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A New General Purpose Relay for Telephone Switching Systems

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This paper describes a new general purpose electromagnetic relay for use in telephone switching systems. It is a wire spring relay known as the AF type relay and, with variations which provide slow release or marginal characteristics, it is known as the AG and AJ relay, respectively. Fig. 1 shows a typical AF type relay, Fig. 2 shows all of the parts of the relay and Fig. 3 is a drawing showing the relay assembly.

1. BACKGROUND

The general purpose relay is one of the most important components of telephone switching systems.[1] These relays constitute the most repetitive building block in switching equipment. Since several million are produced annually, low manufacturing cost is extremely desirable. Also of prime importance are low operating and maintenance costs. General purpose relays are, therefore, under constant observation and study by the telephone operating companies as the users, by the Western Electric Company as the manufacturer, and by Bell Telephone Laboratories as the designer. The AF wire spring relay and its variations are the result of such studies.

A general purpose relay for telephone switching systems must meet a large number of diverse requirements. It must be capable of being assembled with any one of a variety of magnet coils having a wide range

[1] S. P. Shackleton and H. W. Purcell, "Relays in the Bell System", *Bell System Tech. J.*, Jan., 1924, p. 1.

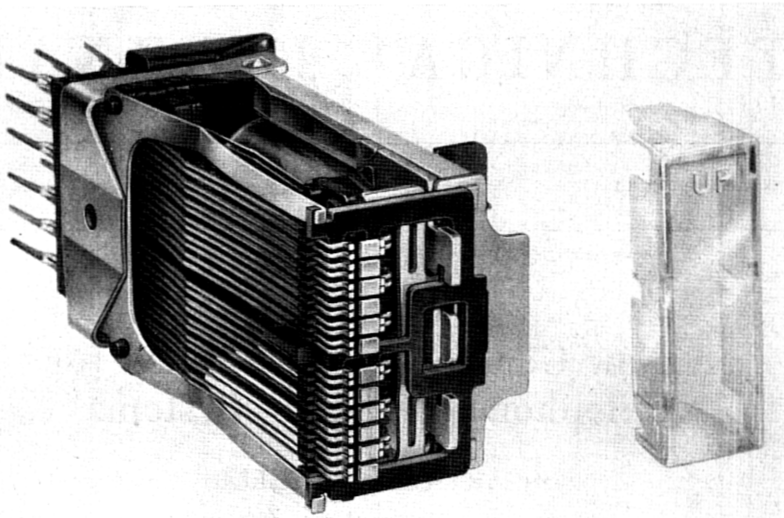

Fig. 1—AF type relay, with contact cover detached.

of resistance values and to operate contacts which vary from one pair to as many as fourteen or more. The basic relay design must also be capable of providing such features as fast operation and release, slow release, high sensitivity, heavy duty and marginal operation. These functions are performed satisfactorily in present crossbar switching systems by U, UA, UB and Y type relays.[2, 3, 4, 5] However, with an objective of a forty-year life for new switching systems and a trend toward unattended operation of switching offices, it is important to attain the best in the performance and reliability of relays.

The general purpose relay must be designed to produce the best economic balance, when used in telephone switching systems, so that the annual charges are minimized. The major ingredients of these annual charges are manufacturing expense, operating electrical power, speed of operation and release, space required and maintenance costs which include reliability and life.

2. REQUIREMENTS AND OBJECTIVES

The requirements for a new general purpose relay were initially broadly stated to be performance and maintenance at least equal to the

[2] H. N. Wagar, "The U-Type Relay", *Bell Lab. Record*, May, 1938, p. 300.
[3] H. M. Knapp, "The UB Relay", *Bell Lab. Record*, Oct., 1949, p. 355.
[4] F. A. Zupa, "The Y-Type Relay", *Bell Lab. Record*, May, 1938, p. 310.
[5] W. C. Slauson, "Improved U, UA and Y Type Relays", *Bell Lab. Record*, Oct., 1951, p. 466.

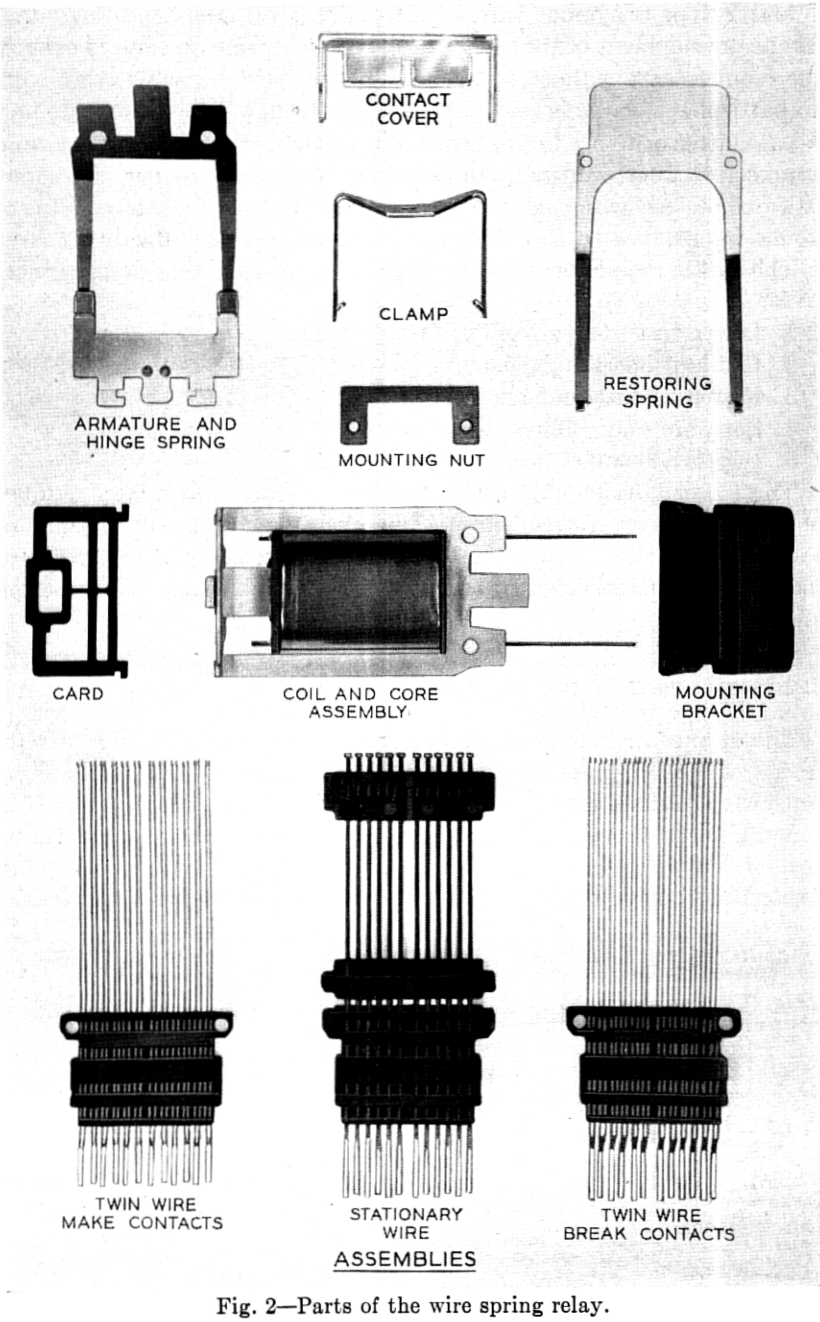

Fig. 2—Parts of the wire spring relay.

U and Y type relays but with substantially lower manufacturing costs. As the development of the relay proceeded, it became possible to expand the requirements without appreciably altering the expected relay cost. In particular, it became possible to design the new relay to operate and release faster or to use less electrical power, to operate more often before appreciable wear occurred, etc. The improved performance characteristics of the AF wire spring relay, as described later, are of equal economic importance to those associated with lower manufacturing cost.

The broad requirements were reduced to the following design objectives:

1. Lower cost—50 per cent of U type relay.
2. Reduced operating electrical power.
3. Faster operate and release times.
4. Long life—one billion operations.
5. Improved contact performance.

These broad design objectives do not specifically state a large number of other characteristics which must be at least as favorable as those of the U and Y relay family. This refers to such items as: space required, magnetic interference, wiring costs, contact combinations, field servicing and repairs.

3. DESIGN POSSIBILITIES

The studies of new relay design possibilities started with a careful review of the U type relay experience. In fact, much of the early thinking considered various modifications of U type and other existing relays. In general, these studies indicated that about half of the manufacturing cost of U type relays came from assembly and adjusting operations. Accordingly, these operations required major revision for a substantial

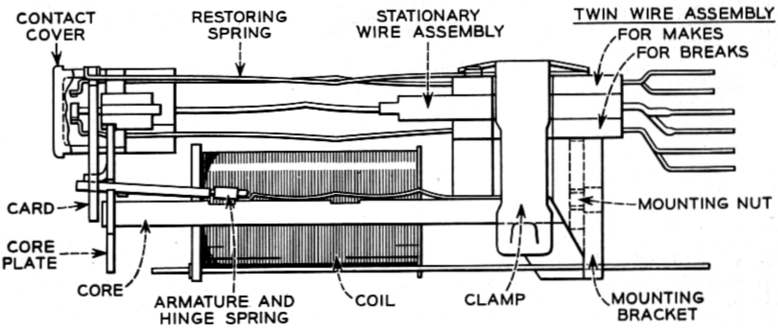

Fig. 3—Top view of the relay, showing location of parts.

cost reduction of the relay. It became evident that the development of new manufacturing methods as well as new designs were essential in reaching the ambitious objectives. For these reasons, the manufacturing engineers of the Western Electric Company were active participants in the development of the new relay from the beginning.

Many new forms of relay designs were considered and studied including such types as miniature, magnetic contact, piezoelectric, etc. As a result, one general form, first proposed by H. C. Harrison, gave the most promise of meeting the manifold requirements. This is the wire spring type characterized by the wire spring subassemblies with code card operation of pretensioned, low stiffness springs. Actually, the general form of the wire spring relay proposed by Mr. Harrison constitutes an entire new class of relays with many possible variations. These include various types of code card operation and various forms of contact operation, operated by any of a number of magnet structures.

The new class of relays has the following important advantages:

1. Pretensioned, low stiffness wire springs make possible (a) assembly to give close control of contact force without individual spring adjustment; and (b) essentially constant contact force throughout the life of the relay and its contacts.

2. Wire spring subassemblies make possible (a) favorable manufacture of a multiplicity of contact springs by molding; (b) lower assembly costs because fewer piece parts are needed; and (c) simple code card operation.

3. Code card operation makes possible (a) standardized and simple assembly; (b) accurate control of contact position; (c) essential elimination of locked contacts; (d) complete independence of twin contacts; and (e) simple means for providing a large number of contact combinations.

A continuous and comprehensive study was necessary of the characteristics and probable manufacturing costs of many forms of the wire spring relay family. As a result, after passing through several major designs, the basic design of the present relay was adopted. H. M. Knapp and C. F. Spahn proposed important features of this design. This form represented advantages over other types in

1. reducing the number and amount of dimensional variations controlling the contact gaps. In turn, this made possible smaller armature movement, shorter operating and release times and less chatter of the contacts;

2. reducing the number of code cards required to provide the large number of contact combinations needed in switching systems;

3. reducing the manufacturing and wiring costs;

4. increasing the mechanical life.

