Development of Reed Switches and Relays

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Improvements in the operating speed, efficiency, compactness and contact reliability of relays may be obtained from the application of sealed-in-glass reed switches. This paper is an account of the development of such switches and relay designs suitable for their use. Because of the close dependence of contact performance and switch operating characteristics upon process methods their development has been an important part of this project.

I — REED SWITCHES

Switches are those basic circuit elements of a telephone system which make it feasible to establish the connections desired by telephone users. To permit remote operation, switches in the telephone plant are usually electromechanical devices and they are used to select and establish needed talking paths. Since switches are used in large numbers their manufacturing and operating costs have a significant impact upon telephone economics and for this reason the development of switching apparatus receives much attention.

HISTORICAL

In 1936 the availability of new magnetic alloys prompted a study of improved means for the operation of switching contacts. As a part of this work there was conceived an extremely simple magnetic structure giving promise of excellent electromechanical efficiency, unusually high operating speeds and lending itself to very compact designs. This paper is an account of the development of this basic concept to the point of practical application in the Bell System.

The basic concept is shown in Fig. 1. Two flat reeds of magnetic material are supported as cantilevers with their free ends overlapping and separated by a small gap. Surrounding the reeds is an operating coil so placed that the overlap of the reeds is at its center. When the coil is energized the flux in the gap pulls the reeds together. The reeds perform the double function of a magnetic operating gap and a contact pair with which to close and open an electrical load circuit. This is a radical departure from the classical relay wherein the operating gap is external to the energizing coil and the armature operates the electrical contacts through mechanical linkages. The result is improved electromechanical efficiency through reduction in magnetic leakage and increased operating speed as the result of smaller displacements and moving masses.

In practice the reeds are supported by sealing them into the ends of a glass tube. This provides a structure sufficiently stable mechanically to assure the maintenance of the critical gap between the reeds and gives excellent electrical insulation between them in their unoperated position. Furthermore, by providing a hermetic seal around the electrical contacts it frees them from the effects of environment. This is of fundamental importance since corrosive or dirt-laden atmosphere is a major cause for expensive contact maintenance.

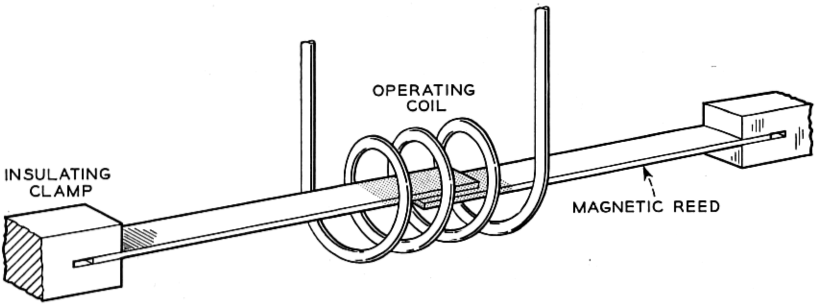

Fig. 1 — Basic reed switch concept.

Initial embodiments of this design concept were not as simple as indicated in Fig. 1. Materials having optimum magnetic characteristics do not in general make sound gas tight seals to available glasses, nor do they serve satisfactorily as electrical contacts if exposed to the air. Consideration of these factors led to the design shown in Fig. 2.* Reeds of the desired magnetic material are welded to supports of materials which will seal to glass and serve as electrical connections to the contacts. One of these supports is a rod, the other is a metal tube. After the switch has been assembled it is evacuated through the tube and filled with the de-

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* U. S. Patent 2,289,830.

