuit terminals, direct current from the ungrounded terminal of the storage battery usually being fed to the right-hand post. The ground usually forms, or at least represents, the return from all circuits to the grounded terminal of the battery.

50. Fig. 16 shows the connections used in a telephone exchange for operating a low- and a high-frequency, ringing. generator set for selective-ringing party-line service. The

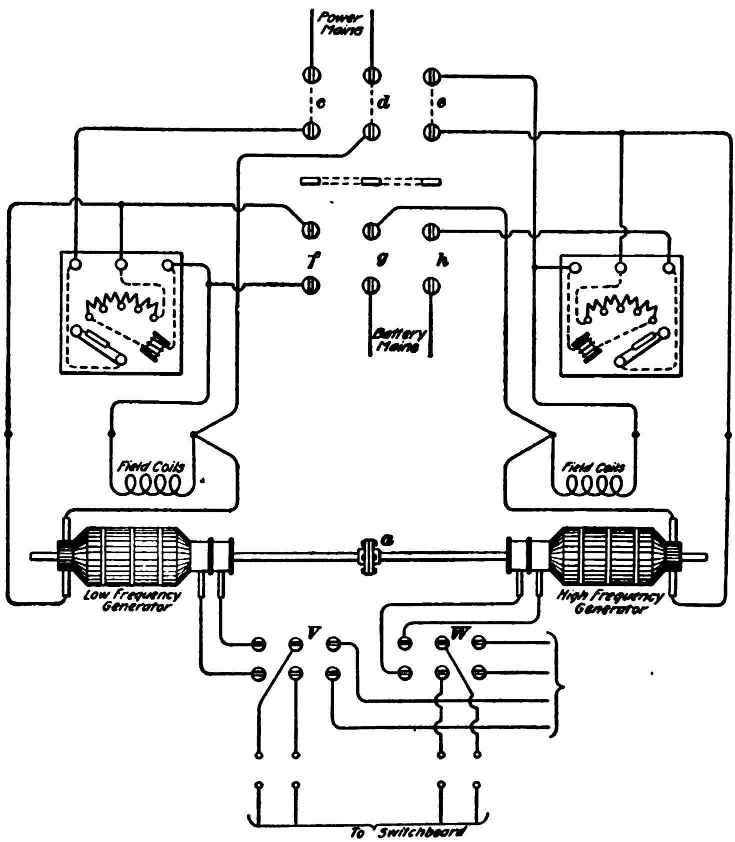


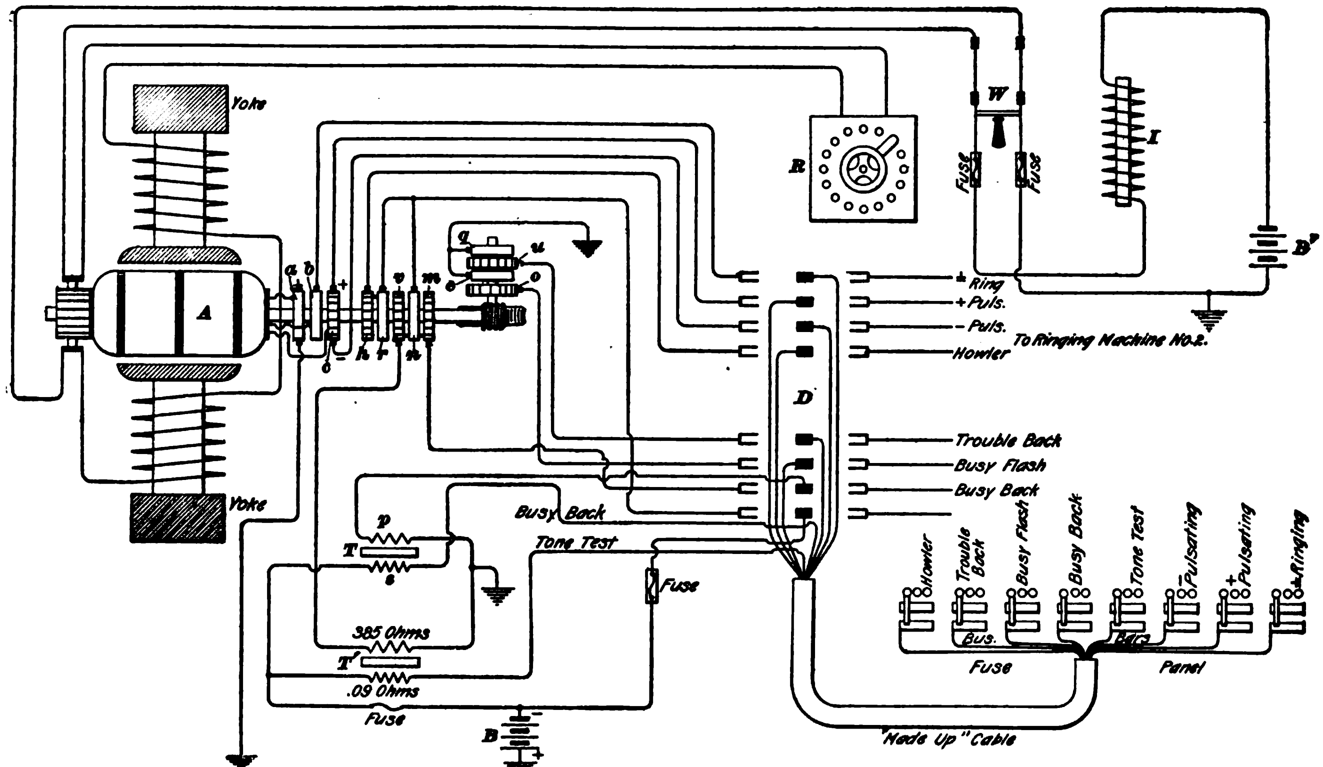
Fig. 16

armatures and field coils of two dynamotors, whose shafts are mechanically coupled together at *a*, are connected with automatic-release starting rheostats and a three-blade double-throw switch, in such a manner that the left-hand machine, when supplied with current from the power mains, will run both machines, and the right-hand machine, when supplied with current from the exchange storage battery, will run both machines.

On each armature, there are two windings, one with its commutator constitutes a direct-current motor armature, and the other winding with its two slip rings supplies alternating current of the desired frequency. Since the two armatures must run at the same speed, the two frequencies always bear the same relation to each other, which is very desirable. The motor windings of the armatures and the field coils may be designed to properly run the machines for the same or different voltages at the power and battery mains. On one end of each armature is a commutator through which direct current passes and on the other end are two slip rings from which the alternating ringing current is taken.

51. When the double-throw switches *V*, *W* are closed toward the left, the switchboard circuits are supplied with high- and low-frequency currents from the machines shown in this figure; when *V* and *W* are closed toward the right high- and low-frequency currents are obtained from spare machines similarly connected but not shown in this figure. When the three-blade switch at the top is closed so as to make the connections shown by the dotted lines *c*, *d*, *e*, current from the power mains, flowing through the field and the direct-current armature winding of the low-frequency machine will cause both armatures to revolve. The field and direct-current winding on the armature of the high-frequency machine will now act as a simple shunt dynamo; the current generated in the direct-current armature winding will flow through and properly excite its own field coils, this circuit being now closed at *e*.

In a similar manner, the motor part of the high-frequency machine will run both armatures when the three-blade switch is closed in the down position so as to close the circuits at *f*, *g*, *h*, and allow current from the storage battery to flow through the field coils and direct-current armature winding of the high-frequency machine; in this case, the direct-current



Yoke
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A
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B'
± Ring
+ Puls.
- Puls.
Howler
To Ringing Machine No. 2.
D
Trouble Back
Busy Flash
Busy Back
Busy Back
Tone Test
Fuse
p
T
s
385 Ohms
T'
.09 Ohms
Fuse
B
Howler
Trouble Back
Busy Flash
Busy Back
Tone Test
- Pulsating
+ Pulsating
± Ringing
Bus.
Bars
Fuse
Panel
"Made Up" Cable

FIG. 17

armature winding of the high-frequency machine has current generated in it to supply its own field coils. Whichever machine is used as a motor, the corresponding automatic-release starting box is used to start it, the other automatic-release starting box being in the off-position.

52. Fig. 17 shows the various circuits pertaining to a small but modern ringing machine, in this case a dynamotor. The machine shown at the left is termed ringing machine No. 1, while the similar duplicate machine No. 2, which is not shown, is connected as indicated to the right-hand terminals of two double-throw four-blade switches *D*. The dynamotor is a shunt-wound bipolar machine, operated from a 24-volt storage battery *B'* and using from 3 to 6 amperes at full load. In series with the battery and the motor side of the machine is an impedance coil *I*, which not only limits the strength of the current but also reduces any humming effect that the operation of the machine in this manner direct from the storage battery tends to produce in all lines in use. As this is a small machine, it is started simply by closing the switch *W*; the coil *I* prevents a too rapid rise in the current at the start. The speed of rotation of the armature, and hence the pitch of the various tones produced, may be regulated somewhat by means of the rheostat *R* in the shunt-field circuit. From the generating side of the machine, the various circuits are carried to the two switches at *D*. The alternating-current collector rings are shown at *a*, *b*; the ring *a* is permanently grounded. From ring *c* is obtained the plus and minus pulsating current for selective ringing. From the storage battery *B*, which is the same battery as *B'*, current is led through the switch to rings *r*, *n*, one of which *r* is connected to the howler commutator *h*, the other *n* to the busy-back commutator *m* and the tone-test commutator *v*. The howler circuit runs to the wire chief's and the chief operator's desks.