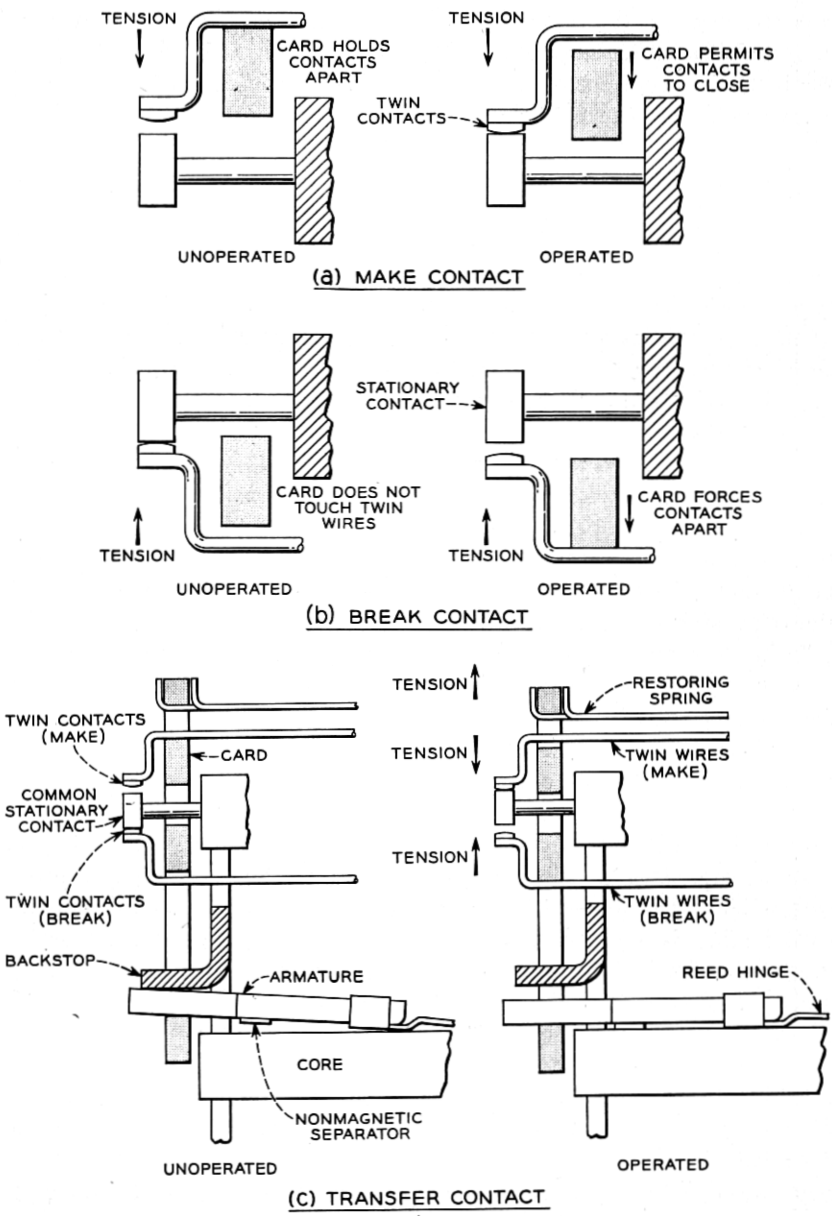

Fig. 4—Principle of contact operation.

4. PRINCIPLE OF CONTACT OPERATION OF THE AF RELAY

The AF relay uses what has been called the "single card system" for actuating the contacts. This is in contrast to other code card systems which require two, three or four coded cards in each relay. The method for obtaining individual make and break contacts with this system is shown in Figs. 4a and 4b, and a means for obtaining transfer contacts, in which both make and break twin contacts are associated with a common stationary contact, is shown in Fig. 4c. As indicated on the figures, the following principles are incorporated in this method of actuation:

1. In general, three basic wire spring assemblies are required. Two of these carry movable twin wires for make and break contacts and are identical except for some details in forming at the terminal ends for convenience in wiring. The twin wire assemblies are mounted on either

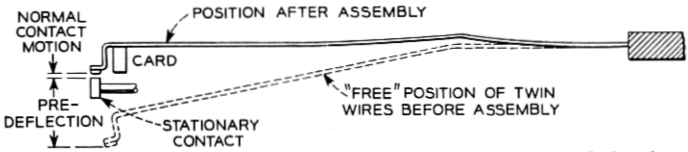

Fig. 5—Contact forces are controlled by relatively large predeflections of the twin wires.

side of the stationary wire assembly, which consists of a group of relatively heavy wires molded into plastic sections, one a short distance behind the contacts and one near the rear of the relay. These sections are rigidly supported in the relay structure.

2. Moving twin contacts on separate twin wires are used with every stationary contact. This arrangement assures good reliability and greater freedom from open contacts in the presence of dust and dirt. In addition, contact chatter is reduced as both contacts must be open simultaneously in order to interrupt the circuit.

3. As shown in Fig. 5, each group of twin wires is tensioned toward the stationary wires by means of large predeflections before assembly, so that the contact forces are determined by this predeflection. Good control of the contact force is assured without need for hand adjustment because small variations in deflection of the low stiffness springs do not result in appreciable changes in force. For this reason, the force is stable and is not appreciably affected by wear of the contacts.

4. The twin wires are actuated by a single punched fiber card. Since the tension in the twin wires is always in a direction to hold the contacts closed, the card serves to hold the make contacts open when the relay is unoperated and the break contacts open when the relay is energized.

5. The card is supported by the armature on one side and a restoring spring on the other. The restoring spring supplies the force to hold the armature against the backstop and to hold make contacts open when the relay is unoperated, while the armature supplies the force to hold the break contacts open when the relay is operated. However, since the armature must also overcome the tension in the restoring spring, the entire spring load must of course be overcome by the pull of the armature.

6. The twin contacts are held in good registration with their associated stationary contacts by means of molded guide slots in the stationary plastic member just behind the card. These guide slots are slightly wider than the diameter of the twin wires so that these wires are free to move in the direction of the armature movement, but are restrained against lateral motion.

7. The close proximity of the card to the contacts is important in minimizing contact chatter and in substantially eliminating locked contacts, i.e., contacts which fail to open because of interlocking of roughened surfaces. The close spacing results in a rigid coupling between the card and contacts, so that the static and dynamic forces associated with the armature and card are available to break loose any incipient lock which might develop.

As the armature moves toward the core, the particular point in its travel at which make contacts close and break contacts open depends upon the dimensions of the card between the surface which bears against the armature and the surfaces which engage the twin wires. By proper selection of these dimensions, any contact can be controlled to operate early or late in the travel as desired. By this means, several sequential contact arrangements may be obtained. For example, if the break contact in Fig. 4c is controlled by the card dimensions to open earlier in the travel than its associated make contact closes, the resulting arrangement is called an "early break-make" transfer. Similarly, an "early make-break" transfer, often called a "continuity" may be obtained by selection of card dimensions which will assure that the make contact closes before the break contact opens. If both contacts operate simultaneously, the result is a "non-sequence" transfer.

From the above it is evident that the card surfaces which engage the twin wires must be in different positions for early contacts as compared with late contacts. This is illustrated in Fig. 6 which shows an early break-make, an early make-break and a non-sequence transfer side by side. Of the contact pairs shown, only two operate early, and this is accomplished by means of steps in the actuating surfaces of the card.

Thus, if no sequences were required, the card would have a single straight surface for makes and another for breaks, and only one card variety would be needed for all combinations of makes, breaks, and non-sequence transfers. Where sequences are needed, however, additional card varieties are required with steps in the actuating surfaces for the early contacts.

In order to obtain a wider variety of the contact combinations including various numbers of make contacts, break contacts, sequence transfers and non-sequence transfers on the same relay, it is necessary to provide a variety of different coded stationary and twin wire assemblies, as well as a variety of cards, some of which are illustrated in Fig. 7. The twin wire assemblies differ as to the number of twin wires provided and in the position of these wires across the width of the molded section.

The stationary wire assemblies are always provided with a full complement of twelve wires in order to support the front molded section, which is held in place by spring tension in these wires. However, only certain of the wires may have contacts at the ends. These stationary contacts consist of base metal blocks with 0.010 inch thick precious metal surfaces on either or both sides as needed for makes, breaks or transfers, and any of the three varieties may be welded to any wire. Thus precious metal is provided only where needed for the particular contact arrangements desired.

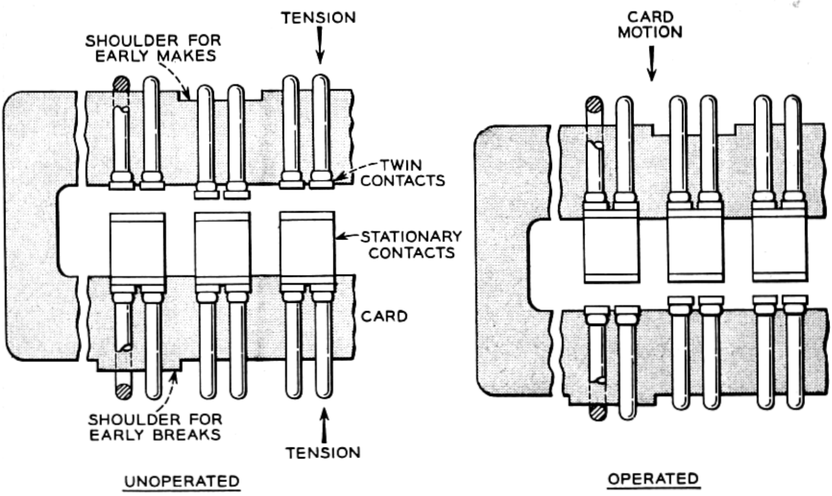

Fig. 6—Early break-make, early make-break and non-sequence transfer contacts, showing how early contacts are obtained by means of shoulders on the actuating card.

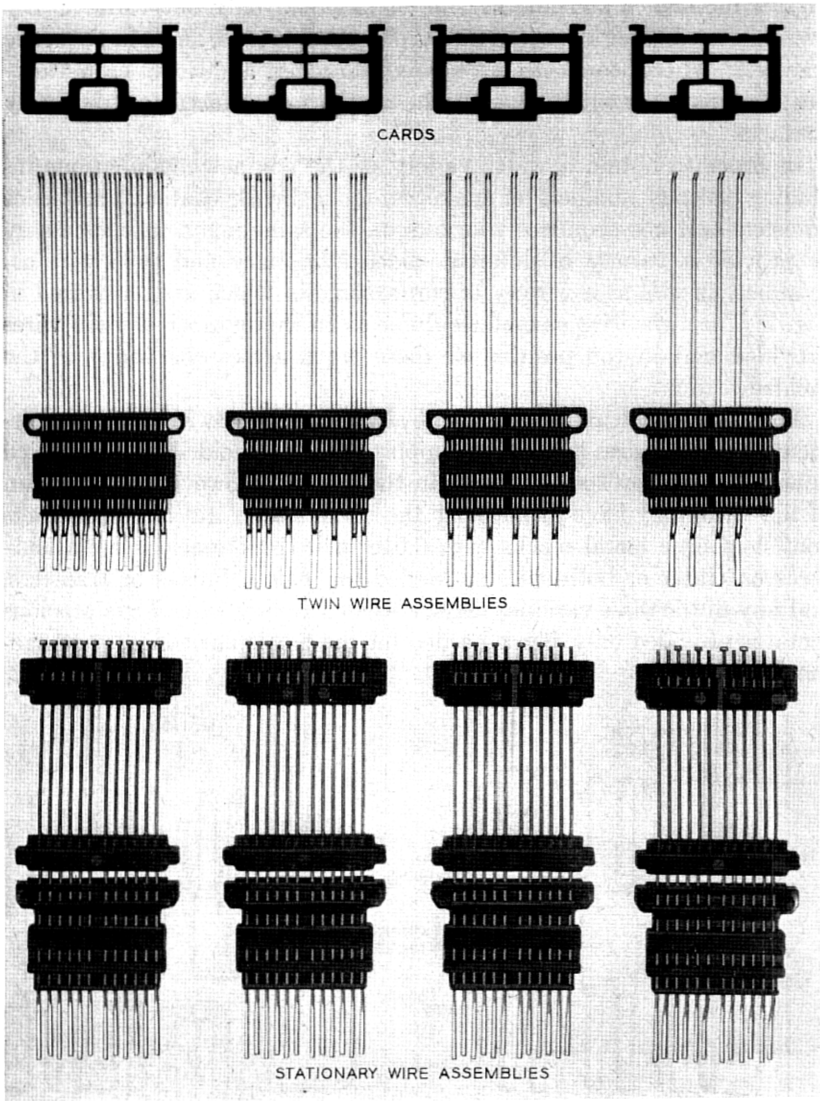

Fig. 7—A few varieties of the coded parts used to obtain various contact combinations.

By using different combinations of stationary and twin wire assemblies with each card variety, a large number of different contact combinations may be obtained. While most of these needed for telephone switching systems use either no sequences at all or a single stage of sequence, a few combinations are provided with "preliminary" contacts. These combinations include two stages of sequence, in which some contacts operate at each of three different points in the armature travel. The preliminary contacts operate earliest in the travel. These are followed by the early contacts of sequence transfers and finally by the late contacts, including ordinary makes and breaks.

To be sure the desired sequences will be maintained during the life of the relays, it is necessary to provide margins in the form of armature travel allowances at each stage. Combinations with sequences will therefore require total armature travels which are longer than those with no sequences, and two stages of sequence will require more travel than a single stage. Accordingly, the AF relay is provided with a choice of three armature travels to correspond with the number of sequences needed. At the card, these travels are 0.026 inch (short) for no sequences, 0.044 inch (intermediate) for one stage and 0.060 inch (long) for two stages.

Thus, combinations including ordinary makes, breaks and non-sequence transfers use short travel. Where sequence transfers are also needed, intermediate travel is used and the early contacts of the sequence transfers operate first. Long travel is used only where preliminary contacts followed by sequence transfers are needed.

