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Relays in the Bell System

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NOTE: Before they can converse people must either be brought together or virtually be brought into one another's presence by the telephone. Any telephone system must establish talking connections between its subscribers, and these connections must be built up, supervised and disconnected when desired. This work is accomplished by the use of relays of various kinds, and the speed and accuracy of service is largely dependent upon them. There are completed daily in the Bell System about 42,000,000 telephone calls. These involve the successful and accurate operation of over one and one-half billion contact connections daily.

Many kinds of relays are employed in the Bell System, varying from the simple electromagnetic drop to the sequence switch, the thermionic vacuum tube and the panel selector. Today a circuit connection between two subscribers served by manual exchanges in a large multi-office district involves about 21 relays. When these subscribers are served by machine switching offices, the number of relays in a local connection may be as great as 146. It not infrequently happens that in setting up a toll connection more than 300 relays are employed.

In the present paper the relay developments leading up to, and making possible the present communication system, are outlined with particular reference to electromagnetic relays. A few typical circuit applications are given with a discussion of the requirements imposed upon relays which influence their design. Several types of relays are illustrated and their distinctive features are described.

The subjects of relay design, manufacture and maintenance and also telegraph relays will be dealt with in future papers.

INTRODUCTION

IN the vast systems of networks which comprise the Bell System one of the most important and varied devices necessary for giving service is the relay. From its use in small numbers in telegraph circuits and as a "drop" in the early magneto switchboard it has come to be numbered by millions and varies in type from the simple electro-magnet which operates a single contact to the vacuum tube and the complete structure which effects an entire series of switching operations.

When a small number of stations is involved in a communicating system complete flexibility of connection may be obtained by means of simple relays controlling a small number of contacts. As the number of stations increases the number of switching operations becomes so great that the use of simple relays which control small numbers of contacts is not economical. The use of power driven selectors and sequence switches and electro-magnetically operated switches for completing a series of switching operations has therefore become necessary.

In present day systems the relay is as essential to a telephone conversation as the transmitter or receiver. Some idea of our dependence on the device may be had from a consideration of the numbers of simple relays involved in a typical connection. A circuit established between two subscribers served by manual exchanges in a multi-office district will involve 21 relays. When these subscribers are served by machine switching offices the number of relays

Fig. 1—Relays in a local manual office

involved in a local connection may be 146. When toll connections are involved even greater dependence is placed on relays to render service. A New York-San Francisco connection requires over 200 relays and very frequently connections are established which require more than 300 relays. The majority of these relays are normally available for doing their bit to provide telephone service to any one of a large number of subscribers. As a matter of fact, approximately 90 per cent of the millions of relays in the Bell System today are available for and may be called upon to serve any subscriber or user of the telephone.

A typical manual office serving 10,000 lines would have from 40,000 to 65,000 relays and their total combined pull if applied at one point would be sufficient to lift ten tons. In the larger machine switching offices there may be as many as 140,000 relays which require in some instances power plants capable of handling peak loads of 4,000 amperes at 48 volts.

Referring to Fig. 1, the space required for mounting some of the relays in an office will be seen. This is a picture taken in one of the New York offices which has over 60,000 relays and the racks shown contain about 22,000 of these. The covers have been removed from a number of the relays in the foreground. Instead of grouping the relays compactly as in a manual office it is the practice in machine switching offices to mount them in close association with the related apparatus units. This is illustrated by the photograph of sender circuit relays shown in Fig. 2.

Invention of the Electromagnet

Prior to 1820, the electro-magnetic structure, now known as a relay, was an impossibility because the scientific facts on which it is based had not been discovered. In the winter of that year, Oersted of Copenhagen established that a mechanical effect could be produced on a magnetized needle by a current of electricity. Oersted discovered that a magnetic needle would be deflected from its normal position when held parallel to a wire conveying an electrical current and that the deflection would be to the right or left, according to the direction of current flow. This discovery aroused such interest among scientists and philosophers that the best minds in Europe were engaged in speculation and experiment, so that further discoveries of great importance followed rapidly. Arago in Paris and Davy in London, working independently, soon observed that, if an electric current passed through a wire of copper or any other material, the wire had the power of inducing permanent magnetism in steel needles.

Oersted's discovery suggested to Schweiger that the mechanical effect on the magnetic needle would be increased if the current were made to pass several times around the needle. He made a coil, elliptical in shape, of insulated wire and suspended the magnetic

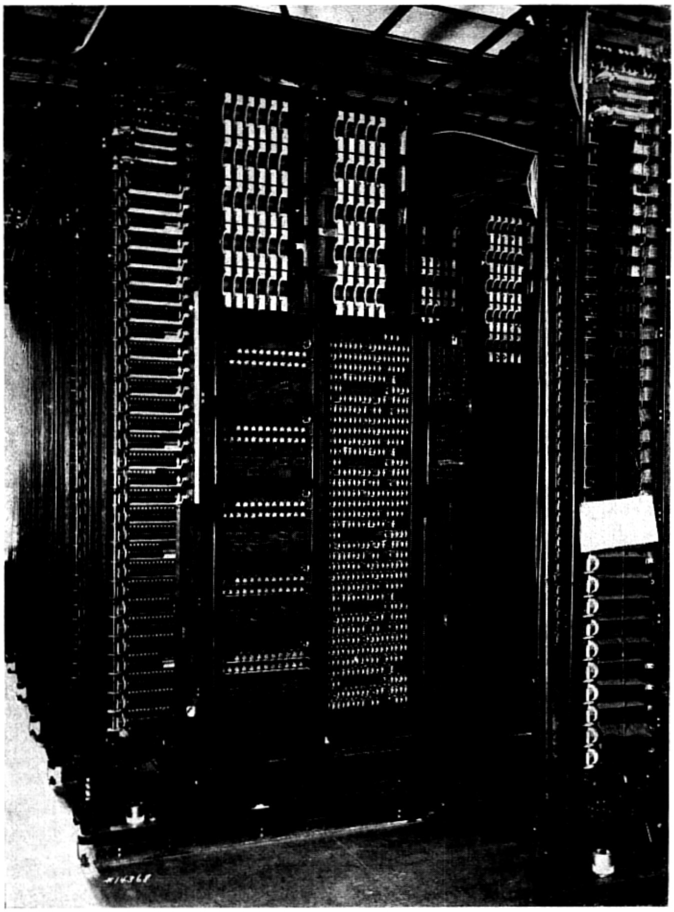


Fig. 2—Sender relay cabinet in machine switching office

needle within it. When current passed through the coil, the result was as he anticipated, and the device became known as Schweiger's multiplier.

Ampere, the brilliant French scientist, in seeking an explanation for Oersted's discovery, evolved an ingenious theory of the relation between electricity and magnetism. According to this theory, all magnetic phenomena result from the attraction or replulsion of electric currents supposed to exist in iron at right angles to the length of the bar, and all the phenomena of magnetism and electro-magnetism are thus referred to one principle—the action of electrical currents on one another. Among other things, he proposed a plan for the application of electro-magnetism to a system for transmitting intelligence. This system was to operate by the deflection of a number of needles at the receiving station by currents transmitted through long wires. By completing a circuit the needle was to be deflected and was to return to normal under the influence of the attraction of the earth when the circuit was opened. This proposed system of Ampere's was never reduced to practice, however.

All these discoveries and results were prior to 1823, and they resulted in the development of needle telegraph systems, which were at one time employed extensively in Europe. These systems utilized a coil of wire around a magnetic needle pivoted in the center and with a pointer attached to the needle, which was suspended over a dial. Deflections to the right or left signified letters and were produced by sending pulsations of one polarity, or alternations of both, as was required.

In 1824, Sturgeon, an Englishman, discovered that, if a current of electricity flows in a coil of wire surrounding a bar of annealed iron, the latter becomes a magnet, and when the current ceases, the iron loses its magnetism. Sturgeon bent an iron rod into the form of a horse-shoe and wound a coil of copper wire around it loosely, with wide intervals between the turns to prevent them from touching each other. Through this coil, he transmitted a current. The iron under the influence of this coil became magnetic and thus, the first electro-magnetic magnet, now known simply as the electro-magnet, was produced. This discovery of Sturgeon's is of great interest to the telephone and telegraph engineer, because it was the direct step which made the invention of the electro-magnetic relay possible.

In 1828, Henry, in America, after repeating the experiments of Oersted, Ampere, Sturgeon, and others and investigating the laws of the development of magnetism in soft iron by means of electrical currents, designed the most powerful electro-magnet that had ever been made. This he accomplished by associating Schweiger's multiplier with Oersted's magnet. For this purpose he wound 35 feet of silk insulated wire around a bent iron bar so as to cover its whole length with several thicknesses of wire.

First Telegraph Relays

In 1824, Morse utilized the electro-magnetic phenomenon, revealed by Sturgeon, and produced a telegraph system which was destined to be the basis of all modern systems of communication. The attenuation of the current from the sending to the receiving end of the circuit had limited the satisfactory transmission of signals. Morse overcame this difficulty by constructing an electro-magnet which would repeat or "relay" the transmitted signals to another circuit having an independent source of energy. The first electro-magnet or relay designed by Morse was a cumbersome structure weighing about 300 pounds, but it exerted a tremendous influence on the art of communication as it served as a stimulus for the development of the complex systems of the present day. When this relay was redesigned its weight was reduced to 70 lbs., but as the laws of electro-magnetism became more generally understood and new materials became available, such great changes occurred that the present telegraph relay weighs about 3 pounds, and one of the modern telephone relays of latest design weighs but 3.6 ounces.

The General Problem

The needs of the present day telephone and telegraph system have produced a multitude of devices but none of them is of greater importance than the relay, as it affords the means whereby the engineer may put ideas into practice. When the limitations of available relays prevent the satisfactory solution of a problem, requirements for new relays are outlined and their development is undertaken if a survey indicates that the advantages to be obtained warrant the expense.

This does not mean that compromises are not made in the matter of using standard designs, for in some instances, it would not be economical to design a new type. Frequently, a relay is required to meet certain conditions in the plant for which the demand will be comparatively limited, and it is obviously uneconomical to spend time and money developing a new type provided a standard structure can be adapted to meet the requirements with sufficient precision.