53. Current from the battery flows through *n*, the commutators *v*, *m* and the 385-ohm primary windings of the repeating coils *T*, *T'* to ground, thus inducing in their secondary windings, which have a resistance of .09 ohm, an alternating electromotive force. The currents thus produced in the secondary windings are superimposed on those generated by the battery. Thus a battery current always flows through the secondary winding of these two coils, in order to hold some relay closed, while a humming tone is also produced periodically in the same circuit. The commutators *m*, *v* have differently spaced segments, so that the intervals of noise and silence is different in the two circuits, which run to jacks at each toll operator's positions. The tone test due to the commutator *v* is used for holding a line for a toll or long-distance connection. The busy-back tone is used to signal back from a trunk board to the calling operator at a toll board when a line wanted is busy.

The rings *q*, *e*, which revolve at a much lower speed than the armature shaft, have their brushes permanently grounded while the commutators *o*, *u* are connected through their brushes and contacts on switch *D* to the switchboard for a purpose that will be presently explained. The circuit coming to commutators *o*, *u* is merely opened and closed by this device, the battery current being supplied through a cord circuit at some incoming toll position. Thus, the incoming toll operator, by inserting a plug in a jack to which ground and *u* are connected, may produce a signal at some other place meaning that the desired circuit is in trouble and by inserting a plug in a jack to which ground and *o* are connected, may cause a lamp signal at some other switchboard position to flash periodically. Such signals are used to operate supervisory signals from a trunk board.

54. Suppose that an operator at one exchange receives a call for a subscriber connected to another board by a trunk and order wire from the board where the original call is received; the operator receiving the call notifies the operator at the distant exchange over an order wire of the number desired. The distant operator assigns, over the order wire, the trunk circuit to be used, and at the same time picks up her plug end of the trunk and tests the multiple jack desired.

In the meantime, the operator at the originating exchange has inserted her calling plug in the trunk jack. If the second, or *B*, operator on testing the desired jack finds the line busy, she, instead of making the connection, inserts the trunk plug in a special busy-back jack. The interrupted current connected to this jack causes the alternate attraction and release of the armature of a relay that controls the supervisory lamp in the calling side of the cord to which the original subscriber is connected. Flashes of this lamp occurring at the intervals determined by the speed and construction

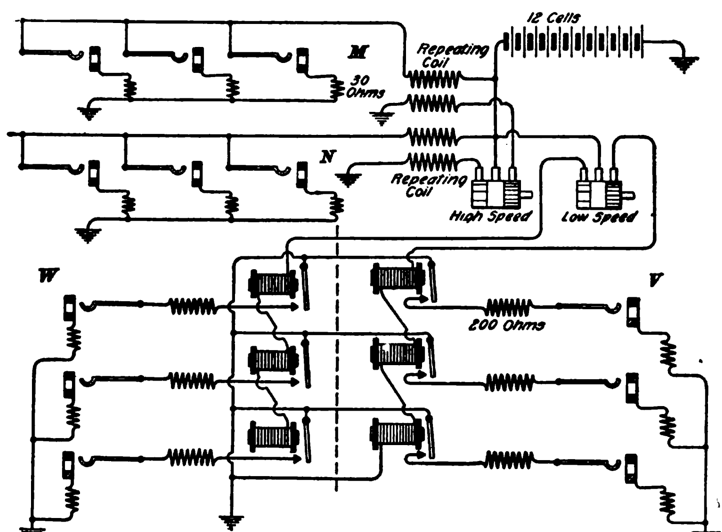


FIG. 18

of the commutator, notify the operator that the desired line is busy. At the same time, a characteristic hum is heard by the waiting subscriber, who usually understands the meaning also and immediately hangs up his receiver.

A different code is used to notify the operator that a line is in trouble. The commutators *o*, *u* have a different number of segments differently arranged. Each circuit runs through a fuse that is usually mounted on the fuse panel.

55. Wiring of Tone-Test Circuits.—Fig. 18 shows the plan of wiring tone-test circuits for a multiple switchboard.

In some cases, the resistances shown will be relays. The multiple jacks *M*, *N* that are connected through a repeating coil are located in the toll operator's position. The multiple jacks *W*, *V* associated with the relays are located at the incoming toll position. At each position, there is at least one of the jacks *W* and its relay and one of the jacks *V* and its relay. The relays in each set are in series and are continuously opening and closing their local jack circuits. The high-speed commutator produces 400 interruptions per second and the low-speed 133 interruptions per second.

AUTOMATIC OVERLOAD AND UNDERLOAD DEVICES

56. When storage batteries are charged from a lighting circuit or from a dynamo or converter, there should be used in the charging circuit going to the batteries a device that will automatically open the circuit if the current becomes too large, and also in case the current becomes too small or drops to zero. A device that will automatically open the circuit should the current become too large or too small is called an **automatic overload and underload switch.** The first is to prevent the batteries from being charged at too high a rate; it also protects the charging machine or electric-light mains from being overloaded. Such a switch should be used in the charging circuit of all storage batteries, in which case no main-line fuses are necessary. A magnetic overload device is much preferable to a fuse, because it is more reliable and can be more quickly and more easily reset.

The object of having the circuit automatically opened when the current drops to zero is to keep the storage batteries from discharging back through the charging circuit, which might cause one of several objectionable things to happen. The current, if discharged back into a dynamo or converter, will tend to run the machine as a motor, thus wasting the energy of the battery, or the armature might be burned out by the excessive current discharged back through it from the batteries. Furthermore, the cells may be injured by the high rate at which they discharge back through the charging circuit. For, when the machine stops running, the storage batteries will be short-circuited by the low resistance of the armature winding. A device that will open the circuit when the current drops to zero is, therefore, very desirable. Of course where there is an attendant constantly on hand watching the charging of the cells, it is not so necessary, perhaps.

57. Cutter Overload and Underload Device.—An underload and overload circuit-breaker, made by the Cutter Electrical and Manufacturing Company, is shown in Fig. 19. This device is double pole, that is, it opens both sides of the circuit like a double-pole knife switch, *o*, *o* being the knife blades. There are two electromagnets *M* and *N*, both connected in series with the main circuit. *N*, which is nearly hidden from view, may be called the overload, and *M* the underload, magnet. The poles of *M* are bridged by the iron keeper *k*. As long as a current flows through the circuit, *k* is held against the pole pieces of the magnet *M*, but if the current drops to zero, *k* is released; this releases a trip and the switch is thrown open by a strong spring. *M* may also be designed to release *k* if the current falls below any given value.

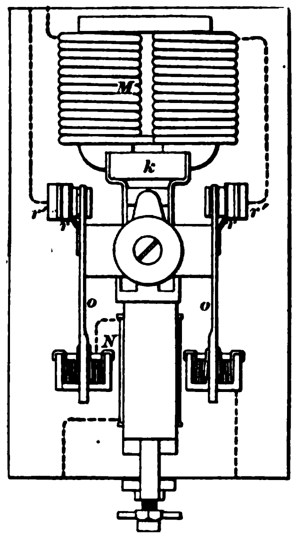


FIG. 19

If, on the other hand, the current becomes excessive, the magnet *N* draws an iron plunger (not shown in the figure) toward it with sufficient force to release the trip, and the spring, as before, throws open the switch. The main contacts are protected against the ruinous effects of an arc at the breaking of an excessive current by causing the current to be finally broken between flat carbon sticks *r*, *r'*. These carbon sticks when worn out can be easily replaced by new ones.

MERCURY CONVERTERS

RINCIPLES OF MERCURY CONVERTERS

INTRODUCTION

58. A **mercury converter,** or **mercury rectifier,** is a device for converting alternating to direct current without the use of vibratory or rotating parts. It consists essentially of a sealed glass vessel filled with mercury vapor and containing the necessary terminals, called **electrodes.** The Cooper-Hewitt Electric Company calls the apparatus of this character, that it makes, a *mercury-vapor converter,* while the General Electric Company calls the apparatus it makes a *mercury-arc rectifier.* Mercury converters, or rectifiers, are very useful for charging storage batteries from alternating-current mains and have certain advantages over motor generators, dynamotors, and rotary converters, which in small sizes are not very efficient and are apt to require more attention. Before discussing mercury converters, it will be well to consider a few terms commonly used and not explained heretofore.

59. An **electric,** or **voltaic, arc** is a hot luminous flame in the air space or gap across which an electric current is passing between two electrodes. The **anode** is the electrode to which the current flows from the external circuit and the **cathode** is the electrode from which the current flows into the external circuit.

Whenever a circuit in which a current is flowing is broken, an arc is formed; and if the gap is not too long, the arc may be maintained continuously, or until it is purposely suppressed by blowing it out by means of a jet of air, or by the repelling effect of a magnet, or by stopping the current flow in some other way. After the arc has been suppressed, the same potential difference that maintained it cannot reestablish it; in fact, before the arc can be reestablished, the difference of potential between the electrodes must be made very much higher or else the gap must be shortened. When the arc is established, the intense heat vaporizes a portion of the material of the electrodes and the vapor acts as a conductor across the gap.

60. Metallic vapor is obtained by vaporizing a metal. When heat is applied to a piece of ice, the ice is first melted, or turned to a liquid, and if the heat is great enough the liquid will be turned to a vapor. The application of sufficient heat to any other solid produces similar results. For example, it is possible to melt iron, and if the liquid iron is made hot enough it will turn to vapor. Mercury, which is often called quick silver, is a silver-white metallic element that is liquid at ordinary temperatures. By lowering its temperature sufficiently it becomes a solid, that is, it freezes; raising the temperature of liquid mercury sufficiently readily vaporizes it.

A vacuum, as commonly understood, is a space from which the air has been more or less removed; the more nearly the air has been completely removed, the more perfect is the vacuum. A perfect vacuum is practically impossible to produce.