5. ARMATURE SYSTEM AND MAGNETIC CIRCUIT

The armature system and the associated magnetic circuits constitute the basic motor element of an electromagnetic relay. The size of the motor element is determined, in part, by the work it must do and here a basic factor is the contact force. On the basis of analytical as well as experimental studies, it was decided to use a contact force of about six grams per single contact, i.e., about twelve grams for the combined force of the twin contacts. Other important factors which react on the design of the magnet are the speed required, winding space, heating,[6] sensitivity, etc. The detailed analysis of the magnetic system and the associated measurements will be covered in separate papers.

The magnetic structure chosen is shown in Fig. 8. The armature is a flat member of U shape which provides desirably large pole face areas.

[6] R. L. Peek, Jr., "Internal Temperatures of Relay Windings", *Bell System Tech. J.*, Jan., 1951, p. 141.

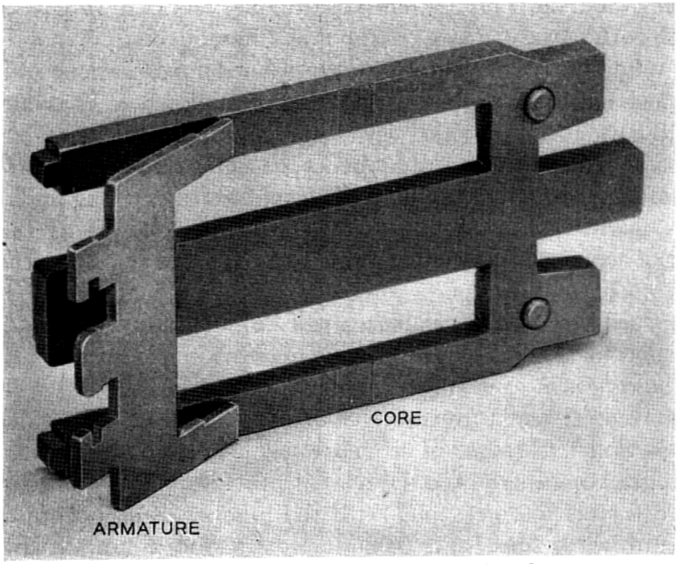

Fig. 8—Magnetic structure of the AF relay.

The core is a simple one-piece E-shape section of sufficient thickness of 1 per cent silicon iron to produce the magnetic flux needed to meet the force and speed requirements and to provide the main member to which all other parts are assembled. The silicon iron has appreciably higher electrical resistance than ordinary magnetic iron and this, together with the rectangular cross-sections of the legs, reduces eddy currents as needed for high speed operation and release. The one-piece construction avoids welded or butt joints common to many magnets. These joints are responsible for added reluctance and hence decrease the magnet sensitivity and require added electrical power to operate a given load. The relatively wide spacing of the legs increases leakage reluctance and, in turn, increases the useful magnetic flux.

After a cellulose acetate filled coil[7] has been assembled to the middle leg of the core, a core plate, shown in Fig. 9, is forced over the ends of the E-shaped core to hold the three legs in good alignment for proper mating with the armature. The core plate also provides the backstop for the armature and serves as a means of gang adjustment of the contacts covered more completely under the Relay Adjustment section of this paper.

The armature is spring supported in a very definite manner to produce

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[7] C. Schneider, "Cellulose Acetate Filled Coils", *Bell Lab. Record*, Nov., 1951, p. 514.

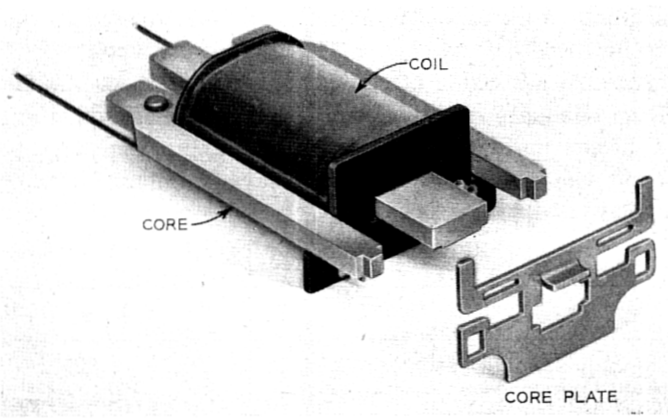

Fig. 9—Legs of the core are held in alignment by the core plate, which is forced over the ends after the coil is assembled.

a minimum of rebound when it is released from its operated position. The conditions for reducing armature rebound were described previously[8] and make it necessary to proportion the forces at the front and rear of the armature properly. The magnitude and the ratio of these forces are a function of the mass distribution of the armature.

The magnet design must not only meet such functional requirements as speed, sensitivity, etc., but it must meet these for several values of armature travel as needed by the variety of contact combinations provided. Another requirement is that the relay be designed to fit on a 2-inch mounting plate and this, in turn, restricts the width of the E-shaped magnet core to slightly less than two inches. The relay is normally mounted with the 2-inch dimension in the vertical direction to allow the contact surfaces to be in vertical planes. The corresponding horizontal dimension in which the relay can be mounted is 1½ inches except for a few special cases. As described in more detail under the section on Relay Performance, the improved magnet design has resulted in a reduction of the magnetic interference between mounted relays to values which are negligible for most practical purposes.

For comparison with the U type relay, the following typical constants of the magnet are of interest (see Table I). The closed gap reluctance, $\mathcal{R}_0$, is the reluctance of the magnetic circuit, excluding leakage paths, with the armature operated and with the iron near maximum permeability. The coil constant, G, is the ratio of the square of the number of turns to the resistance for a full sized coil. The sensitivity, S, is a measure

[8] E. E. Sumner, "Relay Armature Rebound Analysis", *Bell System Tech. J*, Jan., 1952, p. 172.

of the ultimate work capacity of the magnet as related to the power input and has been defined as $S = 5\pi G/\mathcal{R}_0$ ergs per watt.

The favorable low value of closed gap reluctance for the new relay results from adequate cross-sections of magnetic material, the absence of joints, proper mating of the armature and core, and large pole face areas. A low value of reluctance also insures less magnetic interference to other relays and from other relays.

TABLE I

	AF Relay	U Relay
Closed Gap Reluctance $\mathcal{R}_0$, cm^{-1}	0.028	0.065
Coil Constant G, kilomhos	160	160
Sensitivity S, ergs per watt	90,000	39,000

Although the coil constants are the same for the two relays, as can be seen from Table I, the sensitivity of the new relay is more than double that of the U relay, because of the lower closed gap reluctance.

6. MOLDED WIRE SPRING SUBASSEMBLIES

One of the major features of the new relay is the use of molded wire spring subassemblies. Fig. 10 shows a wire spring relay with twelve make contacts, and Fig. 11 shows a comparison of the wire spring assemblies used in this relay and the corresponding parts of the U relay. From this it is clear that the number of parts handled in the assembly of the contact spring members is greatly reduced in the new relay. Not all relays will have twelve contacts and in those cases where fewer contact springs are needed the comparison will not be so unfavorable to the U relay. For six contacts, about one-half of the parts shown will be needed for the U relay, whereas the new relay will again require two wire spring combs. In the new relay three wire spring combs are needed for any contact combination which includes both make and break contacts up to twelve makes and twelve breaks. Four wire spring combs are needed for a relay having twenty-four make contacts.

Two problems had to be solved in providing molded wire spring combs, namely, wire straightening and molding of a multiplicity of wires. Both of these were studied cooperatively at Bell Telephone Laboratories and the Western Electric Company.

Wire is straightened by rotating cam and die members around the unstraightened wire which causes alternating flexing of the wire. For best results, it was found important to shape the cams properly and to

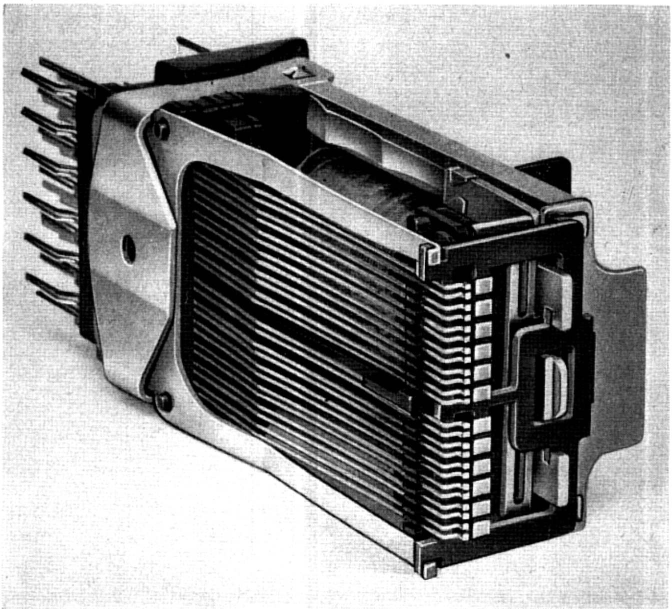

Fig. 10—AF relay with twelve make contacts.

push, rather than to pull, the wire through the rotating cams. By this means it is expected to get straight wire without producing an appreciable twist in it. The Western Electric Company has developed a multiple head wire straightening machine which can be directly associated with the molding press.

A multiplicity of straightened wires is fed into a molding press where plastic molding is used to hold them in proper location. Molding of wire required that the plastic, fed into the die, avoid any appreciable distortion of the wires between unsupported sections. A considerable amount of development work, chiefly by the Western Electric Company engineers, was required to achieve this result. Transfer molding of a thermosetting phenolic plastic has been chosen as the most suitable for producing stable wire spring subassemblies. This is based on the need for stability of the wire positions and because of the ability of the material to withstand the effects of heat. Fig. 12 shows continuous ladders of molded wire spring sections before cutting to length.

The molded sections have a number of features of design importance beyond holding the wires in place. These added features are provided by shaping molded sections to make the remainder of the relay simpler. In particular, these features provide registration pins and holes, guides for

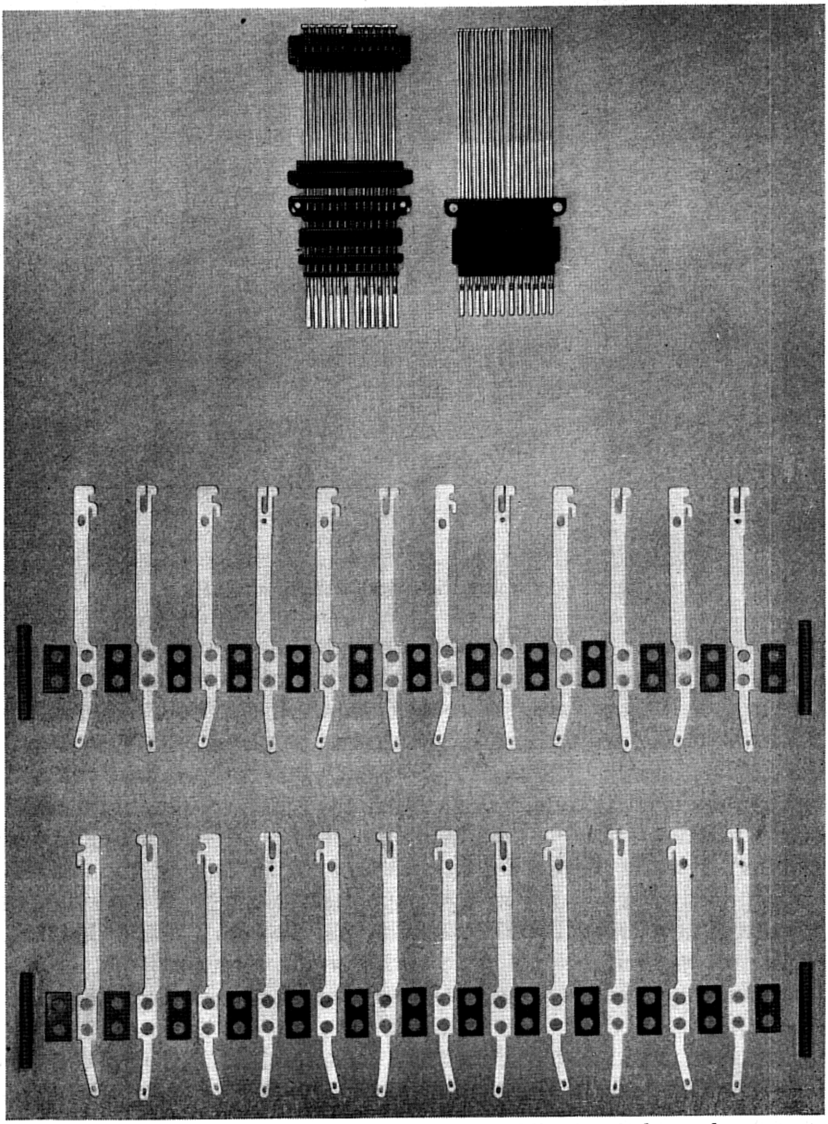

Fig. 11—A comparison of the molded wire assemblies for twelve make contacts with the corresponding U relay parts.