Just as the art of defense in warfare has matched the art of offense, the art of relay design has kept pace with the demands of the circuit engineer. Relays are now required to operate on direct, and pulsating current, and also on alternating current throughout the entire range of frequencies which are used in communication. There are fast relays, slow relays, polarized, high impedance, low impedance and so on. Consequently, a relay designed for one purpose may be wholly unfit for any other use. On this account, as the telephone art has grown, new conditions and new requirements have resulted in the development and manufacture of a large number of relays. At first, this undoubtedly followed previously established precedents, so that new forms were brought into existence which fulfilled immediate needs, but did not receive much consideration from the standpoint of economy, standardization or consistency of design.

At the present time, the Western Electric Company manufactures for the Bell System about 100 types of simple electro-magnetic relays. These types are subdivided into about 3,500 kinds, which differ in minor ways, such as windings and contact arrangements. In 1921, the Western Electric Company produced over 4,800,000 of these relays. These figures serve to indicate the economic importance of the relay in the present day system but do not give any adequate conception of the dependence of the communication network on relays of all types.

From a design standpoint it is possible, as has been pointed out, to attain practically any desired result in an electric circuit, subject of course to certain limitations as to time, and provided no limitations as to economic application are to be met. The methods and means for securing the desired operations involve the use of relays of various types and designs, and may lead to new developments which are obviously not economical. The relay may be called upon to perform a single function, necessitating the opening or closing of a single contact, or it may be required to effect a complicated series of transfers or circuit changes. Its operation may necessitate an accurate synchronizing with other circuit operations involving a time lag in its operation or release, and other requirements as to impedance, power, etc., may be imposed. It frequently happens that the conditions imposed by circuit requirements necessitate a choice between new features of relay design and a complication of the circuit to overcome limitations in existing types of relays.

The economic considerations which govern the final application of circuits in the telephone system are, to a large extent, dependent on the costs and performances of the various types of apparatus, particularly the relays. Frequently, there may be a number of possible methods of accomplishing a given result in an electric circuit and the most economical method is, of course, desired. This does not necessarily indicate the least number of relays or the cheapest but rather the most economical combination, taking into account reliability of circuit operation and its effect on service, cost of equipment and cost of operation and maintenance. The more complicated circuit or the one necessitating additional equipment may be sufficienty more reliable to justify its use.

In considering the application of relays in any telephone circuit, a given problem is usually presented and the various possible methods of accomplishing the desired end are considered. These methods may involve combinations of relays or of relay parts which do not exist and may even involve combinations which are entirely impractical or uneconomical of application. Any simplifications which may be effected are considered and in case the design of any apparatus may effect appreciable savings in the circuit or otherwise appear justifiable, this may be undertaken. Such requirements on relay design are, of course, subordinated to any general design considerations, such as relay structure, etc., which may be governing from the standpoint of the economic production of the relays themselves.

A few considerations which influence the selection of relays and which are very closely associated with the fundamental relay design may be considered from the standpoint of their effect on telephone circuits and their application in the field. It would, of course, be impossible within the scope of this paper to describe all the relay applications in modern telephone practice, but a discussion of the relay requirements for a few typical cases will serve to illustrate the principles involved. While the first relays used in the telephone system were telegraph relays adapted for use in signaling, the vast majority of relays now in use in the Bell System are designed primarily for telephone circuits. The requirements are usually quite different, particularly as regards the energy available for operation, the speed of operation and reliability of contacts and in most cases the cost.

Early Telephone Relays

In the first telephone switchboard for commercial service which was installed in 1878, the electro-magnetic devices consisted of a telegraph relay and an annunciator for each subscriber's line, and a call bell common to all lines. Of these three the telegraph relay was the largest and most costly, so the desirability of reducing the number required and of providing a smaller and cheaper apparatus unit was apparent. Changes were soon made in the magneto system that removed the relay from the subscriber's line and associated each relay with a group of lines for supervisory purposes. In the early switchboard, patented in 1879, from which the standard switchboard was developed, a modified telegraph relay appeared as a clearing out relay to control a clearing out drop. This modified telegraph relay is shown in Fig. 3 and is of particular interest as representing the first step in the development of the telephone relay.

In the magneto systems the indicator or drop was of the first importance, so its development was rapid. It was finally arranged in one extensively used system with two coils, which were known as

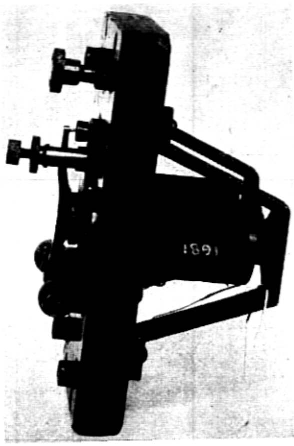


Fig. 3—Early telegraph relay used as telephone drop

the line coil and the restoring coil. The magneto current from the subscriber's station energized the line coil to drop a shutter which was restored through the agency of the restoring coil when the operator inserted a plug in the associated jack. The early development of the drop undoubtedly influenced the forms of relay structures which were developed a little later. The analogy between the line and restoring coils of the magneto system and the line and cutoff relays of the common battery system is very close. In the latter the current over the subscriber's loop energizes the line relay which lights the line lamp. The insertion of the plug in the subscriber's jack energizes the cutoff relay which opens the circuit through the line relay and thus extinguishes the light. In addition, the line and cutoff relays are assembled on a common mounting plate, forming an apparatus unit, although they are not parts of the same structure as were the corresponding coils of the drop.

The early telephone relays resembled more closely in construction and form the early drop than they did the telegraph relay, although the influence of design work on the telegraph relay appears in the development of later types of telephone relays. The early telephone relay shown in Fig. 4 has little relation with the modified telegraph relay of Fig. 3. It is much smaller and lighter than the first relay and, in addition, there is a distinctive structural change in that the armature is suspended by a reed hinge.

At this time the limiting conditions controlling the operation of either telephone circuits or the apparatus in them had not been

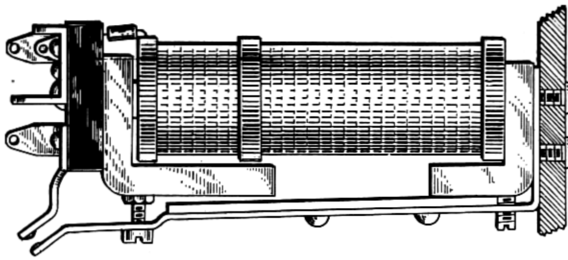


Fig. 4—Early telephone drop relay

established with much precision, so that the requirement for a relay was, roughly, that it should do the work required and any arrangement more sensitive and reliable than a previous arrangement was an improvement. The principle of the reed hinge for an armature support was sound, in that it provided for a good magnetic circuit and an easy means for close air gap adjustment and it is now used extensively with relays of the latest design.

Line, Cutoff and Supervisory Relays

When the common battery system was developed, however, it was found that the reed hinge relay was not capable of meeting the additional requirements imposed by the new system. The common battery cord circuit originally suggested is shown in Fig. 5. It is apparent that the relay shown in the diagram must indicate positively to the operator the position of the switch hook in the substation set and must respond to the motion of the switch hook if the subscriber moves the hook up and down to interrupt the circuit. In addition, as this relay is in the transmission circuit it must not introduce objectionable transmission losses. The reed hinge relay could not meet these additional requirements, and accordingly a new relay was designed especially for the common battery system that was the most important single factor in making the new system possible. In order to obtain an armature that would respond quickly to any change in the holding magnetic force all forms of support for the armature were rejected. The relay developed is shown in Fig. 6

and was first used in the common battery board installed in Worcester, Mass., in 1896.

This relay consists of a tubular magnet with an iron disc armature in the form of a truncated cone. This disc is brought to an edge at its periphery and rests in an annular groove in the cap. When the armature operates, it closes against an insulated contact stud

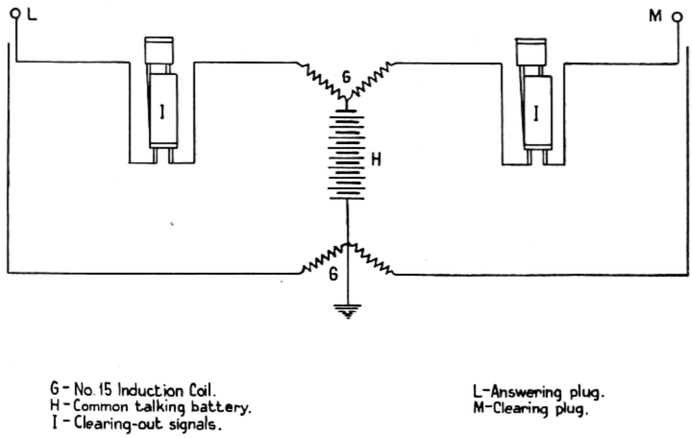


Fig. 5—Early common battery cord circuit

projecting from the core and when released drops away from the core by gravity and rests against a stud projecting from the end of the cap which provides the adjusting means for regulating the armature air gap. As the contacts of this relay were enclosed in the case, they were protected from dust and this arrangement proved so desir-

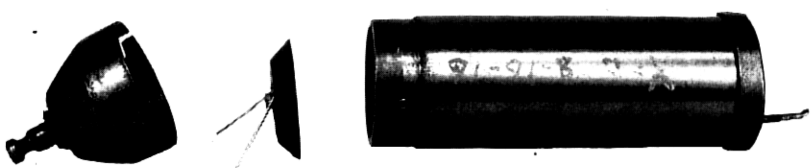


Fig. 6—Early line relay

able that it has been an accepted feature of nearly all relay designs that have followed. This arrangement had the disadvantage, however, of not providing a means for determining the value of the armature air gap or the contact separation. This condition was improved in the next design which is shown in Fig. 7 by making the cap longer and associating the armature with the magnet structure instead of the cap. The knife edge armature hinge and the gravity control of the free armature were the fundamental principles retained in the new design.