THEORETICAL ACTION OF MERCURY CONVERTERS

61. A mercury converter consists essentially of an electric arc in a partially exhausted glass vessel, which becomes filled with mercury vapor. Mercury is used because this metal ordinarily remains in a liquid state, is comparatively easy to vaporize, and is not excessive in cost.

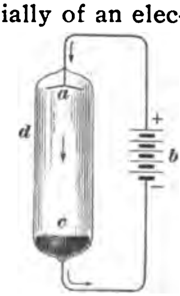


FIG. 20

The action of a mercury converter may be explained by the aid of Fig. 20, in which *b* represents a battery, *d* a closed glass tube from which the air has been exhausted and that has sealed in opposite ends the wires that terminate inside the tube in electrodes *a*, *c*. The anode *a* may be iron or graphite, the cathode *c* is liquid mercury.

62. If by some means an electric arc is started from the anode *a* to the cathode *c*, current will flow in the direction indicated by the arrows. To start the arc requires either that the difference of potential between the anode and cathode be raised to an excessive value, perhaps 25,000 volts, or that the tube be shaken or tipped until the mercury forms a continuous stream between the two electrodes, and then righted again to break the stream. As soon as the stream is made continuous, the current follows it, and then when it breaks, an arc is formed. The heat of the arc immediately vaporizes some of the mercury and the vapor reduces the resistance of the path between the two electrodes sufficiently to allow the maintenance of an arc and, therefore, the flow of current from the anode *a* to the cathode *c*. As long as the current flow is not interrupted, a comparatively low voltage will maintain the arc. The voltage required depends on the length of the arc and not on the strength of the current; that is, in a given tube the voltage across the arc will remain practically constant, even if the current strength varies. This may be explained by assuming that the greater the quantity of current, the more rapid is the formation of mercury vapor; hence, the greater is the conductivity of the path between the electrodes.

63. Another theory is that the conductivity of the path depends, not on the quantity of mercury vapor present, but on the quantity of vapor that is decomposed or broken up by the action of the arc into infinitesimal electrified particles called *ions;* that is, that it is only the ionized vapor that is a conductor. This theory is not fully accepted and need not be further considered here. It is, however, a fact that the presence of too much vapor will smother the arc. The vapor condenses on the walls of the vessel and runs to the bottom; and if the vessel is not large enough to afford sufficient condensing surface, the vapor soon becomes so dense that the arc goes out.

64. With the apparatus arranged as shown in Fig. 20 and if the condensing surface is sufficient, an arc once established will continue as long as the necessary potential difference for maintaining the arc is preserved between the electrodes; but if the arc is allowed to cease, even for an instant, it will not start again, unless the stream of mercury is momentarily reestablished by shaking or tilting or by an excessive increase in the applied electromotive force.

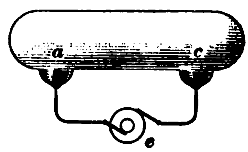


FIG. 21

No matter how quickly the circuit is opened and again closed, the arc will not start again. When an alternating-current dynamo *e* is connected to the terminals *a*, *c* of the glass vessel, arranged as shown in Fig. 21, the intervals in each current cycle, short as they are, during which the current is zero, are sufficient in duration for the production of the conducting vapor to cease and for the arc to go out. For instance, it has been determined that, even with a 10,000-cycle alternating current, which gives 20,000 interruptions per second, a frequency far beyond any used in commercial work, the reversals are not quick enough to maintain the arc. No ordinary commercial single-phase alternating current will, therefore, support an arc with the arrangement of electrodes and tube illustrated in Fig. 21.

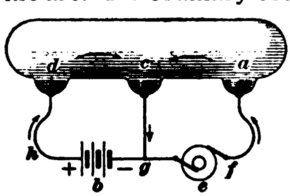


FIG. 22

65. Almost all the resistance to the starting and maintaining of an electric current through a mercury-vapor tube occurs at the cathode, and if enough continuous current can be made to flow through the cathode to maintain the supply of conducting vapor, the arc will be maintained. Fig. 22 shows a tube with three mercury electrodes *a*, *c*, *d*, a battery *b*, and a single-phase alternator *e*. The current from the battery *b* through *h*–*d*–*c*–*g* is strong enough to maintain the supply of conducting vapor after it is once started so that the resistance at the cathode *c* is kept low. The current from the alternator that flows from *a* to *c* can pass, but no current can pass from *c* to *a*; that is, the device acts as a valve that readily allows current to pass in one direction but not in the other. The impulses that tend to flow from *c* to *a* are suppressed by the high resistance of the electrode *a*.

66. Only one-half the alternating current passes through such a device. Fig. 23 shows an arrangement by which the negative impulse of an alternating current can be made to flow in the same direction as the positive impulse; in other words, the alternating current is rectified and the entire current used. The tube has four electrodes; *d* is an auxiliary anode through which current enters the tube from a battery *b*, *c* the cathode, and *a*, *a'* the anodes to which the wires from the dynamo *e* or a transformer are connected.

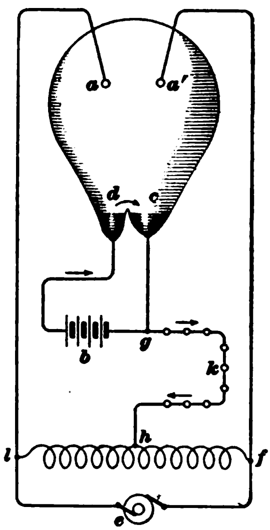


FIG. 23

The action is started by tilting the tube until the mercury forms a stream between the two electrodes *d*, *c*, so that current from the battery *b* can follow the mercury from one electrode to the other; then the tube is righted to break the continuity of the mercury. An arc is thus immediately formed from *d* to *c*, which maintains the supply of conducting vapor. Impulses of one polarity then flow from the source of alternating current *e* through *l–a–c–g–k–h–f–e* and impulses of the opposite polarity through *f–a'–c–g–k–h–l–e*. Thus current flows only in one direction through *g–k–h*, in which circuit may be located direct-current devices as represented by the circles. Comparatively little of the alternating current flows from *l* to *f* or vice versa on account of the high impedance of this whole coil.

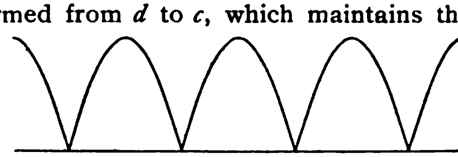


FIG. 24

The direct current thus obtained from the alternator is of a pulsating character and may be represented by the curve in Fig. 24. The direct current represented by this curve will not maintain the arc without a battery, for at the end of each half wave this pulsating current falls to zero.

67. Single-Phase Converter.—Fig. 25 shows an arrangement by which the arc may be maintained by single-phase alternating current only, no battery being required. A choke coil *l* is connected in the direct-current circuit between the cathode *c* and the middle point *h* of an autotransformer coil. The choke coil delays each successive impulse of current until the next impulse from the other electrode has started; that is, it makes each direct-current impulse lag so that the half waves overlap one another, as shown by the dotted lines in Fig. 26.

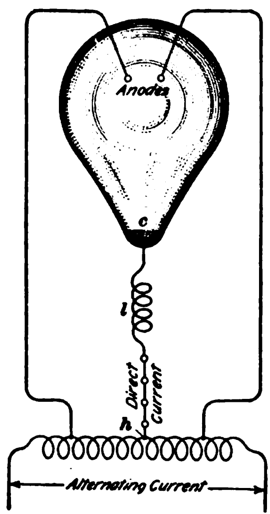


FIG. 25

The direct current from *c* to *h*, Fig. 25, at no time falls to zero, but consists of a series of slight impulses as represented by the heavy curve *a b* in Fig. 26. The inductance causes not only an overlapping of the waves, but also lowers the maximum value of the resultant curve, causing the current to follow the curve *a b* as nearly as can be determined. The loops can be smoothed out still more by increasing the inductance of the coil *l*, thus making the current more nearly continuous. For most purposes, a direct current having slight pulsations is not objectionable, but for charging storage batteries while supplying current to central-energy telephone systems, the pulsations should be smoothed out as much as possible.

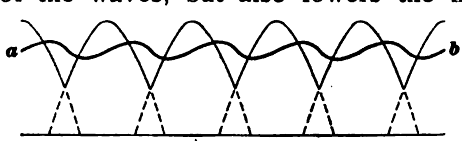


FIG. 26

STARTING DEVICES

68. The difficulty of starting an electric arc has been mentioned. The same difficulty is experienced whether the arc is started in air or in a metallic vapor, therefore many devices for starting an arc in a mercury vapor have been invented. Probably the most largely used method consists in bridging the gap between the electrodes with a conductor, and then break the bridge after the currents begins to flow. The same thing could be done by bringing the electrodes together, as is done to start the arc between ordinary carbons for lighting purposes, and then separating them after the current begins to flow. The usual method of starting consists in tilting the vessel until the mercury of the cathode comes in contact with an anode and forms a bridge over which the current temporarily passes from the anode to the cathode; as soon as the resistance of the cathode is broken by the production of a conducting vapor, the alternating current will maintain the arc, provided that the inductive resistances are so arranged as to produce the proper phase relation. For starting purposes, the tubes in commercial use for mercury converters have an auxiliary mercury anode near the cathode.

COOPER-HEWITT MERCURY-VAPOR CONVERTERS

69. Simplified Diagram of Connections.—The operation of the **Cooper-Hewitt mercury-vapor converters** made for charging storage batteries will be explained by the aid of the simplified diagram of connections shown in Fig. 27. By comparing this figure with Figs. 29 and 30, in which the same reference letters are used, the actual location of the various parts and their connections may be readily seen.