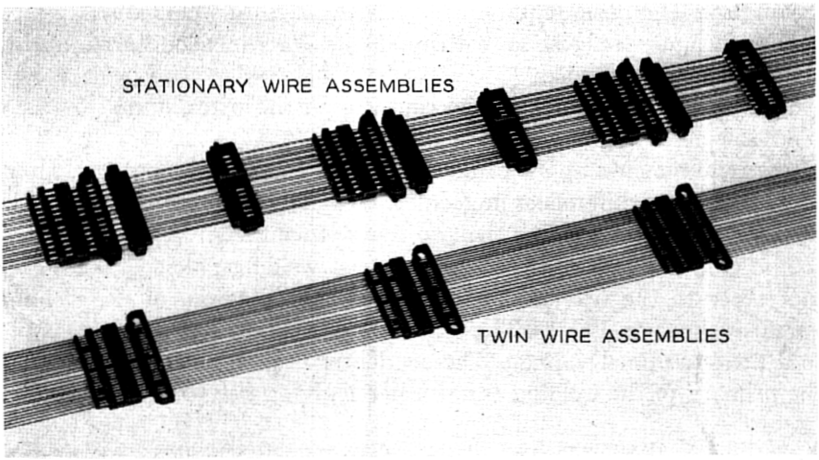

Fig. 12—Molded stationary and twin wire assemblies, before cutting to length.

the ends of the twin wires, cover anchorage, damping material support, etc.

7. CONTACTS AND CONTACT WELDING

Since the primary purpose of the relay is to open and close electrical circuits through the contacts, there has been a special effort to make these contacts as reliable as possible. Accordingly, palladium is used for all contact surfaces. This use of precious metal substantially eliminates opens due to corrosion. Palladium not only gives outstanding reliability but studies indicate that its use results in the best economic balance between manufacturing cost and service because of the reduced maintenance expense.

Open circuits due to particles of dirt between the contact surfaces are largely eliminated by the use of a contact cover, complete independence of the twin contacts described in the section Relay Performance, and the dynamic characteristics of the wire springs. However, to further reduce the incidence of dirt troubles, the surfaces of the twin contacts are coined to a cylindrical shape. This greatly reduces the effective bearing area between the twin contacts and the flat surfaces of the single contacts. Thus, even if an occasional dirt particle should come to rest on one of the contact surfaces, there is small likelihood that it would be in the contact area.

Since welding contacts to wires instead of flat springs is relatively new, considerable attention was given to the development of suitable techniques. The basic requirements for satisfactory welds are:

1. Sufficient strength to withstand the forces encountered during manufacture and service;
2. Accurate positioning of the contacts on the wires, and
3. Low cost.

These requirements apply to both stationary and twin contacts. However, because of differences in geometry, entirely different methods have been developed for welding the two types of contacts.

The twin contacts are produced by spot welding precious metal contact tapes to the tips of the twin wires. The diagram of the welding circuit is shown in Fig. 13. The condenser C is charged by a power supply to a predetermined voltage. The condenser is then discharged through the primary of the welding transformer T giving rise to the low voltage

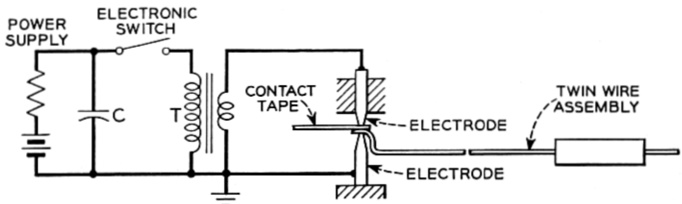

Fig. 13—Diagram showing the essential elements of the spot welding process used for the twin contacts.

high current surge which produces the weld. The contacts are then sheared to length and the surfaces are coined to a cylindrical shape.

The spot welding process did not appear best for welding the stationary contacts to the ends of the wires because of the need to grip the wires with heavy welding electrodes in the limited space directly behind the contacts. Accordingly, a type of welding known as "percussive welding" was developed, which permits one of the electrodes to be placed near the wiring end of the wire springs without developing excessive heat in the wires and which also permits the accurate positioning needed for the contacts in order to control the point of contact closure on the assembled relay. The welding circuit is shown in Fig. 14. The condenser C is charged by means of a direct current power supply, and the condenser voltage also appears on the stationary wire. As the contact to be welded is moved toward the end of the wire, the condenser discharges forming an arc which melts the abutting surfaces of the contact and wire. The constants of the electrical circuit and mechanical system were chosen to assure melting a proper amount of metal at a controlled rate to assure high weld strength. The parts are held together during the very brief cooling period as the weld is completed. A small resistance R is added in series with the discharge circuit to limit the current and control the arcing period.

That high weld strengths are obtained by this process is indicated in Fig. 15 which shows typical distributions of weld strength for both the percussive-welded contacts and the spot-welded twin contacts. The plots show the percent of contacts with weld strengths equal to or less than any prescribed value within the range of the chart. As shown, the percussive welds are generally stronger than the spot welds which is, in part, due to larger welded areas.

Although percussive welding is more suitable for the stationary contacts welded in the factory, it is planned that occasional replacement of both stationary and twin contacts will be made in the field by spot

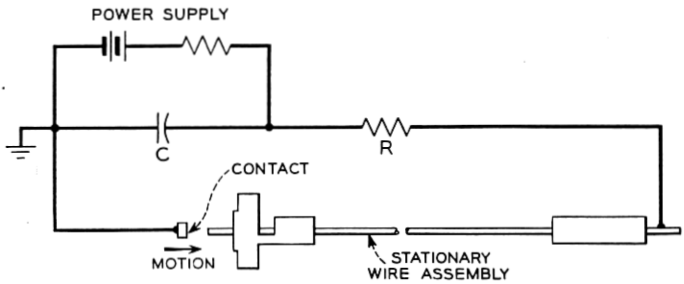

Fig. 14—Diagram showing the essential elements of the percussive welding process used for the stationary contacts.

welding. This will be done with the Bell System field welding equipment[9] provided with suitable electrodes. In this case, however, more expensive all-palladium stationary contacts of special shape would be used to facilitate the spot welding and individual hand adjustment for final position of the contacts will be necessary.

8. STANDARDIZED ASSEMBLY OF CODED PARTS

Since assembly was one of the most promising fields for reducing costs in a new relay design, special effort was made to reduce the assembly cost of the AF relay. Some of the major design features which contribute to low cost assembly are:

1. The continuous molding and fabricating processes for the wire spring subassemblies, which avoid all individual handling of wires and contacts.

[9] W. T. Pritchard, "Relay Contact Welder", *Bell Lab. Record*, April, 1944, p. 374.

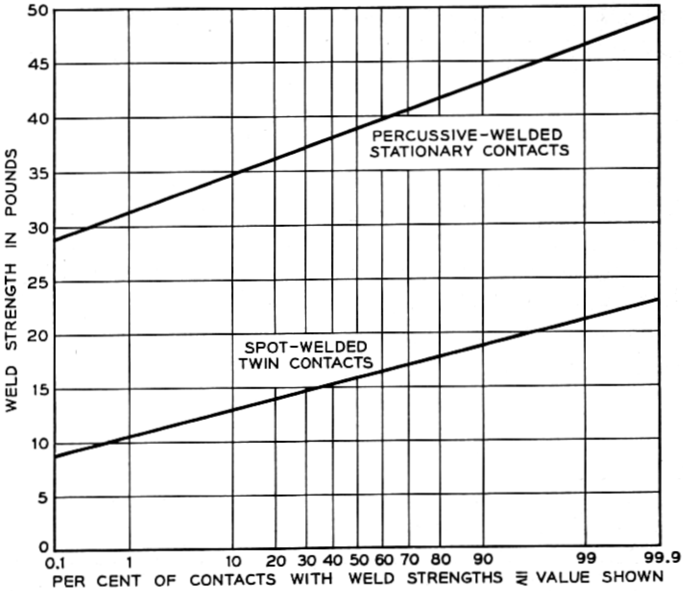

Fig. 15—Typical weld strength distributions for the stationary and twin contacts. The horizontal scale is graduated so that normal distributions will plot as straight lines.

2. Clamping the relay pile-ups by means of a simple spring clamp instead of the more conventional method using screws.

3. A single, easily mounted, operating card.

Less obvious, but equally important is the basic philosophy whereby a large variety of different relay codes are obtained by assembling parts which for assembly purposes are essentially identical for each code. As previously described, the spring combination for each relay is controlled by selection of the proper code card, twin wire assemblies with wires in the proper positions for that combination, and a stationary wire assembly with the right kind of contacts welded to the proper wires. At the present time six different card varieties, fifty twin wire assemblies and seventy-five stationary wire assemblies have been standardized. The twin wire assemblies are provided with any number from one to twelve pairs of wires in various positions while the stationary wire assemblies have from one to twelve contacts in matching positions, with the added variable that each contact may have precious metal on either or both sides as needed. With these it is possible to obtain more than 300 different contact combinations, although only about 100 of these are now needed. Yet, with a few exceptions, each relay code is assembled from the same number of parts put together in the same manner. By using additional varieties of cards and wire spring assemblies the total number of contact combinations which are possible with the basic design is many times larger than the 300 indicated above.

Other examples of coded parts which are assembled in a standardized manner are the coils, core plates and restoring springs. Although coils vary greatly as to turns, resistance, etc., all are assembled to the cores by the same procedure, using identical spoolheads. The three values of armature travel are controlled by selection of core plates with the proper size of openings, but all core plates are assembled alike. Similarly, the restoring springs are provided in seven varieties including six different thicknesses and seven predeflections to give the desired restoring force, but these variations do not affect the assembly operations.

Standardized assembly of coded parts is of value, not only in reducing the cost of hand assembly operations, but also in providing a more uniform product and as a principle which may make machine assembly practicable.

9. RELAY ADJUSTMENT

Since adjustment expense accounts for a considerable part of the manufacturing costs of older type relays, special efforts were made in the design of the AF relay to reduce the need for adjustment. As a result several types of adjustment used with other relays have been eliminated completely and the remaining adjustments have been simplified. All individual contact adjustment has been eliminated and only two types of factory adjustments are made with the AF relay. These include adjustment of the restoring spring to control armature back tension and a gang adjustment of the stationary contacts to control the points in the armature travel at which the contacts operate. Even these adjustments are needed for only a fraction of the relays as close control of the tolerances in manufacture often causes the back tension and contact operate points to fall within acceptable limits as the relays are assembled.

The gang adjustment of the stationary contacts is made by bending the arms of the core plate, thereby changing the position of the front molded section of the stationary wire assembly which rests on the ends of the arms. Each arm may be bent by means of a screwdriver inserted in the slot as shown in Fig. 16. Rotation of the screwdriver in a counterclockwise direction causes the upper end of the core plate arm to move to the left, carrying with it the upper end of the stationary wire assembly, including the stationary contacts. This reduces the gap between these

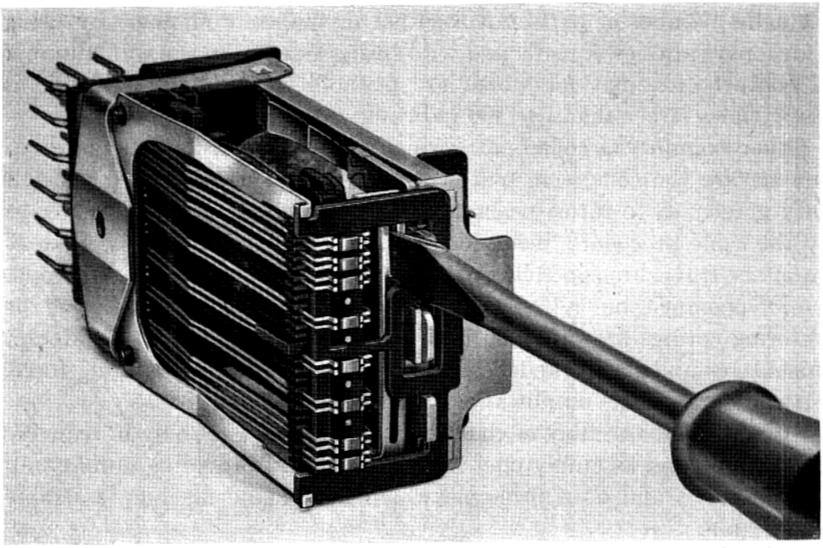

Fig. 16—Contacts may be gang adjusted to operate at the proper points in the armature travel by bending the arms of the core plate with a screwdriver.

stationary contacts and the make twin contacts, thereby causing these contacts to operate earlier in the armature travel. Since the break twin contacts rest against the stationary contacts, these are also moved to the left, reducing the space between the break twin wires and the actuating surface of the card. Thus, bending the core plate arms to the left causes both make and break contacts to operate earlier in the armature travel, while bending the arms to the right causes these contacts to operate later. By bending both arms in the same direction, the operate points of all contacts may be shifted in the same direction. On the other hand, separate arms permit adjustment of the upper relay contacts independently of the lower contacts, thereby increasing the latitude of adjustment.