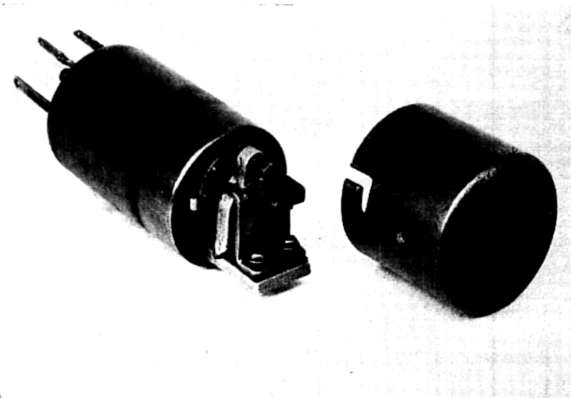


Fig. 7—Early supervisory relay

The tubular shield for the return magnetic path was abandoned for a return pole piece which provided a means for mounting both the armature and the air gap adjusting screw. The cover protected the contacts from dust but it was soon found that magnetic interference between adjacent relays was responsible for both faults in

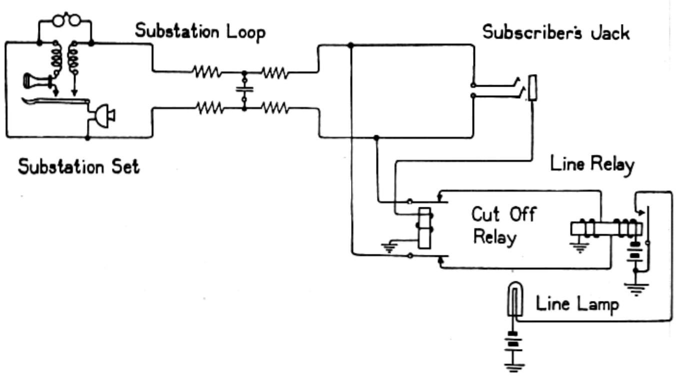


Fig. 8—Line and cutoff relay circuit

operation and crosstalk, so the cover had to meet the additional requirement of being an effective shield. This was eventually accomplished to best advantage by making the cover of copper.

As has been shown two general types of structures were now available for common battery system relays. In one, the armature was suspended by a reed under tension to provide a restoring force. In the other, which was more sensitive but less capable of carrying a heavy spring load, the armature operated in a knife edge hinge and the restoring force was gravity.

Each subscriber's line required a l'ne relay for lighting a lamp when the substation receiver was removed from the hook, a cutoff relay for removing the line relay from the circuit when the operator responded, and a supervisory relay for controlling lamp signals to inform the

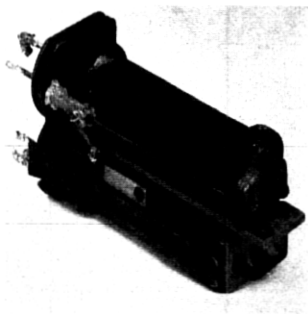


Fig. 9—Line and cutoff relays

operator whether the substation switch hook contacts were open or closed. The circuit arrangement for the line and cutoff relays is shown schematically in Fig. 8.

The rapid extension of telephone service necessitated establishing standards of excellence, and definite requirements for apparatus units were gradually formulated. At first, the available relays were adapted as closely as possible to existing conditions, but as requirements became definitely established, relays were designed specifically to meet them and careful consideration was given to manufacturing costs, mounting space, maintenance expense and all other factors of economic importance. By 1910 several million of the line and cutoff relays shown in Fig. 9 and the supervisory relay of Fig. 7 were in service.

The cutoff relay armature was of the reed hinge type, while both the line and supervisory relays were assembled with the more sensitive knife edge armature. The line relay was eventually wound with 12,000 minimum turns to a resistance of 2000 ohms ± 5 per cent. and after considerable service experience requirements were formulated for a line relay which would be a satisfactory substitute. These requirements were as follows:

(1) Battery potential, 20–28 volts.

(2) Maximum line resistance, including subscriber's station, 1000 ohms.

(3) Resistance across line to represent maximum insulation leakage, 10,000 ohms.

(4) Winding of relay 12,000 turns, 2000 ohms ± 5 per cent.

(5) Minimum operating ampere turns =

$$\frac{\text{Turns} \times \text{Minimum Voltage}}{\text{Maximum Resistance}} = \frac{12{,}000 \times 20}{1000 + 2100} = 77.4.$$

(6) Maximum releasing ampere turns =

$$\frac{\text{Turns} \times \text{Maximum Voltage}}{\text{Leak Resistance} + \text{Minimum Relay Resistance}} = \frac{12{,}000 \times 28}{10{,}000 + 1900} = 28.2.$$

Reference to the circuit will show that the line relay must release on a low resistance loop in case the subscriber flashes the line lamp to attract the operator's attention. Due to residual magnetic effects, a relay does not release after operation on short loops over which the operating current is high as quickly as it does after operating on long loops, with a lower current in the winding. It is, therefore, necessary to specify the maximum ampere turns the line relay may receive and adjust it to release immediately afterward with the maximum leak across the line.

(7) Maximum ampere turns $= \frac{12{,}000 \times 28}{1900} = 176.8.$

In addition:

(a) The relay must close one set of contacts which controls a signal lamp as shown in the circuit.

(b) Contacts must carry the energy for lighting the lamp without undue sparking, sticking or wear.

(c) The relay must operate reliably on 77.4 ampere turns.

(d) The relay must release on 28.2 ampere turns immediately after operating on 176.8 ampere turns.

(e) As there is a constant potential between windings, the coil must be protected from corrosion, so the materials chosen for the construction of the relay must not contain substances which tend to encourage or assist electrolytic action.

It was found that the line relay introduced high maintenance charges because of the knife edge armature hinge and the close adjustment required. The armature being comparatively light in weight, a slight amount of dust or corrosion in the armature slot frequently made the contact resistance in the slot so high that the line lamp would fail to light.

The supervisory relay in the cord circuit also introduces maintenance charges for the same reason. It had to meet the same requirements as the line relay but, in addition, it required a crosstalk proof cover that would also adequately protect the contacts from dust.

The solution of this problem was very difficult because the only means of obtaining relays of increased sensitivity or greater operating range was to make mechanical refinements, which would increase manufacturing costs quite out of proportion to the advantages obtained, to discover new magnetic materials of higher permeability at low flux densities and with a lower remanence characteristic or to develop an entirely new relay structure. To obtain any advantage from the development of a new structure built from the same magnetic materials, it would be necessary to design it in such a manner as would enable the engineer to obtain the proportion of copper and iron required for maximum efficiency, greatest economy, extreme sensitivity, maximum operating load or any other specific requirement which was the controlling factor of a particular design. Analytical studies had shown that smaller relays with less iron could be substituted for those in use but such a change could not be made without increasing manufacturing costs because a reduction in core diameters would increase breakage during manufacture as well as entail a greater cost of handling the smaller structures.

The Flat Type Relay

An analysis of the manufacturing costs had shown labor costs to be greater than material costs in the production of relays so that any changes which would result in large savings would have to be of such a nature as to reduce labor charges. This could be accomplished only by changing production methods which had already been established with reference to greatest economy in manufacture considering the volume of production. The demand for relays, however, was increasing steadily and it was evident that with increased production the prevailing manufacturing methods would not continue to be economical. With other pieces of apparatus manufactured in large quantities, it had been found that production costs could be reduced to a minimum by designing a unit which could be assembled from interchangeable parts stamped out by a punch press and formed in bending fixtures to the desired shapes. To accomplish this for relays, it was first necessary to conceive of an entirely new type of structure composed of parts that could be made easily by the punch press method, and it was then necessary to determine the modifications which must be made in such a structure, in order that the proportions of copper and iron required for any one of a number of design conditions might be obtained.

The design of a punched type relay was first attempted in an effort to find a better relay than the line relay, and with the intention,

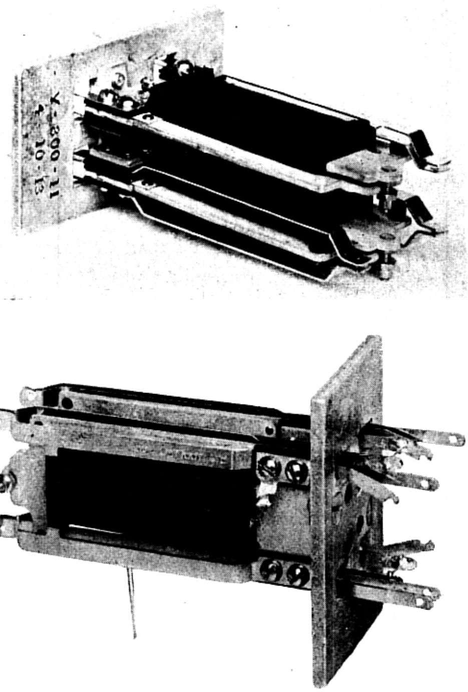


Fig. 10—First punched frame relay

if the design were successful, of employing the same structure with a different winding as a substitute for the cutoff relay. It will be remembered that the line relay had a gravity type armature, whereas the cutoff relay had a reed-hinged armature so the effort to replace two relays of different construction by a single structure was the beginning of an attempt to standardize a type of relay structure which could be used universally.

After some years of development work, a commercial design was completed and punched-type relays were produced as substitutes for the line and cutoff relays. The structures were exactly alike, the relays differing only in windings and in the number of contact-carrying springs with which they were equipped. The development of these relays resulted in a price reduction for the line and cutoff relay unit of about 25 per cent. and a reduction in the mounting space occupied of 40 per cent. The flat core and the manner of suspending the armature on a reed hinge, in order to present the armature to the pole face, were the distinctive features of the new

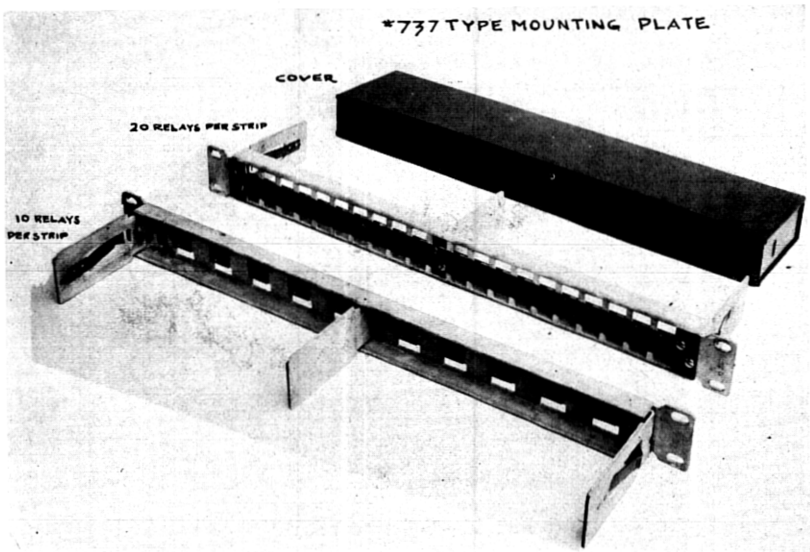


Fig. 11—Mounting plate for strip of punched frame relays

relay structure, as will be seen by referring to Fig. 10, in which the line and cutoff relays may be distinguished because they are equipped with a single pair and a double pair of contacts, respectively. The method of mounting the relays and protecting a strip of 20 with a common dust cover is shown in Fig. 11 from which it will be observed that the mounting plate, all the mounting details and the cover, are products of the punch press.