If the direct-current load is a storage battery, which is commonly called a *live load*, the converter is started by turning the switch lever *i* to the right-hand contact *j* and closing both the alternating-current and the direct-current switches *q*, *u*, Current then flows from the positive terminal of the storage battery *w* through the ammeter *A*–cut-out magnet *k*–sustaining coil *l*–tilting magnet *n*–cut-out switch *p*–starting resistance *r*–starting switch *i*–*j* to the negative terminal of the battery. This current is too weak on account of the resistance *r* to operate the cut-out magnet *k*. The tilting magnet, however, tilts the bulb until the mercury connects the two electrodes *s*, *s'*, then the current flows through the mercury instead of through the tilting magnet, which is thereby so weakened that the bulb falls back to its upright position, thus breaking the stream of mercury between *s*, *s'* and therefore starting an arc, which is at once picked up by one of the main anodes *t*, *t'* and a current is forced back through the sustaining coil *l*, cut-out magnet *k*, and the ammeter to the storage battery from which the returning current flows to the neutral point *d* of the transformer. This current is strong enough to operate the cut-out magnet *k* and open the circuit through *r* and *s'*. The main voltage regulation for the

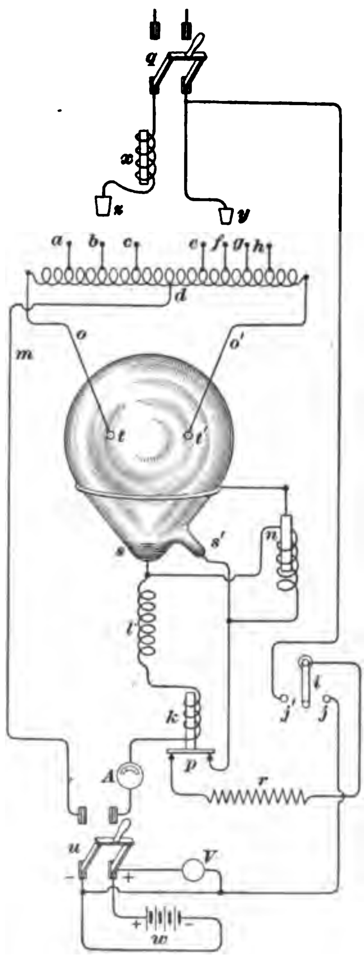


FIG. 27

direct current is obtained by placing the plugs *z*, *y* in connection with suitable taps *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h* along the autotransformer coil; the voltage with these plugs in any position may be further varied somewhat by varying the position of an iron core in the regulating coil *x*, which varies the impedance of the coil. The plugs *y*, *z* are different in size so that *z* can only be placed in *a*, *b*, *c* and *y* in *e*, *f*, *g*, *h*. When the apparatus is in operation, the resistance *r* and tilting coil *n* are both cut out.

70. The Cooper-Hewitt standard mercury-vapor converter made for charging storage batteries consists of a bulb, a panel, a frame, and autotransformer.

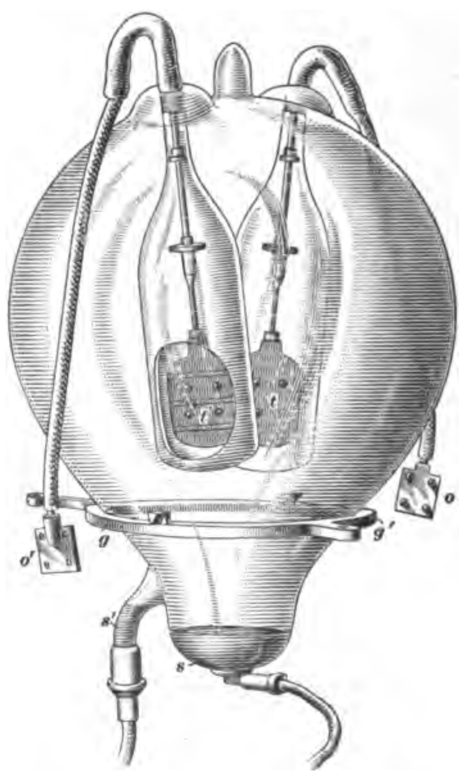


FIG. 28

The bulb, which is an exhausted glass vessel about 9 inches in diameter and containing the electrodes, is shown in Fig. 28 in which the same reference letters are used as in Fig. 27. *s'* is the auxiliary or supplementary starting anode; *s*, the cathode; *t*, *t'*, the anodes made of iron and almost completely enclosed in bottle-shaped glass vessels, in order to hinder the formation of arcs between the anodes *t*, *t'*. Openings in the bottle-shaped vessels opposite the anodes permit arcs to pass from the anodes *t*, *t'* to the cathode *s*. All wires leading into the bulb are sealed air-tight in the glass walls, and after inserting the mercury for the cathode and the starting anode through a glass tube in the top of the bulb, air is exhausted from the bulb and it is sealed, leaving a tip on the end. The bulb is large enough so that the surplus vapor condenses on the inside and runs back to the electrode in the bottom. The terminals *o*, *o'* are used for connecting to the alternating-current supply circuit.

When assembled in its frame, the bulb rests in a ring *g*, *g'*

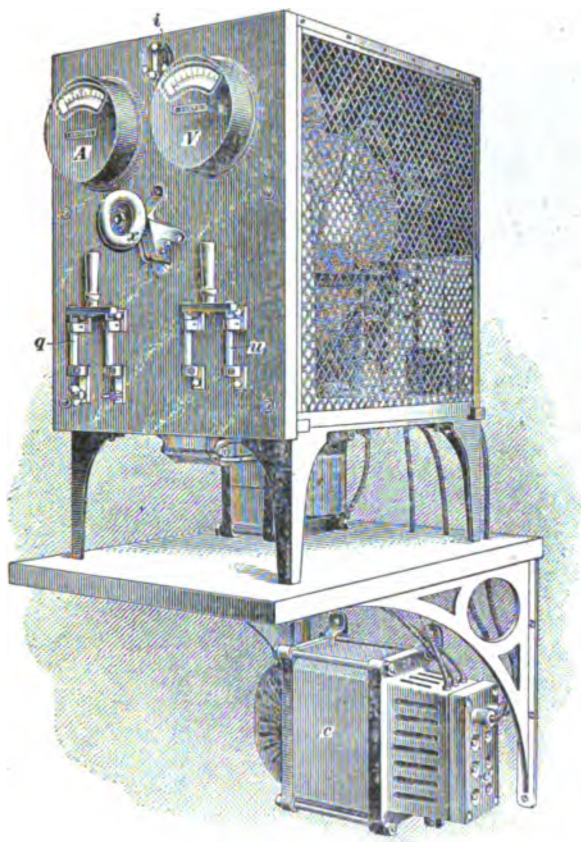


Fig. 29

that is supported on knife edges so that the bulb, when the starting switch is closed, may be automatically tilted by the tilting magnet, which is provided for the purpose, until the mercury in the starting anode comes in contact with that at the cathode. The circuit through the tilting magnet is then automatically opened, the globe rights itself, and the arc starts.

71. Panel and Frame.—Fig. 29 shows the complete standard type PA converter, including the front of the panel and the cage used to enclose the apparatus. The cage occupies a space 15 in. × 22 in. and is 22 inches high. The out-

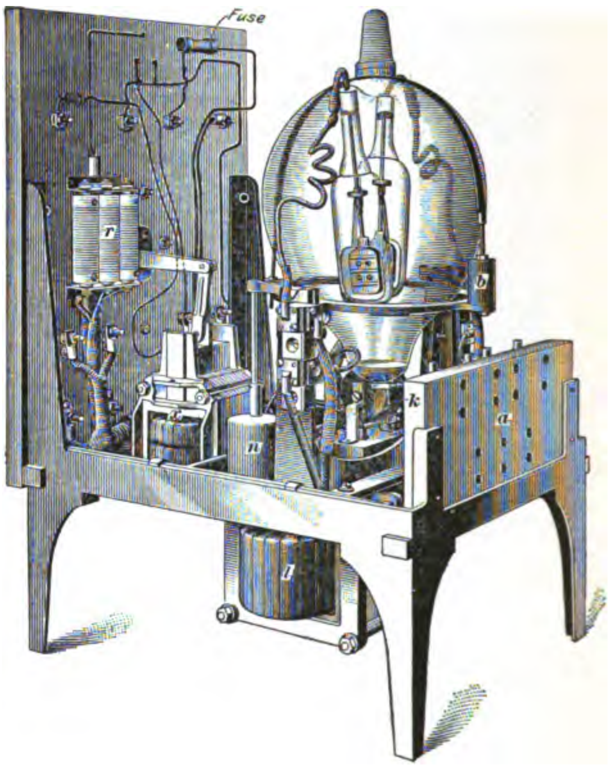


FIG. 30

put is from 6 to 30 amperes direct current at any voltage from 50 to 115, as explained later.

On the front of the marbleized slate panel are mounted a direct-current voltmeter *V*, a direct-current ammeter *A*, a regulator handle *x* that turns a worm-wheel to move a plunger or core in or out of a choke coil connected in the alternating-current supply circuit, a switch *q* in the alternating-current circuit, a switch *u* in the direct-current circuit, and a three-way starting switch *i*. Fig. 30 shows the back of the panel and the apparatus with the cage removed. On the back of the panel are the terminals of the instruments and switches and the starting resistance *r*, which is wound on porcelain tubes.

72. The panel is supported on a cast-iron frame, which also carries the supporting mechanism for the bulb; the regulating coil *x*, the core of which is moved by means of the hand wheel on the front of the board; the tilting magnet *n*; the sustaining coil *l* for steadying the direct current and causing the necessary lag of the rectified impulses, the cut-out magnet *k* and a connection board *a*, having lugs for seven circuits or fourteen wires. A weight *b* helps to return the bulb to the vertical position after it has been tilted.