The parts of the relay are dimensioned so that no adjustment of the core plate arms is required, except to compensate for variations in manufacture of the relay parts. Hence relays assembled from parts made with sufficient accuracy do not generally require adjustment.

The restoring springs may be adjusted for the proper armature back tension by the use of a simple spring bending tool applied to the side arms. However, springs are provided with various predeflections and thicknesses to correspond with various numbers of make twin contacts which must be held open in the unoperated position. Again, no adjustment for back tension is necessary except to compensate for variations in manufacture, as the restoring spring tension is normally just sufficient to overcome the tension of the make twin wires and hold the armature against the backstop within acceptable force limits. Close control of the tension bends in the wires and restoring springs reduces the frequency with which adjustments are needed and a large portion of the relays do not require this adjustment.

Types of factory adjustment which are common on other relays but which have been eliminated entirely on the AF relay include adjustments for contact force, individual adjustment of contacts for contact operate point, and adjustment for armature travel. Contact force is controlled by means of the large predeflections of the twin wires as mentioned previously. Individual contact adjustment is eliminated by close control of tolerances combined with the single card method of actuation, and by the simpler gang adjustment used when necessary. Adjustment for armature travel is eliminated by the use of close tolerances on the controlling dimensions of the parts.

Adjustments of worn relays in the field may be limited to gang adjustment of the contacts and back tension adjustment as described above. Other adjustments may include burnishing the contacts to remove surface irregularities, replacement of contacts and individual contact adjustment as mentioned previously, and replacement of the card if it should become badly worn or damaged. If card replacement is necessary this may be done without dismounting the relay from the mounting plate and without disconnecting the associated wiring.

10. RELAY PERFORMANCE

As previously stated, the broad objective in the design of the AF relay has been to reduce the annual charges for the use of this relay in the telephone system. Part of this reduction comes from lower manufacturing costs; the remainder comes from savings associated with the improved performance characteristics, such as long life with relatively low maintenance expense, reduced power consumption, and increased speed which reduces the number of units of certain types of equipment, such as markers, needed for telephone central offices. A brief description of some of the principal characteristics of the new relay follows.

Load and Pull Characteristics

Typical load and pull curves for a wire spring relay with twelve early break-make transfer contacts are shown in Fig. 17. The abscissa shows the motion of the armature as it travels from the unoperated position to the operated position, and back again. This is measured at the centerline of the card and hence is also the card motion. In the unoperated position the armature rests against a backstop, which is part of the core plate. In the operated position it rests against 0.006-inch thick non-magnetic separators which prevent the armature from touching the core. The ordinate shows the spring load, which opposes the armature motion

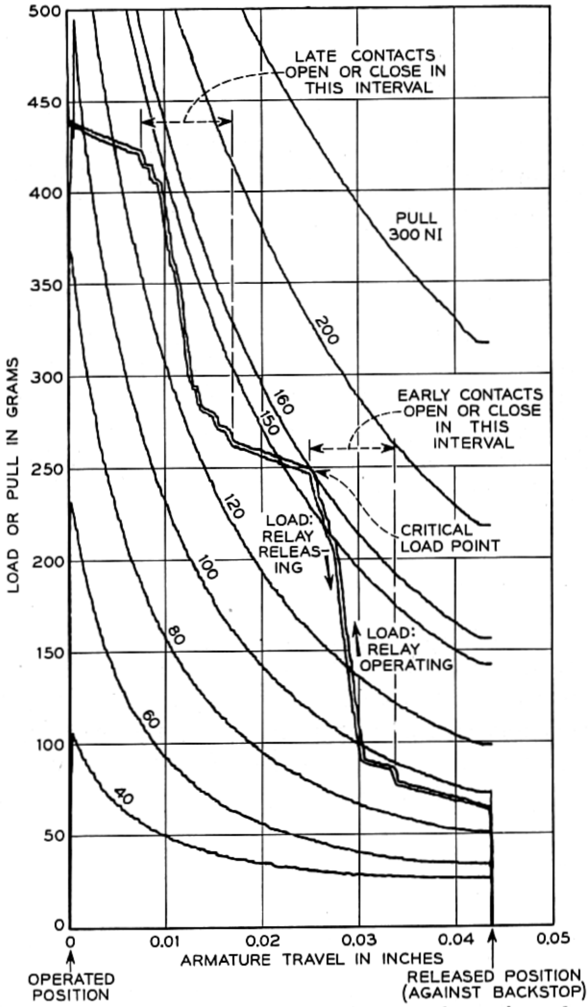

Fig. 17—Typical load and pull characteristics of a wire spring relay with twelve early break-make transfer contacts.

toward the core, and the magnetic pull acting on the armature for various numbers of ampere turns in the winding. These pull and load curves are also measured at the card.

Examination of the load curves shows several features of the relay. The armature back tension, or force, holding the armature against the backstop is about 65 grams in this case. As the armature moves toward the core, the spring load increases along the upper of the two nearly-parallel load curves until it reaches a final value of about 440 grams in the operated position. As the armature is allowed to return to its original position, a second curve, just below the original curve, is obtained. The area between these two curves is a measure of the energy loss due to mechanical hysteresis, or friction, in the relay. As can be seen from the curves, the friction in the new relay is very low and is a small fraction of the spring load at all values of armature travel.

The shape of the load curves is characteristic of AF relays with intermediate travel (0.044 inch). The load increases rapidly in two regions, corresponding to the intervals in which the early and late contacts operate. The rapid increases are caused by the armature and card picking up the additional load of the twin wire springs. Each of the 48 twin wires is picked up almost abruptly at various points and the summation of these additions to the load gives the irregular appearance shown.

The pull curves of Fig. 17 are for essentially static conditions since the armature was restrained to move slowly through its travel while the curves were automatically recorded. These curves are of interest because they show the ampere turns necessary to assure operation of the relay and also values which will assure the armature will not leave the backstop. For example, the "critical load point," or point on the load curve which requires the greatest number of ampere turns, is seen to occur at 0.025-inch travel and 250 grams, which under static conditions would require at least 160 ampere turns in the winding to assure complete operation. On the other hand, as little as 94 ampere turns could cause the armature to leave the backstop and might cause operation of one or two contacts. Hence, a lower value must be maintained to assure that the armature will remain at rest against the backstop. This information is important for relays having non-operate requirements. Similar information may be obtained for limiting ampere turn values which will assure that the armature will remain in the operated position (hold requirements) and, again, which will assure complete release to the backstop position (release requirements).

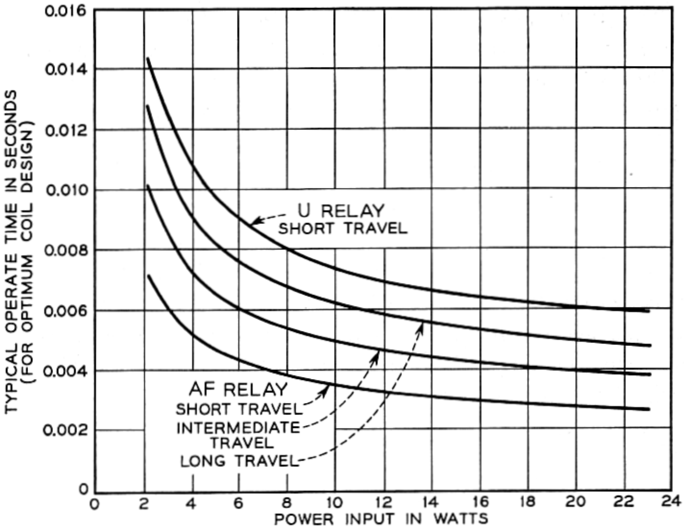

Fig. 18—Typical operate times of speed relays with optimum coil designs for high speed operation.

Speed of Operation and Release

Typical operate and release times of the AF relay are shown in Figs. 18 and 19. Fig. 18 shows the operate times for "speed relays" in which the speed is limited primarily by the time needed to accelerate the mass of the moving system, and is not affected appreciably by the spring loads. These are relays with coil windings of about 1000 ohms resistance, or less, corresponding to power inputs of 2.3 watts, or greater, when connected to a 48-volt supply. For each value of resistance, the operate time shown is obtained with windings having the optimum number of turns for shortest operate time. This time is plotted as a function of power input for various armature travels. Short travel relays have typical operate times varying from about 2.5 to 7 milliseconds as the power is reduced from 23 to 2.3 watts, or as the resistance is increased from 100 to 1000 ohms, using the appropriate number of turns in each case. Intermediate and long travel relays have longer times. For comparison, a short travel U relay is also shown. This relay requires about twice the time to operate as the corresponding AF relay. The improvement with the AF relay is due primarily to the lighter mass of the moving system and slightly shorter travel due to better control of tolerances. Better control is inherent with the single card system for contact actuation and is accomplished without individual adjustment of contact or backstop position, both of which are hand adjusted on U relays.

Typical release times for the AF and U relays are shown in Fig. 19, with time plotted as a function of the number of contact pairs for relays equipped with standard 0.006-inch thick nonmagnetic separators. In this case the improvement is greater than two to one, due principally to the lighter moving parts of the AF relay and lower eddy current effects of the rectangular silicon iron core.

Power Requirements

The nominal power required to assure operation, with some margin, of relays with windings designed for minimum power consumption is shown in Fig. 20. Included is an allowance for adverse variations in magnetic structure, winding and loads. Since least power will be used by the largest coil wound with the finest wire consistent with meeting the ampere-turn requirements for the various contact loads, the curves are discontinuous and have steps as the wire sizes are shifted from one size to the next to meet the ampere turns needed for increasing loads. Again, the corresponding U relay power is shown for comparison. For corresponding numbers of contact pairs, the AF relay requires about half the power of the U relay, except with fewer contact pairs where the power in each case depends upon the use of No. 41 gauge wire. This comparison applies only when coils of optimum design for minimum power are used on both relays. In practice, the coils are selected for the best economic balance between power consumption, cost of the coils and value of speed of operation. Coils designed for minimum power are rela-

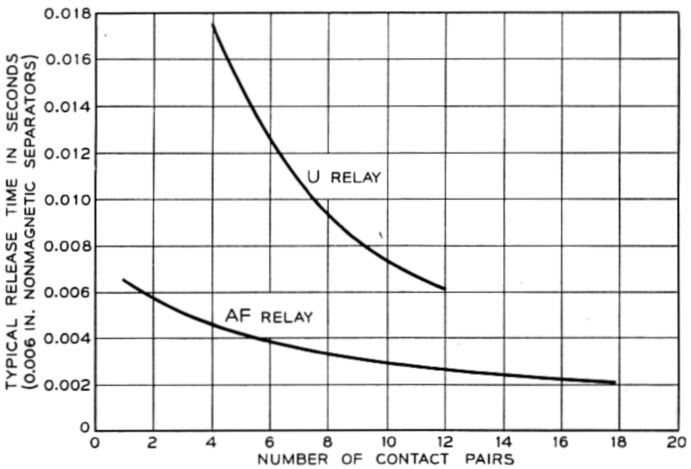

Fig. 19—Typical release times of AF and U relays.

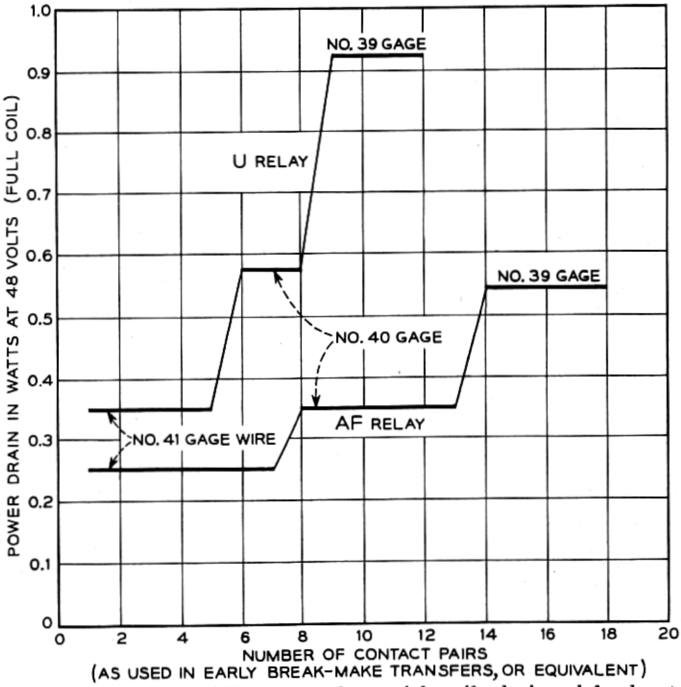

Fig. 20—Power used for AF and U relays with coils designed for least power.

tively expensive because they contain as many turns of fine wire as the available space permits, and their use is economical only on relays which are operated an appreciable portion of the time and where speed is relatively unimportant. The reduced power required for the AF relay is due principally to an improved magnetic structure, shorter travels for similar contact combinations, and lower contact forces.