When it was seen that the development of the new line and cutoff relays was proceeding favorably, development work was also begun on a similar punched-type substitute for the round core supervisory relay which has previously been described. It was known that the quantity of iron in the supervisory relay was greatly in excess of the amount required, as the core flux density was far below saturation when the relay operated over the longer substation loops and the magnetizing ampere turns were reduced by the high resistance of the loop. Advantage was taken of silicon steel, a new material at that time, which had a higher permeability than Norway iron and less pronounced residual magnetic effects, after saturation. In addition, it had greater tensile strength and, since the new type relay core was rectangular in shape and therefore had the stiffness of a beam, it was possible to make a core of silicon steel of such small cross section that the flux density was much higher with a small

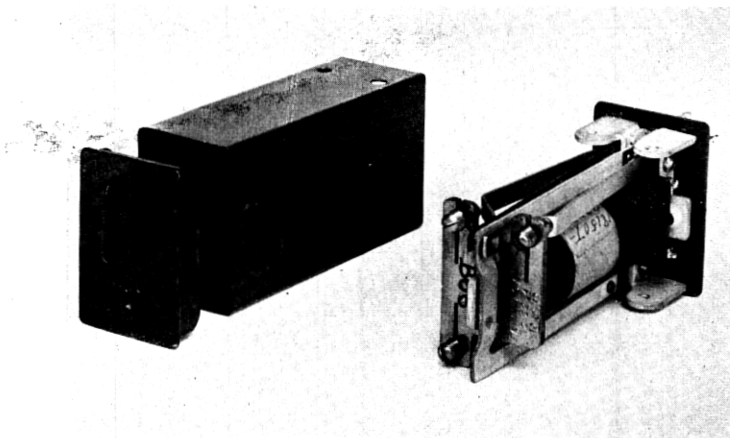
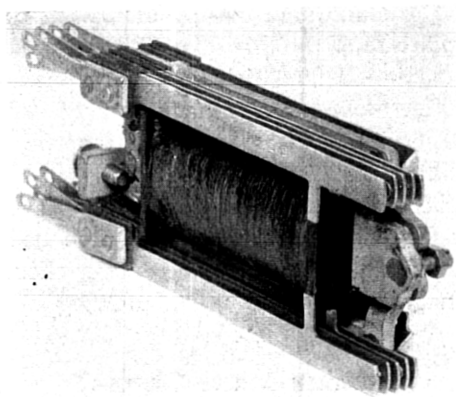


Fig. 12—"B" type relay

magnetizing force than it would be with a Norway iron core of the minimum cross section necessary for structural strength. A supervisory relay was, therefore, produced which was similar in construction to the line and cutoff relays and occupied the same mounting space. It was necessary to develop a dust protecting cover for this new relay which was also cross-talk-proof, in order to prevent the reproduction of conversation by mutual induction between adjacent relays. The design of this relay was such that spring tensions and contact adjustments were controlled by screws mounted in a brass plate at the front of the relay. The increased sensitivity of this relay over that of the round core type permitted the limits for substation loop resistance to be increased from 750 to 1,000 ohms, and the combined resistance of the windings to be reduced from 12 to 9.4 ohms, which decreased the transmission loss in the relay about 30 per cent. In addition, this new relay was superior in flashing ability and also released on a higher number of ampere turns. The mounting space was reduced 25 per cent. Large savings also resulted from a reduction in maintenance costs from approximately $5.00 per switchboard position per year to a negligible amount. The new relay is shown in Fig. 12, which shows the adjusting screws in the plate



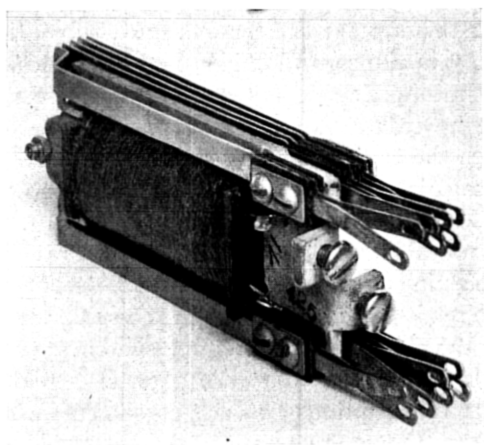


Fig. 13—"E" type relay

in the front of the relay, the cover and the cover cap. By removing the cover cap these screws become accessible and the replacement of the cap does not influence the magnetic conditions or disturb established adjustments.

A General Utility Relay

The success of the punched-type line, cutoff, and supervisory relays suggested the use of this type for a general utility relay which would carry a load of either one pair or several pairs of springs and permit an almost unlimited number of contact spring combinations to be made. This was accomplished by increasing the cross section of the core and armature of the line relay as the increase in iron cross section provided maximum flux with large magnetizing forces. This relay is shown in Fig. 13 and is now manufactured in large quantities with about 3,000 varieties of windings and spring arrangements. About twenty million such relays are already in service and the number is increasing constantly. Had it not been for the development of this punched-type relay, it would have been necessary to greatly increase the manufacturing facilities over those now provided because of the magnitude of the manufacturing operation on the old basis.

Certain Relay Groups

Having outlined the development of the most commonly known relays and given the reasons responsible for major design changes, it will be interesting to consider uses of simple relays in the full mechanical system. In this system the removal of a substation switchhook causes a line relay in the central office to operate and associate a line finder with the calling line, after which a cutoff relay removes the line relay from the circuit as is done in manual practice. A sender is associated with the calling line and the circuit is completed through the substation set dial and a relay in the sender, known as the pulse relay, because it reproduces the dial pulses.

A schematic for illustrating the principle of this circuit is shown in Fig. 14. Referring to this figure, it will be seen that the operation of the pulse relay provides a ground for a slow release relay which in turn extends the circuit of the stepping switch to the back contact of the pulse relay. Suppose that the digit *O* is dialed. Then the resulting current interruptions consist, as shown in Fig. 14, of ten break periods and ten make periods, the final make period being permanent and the remaining nine consisting of approximately one-third of the total time of a single pulse. The first break of the dial opens the circuit through the pulse relay, which releases and opens the circuit of the slow-release relay, but the latter remains operated throughout the break period. The pulse relay when released, provides a ground from its back contact, for the magnet of the stepping switch, through the make contact of the slow release relay. The stepping switch magnet operates the switch armature and holds it in a position to advance the switch a single step when the magnet is released. When the dial contacts close the circuit again the pulse relay re-operates, releasing the stepping switch, which advances one step, and reestablishing the circuit for the slow-release relay. This cycle is repeated for each break and make pulse period in order to advance the stepping switch over the number of terminals corresponding to the digit dialed.

The adjustment of substation dials is such that pulses are sent at a rate of speed of not less than eight, or more than twelve pulses per second. The break period of individual pulses may vary from .045

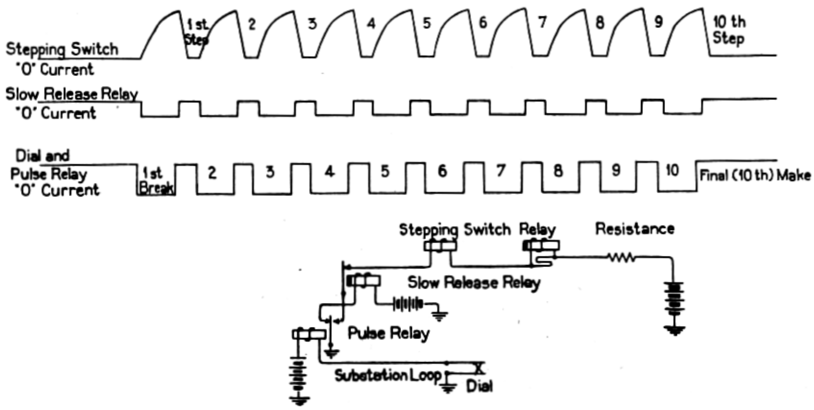


Fig. 14—Curve showing pulsing impulses

to .100 second and the make period may vary from .025 to .050 second. The magnet of the stepping switch must, therefore, complete the movement of the armature in a minimum of .045 second and the switch must advance a single step in a minimum of .025 second. In addition, the slow-release relay must remain operated for a maximum of .100 second; for if it releases during the break-pulse period, the circuit to the stepping switch will be opened. These time values assume that the pulse relay accurately reproduces the dial pulses and it is evident that to accomplish this, its time of operation and release must be independent of the battery potential, between the voltage limits prescribed for the battery, and must also be independent of the differences between the electrical constants of different lengths of substation loops. These are difficult requirements and a punched-type general utility relay, shown in Fig. 13, was used for the purpose as it appeared to be the most suitable available relay. Its time constant, however, is influenced by the electrical constants of the loop with which it is associated; so that the length of the loop effects the speed at which the armature operates and releases and thus causes the relay to introduce some pulse distortion.

An Accurately Adjustable Flat Type Relay

In order to decrease this distortion a new punched-type relay was designed which reproduces dial pulses with much greater accuracy. It will be seen from the picture of this relay shown in Fig. 15 that the armature is light, that the air gaps can be adjusted closely and with great precision, and that the reduction in the inertia of the armature was obtained by changing the position of the supporting

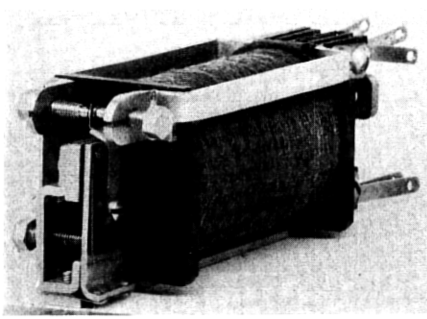


Fig. 15—"L" type pulsing relay

reed hinge. The core of this relay is of small cross section, so that a condition of magnetic saturation is obtained with small current values. With maximum flux on long loops, the increase in current as the length of the substation loop decreases produces very little change in the total flux. Also, changes in the armature air gap as the armature approaches the core do not reduce the reluctance of the magnetic circuit appreciably; so that the armature operates and releases with little time variation irrespective of changes in the electrical constants of the loop.