Under the table, or bench, on which the iron frame stands, is shown the autotransformer *c*, Fig. 29, with a plug board *e* attached and into which two of the wires from the connection board *a*, Fig. 30, may be plugged, as will be explained further on. Five wires are connected to the autotransformer; these, with the two alternating-current supply wires, constitute seven of the wires leading to the connection board. The other seven, connected with these on the board, lead to various parts of the converter apparatus. The frame work supporting the converter, instead of being cast with supporting legs as shown, may be provided for bolting to a wall, and the autotransformer may be placed at any convenient point nearby.

73. Fig. 31 is a diagram showing the principal parts of the converter laid out in a horizontal plane and also showing the connections. The anodes are connected to lugs *15* and *16*, the starting electrode to lug *21*, which is connected to lug *19*, and the cathode to lug *22*, which is connected to lug *20*. The alternating-current wires are connected through suitable fuses to lugs *1* and *2* on the connection board, these being connected to lugs *8* and *9*, respectively; the path of the

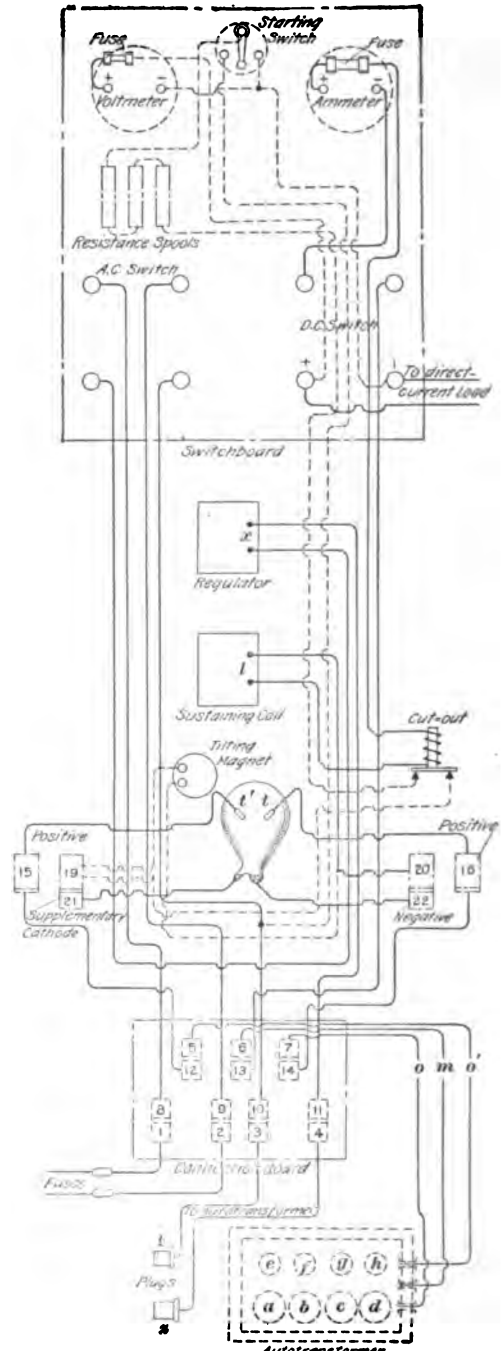

Starting Switch
Fuse
Fuse
Voltmeter
Ammeter
Resistance Spools
A.C. Switch
D.C. Switch
To direct-current load
Switchboard
x
Regulator
l
Sustaining Coil
Cut-out
Tilting Magnet
t' t
Positive
Positive
15
19
21
20
22
16
Supplementary Cathode
Negative
5
12
6
13
7
14
o m o'
8
1
9
2
10
3
11
4
Fuses
Plugs
e f g h
a b c d
Autotransformer Plug Board

FIG. 31

alternating current may be readily traced to the alternating-current switch on the switchboard. Lugs *10* and *11* are connected, respectively, to lugs *3* and *4*; and from these extend flexible leads terminating in plugs *y*, *z* that may be inserted into various holes in a plug board attached to the autotransformer according to the voltage transformation desired. The holes *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h* on the transformer plug board correspond to the similarly lettered taps in Fig. 27. Lugs *15* and *16* are connected, respectively, to lugs *12* and *14*, which, in turn, are connected to lugs *5* and *7*. From lugs *5*, *6*, and *7*, wires *o*, *o'*, and *m* extend to the autotransformer—*o*, *o'* being connected to the extreme ends of the transformer coil and *m* to the middle or neutral point. These wires are lettered the same as in Fig. 27. Lug *13* is connected to lug *6* and also to the direct-current switch on the switchboard.

The two lower terminals of the direct-current switch are connected to the load—which may be a storage battery, a motor, or lights—and also to the voltmeter, so that if the load is a storage battery its voltage may be read before closing the switch. One terminal of the ammeter is connected to the direct-current switch and the other through the cut-out magnet and the sustaining coil to lug *20* on the connection board, the polarity being plainly indicated by the signs + and −. The plugs *y*, *z* on the ends of the alternating-current leads differ in size, and the holes in the plugboard of the autotransformer are of similar size, so that it is not possible to insert the plugs in holes in which they are not intended to go. The autotransformer should be set with the plugboard vertical, so as not to catch dust in the holes.

74. Voltage Transformation.—The eight holes in the plugboard are lettered *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*. Table I gives the plug positions necessary to secure various voltage transformations. The two direct-current voltages given in the first column are the extremes that may be obtained with the plugs in the given position by means of the hand regulating wheel shown at *x* in Fig. 29. The table will serve as a guide in choosing the plug combinations for different voltages.

The order in which the changes are made to raise or lower the direct-current voltage with any alternating-current voltage is the same; for example, the highest direct-current voltage with any alternating-current voltage is obtained with the plugs in holes *b, f* and the lowest with the plugs in holes *a, h*. If it is desired to raise or lower the secondary voltage by changing the plugs, the necessary change can easily be made by following the sequence given in Table I.

TABLE I

Alternating Current Volts 200		Alternating Current Volts 220		Alternating Current Volts 240	
Direct Current Volts	Plugs In	Direct Current Volts	Plugs In	Direct Current Volts	Plugs In
80–130	*b–f*	95–140	*b–f*	105–140	*c–g*
75–120	*c–g*	90–130	*c–g*	100–130	*b–g*
70–110	*b–g*	85–120	*b–g*	90–120	*b–h*
65–100	*b–h*	85–95	*c–h*	85–110	*a–f*
60–90	*a–f*	80–110	*b–h*	75–105	*a–g*
55–85	*a–g*	75–85	*a–e*	70–90	*a–h*
50–70	*a–h*	70–100	*a–f*		
		65–95	*a–g*		
		60–80	*a–h*		

A plug position should be chosen such that the exact voltage desired is obtained with the regulator plunger as far out as possible, thus allowing the best circulation of air in the interior of the regulator. The plugs should never be changed while the current is on.

75. Starting on Live Load.—When starting the converter on a live load, it will not continue to run unless the direct-current voltage of the converter is great enough to force more than about 5 amperes through the storage battery. If the converter starts and then goes out in a few seconds, the regulator handle should be turned to the right to raise the voltage until the arc continues. The converter will run on a lower current when hot than when cold, and if it is desired to run on a low current it is best to start on a higher one and then reduce it by turning the regulator handle to the left when the apparatus is warm. If when charging a storage battery the starting switch is left in the central position, the converter will automatically cut out without injury when the battery voltage rises enough to reduce the charging current to about 5 amperes.

76. Starting on a Dead Load.—If the converter is to be started on a load consisting of incandescent lamps or other resistance, which is termed a *dead load*, the starting switch is moved to the left-hand contact, shown at j' in Fig. 27, and enough alternating current flows through the tilting magnet and then across the electrodes s, s' to start the arc. The converter may also be started by hand by tilting the bulb through a slot in the top of the cage. When running on a dead load, the starting switch may be left on the left-hand contact and, if the converter stops due to the failure of the alternating current from any cause, it will automatically start again when the current returns.

77. The following general instructions and precautions should be observed:

1. Before attempting to start the converter, see that the apparatus is properly set up, that all connections are correctly made and tight.

2. If starting on a live load, first see that the voltmeter reads in the right direction and select a plug position that will give about the required voltage. The positive terminal of the battery should be connected to the side of the switch marked +. See that the starting switch is in the right position; set the regulator with the plunger almost all in, that is, turn the handle to the left almost as far as it will go; and close the alternating-current and direct-current switches. The converter should then start, but if on a live load it may be necessary to increase the current a little, as already explained, in order to make the operation continuous. After the converter is running, the desired current can be

obtained by turning the regulator handle to the right for an increase and to the left for a decrease.

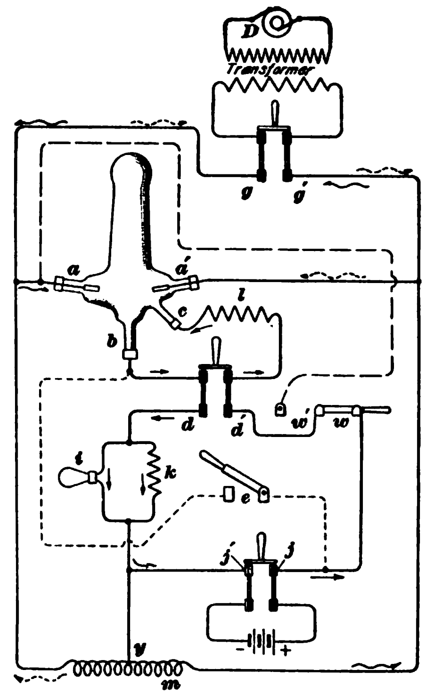
3. To stop the converter, put the starting switch in the off-position and open both the alternating-current and direct-current switches, either one first, but the direct-current switch should not be left on after the other one is opened.