Contact Performance

The principal characteristics which must be considered in evaluating contact performance include chatter, erosion or wear, susceptibility to open contacts and locking, and changes in these characteristics with wear of the relays. In general, all these features are improved on the AF relay compared with the U type.

Typical chatter on closure of make and break contacts on U and AF relays built for moderate and fast operation is shown in Fig. 21. The degree of improvement of the AF relay is striking. The reduction in chatter has direct circuit advantages in reducing the possibility of false

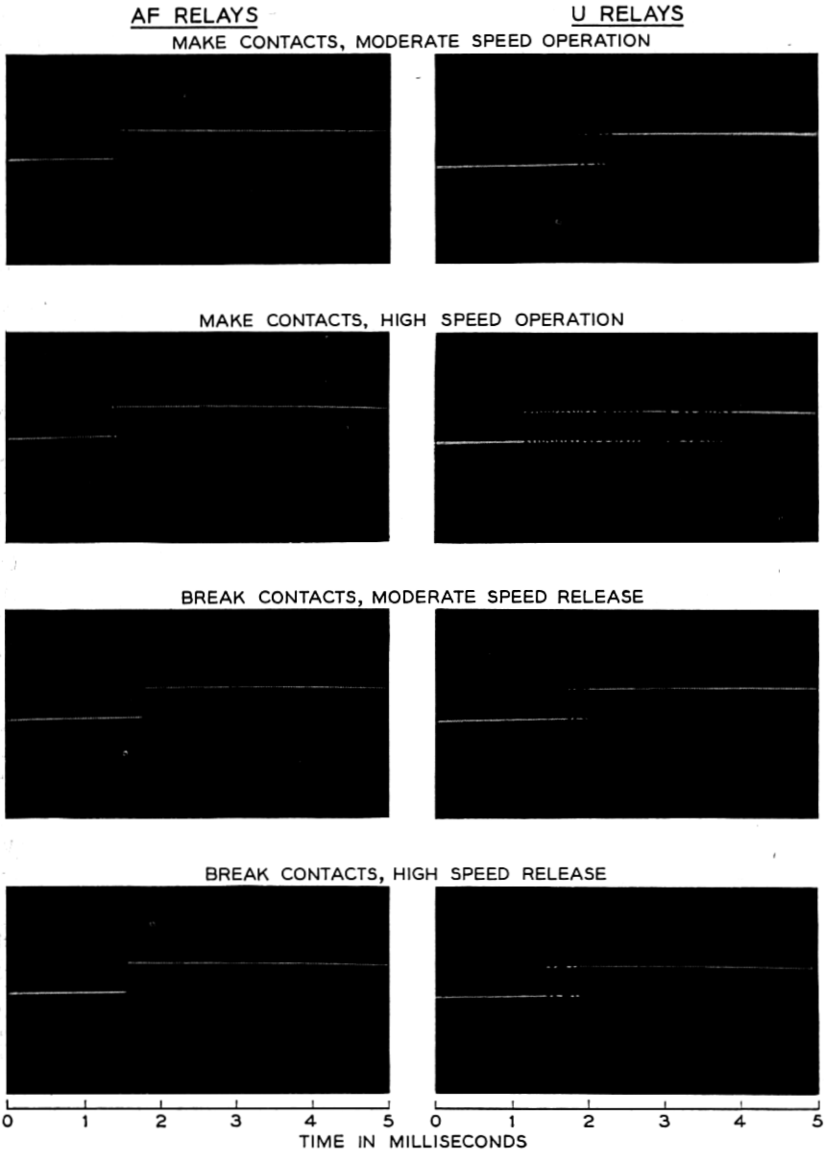

Fig. 21—Typical chatter on closure of contacts.

operation of associated high speed equipment and also indirect advantages in prolonging the life of the contacts. The improvement is due largely to the type of card operation of the completely independent, low-mass twin wires and also to the low mass of the moving system which excites less vibration of the relay structure as a whole. The placement of the card close to the contacts allows the full contact force to be developed within a very short time, and the low mass of the twin wires stores little kinetic energy to cause reopening due to wire vibration.

A particularly troublesome type of chatter occasionally experienced is caused by rebound of the armature after striking the backstop. This chatter is objectionable because of its long duration which is of the order of a millisecond and may occur several milliseconds after the initial opening or closure of the contacts. This increases the possibility of false operation of associated circuits. Accordingly, a fundamental study was made of the means for reducing armature rebound, as previously mentioned. As a result, changes were made in the suspension of the armature and in the position of the backstop which substantially eliminated chatter due to armature rebound.

Electrical erosion of the contacts is reduced on the AF relay because of less chatter and because of the lower energy levels controlled by the contacts, where these are used to operate other AF relays. This improved performance not only reduces maintenance but permits the use of less expensive, smaller size contacts.

Contact locking is substantially eliminated on the AF relay because of the card operation, where the static and dynamic forces associated with the card and armature are available to break loose any incipient lock. Open contacts are reduced by (1) protecting the contacts from dust with a small cover, (2) rounding the twin contact surfaces to reduce the effective areas on which particles must lodge to cause opens and to increase the pressure on the areas, (3) the use of palladium contacts, (4) the dynamic characteristics of the wire springs, and (5) the use of twin contacts on completely independent twin wires. The complete separation of the twin wires is an important feature in reducing open contacts. As shown in Fig. 22, the flat punched springs of the U relay carry twin contacts but these are mounted on tips which are separated by a relatively short punched cutout. This limited separation did not achieve the full advantage of twin contacts as a sufficiently large particle of dust under one contact could cause both contacts to be held open. A subsequent design, known as the UB relay,[3] used a longer cutout, resulting in greater independence of the twin contacts with a significant reduction in contact opens. The AF wire spring relay achieves complete separation by use of separate twin wires and a significant part of the improvement with respect to contact opens is due to this feature.

The improvements in contact chatter and open contacts become even more evident during the life of the relay. As shown in Fig. 23, the contact forces on U relays diminish rapidly with wear of the contacts resulting in increased chatter, more frequent opens and the need for earlier readjustment. Card operation of wire springs with large predeflections, however, assures substantially constant forces, thereby maintaining the initial chatter-free performance and fewer open contacts.

Life

Tests of relays with contacts protected electrically with resistance-condenser networks indicate that the standard AF relays with winding resistances of 700 ohms or greater will have a life in the order of 250–500 million operations before readjustment becomes necessary. With readjustment, of course, these figures can be increased several times.

Where longer life is essential, special features are used to increase the life. With these features a life, before readjustment, of a billion operations is expected for some relays and, with readjustment, all relays equipped with the special features for long life should be capable of a billion operations.

The special features for long life include vibration dampers attached to the twin wires and the stationary wire assembly as shown in Fig. 24, wear-resistant nickel and chromium plate on the armature, core, and core plate, and a long-wearing alloy for the nonmagnetic separators

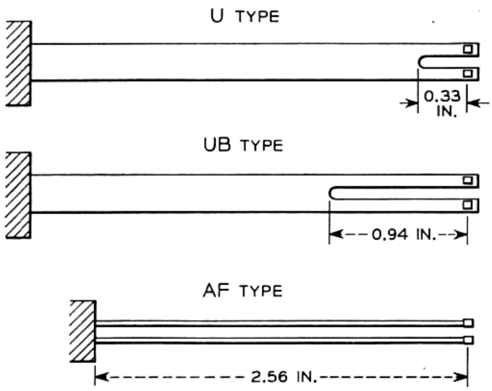

Fig. 22—Independent action of the twin contacts is limited on U and UB relays because both contacts are mounted on a single spring which is notched. The AF relay achieves complete independence by mounting the contacts on separate wires.

welded to the armature. The special features consist largely of variations in finish and material which do not greatly affect the manufacturing processes. The only added parts are the damping members. These are molded from soft but stable polyisobutylene with grooves to receive the twin wires. One damper is attached to each side of the shelf provided on the stationary wire assembly. The twin wires pass through the grooves and are cemented in place. As shown in Fig. 25, these dampers reduce the vibration of the twin wires between the card and the molded section at the rear, thereby reducing the slide between the wires and the card.

Early designs of relays indicated that wear between the twin wires and the card was excessive and that changes in materials would not produce the improvement needed for very long life, particularly with high-speed relays. A fundamental study[10] of the conditions which cause wear was made and it was found that reduction of the sliding motion between the wires and card to 0.001 inch or less was necessary to substantially eliminate such wear. The AF relay meets this requirement. The necessity for such a requirement will be better understood when it is

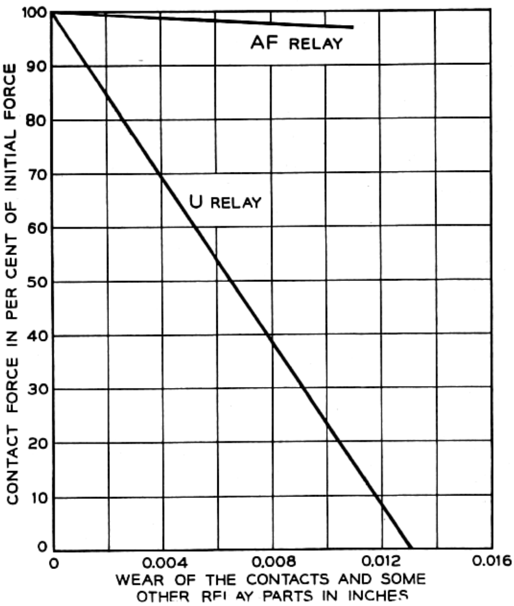

Fig. 23—Contact forces on the AF relay remain almost constant with wear, while U relay contacts lose force rapidly.

[10] W. P. Mason and S. D. White, "New Techniques for Measuring Forces and Wear in Telephone Switching Apparatus", *Bell System Tech. J.*, May, 1952, p. 469.

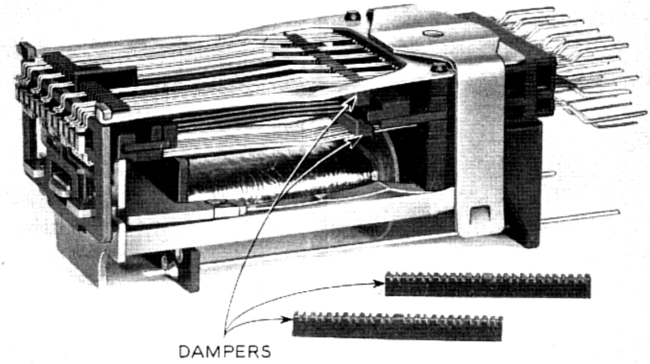

Fig. 24—Where very long life is needed, polyisobutylene dampers are mounted between the twin wires and a molded shelf on the stationary wire assembly.

noted that, for one billion operations, the total slide corresponds to a distance of about thirty-two miles.

Stability

The AF relay is a distinct improvement in stability compared with earlier designs when subjected to shock or temperature and humidity changes. Under severe and repeated variations in temperature and humidity, the largest changes in contact separation are not more than 0.002

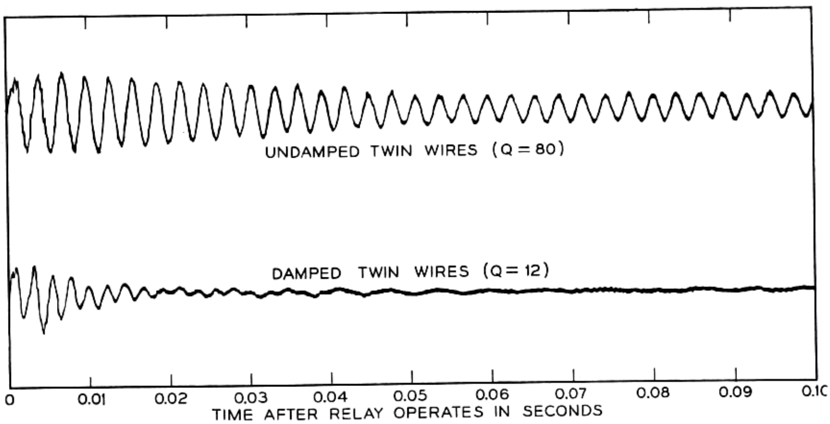

Fig. 25—Oscillograms showing the effectiveness of the polyisobutylene dampers in reducing the vibration of twin wires following operation of the relay. The vibration is measured in the horizontal plane, about midway along the length of the wires.

to 0.003 inch. The improved stability is expected to permit final adjustment and inspection of the relay at the time it is assembled without need for readjustment after it is wired into equipment and installed into service after shipment.