The slow-release relay, in Fig. 14, is a round-core relay with a reed hinge armature, similar in general construction to the cutoff relay previously described in connection with the early manual system. It is provided with a copper sleeve on the core which acts as a short circuited secondary transformer winding of very low resistance.

Relays in Fundamental Selecting Circuit

For another interesting example of the importance of relay operation in machine switching circuits assume that it is desired to select the fourth terminal in a particular group of a final selector bank as this terminal represents a subscriber's line which has been called from another station. A schematic illustrating the principle of the fundamental circuit for selecting this terminal is shown in Fig. 16. The calling subscriber, by dialing the number of the called station, has

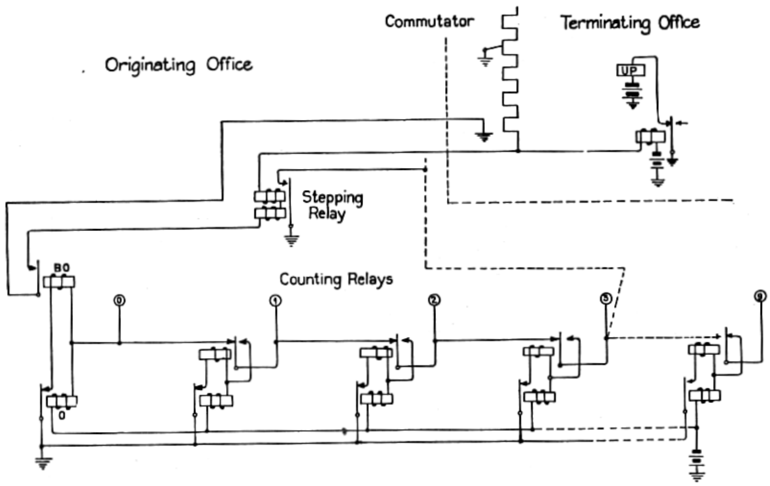


Fig. 16—Schematic of selecting circuit

established the circuit condition shown in this figure through the medium of the sender, so that both the line relay on the final frame in the called office and the stepping relay in the calling office are operated. The circuit is also closed through the up-drive magnet of the final frame, and the selector multiple brush is advancing toward the bank terminal to be chosen. As the selector is driven upward, the commutator brush making contact with the first commutator segment, of the particular group desired, places ground on the interoffice trunk in the called office which shunts down the stepping relay in the calling office. This releases the stepping relay, which had established a circuit when operated through the lower relay of the fourth pair of counting relays and had shunted the upper relay of the pair so it would not operate. The release of the stepping relay removed this shunt and permitted the upper relay to operate, locking both relays through the make contact of the lower relay and transferring the start lead to the lower relay of the third group which operates when the start lead is again grounded through the make contact of the stepping relay. This cycle is repeated for each segment which the commutator brush passes over until the upper relay of the fourth or zero group of counting relays operates and opens the fundamental selecting circuit, thus allowing the line relay in the final frame to release when the commutator brush again removes the shunt. The line relay, on releasing, opens the up-drive circuit and the selector stops with the multiple brush resting on the particular terminal desired.

There are three different types of relays in this circuit. The line relay on the final frame is the general utility punched-type relay of Fig. 13 with the contact spring assembly and mechanical adjustments required by the specific circuit condition. It is evident that this relay must release quickly enough to enable the up-drive clutch magnet to release before the selector is driven beyond the desired terminal or a false bank terminal selection will be made. An examination of some of the factors influencing the release time of the line relay will therefore be of interest.

When the commutator brush made contact with the commutator segment both ends of the inter-office trunk were grounded but before the brush left this segment the condenser charge on the trunk leads was dissipated and the distant end of the trunk was opened by the operation of the upper counting relay of the zero group. On leaving the fourth commutator segment the brush opened the circuit of the line relay which could not release instantaneously because of its own time constant, the transient current through its windings for charging the trunk capacity, and the leak current in its windings resulting from trunk leakage.

The time constant is determined by the electrical and magnetic constants of the relay and for a given winding is inherent to its structure. If the time constant is such that adjustments, for armature air gap, spring tension and contact separation, cannot be made which will enable a relay to meet all the circuit requirements, a different type of relay structure having a more favorable time constant must be used.

The magnitude of the charging current for the trunk is determined by the trunk capacity and is in direct proportion to the length of the trunk which is limited to 12 miles corresponding to a maximum capacity of about 0.84 mf. The limiting open circuit resistance of the trunk is 30,000 ohms and the standard of maintenance is such that the insulation resistance is not allowed to drop below this value.

In addition the maximum resistance of the trunk is 1300 ohms. The line relay must therefore be adjusted to operate over this resistance and in series with the stepping relay when the battery potential is a minimum of 44 volts. It must also be adjusted to release quickly enough to insure the positive selection of a particular terminal when the battery potential is a maximum of 52 volts and both the trunk capacity and trunk leakage are maximum. These are very severe requirements to be met by a relay which is produced commercially in large quantities at a small cost; and more severe conditions such as would result, for example, from increasing the length of the trunk could not be imposed on this particular relay unless the iron structure were made from some new material having more favorable magnetic constants.

The requirements for the stepping relay, however, are more severe than those for the line relay, for the stepping relay must continually operate and release as the commutator brush alternately grounds and frees the trunk in the distant office. Also the insulation resistance and capacity of the trunk exert a somewhat different influence on the functioning of the stepping relay than on the functioning of the line relay. The trunk leakage current resulting from low insulation resistance interferes with the operation of the stepping relay, instead of its release, so it must be adjusted to operate on a minimum battery potential of 44 volts and a minimum trunk insulation resistance of 30,000 ohms. The trunk capacity interferes more seriously with the release of the stepping relay than with the release of the line relay. When the ground is removed from the latter the trunk is at zero potential and the charging current through the relay windings is maintained for a very brief period of time but when the incoming end of the trunk is grounded to release the stepping relay in the distant office, the trunk capacity is fully charged and the discharging current is sustained for a much longer time interval.

The Stepping Relay

The time constant of the line relay is such that it cannot be given adjustments which will enable it to meet the more severe requirements of the stepping relay, and consequently an entirely different type of structure, as shown in Fig. 17, is used for a stepping relay. This design is of particular interest because it is not used for any other purpose and is the only relay of its type in the telephone plant. Many attempts have been made to replace it with some sort of punched type structure that is more adaptable to the established manufacturing methods but they have been ineffectual as yet, for the equivalent combination of sensitivity and reliability and a delicate means of adjustment is difficult to attain. In order to satisfy the severe circuit conditions the stepping relay is adjusted to operate on 10 mil-amperes and not to operate on 9 mil-amperes, a difference of only 10 per cent. in the operate and non-operate adjustments.

The stepping relay must reproduce the pulsations of current originated by the commutator brush with sufficient accuracy to insure

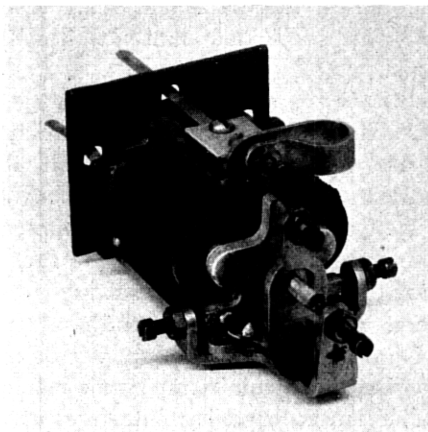


Fig. 17—Stepping relay

the positive operation of the counting relays, for any failure of the latter will result in false selection. The stepping relay must therefore maintain a circuit through its make contact for a sufficient time to enable the lower relay of any counting pair to operate and must open the circuit through the same contact long enough to permit the upper relay of the pair to lock up in series with the lower relay. Since the stepping relay does not always reproduce the commutator pulses perfectly and since any pulse distortion must necessarily reduce the operating time margin for one of the relays of a counting pair, it is evident that rapid operation and reliability of operation are essential characteristics for the counting relays. A punched type relay similar to the line relay cannot operate with sufficient speed. The stepping relay would qualify for speed, but a complete set would require considerable space and would be inconvenient to mount.

The Counting Relay

The relay designed for a counting relay is shown in Fig. 18 and has the qualities of speed and reliability that are required. It is equipped with a light armature, on a pivot suspension, that operates

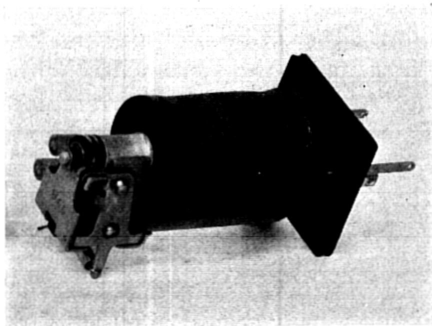


Fig. 18—Counting relay

through a small air gap. The contacts are mounted on rigid springs that cannot be adjusted readily, but which maintain a given adjustment, without change, for a long time. This relay, like the stepping

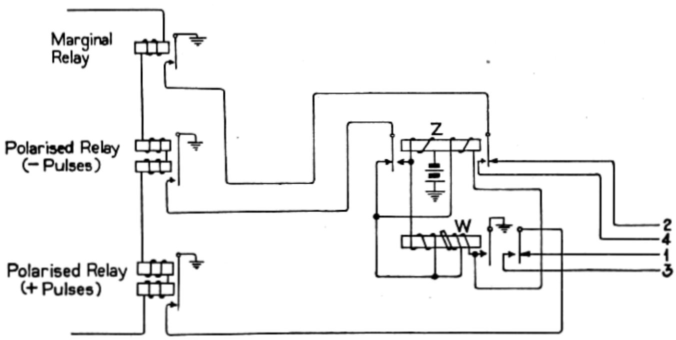


Fig. 19—Call indicator circuit

relay, is unique, in that, it is not used for any other purpose in the telephone system, and in addition all attempts to design a punched type relay that is a satisfactory substitute have, so far, been unsuccessful.