4. Do not attempt to overload the converter, even for a few moments, or the apparatus may be injured. The maximum capacity is plainly indicated on the name plate and in the manufacturer's instructions.

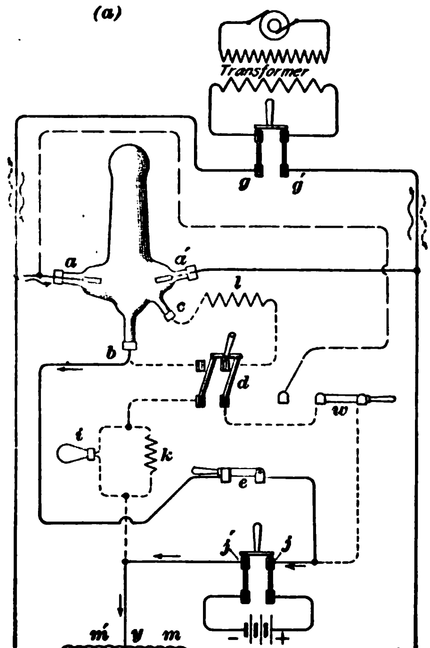
5. The alternating-current voltage between lugs *5* and *7* on the connection board, Fig. 31, with 220 volts supply is about 350 volts, and care should be taken to avoid accidental shocks. These terminals are on the bottom of the board where there is ordinarily little likelihood of accidental contact. There are no live contacts on the face of the board, except at the switches, and the voltage there is seldom over 250.

GENERAL ELECTRIC MERCURY-ARC RECTIFIER

78. A simplified diagram of connections of the **mercury-arc rectifier** made by the General Electric Company is shown in Fig. 32. The connections for starting the rectifier are shown at (*a*), in which dotted lines and dash lines represent circuits that are then open and need not now be considered. The same switches are shown and the various parts lettered as far as practicable as in the more complete and actual diagram of connections to be shown in the next figure. The rectifier is started by a slight tilting of the tube that causes mercury in the starting anode *c* to join that in the cathode *b*, thereby allowing current to flow through *j*–*w*–*d'*–starting anode resistance *l*–starting anode *c*–cathode *b*–*d*–pilot lamp *i* and starting resistance *k* (which are in parallel)–*j'*–back to the battery. The arrows show the direction and path of this current. The breaking of the mercury stream on the righting of the tube causes an arc to be formed between *c* and *b*. The alternating current then starts to flow through *g*–*a*–*b*–*d*–pilot lamp and resistance *k* in


D
Transformer
g
g′
a
a′
l
c
b
d
d′
w′
w
i
k
e
j′
j
y
m

(a)


Transformer
g
g′
a
a′
l
c
b
d
w
i
k
e
j′
j
m′
y
m

(b)

FIG. 32

parallel–*y*–*g*′, as shown by the full wavy arrows, and through *g*′–*a*′–*b*–*d*–pilot lamp and resistance *k* in parallel–*y*–*g*, as shown by the dotted wavy arrows.

The current through the tube soon warms it, then the so-called load switch *e* is closed. Two paths are now available for the alternating current. It may flow from *a* or *a*′ through *b*–*d*–*i* and *k* in parallel to *y* and also through *b*–*e*–*j*–battery–*j*′–*y*. When the rectifier is operating properly, the switch *d* is opened, thereby giving the circuit shown by the full lines in Fig. 32 (*b*), the circuits shown by dotted lines being now open at the switch *d*. The pilot lamp *i* is now dark. The starting resistance *k* prevents the current from rising to an excessive strength and the drop across this resistance allows the pilot lamp to light until the starting switch *d* is opened.

79. The source of alternating current is an alternator *D*, which supplies the rectifier with current through an ordinary static transformer that steps the line or alternator voltage, which may be 1,000 or more volts, down to 220 or 110 volts. Consider, now, the conditions when the terminal *g* of the supply transformer is positive; the anode *a* is then positive and current flows through *g*–*a*–*b*–*e*–*j*–battery–*j*′–*y*–*m*–*g*′, as shown by the solid wavy arrows. As the potential falls below a value sufficient to maintain the arc, the inductive resistance *m*, whose inductance has been heretofore opposing the increasing current, and storing up energy in its magnetic field, now produces a current that discharges through *a*′–*b*–*e*–*j*–battery–*j*′–*y*, and thus maintains the arc while the supply alternating electromotive force passes through zero, reverses and builds up in the opposite direction to such a value as to cause *a*′ to have a sufficiently positive value to maintain the arc between it and the cathode *b* and cause a current impulse to pass through *g*′–*a*′–*b*–*e*–*j*–battery –*j*′–*y*–*m*′–*g*, as shown by the dotted wavy arrows. The inductive resistance *m*′ is now charging and a moment later, as this alternating impulse decreases in potential, discharges through *a*–*b*–*e*–*j*–battery–*j*′–*y* and maintains the arc until the alternating current again reverses and flows through *g–a–b–e–j*–battery–*j′–m–g′*.

80. When the rectifier is used for operating lamps or some other kind of a dead load, no storage battery may be available for starting purposes. In such a case, the switch *w* will be closed in the position *w′*, Fig. 32 (*a*), thereby allowing the tube to be started with alternating current. The

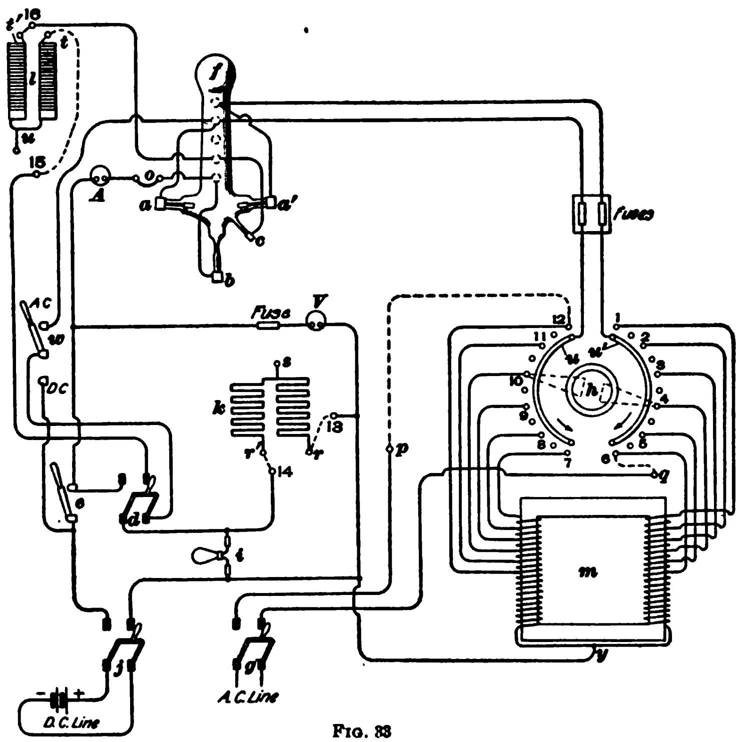


FIG. 33

load, whatever it may be, will occupy the position now held by the storage battery. The rectifier is started in the same way as before, but in this case the starting current is alternating and flows through *g–w′–d′–l–c–b–d–i* and *k* in parallel–*y–m–g′*, Fig. 32 (*a*).

81. Complete Diagram of Connections.—A diagram of connections of the apparatus as actually used is shown in

TABLE II

Direct-Current Voltage	Connections for			
	Starting Resistance	Starting Anode Resistance	Reactance for	
			220-Volt Alternating Current	110-Volt Alternating Current
80 to 120	*13* to *r* and *14* to *r'*	*15* to *t* and *16* to *t'*	*q* to *6* and *p* to *12*	
46 to 80	*13* to *s* and *14* to *r'*	*15* to *u* and *16* to *t'*	*q* to *1* and *p* to *7*	
30 to 46	*13* to *s* and *14* to *rr'*	*15* to *u* and *16* to *tt'*		*q* to *6* and *p* to *12*
16 to 30	*13* to *s* and *14* to *rr'*	*15* to *u* and *16* to *tt'*		*q* to *1* and *p* to *7*

Fig. 33, in which *o* is a circuit-breaker or cut-out; *A*, the direct-current ammeter; *V*, the direct-current voltmeter; *d*, the starting switch; *e*, the load switch; *f*, the tube; *g*, the alternating-current circuit switch; *i*, the pilot lamp, which serves as a signal to warn the operator when to open the starting switch; *j*, the direct-current circuit switch; *l*, the starting anode resistance; *k*, the starting resistance, which is in parallel with the pilot lamp *i*; *m*, a compensating reactance that is connected directly across the alternating-current supply circuit and divided into several sections with leads running to a dial switch *h*; and *w*, a single-pole, double-throw switch on the back of the panel and used only when it is desired to change the connections so that the rectifier can be started on either direct or alternating current.

82. Voltage Transformation.—The connections of the resistances and reactances depend on the direct-current voltage desired and the alternating-current voltage available. The connections are as given in Table II. It will be noticed that for the higher direct-current voltages the two halves of both the starting resistance and the starting-anode resistance are connected in series, and for the lower voltages, but one-half of each is used or the two halves are connected in parallel.

Assuming that forty-four storage-battery cells requiring approximately 2 volts each, or a total of about 88 volts, are to be charged by such a rectifier operating on 220 volts alternating current, the connections will be as given in the table, namely *13* to *r*, *14* to *r'*, *15* to *t*, *16* to *t'*, *q* to *6*, and *p* to *12*, as shown by dotted connections in Fig. 33.