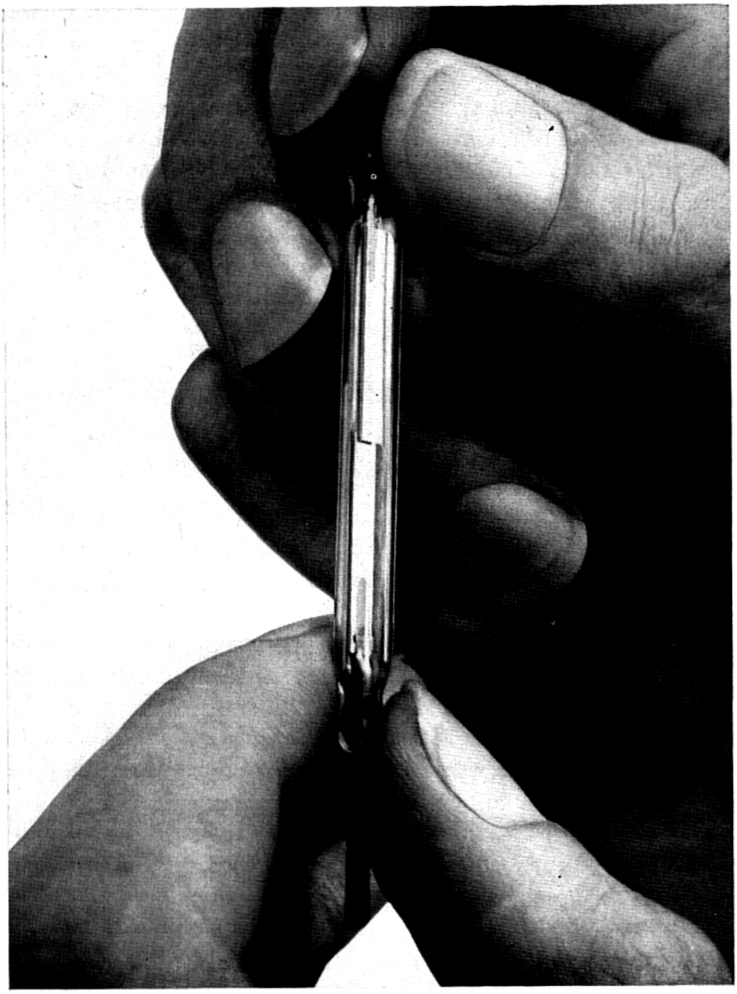

Fig. 2 — One type of early reed switch design.

sired gas and the tube is closed with a plug of solder. The proportions of this design were very suggestive and the first application, in about 1938, was in a carrier system where the switch was made a part of the central conductor in a coaxial line. The operation of the switch is controlled from a coil surrounding the line and complete isolation is obtained between the high frequency paths and the control circuits. Switches in this use have given trouble-free service for more than fifteen years.

It was natural that this radically new switching element should find important military application because of its independence of such environmental factors as corrosion, dirt and altitude. Under the impetus of World War II a dozen or more designs were evolved for specific applications and much was learned about the basic design as well as the process problems of manufacture. This experience demonstrated that with its inherent compactness, efficiency and operating speed this switch could find broader application in the telephone plant and its development for this purpose was undertaken. To fully attain this goal the design and manufacturing process must result in a cost comparable to that of a pair of nickel silver springs carrying the customary precious metal contacts and the operating life of the switch should approach one billion operations for electrical loads up to one-half an ampere.

DEVELOPMENT

The operating characteristics of a switch, i.e., the ampere turns to cause it to close, to hold it closed or let it open, depend upon the magnetic characteristics of the reeds, their dimensions, overlap, separation in the unoperated state and the amount of contact plating. These factors also influence the relationship between operating speed and power and thus affect switch efficiency. In addition to these design factors such process matters as the flatness of the reed surfaces, precision of their alignment and the accuracy with which the unoperated gap is established determine the tolerances which can be placed upon the switch operating characteristics. Switch and process design are inseparable and the degree of development of the latter becomes controlling in the determination of attainable switch operating tolerances. Therefore, studies were made to explore both of these phases of reed switch development.