Certain Marginal and Polarized Relays

Another interesting and unusual use of relays is the arrangement at the terminating end of a call indicator trunk from a full mechanical to a manual office. This arrangement consists of three relays in series in the manual office, as shown in Fig. 19. One of them is a marginal relay adjusted to operate on any current greater than a particular value. The other two are polarized relays, one being adjusted to respond to negative pulses only, while the other responds only to positive pulses.

Each digit of any number transmitted over the trunk to the manual office consists of four pulses. The second and fourth of these pulses are always negative, but either or both of them may be a light or heavy negative. The first and third pulses may either be positive or zero, a zero pulse representing a no current interval. This combination of pulses is shown in the following table:

1	2	3	4
+	–	+	–
0	–	0	–

As each pulse interval may consist of either of two kinds of pulses, there are sixteen combinations which can be transmitted but six of them are not used, as only ten are required.

The marginal relay is adjusted to operate on heavy pulses only and as all the positive pulses are light, it does not respond to any positive pulses or the light negative pulses. The negative polarized relay responds to both light and heavy negative pulses and the positive polarized relay responds to all positive pulses. During a zero pulse period all of the relays remain unoperated. For the second and fourth pulse periods the negative polarized relay will be operated and the marginal relay may or may not be operated. During the first and third pulse periods the positive polarized relay may be operated or all the relays may remain unoperated. From the operation of these relays an arrangement of register relays is set up which lights before the manual operator the lamps corresponding to the digits transmitted. The marginal relay used is a counting relay of the type shown in Fig. 18, as this relay has the qualities of sensitiveness, stability and permanence of adjustment that are essential for satisfactory operation. The other two relays are very sensitive polarized relays with micrometer adjustment screws and are representative of the best standards of design for relays of their type. This type of relay is shown in Fig. 20.

The Sequence Switch

Most of the relays previously described were designed to meet specific requirements of unusual severity which limited the design to individual structures having their armatures in close association with the contact carrying springs. Many of the switching operations required for relaying a circuit from point to point through an office can be performed under conditions allowing greater latitude in relay design which has led to the development of several interesting and unusual forms of multi-contact relays in which the armatures

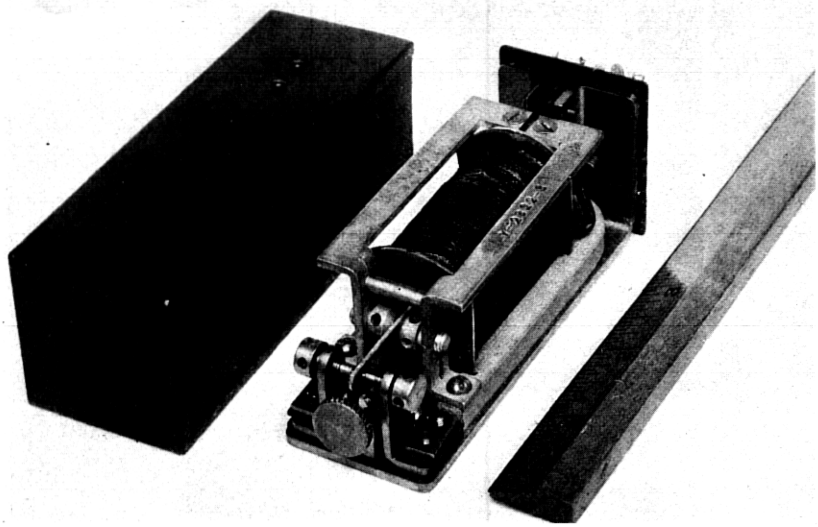


Fig. 20—Call indicator polar relay

indirectly control groups of contact carrying springs. In the development of the machine switching system the work of establishing circuits performed by human relays was transferred to mechanical relays and it soon became evident that the number of individual relay structures of the conventional type required for such a substitution would be so great and the circuit arrangements would be so complicated that the cost would be prohibitive.

The 24 cam sequence switch shown in Fig. 21 is an interesting example of the remote contact control multi-contact relay that not only performs the functions of a multitude of individual relays but actually replaces entire circuits which would require large numbers of relays to control the particular relays that transferred the circuit from point to point. The relay sequence switch shown in the figure is assembled with a shaft that may be rotated into any one of 18 positions which are stamped on an index wheel and are indicated by the position of the wheel with reference to a pointer fixed to the frame of the switch. Each of the circuit switching cams is associated with four brushes and it is possible to so arrange the contact carrying segments on these cams that 6624 different circuit combinations can be established by advancing the switch successively into each of the 18 positions.

The switch is propelled by a driving disc mounted on a power driven shaft that revolves constantly at a speed of 36 r.p.m. The driven disc on the switch in association with the driving disc constitutes a

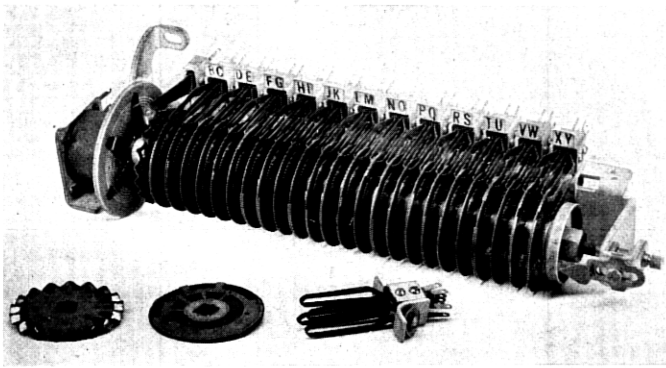


Fig. 21—24 cam sequence switch

friction clutch under the control of an electro-magnet which deflects the driven disc to bring it into relation with the driving disc when it is desired to advance the switch. The electro-magnet corresponds to the winding of an individual relay structure and the driven disc is the armature, the combination of the winding and armature simply serving as a means for controlling the contact relations of a multiplicity of springs.

The Power Driven Selector

The power driven selector shown in Fig. 22 is another example of an entirely different form of multi-contact relay for transferring the three contacts of any one of 500 circuits to the contact springs of a brush that will relay that circuit to any desired point. These 500 circuits are assembled in five groups of 100 each in five banks that are mounted on a frame as shown in the figure. Five brushes, one for each bank, are assembled on a vertical rod in such relation to the banks that the mechanical tripping or release, of any brush brings its springs in contact with the terminals of the bank with which it is associated. The corresponding springs of each of the five brushes are connected in multiple so that in relaying a circuit it is necessary to trip only that brush which is presented to the bank in which the terminals appear. Bringing the brush springs in contact with a par-

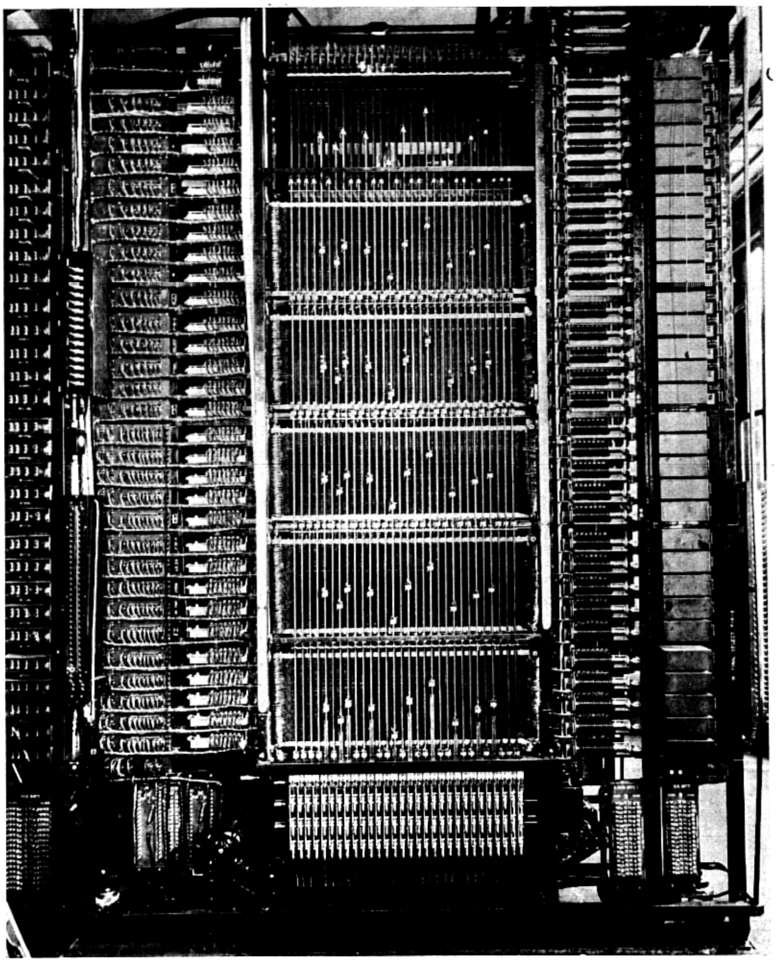


Fig. 22—Power driven selector

ticular group of terminals is referred to as a process of selection and is accomplished by driving the brush rod upward until the desired terminals are reached. When the circuit arrangement is no longer desired the brush rod is driven downward to a normal position where the tripped brush is also restored mechanically to its original condition.

The power for elevating and restoring the brush rod is provided by continuously revolving motor driven steel rolls covered with cork and mounted at the base of the frame. The driving of the brush rod, the tripping of the desired brush, the stopping of the rod and its restoration to normal are all controlled by a series of electro-magnets assembled in a single structure called a clutch which is also mounted at the base of the frame directly in front of the rolls. When a brush rod is driven either up or down, a clutch armature establishes a friction contact between a flat strip of phosphor bronze fastened to the lower end of the brush rod and the cork on the revolving rolls. This clutch is comparable to an individual relay structure with a multiplicity of windings and armatures that are so related that each armature will operate only when its associated winding is energized. The clutch thus does the work of either an exceedingly intricate individual relay or a whole group of less complicated relays. The clutch windings are in effect, relay windings that control the positions of remote contact springs through the operation of armatures which associate or disassociate electro-magnetic and mechanical energy as is desired.