83. Starting the Rectifier.—The single-pole double-throw switch *w* on the back of the board is closed in the direct-current position *D C* and allowed to remain there as long as the rectifier is used for charging storage batteries. With this switch closed in the direct-current position, the rectifier is started by closing the circuit-breaker *o*, the starting switch *d*, and the circuit switches *g* and *j* and giving the tube a slight shake, thereby connecting the electrodes *b*, *c* together by means of the mercury. Current then flows from the positive terminal of the battery through switches *j*, *w*, and *d*–*15*–starting anode resistance *l*–*16*–anode *c*–mercury arc–cathode *b*–circuit-breaker *o*–ammeter *A*–switch *d*–$\left\{\begin{array}{c}\text{pilot lamp } i\\ 14\text{–starting resistance } k\text{–}13\end{array}\right\}$–switch *j*–negative terminal of the storage battery. As soon as the tube comes to rest, the mercury stream connecting anode *c* to cathode *b* breaks and the arc starts.

The current through the tube soon warms it and then the load switch *e* is closed, thereby connecting the positive terminal of the storage battery directly to the cathode *b*. If the rectifier voltage is lower than the battery voltage, the arc will go out at once because the current tends to flow from the battery to the cathode *b* and thence to one of the anodes *a* or *a'*, but the arc will not carry current in that direction. If the arc goes out, switch *g* and then the switch *e* should be opened, the dial switch moved one step counterclockwise, and the arc started again as before. This process should be repeated until the arc continues to burn when the load switch is closed. As the dial switch contains five steps and as the whole switch is capable of producing a change of 40 volts (120 to 80), each step causes a change of about 8 volts. If 88 volts are needed, it is evident that the dial switch must be on the second step from the lowest position. This gives about 96 volts across the direct-current circuit—enough in excess of the battery voltage to force a charging current through the battery.

84. As soon as the rectifier is operating properly, the starting switch *d* should be opened, thereby cutting out the starting resistance *k* and the pilot lamp *i*, which then goes out; and also opening the circuit containing the starting anode resistance *l*. When the rectifier is operating properly on alternating current, the path of the current may be traced as follows: Assuming an instant when point *p* in the alternating-current circuit is positive, current flows through *p*–*12*–two sections of the reactance to *10*–contact arm on the dial switch–circular ring *u*–anode *a*–arc to cathode *b*–circuit-breaker *o*–ammeter *A*–load switch *e*–direct-current line switch *j*–positive terminal of battery–negative terminal of battery–direct-current circuit switch *j*–middle, or neutral, point *y* of the compensating reactance *m*–one portion of the reactance to the point *6*–*q*–other side of alternating-current circuit. During the next half cycle, the direction of the alternating current through the reactance is reversed and it flows from anode *a′* to cathode *b*, otherwise the circuit is similar to that just traced. The current always flows from one or the other of the two anodes *a*, *a′* to cathode *b* and through the battery as a direct current back to the middle point *y* of the reactance.

85. The strength of the direct current can be regulated by turning the dial switch; for example, turning the switch until the arm rests on contacts *3* and *9* instead of *4* and *10* will raise the voltage in the direct-current circuit about 8 volts and thus increase the current proportionately.

Until thoroughly familiar with the operation of the rectifier, it is best to place the dial switch on the lowest-reading points, that is, on *6* and *12*, when starting. When the required voltage and current are known and the action of the rectifier well understood, the dial switch can be placed on the proper points before trying to start.

When starting the rectifier on a load other than storage batteries, the switch *w* is closed in the alternating-current position *A C*. The process of starting is similar to that already described.

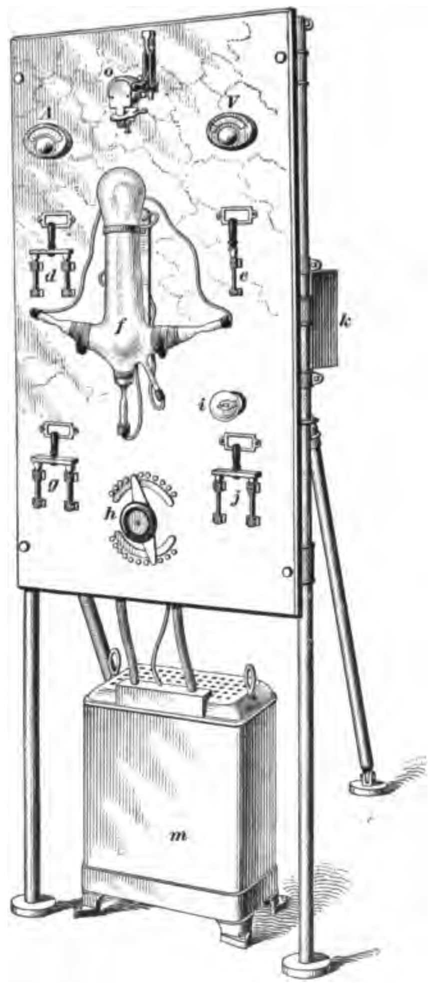


Fig. 34

86. The General Electric mercury-arc rectifier, as built for commercial use, consists of a panel, tube, holder, and compensating reactances. As far as practicable the same reference letters are used as in the preceding figure.

The **panel** for a 30-ampere, 115-volt, single-phase rectifier with the various devices assembled thereon is shown in Fig. 34. It occupies a floor space of 24 in. × 18 in.; and when mounted on its frame, the top of the panel stands 76 inches above the floor. On the front of the board are mounted a circuit-breaker *o*, a direct-current ammeter *A*, a direct-current voltmeter *V*, a starting switch *d*, a load switch *e*, a tube *f* and its holder, an alternating-current line switch *g*, a dial switch *h* for adjusting the reactance coil, which is contained in the case *m*, a pilot lamp *i*, and a direct-current switch *j*.

The reactance may be mounted on the back of the panel or may stand on the floor underneath as shown at *m*, Fig. 34. Special reactances for smoothing out nearly all the direct-current pulsations are furnished with rectifiers for telephone and telegraph work.

On the back of the panel is mounted the single-pole, double-throw switch for changing connections so that the rectifier can be started on either direct or alternating current, also the starting-anode resistance and fuses for protecting the circuits. The starting resistance is mounted at *k* on one of the pipe supports for the panel.

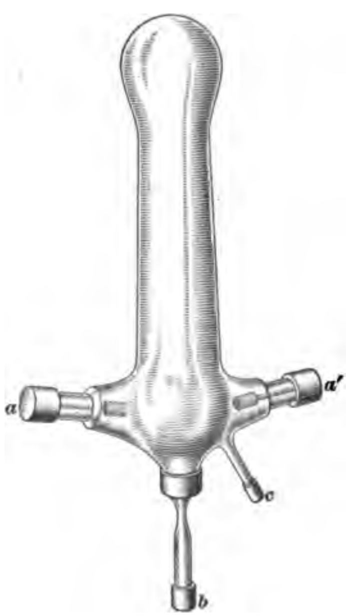


FIG. 35

87. The **tube**, which is an exhausted glass vessel, is shown in Fig. 35. It has two anodes, to which connections are made through the metal caps *a*, *a'*; a cathode connected to cap *b*; and a starting anode connected to cap *c*.

The **tube holder** consists of a supporting frame so arranged that the tube may be tipped sidewise, but it returns to its normal position when released. Terminals, which are connected by flexible wires with the tube electrodes, are mounted on the panel.

88. If the rectifier is used for charging storage batteries, the polarity of the connections must be correct before the apparatus is started, else the tube may be ruined. The panel must be kept in an upright position in order that the mercury may remain in the two lower electrodes. The tube must be handled very carefully and the seals must not be broken or damaged when installing or connecting. When stopping the charging of a battery, the alternating-current circuit switch should be opened first. On another type of rectifier, the tube is placed on the back of the panel, where it is less liable to injury and a handle attached to the tube holder extends through the board to the front for tilting the tube.

89. The rectifying devices thus far described are for direct-current outputs not exceeding 30 amperes at not over 120 volts, the alternating voltage being not over 220 volts. Such converters have been developed primarily to meet the demand for simple and easily operated storage-battery charging sets. Tubes for larger direct currents have been built, but they are not very extensively used. The larger the current output, the larger must be the tube. Experimental tubes have been built for as high as 100 amperes.

The General Electric rectifiers are designed for a frequency of 60 cycles, but they will operate practically as well on any other frequency from 25 to 140. The Cooper-Hewitt converters will also operate satisfactorily over a wide range of frequency.

90. Efficiency of Rectifiers.—The voltage required to force the current through the tubes in commercial use for charging storage batteries is practically 15 volts at all loads. The efficiency must, therefore, depend on the voltage used. For example, if the rectifier is delivering 80 volts, a loss of 15 volts in the tube is $18\frac{3}{4}$ per cent., while if it is delivering 120 volts, a loss of 15 volts is only $12\frac{1}{2}$ per cent. There are some additional losses, so that as a matter of fact, tests on the General Electric 30-ampere rectifier operating on a 220-volt, 60-cycle, alternating-current circuit showed the efficiency to be over 75 per cent. from one-quarter to full load when giving 80 volts in the direct-current circuit, and over 80 per cent. when giving 112 volts in the direct-current circuit. The efficiency is very nearly as high at one-quarter load as at full load.