Magnetic Interference

In the past it has often been necessary to maintain large spacing between relays where critical values of current to operate or release the relays must be maintained. In some cases special iron shields were used for further magnetic isolation. Without these precautions, the leakage flux from adjacent relays entered the magnetic circuit of the critical relays and the operate or release currents varied according to whether the adjacent relays were energized.

Magnetic interference between AF relays is substantially eliminated as shown in Fig. 26. This is largely because of the low reluctance of the magnetic circuit resulting from the one-piece core and the large pole face areas between the core and armature. As shown in the figure, the

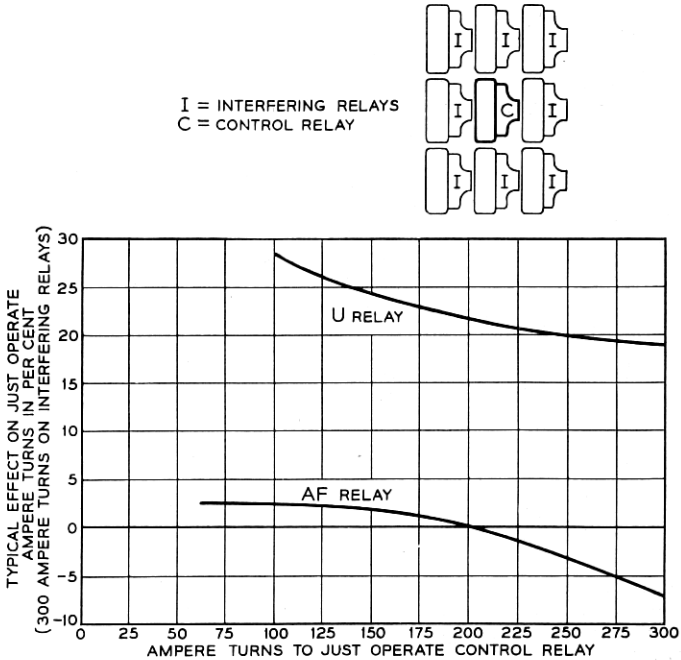

Fig. 26—Typical magnetic interference between AF relays and between U relays, with the relays mounted in the pattern shown.

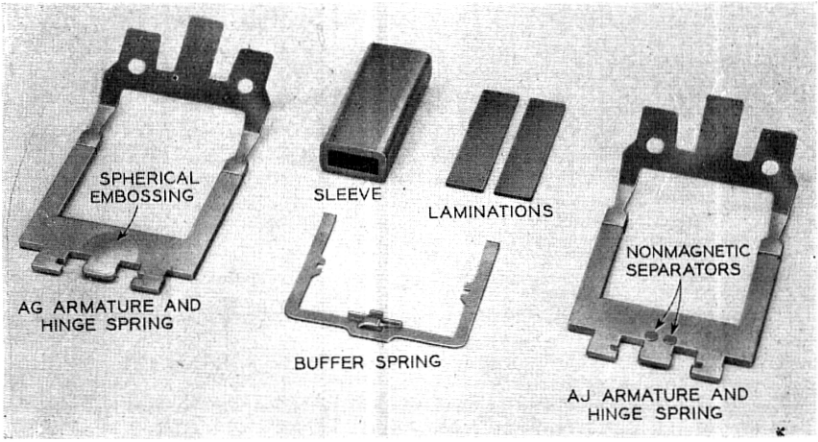

Fig. 27—Additional parts for AG and AJ relays.

measurements were made by surrounding a control relay with eight adjacent closely-spaced interfering relays. The ampere turns to just operate the control relay were varied by changing the mechanical load on the relay, and for each value the change caused by simultaneously energizing the adjacent relays was observed. The improvement of AF relays with respect to the U type is seen to be of the order of ten times for most of the range, with the effects of the adjacent relays being well under 10 per cent up to 300 ampere turns. This is small enough so that no shields or precautions with respect to spacing are required.

11. AG AND AJ TYPE RELAYS

The AG and AJ type relays include modifications of the basic AF design to provide slow release, sensitive, marginal and other additional characteristics. For the most part these modifications are not extensive and the assembled relays closely resemble the AF design.

The additional parts most often used in the AG and AJ relays are shown in Fig. 27. Both relays use thicker armatures with longer side legs than the AF relay, and the armature of the AG relay has a spherical embossing instead of nonmagnetic separators. This reduces the magnetic circuit reluctance of the AG relay when it is in the operated position. In addition, for longer release times, a metal sleeve is assembled over the middle leg of the core, inside the coil. Induced eddy currents in this sleeve oppose rapid changes of flux through the core.

The use of the heavy, embossed armature and a sleeve are sufficient

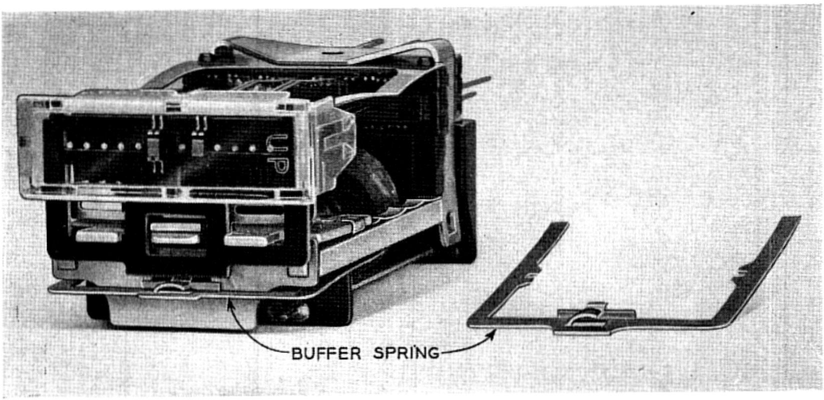

Fig. 28—The buffer spring is used to control the operated spring load, and therefore the release current and release time.

to make the relay slow to release.[11] When the current in the winding of such a relay is interrupted, the flux decays slowly due to the circulating currents in the sleeve. Also, the low magnetic reluctance increases the time for the flux decay by permitting relatively high flux values to be maintained by smaller circulating currents. However, to achieve better control of the release times and to maintain stable adjustment during the life of the relays, the following additional features are used:

1. The cores are annealed in a hydrogen atmosphere, chiefly to stabilize the coercive force of the iron.

2. The core and armature have a wear-resisting chromium plate finish to maintain the nonmagnetic gap between the embossed surface of the armature and the core.

3. The use of a spherical embossing reduces variations in reluctance caused by small angular misalignments between the armature and core.

4. Four sleeves are available including light, medium and heavy copper sleeves and a light aluminum sleeve. These sleeves provide various ranges of release time.

5. A buffer spring is provided on the relay to control the operated load and therefore the release time. As shown in Fig. 28, the buffer spring is normally tensioned against the end of the middle core leg. As the relay operates, however, the card strikes the adjustable tab in front of the middle leg and lifts the spring away from the core so that the spring tension is added to the operated load of the relay. The spring may be adjusted for any desired tension, within limits, and the tab can

[11] H. N. Wagar, "Slow Acting Relays", *Bell Lab. Record*, April, 1948, p. 161.

be adjusted so that the load may be picked up at any desired point in the armature travel.

When a relay is designed for a specified release time, the spread between maximum and minimum times obtained with a particular sleeve is usually greater than desired. Accordingly a sleeve is selected which under normal conditions would produce a somewhat longer time than the specified value. This time is then reduced, as needed, by increasing the buffer spring tension.

Typical release times plotted as a function of the contact load for AG relays with and without sleeves are shown in Fig. 29. Since this figure illustrates release times that are characteristic of the various sleeves, no buffer spring tension is assumed. As would be expected, the heavier sleeves produce the longer release times, which are also greater for relays with fewer contacts. Even the light aluminum sleeve produces several times longer release times than no sleeve at all. For comparison, release times are also shown for the AJ relay, which has a magnetic structure similar to the AG but with nonmagnetic separators in place of the spherical embossing on the armature. The difference between the AJ

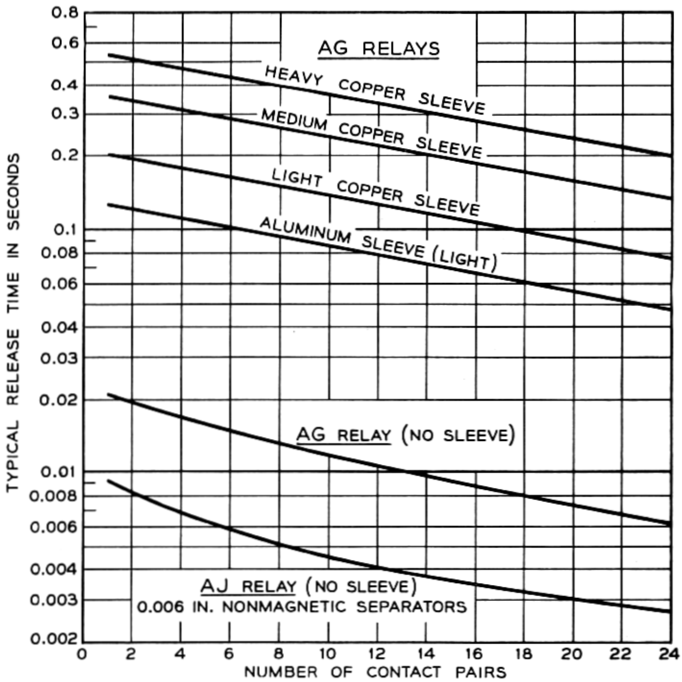

Fig. 29—Typical release times of AG and AJ relays.

release times and those for the AG relay with no sleeve shows the time advantage obtained with the domed armature.

The AJ relay, with its long and relatively heavy armature, is suited for the more critical marginal applications and is capable of operating heavier contact loads than the AF relay. All relays with more than eighteen contact pairs are provided only on the AJ structure. For example, Fig. 30 shows an AJ relay with a full complement of 12 transfers.

A measure of the power requirements for the AJ relay is given in Fig. 31. This shows the power required to assure operation with various numbers of contact pairs for coils designed to consume minimum power at 48 volts. The chart includes allowances for variations in load, magnetic structure and coil, with some margin for changes in these characteristics. Comparison with Fig. 20 shows the power requirements to be slightly lower than for the AF relay except for small numbers of contacts where limitation of wire sizes of the coils is controlling. Under limiting conditions the AJ relay will operate on as little as 0.025 watt.

Other features which may be used to extend the use of the AJ relay for special marginal applications include armatures with various thicknesses of nonmagnetic separators, wire spring assemblies with reduced contact forces, core laminations (strips of iron placed inside the coil, against the middle leg of the core to increase the effective cross-section) and the buffer spring which may be used to control the operated load of the relay and therefore the hold and release currents.

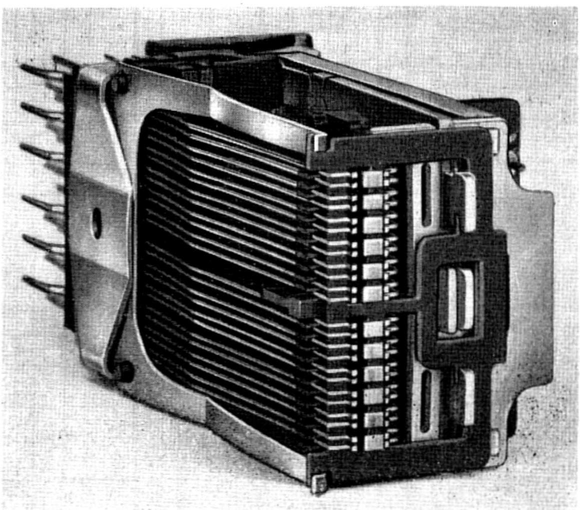

Fig. 30—AJ relay with twelve transfer contacts.

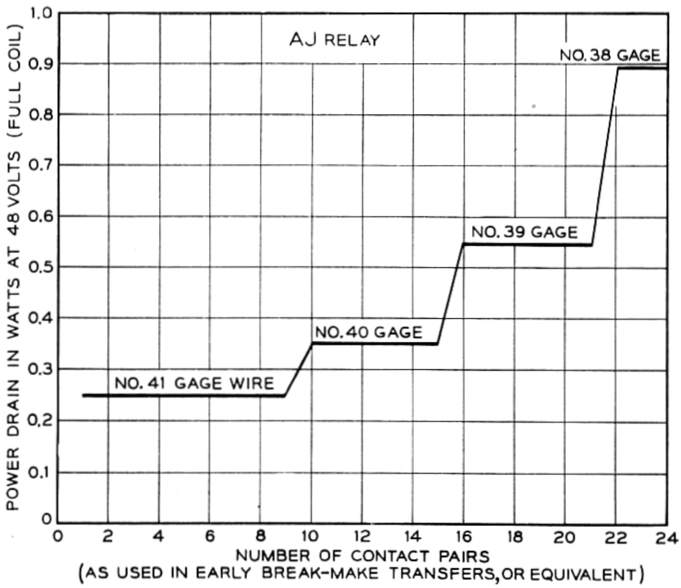

Fig. 31—Power used for AJ relays with coils designed for least power.