The relationship between the operating characteristics and the unoperated gap of an experimental reed switch is shown in Fig. 3 for several values of reed overlap. As the gap is increased, the reed deflection and the magnetic pull required to close the switch increase. Therefore, the flux density in the gap must be increased correspondingly, and, as shown by the curves, the onset of magnetic saturation of the reeds and increased leakage across the gap cause the relationship between the ampere turns required to close the contacts and the switch gap to become increasingly nonlinear. Magnetic saturation of the reeds will therefore determine the maximum gap at which a given switch design can be closed. The restoring forces to separate the reeds, i.e., release the switch, when the operating flux is removed are obtained from the deflections of

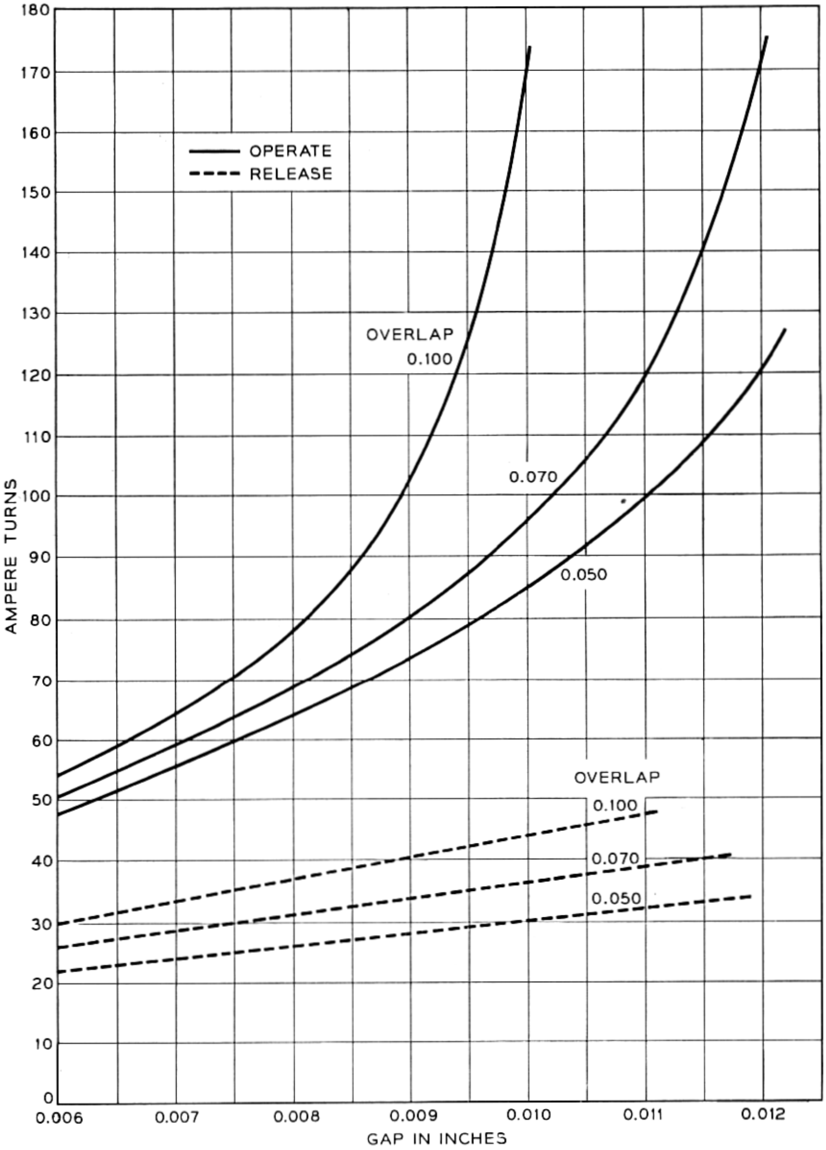

Fig. 3 — Operating characteristics of a reed switch versus the gap in the unoperated switch.

the reeds upon switch closure and therefore are proportional to the unoperated switch gap. A switch will open when the restoring forces exceed the magnetic pull between the reeds. Although under these conditions the flux density in the reeds and the gap leakage are low, there are magnetic saturation effects at the surfaces of the reeds which cause the