The Step-by-Step Selector

Another type of multi-contact relay in general use that differs in form from both the sequence switch and the power driven selector is the step-by-step selector shown in Fig. 23. It consists of six semicircular contact levels assembled in a bank and an electro-magnet which drives a set of six, double ended, rotary brushes over the terminal arc by means of a driving pawl and ratchet wheel. Each time the magnet is energized and released the driving pawl engages the next tooth on the ratchet wheel which rotates to advance the brushes a single step so that they make contact with the next set of terminals. In 44 successive steps the six brushes move through a complete revolution but as they are double-ended all the possible circuit combinations are set up in the first 22 steps and are then repeated.

In this selector the winding of the electro-magnet corresponds to the winding of an individual relay. The armature in operating elongates a spring that is shown in Fig. 23 and the energy stored in this spring restores the armature to normal and advances the six contact making brushes to the next set of contact terminals. Thus the relay winding and armature control the position of the contact springs through the agency of a flexible mechanical link. The relay winding may be alternately energized and released by current interruptions from an outside source or the armature may be arranged to interrupt the circuit through the winding by opening a pair of contacts in the operated position to advance the selector by self interruptions.

Relays in Toll Circuits

Supervision on all of the longer toll circuits and on most of the shorter ones is provided on what is known as a ringdown basis. This

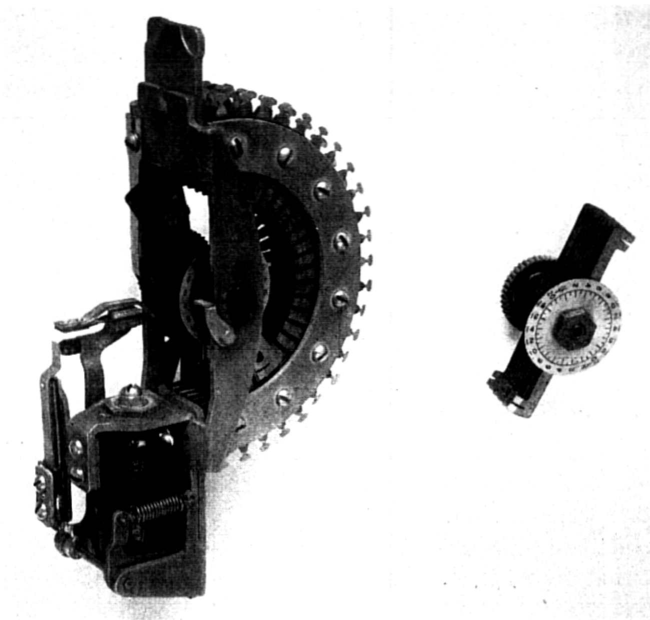


Fig. 23—Step-by-step rotary switch

usually involves a ringup relay at each end of the line, which operates in response to 20-cycle signaling impulses. These impulses may be transmitted over the line from one office to the other or they may originate in the same office as the relay and be impressed on the line by the operation of a so-called composite ringer in response to signals of a different frequency. The ringup or drop relay provides the signal in the toll switchboard. It is usually removed from the circuit when the line is taken up by the operator and the supervision is then transferred to the toll cord.

The toll cord supervisory circuit is shown in Fig. 24 and illustrates a typical condition which has imposed particular requirements on the relays involved. The signal receiving relay *A* may be bridged directly across the line conductors, in which case its winding must be of such high impedance that it does not materially affect the efficiency of the talking circuit. Experience has indicated that with the windings commonly used on relays there is some chance of sufficient short circuited turns to materially reduce the inductance of the winding. This may occur in a relay which would otherwise give satisfactory operation, the short circuited turns merely reducing

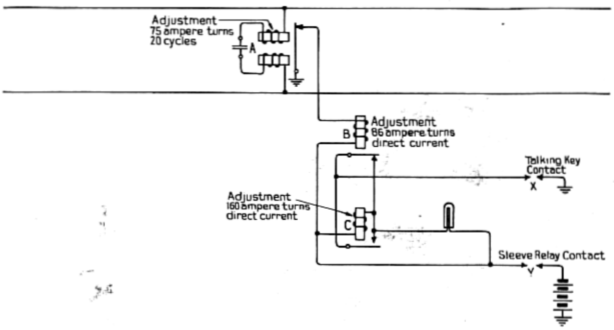


Fig. 24—Toll cord supervisory circuit

slightly the low frequency or direct-current efficiency. For this reason, the relay winding has been divided into two parts, on separate cores, either one of which has sufficient inductance to safeguard the telephone transmission.

The incoming 20-cycle signaling current may be of small value and the portion through the relatively high impedance of the relay will be still smaller so that this relay must be extremely sensitive. The relay has small moving parts and a comparatively light spring tension. These factors contribute to sensitive operation but also permit the opening of the contact on impulses other than those intended for signaling. Such impulses are usually of short duration and the other relays of the circuit have been designed to limit their effect to prevent false signals.

Both relays "*B*" and "*C*" are of the same type, designed to operate with a slight time lag so that other things being equal they would be expected to operate at the same time when the circuit is closed at x and y. Relay "*B*," however, receives, under the worst condition, 150 per cent. of its rated operating current, while relay "*C*" receives 105 per cent. This will tend to make relay "B" quicker in operation than relay "*C*," so that when the battery and ground are connected to the circuit, relay "*B*" will operate first and open the winding of relay "*C*." This is therefore the normal condition of the circuit and is further insured by the fact that the opening of the winding of "*C*" occurs at a back contact of relay "*B*" while the locking of "*C*" occurs only after the relay has pulled up to close its front contact.

The sequence of operation and release resulting from this series of relay operations affords protection against false signals since relay "*A*" must operate continuously until "*B*" has released and "*C*" has operated before the lamp circuit is closed. Relay "*B*," in addition to being slow in operation, is also slow to release, so that the time interval thus introduced tends to bridge over any transient impulses that may tend to operate the signal.

The slow operation of relays is secured by means of a copper sleeve over the relay core. Slow operation results from the transient condition existing during the time between the application of voltage to the relay winding and the building up of the magnetic field to a steady state. Slow release results from the transient condition existing during the time between the removal of the voltage from the relay winding and the decay of the magnetic field until the magneto-motive force falls below the armature restoring force. These conditions are more easily seen when the relay winding is considered as the primary of a transformer and the copper sleeve as a short-circuited secondary winding consisting of a single turn having a very low resistance. The operating current, before it reaches its steady value, may be considered as an alternating current of one-quarter of a cycle, starting from zero and building up to a maximum value. Slow operation of the armature results from opposing the building up of the flux in the core. Slow release is due to retarding the decay of the flux in the core. The speed at which the armature operates or releases is not changed but in the first case the application of the magneto-motive force required to move the armature is delayed, and in the second case the removal of the magneto-motive force holding the armature in the operated position is also delayed. When a voltage is first applied to the terminals of the winding, the current tends to build up and establish the magnetic flux at its maximum value in the relay core. The instant the flux threads the copper sleeve, a voltage is induced in the latter, causing a current to flow in it. This current in the copper sleeve sets up a flux in the same magnetic path which opposes the flux building up from the current in the relay winding. Due to leakage, the winding flux is greater than the opposing flux set up by the sleeve and the resultant flux continues to build up until it reaches a maximum value. This opposition of the winding flux and the flux produced by the induced current in the copper sleeve increases the time for the building up of the magnetic force necessary to move the armature from the normal position. It also increases the time for such a reduction in the magnetic force as will permit the armature to release.

The slow release feature is further secured by omitting the stop pins which are usually provided between the armature and the pole

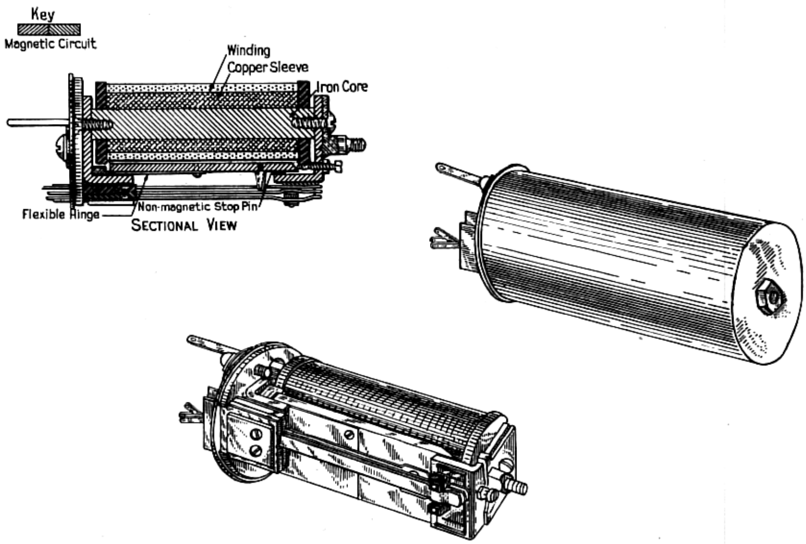


Fig. 25—Sectional view of No. 162 type relay, a slow operating relay

piece. This tends to delay the decline in flux through the magnetic circuit when the current is interrupted. Fig. 25 illustrates diagrammatically the structure of these relays.

Relays of the Composite Ringer

A somewhat similar use of relays is to be seen in the composite ringer circuit mentioned above. The relay circuit of such a ringer is shown in Fig. 26, in simplified form. This circuit is designed to receive 20-cycle signals from the switchboard and transmit out on the line signals of a higher frequency and to receive the higher frequency impulses and in turn transmit 20 cycles to the switchboard. In this case, the 20-cycle relay "*A*" does not meet the requirement for high impedance since protection to the telephone circuit is afforded by coil "*C*." A single core is therefore satisfactory and a positive make-contact relay is used. In this case, the chief requirement is that relay "*B*" should be slow in operating.

The chain of relays operating from the high frequency signals consists of relays *D*, *E* and *F*. Relay "*D*" must be a very sensitive structure in this case and a polarized relay with a vibrating contact has commonly been used. The circuit requirements are such that the energy available for the operation of this relay is seldom more than a few hundred microwatts and may be much less. The cir-

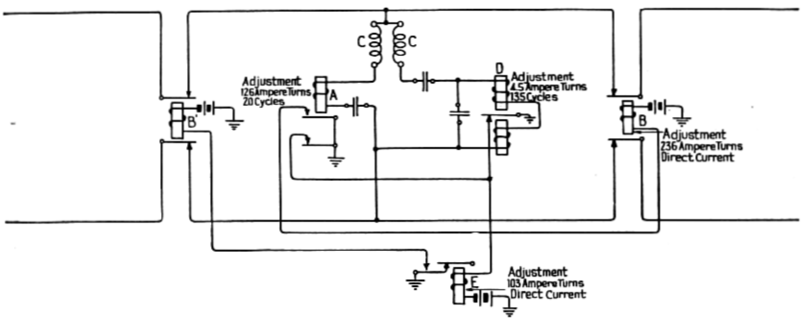


Fig. 26—Composite ringer circuit.

cuits are being designed on the basis of giving reliable operation on 20 microwatts. The operation of relay "*D*" releases relay "*E*" which in turn operates relay *F*.