A special variety of AJ relay is provided with twenty-four pairs of make contacts as shown in Fig. 32. This relay uses four layers of wire springs and a number of other special parts. As a result, it is often possible to use one twenty-four make contact AJ relay rather than two relays with fewer contacts on each.

12. WIRING THE RELAYS

Connecting wires to the wire spring relay terminals presented a problem which was solved not only for the new relay but by methods which have become important and useful for other apparatus also The solution came from the invention of a tool, first proposed by H. A. Miloche,[12] for quickly and easily wrapping the connecting wire to the straight end of the wire spring relay terminal.

Early suggestions for making connections to the wire springs included various hooks or bends to simulate the common flat punched terminal having either a hole or notch to facilitate attaching the wires. All of these added some expense to the manufacture of the relay. The added costs were due to two factors (1) forming the wire spring ends required

[12] H. A. Miloche, "Mechanically Wrapped Connections", *Bell Lab. Record*, July, 1951, p. 307.

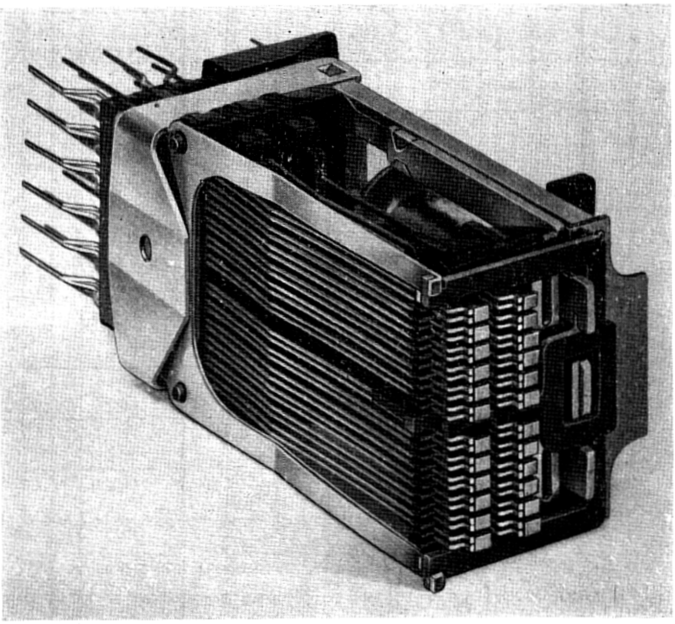

Fig. 32—AJ relay with twenty-four make contacts.

additional operations and (2) the greater flexibility of the wire spring terminals caused some difficulty for the operator so that some increase resulted in the time required to make a connection.

The wrapping tool was first visualized as a simple, trigger-operated hand tool, later as an air or electrically operated tool and still later as a combination tool to do additional operations including cutting and skinning the connecting wire.

Although the wrapping tool was developed to solve a problem which arose in the development of the wire spring relay, it was first applied in commercial practice by the Western Electric Company for wiring to the flat spring relay terminals. Wrapped connections are now used extensively with these terminals, resulting in an improved product at a lower cost. In making wrapped connections to either flat or round terminals, it was the expectation that tinned terminals and wire would be used and soldered together to give a stable, low resistance junction. More recently, however, it has been possible to show that soldering is not required if certain definite dimensional conditions are satisfied by the terminal and the wrapping tool. Solderless wrapped connections will be described in detail in a separate paper.

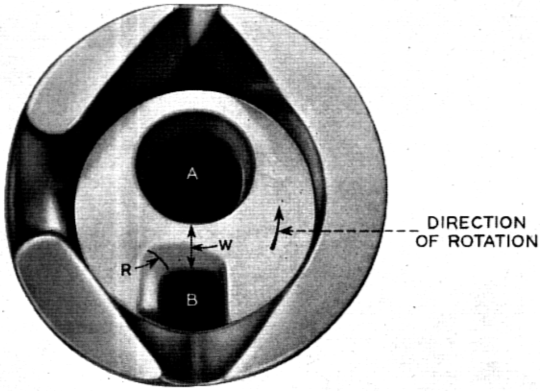

Fig. 33—Muzzle of wiring tool for making wrapped connections.

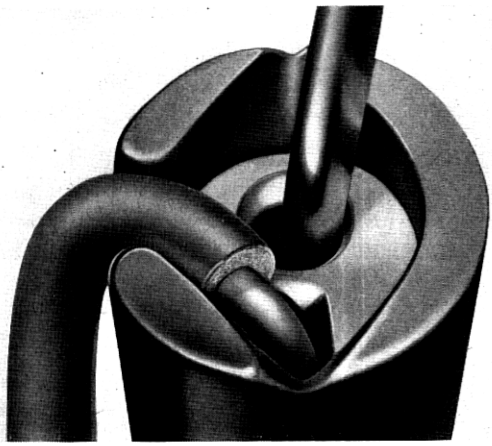

Fig. 34—Muzzle of wiring tool showing terminal and connecting wire in position ready for wrapping.

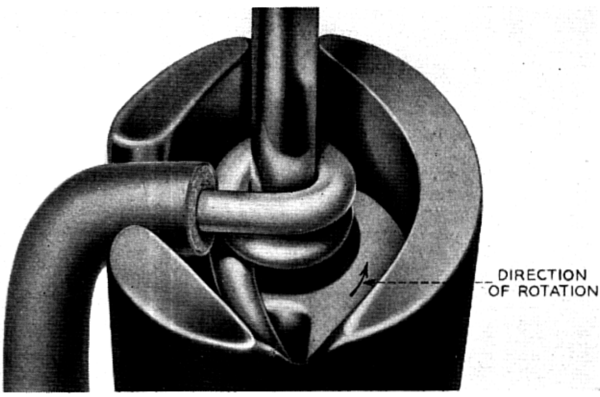

Fig. 35—Muzzle of wiring tool showing two turns wrapped by rotation of the inner cylinder.

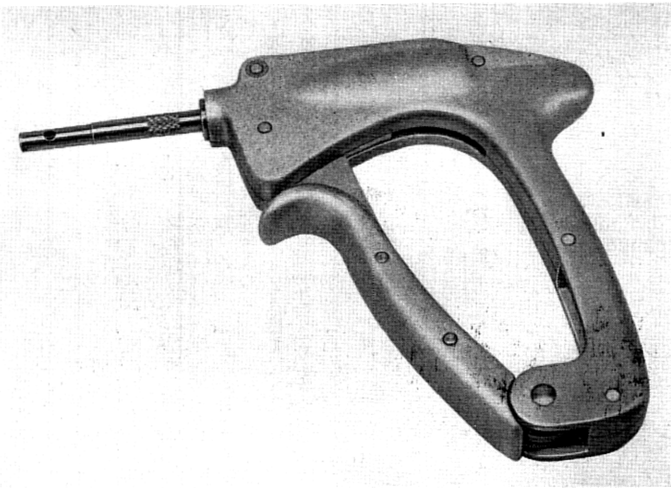

Fig. 36—Hand operated wrapping tool for installation and repair service.

Basic Principles of Wrapping Tools

A drawing of the arrangement and action of a wire wrapping tool is shown in Fig. 33. There are a number of dimensions of the tool and of the terminal which have engineering importance. For the purposes of this paper, it will suffice to note that the radius, R, and the wall thickness, W, are important in producing the best wrapped connection.

As shown in Figs. 34 and 35, the inner member of the tool rotates

Fig. 37—Wrapping tool operated by air pressure for factory use.

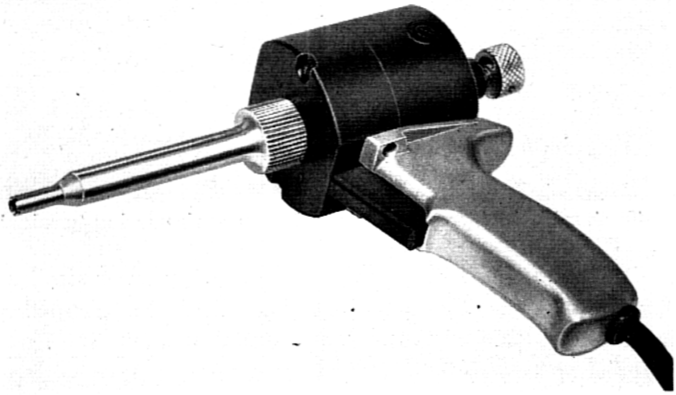

Fig. 38—Wrapping tool operated by electric motor for factory use.

around the terminal which is inserted in hole A of the rotating member. The connecting wire is inserted at B and is anchored by a slight force against the outer stationary member of the tool. As the inner member rotates, the connecting wire is stretched and formed around the terminal until all of the wire length is used. It should be noted particularly that all of the wire is used, making it unnecessary to clip a wire end as in other wiring methods. This is an important detail in avoiding wire clippings which sometimes cause unwanted cross connections in wired equipment units. The tool tip described can be operated by a hand trigger or by motor. Fig. 36 shows a hand powered tool primarily for installation and repair service. Fig. 37 shows a production type tool driven by air pressure developed by the Western Electric Company at the Hawthorne Works. Fig. 38 shows a tool driven by an electric motor used by the Kearny Works of the Western Electric Company. Fig. 39 shows a wrapped connection on a wire spring relay prior to soldering.

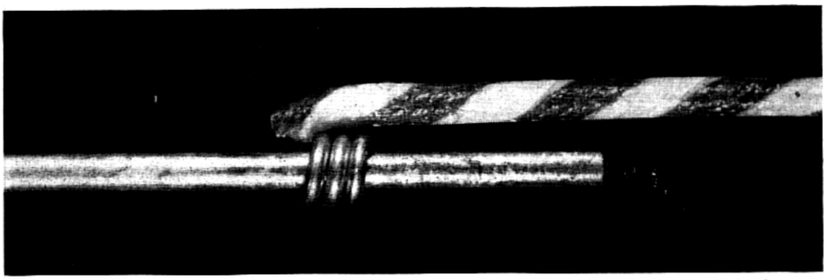

Fig. 39—A wrapped connection on a wire spring terminal, before soldering.

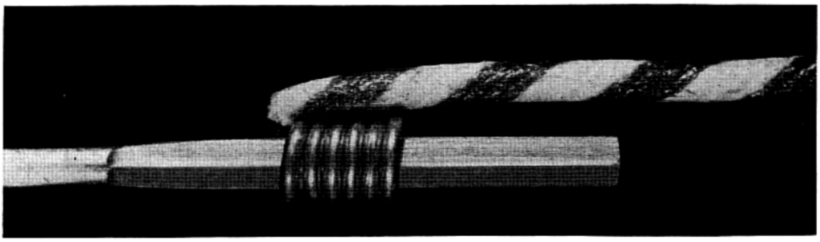

Fig. 40—A solderless wrapped connection on a wire spring terminal.

Another wrapped connection of the solderless type on a similar terminal is shown in Fig. 40. Studies indicate that solderless wrapped connections can be used with a wide variety of materials, including aluminum.

It is interesting to note that a troublesome problem in wiring to the new wire spring relay was solved by the development of a new method which itself has become an important development with broad applications. The wrapped connection with or without subsequent soldering has resulted in better, more uniform and less costly connections made in less time than those made by previous methods.

13. CONCLUSIONS

A description has been given of a new type wire spring general purpose relay for telephone switching systems. Although accurate manufacturing costs will not be available for some time, the new relay is expected to be substantially lower in cost. It provides major improvements in contact performance, reduced power, faster operation and longer life. The new relay also covers a wider field of application than any previous general purpose relay in such characteristics as speed, slow release, marginal operation, number of contacts, etc.

Important economic advantages include lower manufacturing cost of the relay itself and a reduction in switching systems costs resulting from less equipment and reduced power.

The new relay has shown considerable improvement in mechanical life and in contact performance. The life of the relay is of the order of one billion operations. These improvements can be expected to reduce the cost of maintenance of switching systems appreciably.

The development of the new relay has called for a major cooperative effort of many sections of Bell Telephone Laboratories, including such departments as Switching Apparatus Development, Switching Systems Engineering, Switching Systems Development, Research, Materials, Chemical, etc. Without the cooperation of the many members of these organizations and their special skills, this development would not have resulted in the important and balanced design which has been described. Throughout the development, the associated organizations in the Western Electric Company and the American Telephone and Telegraph Company have made important and guiding contributions, and the New York Telephone Company has cooperated in field trials.

As the spokesman for the project, I wish to express appreciation to the many people who have contributed to this important technical accomplishment. The few names which have been mentioned in the paper were given for historical reasons and cannot replace the large number of important contributors to the project.

To D. C. Koehler, I am indebted for assistance in preparing the paper and the illustrations.