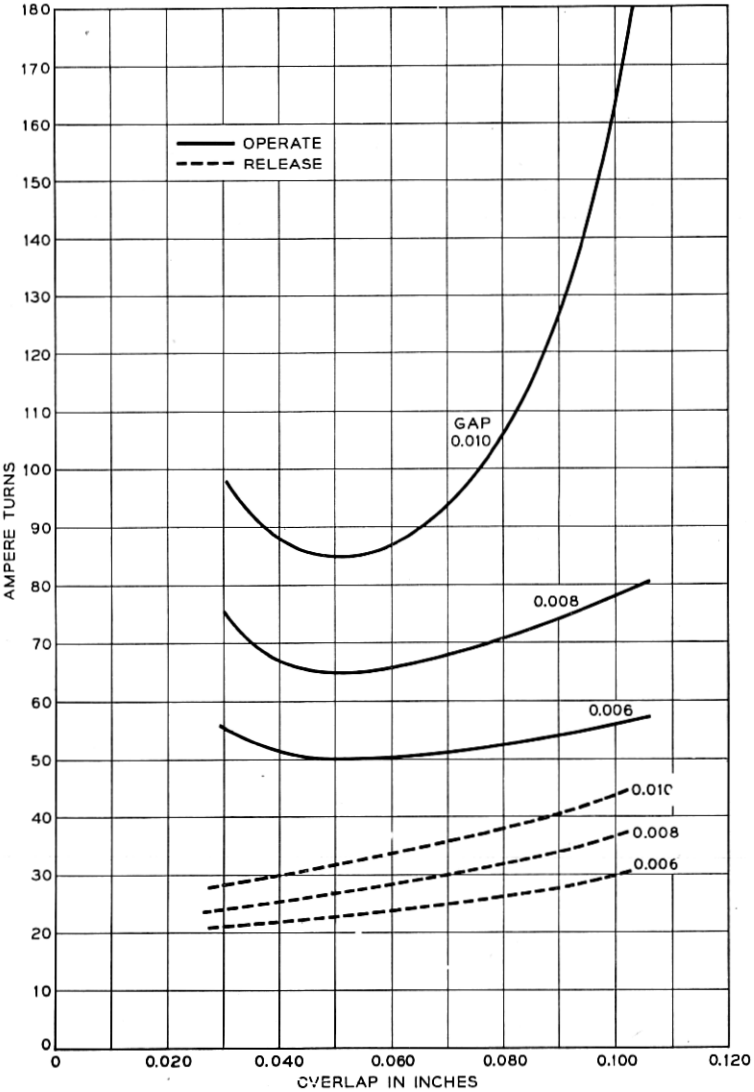

Fig. 4 — Operating characteristics of the same reed switch as in Fig. 3 versus the reed overlap.

relationship between switch release and switch gap to be approximately linear. The relationships for the same reed design as a function of reed overlap is shown in Fig. 4. The shape of the operate characteristic arises from the decrease in percentage of leakage flux around the gap and the decrease in the gap flux density as the gap area is increased. These factors have opposing effects upon the switch ampere turn operate value, the former predominating at small overlap, the latter for large overlap, and therefore the characteristic exhibits a minimum when the reluctance of the working gap equals that of the remainder of the magnetic circuit. The extreme curvature for the 0.010″ gap at the higher values of overlap is caused by magnetic saturation of the reeds. The rising character of the release curves is due to the decrease in flux density as the overlap is increased. This results in less magnetic pull and a higher switch ampere turn release value.