Where such a circuit depends on the operation of a vibrating contact relay, the current through this contact is of vital importance. Whenever the contact is closed, current tends to flow through the winding of relay "*E*." Fig. 27 illustrates the effect of very weak signaling currents and of currents sufficient to give proper operation. The current values through the vibrating relay winding and through the winding of the secondary relay are shown for two different typical conditions. Also, the average or effective value in winding "*E*" is shown.

A circuit feature which has recently been introduced to increase the sensitivity of relay "*D*" and to improve the operation of the secondary relay consists in the introduction of a condenser and the operation of the vibrating contact as a normally open contact. The closing of the contact charges a condenser which tends to operate the secondary relay by its discharge as soon as the contact opens. By this combination, the effect noted in Fig. 27 is eliminated and positive operation of the secondary relay is secured as soon as the armature vibrates sufficiently to make contact. The local circuit embodying this feature is shown in Fig. 28. Referring to this figure and to Fig. 26, relays "*D*" and "*E*" represent the alternating current relay and the secondary relay in each case. In the one case, however, relay E' operating when relay "D" operates gives positive release of relay "E" instead of introducing an uncertain resistance in its circuit.

This circuit embodies several features which are not common in relay systems. The operation of relay E' is dependent on the values

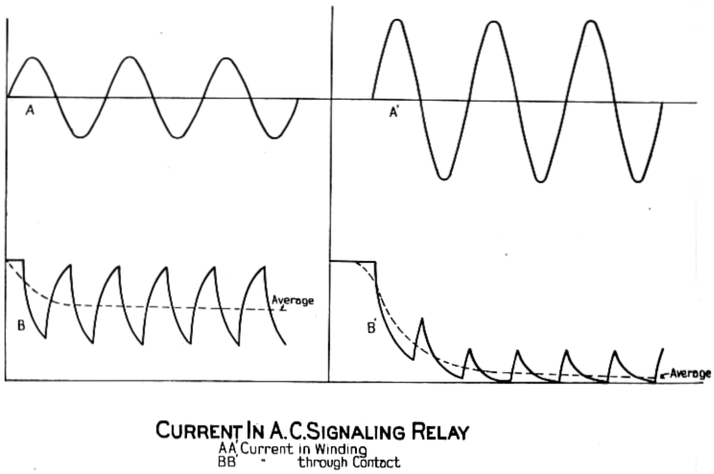


Fig. 27—Curve showing signal impulses in a.c. signaling relay
AA¹, current in winding
BB¹, current through contact

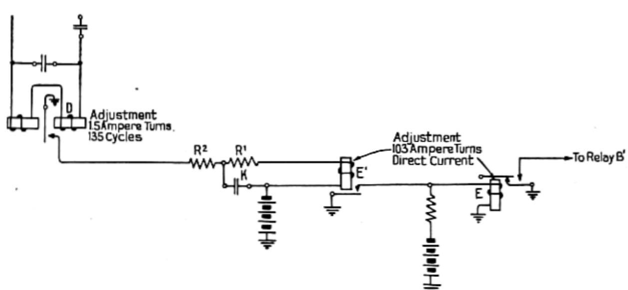


Fig. 28—Circuit for a make contact 135 cycle relay

selected for resistances R' and R^2 and for condenser K. These values must be such that the current in the relay winding is maintained during the opening of the contact of relay "D" by means of the discharge current from the condenser. On the other hand K and R^2 must be proportioned to limit the arcing of the contact of "D" at the frequency of the signaling impulses. The method of releasing relay "E" by short-circuiting its winding has advantages over opening the circuit for the purpose under consideration. The arcing at the contact of relay E' is less severe than would be the case if an inductive circuit were broken.

An added feature which has been incorporated in the mechanical design of relay "D" and which has an important bearing on its performance electrically, is an adjustment limiting the armature travel. This limitation of movement prevents a wide deflection when the relay receives excessive current. Such deflection would tend to set the armature into vibration and would result in a sufficient number of impulses to operate relay E' and cause false signals.

The Vacuum Tube

The vacuum tube is used for the relaying of energy in a number of ways. It may be connected in circuit to amplify the received impulses in which case it sends out energy from a local source with the same wave shape as that of the received current. In this case the tube serves to relay the impulses with as little distortion as possible. In the case of a tube used as a modulator or a demodulator it is required to combine or separate impulses of different character, the two operating together to preserve the same impulses at the output of the demodulator tube as is received at the input of the modulator. The impulses which are transmitted between the two tubes have an entirely different wave form and may be amplified any number of times by means of amplifier tubes without affecting the action of the modulator and demodulator.

The vacuum tube may also be used as a rectifier to convert alternating current to direct or pulsating current or it may be used as an oscillator to produce alternating current from a local source of direct current. In all of these applications of vacuum tubes, the tubes serve as relays to introduce a fresh supply of energy or a desired wave form or a combination of the two to serve their purposes in the communication system.

Relays for Telegraph Circuits

The use of relays for telegraph circuits presents an entirely different set of problems than those usually encountered in the consideration of telephone circuits. Most telegraph relays are used for repeating signals from one circuit to another rather than for switching local circuits. While some marginal operating conditions are imposed on telephone relays there is not the wide range of operating conditions to be met under which most telegraph relays are required to operate. The numbers involved are usually much less so that economies in production play a somewhat less important role and the cost is not quite such an important item. Similarly the methods of assembly and mounting afford a somewhat wider latitude than can be permitted where many thousands of relays must be mounted in comparatively small space.

Because of the exacting requirements imposed on telegraph relays and to insure continuity of service as far as possible, they are usually made interchangeable to a much greater degree than telephone relays. They may be connected by means of screws instead of soldered connections or they may be inserted in the circuit by means of spring clips in a connecting block.

In a telegraph system speed of operation and reliability are the most important requirements and are very large factors in determining the mechanical design of the relays. The relay must operate quickly and accurately so as to cause as little distortion as possible to the signals. In addition it must be extremely rugged and maintain its adjustment well throughout long continued operation. A very ordinary day's work for a telegraph relay requires the reliable operation of its contacts several hundred thousand times and it may be called upon to open and close its contacts a million times a day. Where a telephone relay might hesitate and still pull up and perform its function properly or might make uncertain contact at first, such behavior on the part of a telegraph relay would result in false impulses and would quickly call for a readjustment or a change of relays.

With the exception of some of the alternating current signaling relays in telephone circuits the energy available in telegraph relays is usually less than that available for telephone relays. The more sensitive relays are called upon to operate from line current which has been attenuated by leakage or by parallel paths and which may have been limited at the distant station. Systems operating over open wire lines are usually restricted to about .075 ampere at the sending end and in cable the normal current is about .005 ampere. This difference is not as great in actual operation as would appear since the open wire system operates on a ground to ground basis and the cable on a metallic basis. In operating from ground at one station to ground at another differences in ground potential and leakages occur which require a greater margin than is necessary with the metallic system.

If satisfactory telegraph service is to be rendered, particularly on long circuits involving a number of relaying points, it is essential that the telegraph relays employed have such operating characteristics that they introduce as little distortion to the signals as possible. It has been found that the polarized type of relay fulfills this condition to a greater extent than the neutral type of relay which is used in local circuits and in some telegraph circuits where extreme accuracy is not required. The polar relay permits arrangements of circuits which minimize the effect of poor wave shape and line leakage. It also is more easily adapted to variations in current strength and may be adjusted to give more accurate repetition of the signals under all conditions.

A number of important developments in telegraph relays have led up to the relay shown in Fig. 29. This relay gives reliable operation with 4-ampere turns in the winding and by careful adjustment may be made to operate on a small fraction of that.

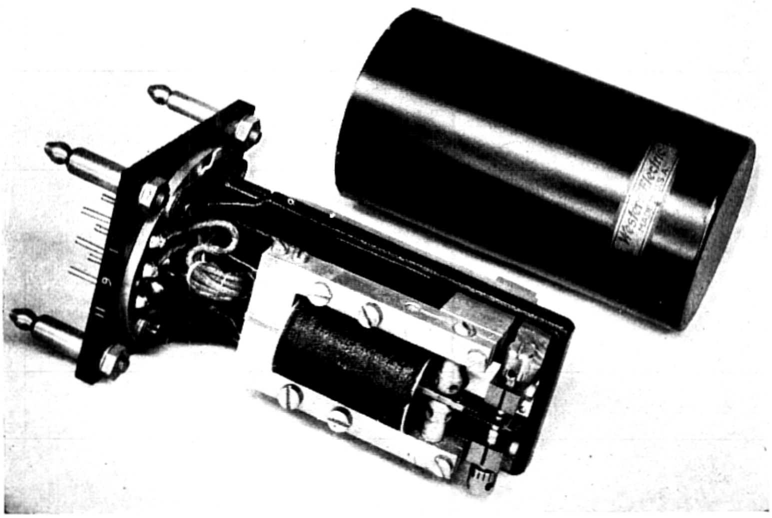


Fig. 29—Photograph of telegraph type relay

While the telegraph relay may be called upon to operate on very small energy, its contact must be capable of handling much larger quantities. Due to the speed of operation desired and to the dependence on accurate transmittal of each impulse the contacts must operate without chatter or vibration. Great care has been taken in the design of the relays and the circuits to protect the contacts and insure good operation. Chatter can be largely eliminated by careful mechanical design and the effect of the arc set up when the contact is called upon to break the current in a circuit carrying several watts can be minimized somewhat by means of, so-called, spark killers. These consist of condensers and resistances so proportioned as to absorb the force of the arc in the charging of the condenser when the contact opens. They can be utilized still further in modifying the shape of the transmitted wave by the charging of the condenser when the contact is opened.

Telegraph relays and their applications have been referred to in this paper only in the most general terms because of the variety of their forms and uses. It is planned to cover this as well as other subjects pertaining to relays in a series of later papers.