91. Voltage Regulation.—The regulation from maximum to minimum current was 6 to 8 per cent., that is, as the current fell from its highest to its lowest value, the voltage rose 6 to 8 per cent. This is a good condition for storage-battery charging because the counter electromotive force of a battery rises as the charging proceeds and this tends to reduce the current; but as the current tends to decrease, the voltage of the rectifier increases and thus the two conditions tend to balance each other. The power factor of the rectifier during the efficiency test referred to averaged about 90 per cent.

92. The alternating electromotive force that can be rectified is practically unlimited. Doctor Steinmetz has stated that it is not probable that any of the high voltages now coming into use for power or lighting purposes will exceed the capacity of a properly designed rectifier with a good vacuum. A small current has been rectified with an alternating difference of potential of 36,000 volts applied to the rectifier terminals. Numerous tests have been made with an alternating difference of potential of 24,000 to 25,000 volts giving about 60 kilowatts at 10,000 volts in the direct-current circuit with a tube slightly larger than can easily be put in a coat pocket. Rectifiers are in regular use supplying direct current for arc lighting on the streets of Schenectady, New York, giving 6.6 amperes at 2,000 volts. They are also used for the same purpose in other cities.

WIRING AND EFFICIENCY OF POWER PLANT

THE POWER BOARD

93. The **power board** is usually constructed of a number of marble or oiled slate slabs, mounted on angle-iron frames, which are securely fastened to the floor and braced by iron pieces from the wall in the rear. The slabs are cut to a convenient size, ordinarily 6 ft. × 3 ft. × 1¼ in., or thereabouts, and carry the proper equipment for rapid and convenient handling of all power circuits. For large exchanges, four panels arranged as follows will be found practicable:

94. Panel No. 1, or starting panel, carries the motor switches and enclosed fuses for the primary power circuits, the starting boxes or compensators, an ammeter, and a two-way ammeter switch.

Panel No. 2, or the battery panel, carries the adjustable field rheostats for the generators, an underload and overload circuit-breaker connected in the charging circuit, a voltmeter and six-point switch and generally four double-pole, double-throw knife switches, for throwing either battery on the charge or discharge circuit, for throwing either generator into service, or for floating either or both batteries on the system while being charged; and in cases of emergency for throwing the generator directly on the discharge circuit with both batteries cut out.

Panel No. 3 carries the various knife switches for manipulating the signaling circuits, fuse bars for fusing the various signaling current leads to the switchboard positions and lamp resistances for the same, if such are used; and a low-reading voltmeter with two multiple-contact switches for voltage readings on the individual cells of the two storage batteries.

Panel No. 4 carries the various battery, fuse, and terminal bars for the power leads to the switchboard and relay bays and an ammeter with a multiple-contact switch for reading the discharge on the various circuits.

In addition to these, each panel has mounted in the upper center a single lamp bracket with incandescent lamp and half shade for illumination.

THE CONDUIT SYSTEM

95. All power wires and cables between the power board and machines and the batteries should, where feasible, be run in iron-armored conduits. The conduits should be brought up against the wall in the rear of the power board to a height of at least 6 feet above the floor, where they are bent over toward the board, so as to line up nicely, thus bringing all leads in at the top of the switchboard, whence they are taken down to the proper terminals. This arrangement leaves the space back of the board clear and open, allows plenty of headroom, and presents a clean and finished appearance.

From the wall in the rear of the board, the conduits are laid in or under the floor to the machine pier and battery terminals. This machine pier should be built hollow. It may be constructed either as a rectangular brick well, covered on top with slate or marble slabs, or with a heavy iron framework completely covered with marble slabs bolted to the iron. With a hollow pier, the conduits may be brought straight out from the power board without making any awkward crossings, the conduits all having outlets in the well, where the conductors may be crossed in flexible duct over to the proper positions for connecting to the machine terminals. Means should always be provided for getting into the pier, so that any change in wiring may be easily made.

A very neat and highly finished appearance is imparted to the work by carrying the conductors up through the slabs in polished brass or copper risers so bent as to deliver the conductors within a few inches of the terminals. Where metallic conduit is used the two or more wires constituting any alternating-current circuit should be drawn in the same conduit to prevent excessive heating of the metal conduit by induction and an excessive drop of voltage in the wiring itself due to self-induction.

EFFICIENCY OF TELEPHONE POWER PLANT

96. Efficiency is the ratio of the total energy delivered to the plant to the energy delivered by it. Power is usually derived from a commercial electrical circuit or developed by a steam engine, gas engine, or water motor installed by the telephone company. The combined efficiency of a motor and generator varies with the size of the machine, as there is a certain amount of friction to be overcome, and the friction loss does not increase as rapidly as the output of the machine.

The combined efficiency of motor generators at the full rated load, according to B. D. Willis in the American Telephone Journal, will vary from 55 per cent. in machines of 1 kilowatt output up to 72 per cent. in machines of 18 kilowatts output. The former corresponds to about 75 per cent. efficiency in the motor and the same in the generator, and the latter to 85 per cent. in each machine. Sixty-six per cent. is a fair average for the combined efficiency of motor and generator of 4 kilowatts at the full rated load; the efficiency decreases as the load drops off, to 50 per cent. at one-third full load.

The efficiency of the storage battery is a quantity that varies with the rate of charge and discharge. The combined efficiency of the motor generator being taken at 66 per cent. and that of the battery at 80 per cent., gives an efficiency of (80 per cent. of 66 per cent.) 52.8 per cent. from primary power to battery terminals exclusive of the loss in the conductors, which may be taken as 2 per cent., thereby bringing the combined efficiency of motor generator, battery, and leads down to $.98 \times 52.8 = 51.7$ per cent.

97. The use of a gas engine, as prime mover, belted to a direct-current charging generator gives the following results: Gas engines of 3 horsepower or over will develop 1 horsepower for 1 hour on 1 pint of 72° gasoline or 20 cubic feet of coal gas. Allowing an efficiency of 75 per cent. for the belted generator, and with gasoline at 16 cents per gallon, gives 3.39 cents per kilowatt-hour. With coal gas at $1 per 1,000 cubic feet, the cost is 3.5 cents per kilowatt-hour. These figures are for current at the charging voltage.

Rates charged for electric current vary from 5 cents to 20 cents per kilowatt-hour, depending on whether competitive plants exist and on the quantity of electricity that is purchased. At present, the Edison companies, particularly in the larger cities, make a sliding scale of prices whereby large consumers can obtain considerable quantities of electricity at exceedingly favorable rates.

For operating a motor generator with current costing 15 cents per kilowatt-hour the cost is $22\frac{8}{11}$ cents per kilowatt-hour for charging current; at $12\frac{1}{2}$ cents per kilowatt-hour, the cost is 19 cents per kilowatt-hour for charging current; at 10 cents per kilowatt-hour, the cost is 15.1 cents per kilowatt-hour for charging current.

98. Summing up, we have the following data:

Charging From a 110-Volt Street Circuit	
Charging With a Motor Generator	**Charging Through a Resistance**
Motor-generator efficiency . . . . . . 66.0 per cent.	110-volt to 40-volt efficiency . . . . . . 40.2 per cent.
Battery efficiency . 80.0 per cent.	Battery efficiency . 80.0 per cent.
Loss in leads . . . 2.0 per cent.	Loss in leads . . . 2.0 per cent.
Combination efficiency . . . . . . 51.7 per cent.	Combination efficiency . . . . . . 31.5 per cent.
Cost per kilowatt-hour, of charging current at dynamo $22\frac{8}{11}$ to $15\frac{1}{10}$ ct.	Cost, per kilowatt-hour, of charging current at dynamo $37\frac{3}{10}$ to $24\frac{8}{10}$ ct.

When charging with a gasoline engine, the cost will be 3.39 cents and with a gas engine 3.5 cents per kilowatt-hour at the dynamo.

From the foregoing, the following conclusions are drawn: Current for the operation of the exchange costs about one-fourth as much when generated with a gas-engine dynamo outfit as when transformed from the average commercial circuit by means of a motor generator.

With the ordinary voltages used in telephone exchanges, it is seldom advisable to charge direct through a dead resistance to save the first cost of a generating machine. The motor generator delivers current direct to the switchboard at an efficiency of 66 per cent., while if the current is stored in the batteries and fed by them to the switchboard the efficiency drops to about 52 per cent.—a loss of 14 per cent.

99. Batteries should be of ample capacity and should be worked only between three-quarter charge and full charge. Charging machines should be of such size that they may be worked at full load for at least 8 hours each day—i. e., they should not be too large. Unfortunately, all these conditions cannot be met, as it is always necessary to provide for growth of an exchange; and while the capacity of the storage battery may be increased by the addition of plates the motor generator cannot so easily be altered, although it would without doubt pay to replace with larger machines every 3 or 4 years in case of phenomenal growth.

The current derived from the gas-engine-driven generator is much cheaper than the transformed commercial electric current; the ratio of cost is about one to four. However, it is difficult to charge a storage battery in a telephone system constantly when the charging current is being furnished by a dynamo driven by a gas engine, without causing more or less noise on the lines. Therefore, when a gas engine is used, there should be two batteries installed, being charged and discharged alternately.

The 14 per cent. lost by storing the energy in a storage battery, which process is necessary when a gas engine is used, is almost negligible in comparison with the gain in cost of operation from 15 to $3\frac{1}{2}$ cents per kilowatt-hour; on the other hand, the first cost of a gas engine is higher than the first cost of a motor. In exchanges having a gas-engine set and motor-generator set, the engine should be used as the regular power and the motor generator as a reserve.

It should be borne in mind that the foregoing considers only the question of economical operation, and that there are numerous considerations met with in practice that go to determine the better practice in each case.

INDEX

NOTE.—All items in this index refer first to the section and then to the page of the section. Thus, "Advantages of dynamos, §40, p2," means that advantages of dynamos will be found on page 2 of section 40.

B

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E