The contacts of reed switches are subject to electrical erosion which may take the form of a buildup on one reed associated with a pit on the mating reed. As with ordinary contacts, such buildups can give rise to mechanical locking of the reeds causing failure of the switch to open. The reeds may also become welded upon closure by excessive currents or capacitive discharges from the electrical load circuits. The restoring forces of the reeds are counted on to rupture such locks or welds as may occur within the specified limits of contact operation. Since the restoring forces are proportional to the switch gap better margins against locking or welding will be provided with larger switch gaps. However, the characteristics described above show that increases in the gap rapidly decrease the switch magnetic efficiency. Furthermore, the increase in the slope of the characteristic indicates that, for larger gaps, we should expect greater dispersion in the operate characteristic for a given precision in establishing the nominal gap in manufacture. Small gaps look attractive from the standpoint of switch efficiency but are more difficult to establish in switch assembly. In addition, the by-products of contact electrical erosion are magnetic and tend to collect in the switch gap and cause trouble if this is too small. The selection of the gap size for a given switch design is a compromise of these factors of switch application and process design. The reed overlap is selected to fall at the minimum point of the characteristic which at once provides maximum switch response and minimum sensitivity to manufacturing variations in overlap.

In the assembly of a reed switch the seals are the anchorage for the reeds and their location determines the effective cantilever lengths and the stiffness of the reeds, and the lengths of the seals influence the rigidity of the reed anchorage. Thus it is important that the sealing technique permits good control of this process step. Since a switch is only about three inches long the close proximity of reed holding chucks and mechanisms for aligning and spacing the reeds make the open flame sealing techniques of the vacuum tube art unattractive. Furthermore, with open flame techniques it would be difficult to obtain adequate control of seal

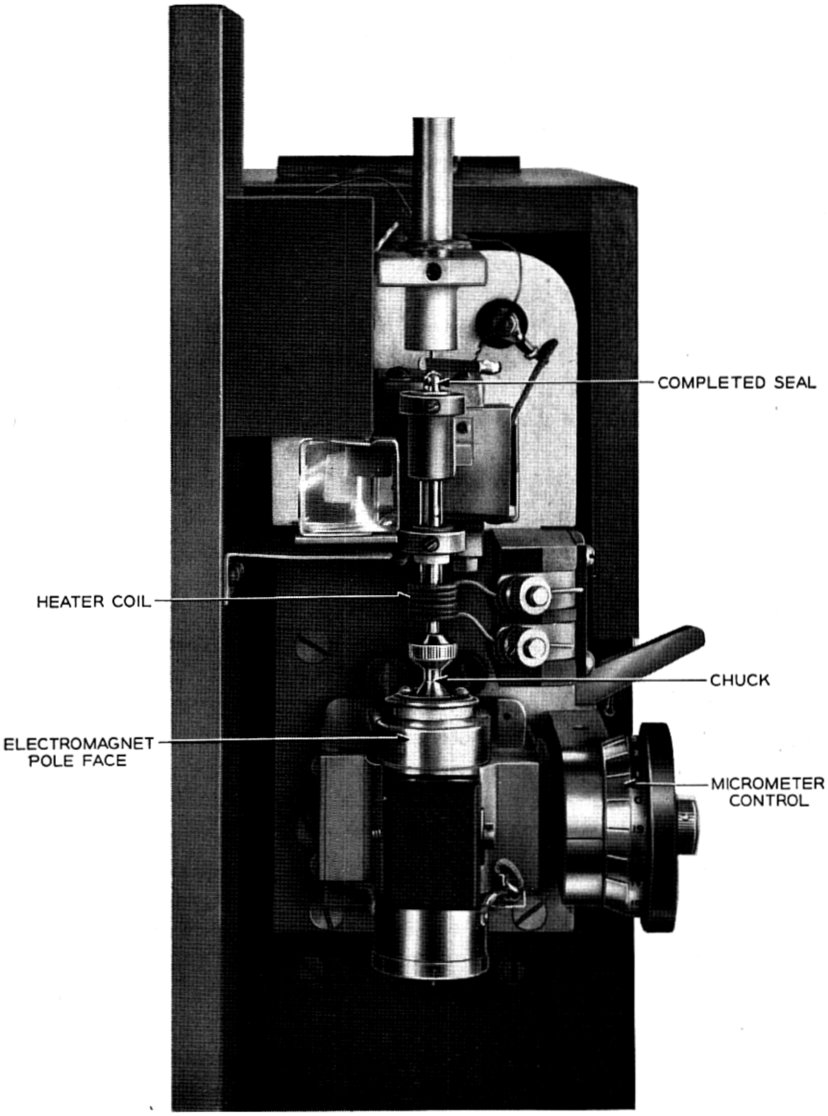

Fig. 5 — Early laboratory type machine for assembling reed switches.

location and dimensions. A new method had to be conceived and this has taken the form of an electrically heated coil of resistance wire surrounding the ends of the glass envelope. A laboratory facility for assembling switches is shown in Fig. 5. One of the reeds has already been sealed into one end of a glass envelope by a previous operation and this subassembly is shown mounted in position for receiving the second reed. The glass tube of the switch is to the right of a prism used in the process of aligning the reeds. The seal already made can be seen projecting from the mechanism just below a spring clip providing an electrical contact to the reed support. The lower end of the glass tube projects into and is closely surrounded by an electrical heater coil. Below the heater is a chuck for supporting the reed about to be sealed into the switch. This chuck is of magnetic material and can slide on a steel surface which is also the pole face of an electromagnet. The chuck may be moved in rotation and translation until the reeds are in alignment as determined by visual inspection through the prism after which it is locked in position by energizing the electromagnet. The chuck and its support are fastened to a carriage which can be moved in translation under control of a micrometer having a calibrated head, and this is the means for establishing the desired switch gap. After this operation the heater coil is energized to make the seal. The temperature of sealing is controlled by the voltage applied to the heater coil and the time of application by an electrical timer. Most of the heat is transferred to the glass by radiation and the temperature of the glass is raised sufficiently so that its surface tension can overcome its viscosity. Surface tension draws the open end of the glass body inward until the glass comes into contact with and wets the metal oxides of the reed support thereby effecting a seal. In addition to performing well the sealing function, this method also permits control of the seal cooling so as to provide a desirable strain relieving anneal of the glass.

In developing the process for making a metal-to-glass seal it is necessary to obtain detailed knowledge of the thermal characteristics of the materials to be used as well as the temperature-time phenomena involved. In the range between room temperature and the softening point of the glass the coefficient of expansion of the metal is essentially linear and its magnitude depends on the composition of the alloy. In this same range the coefficient of the glass is nonlinear but it is possible to select metal and glass combinations which will exhibit low seal strains after the combination has cooled to room temperature. At temperatures between the softening point of the glass and room temperature a seal will be subjected to varying degrees of stress depending upon the choice of alloy composition and these stresses may become serious enough to cause the seals to crack. The stresses at intermediate temperatures may be reduced by suitably annealing the seal but they can become greatly aggravated if the thermal characteristic of the sealing machine does not permit the metal and the glass to cool at approximately the same rate. In consequence the thermal characteristics of the means for supporting the reeds during sealing, the rate of cooling of the electrical heater coils and the susceptibility to the effects of drafts are all matters which must be studied in the design of the sealing process.

To obtain switches with operating characteristics that are predictable within acceptable tolerances it is necessary that the reeds be parallel to each other. This requires that the reeds be flat and straight because their final position in the switch is determined by reference to the means for supporting them during sealing. It is obvious that if the reeds are bowed or otherwise not flat it will not be possible to obtain good alignment of the overlapping ends. As the reeds are held in some form of chuck this must be capable of seizing a succession of straight reeds in exactly the same manner and its function must not be interfered with by residual burrs or surface roughness or by reasonable manufacturing variations of the reeds. After the reeds have been placed in the chucks it is necessary to establish the operating gap between the overlapping ends. This is of the order of 0.01 of an inch and it is desired to hold this to within a range of about 0.001 of an inch. There are two basically different ways in which the desired gap can be established. One of these is to provide a means for bringing the two reeds exactly into contact and then, using this position as a reference, separate the reeds by the desired amount. This method is relatively simple to execute to the desired precision but it provides no means to allow for the effects of such process variables as the failure of the reeds to be ideally straight or minor failures of the chucks to grasp properly. Another method is to place the reeds initially so that the gap is larger than that finally desired, subjecting them to a suitable magnetic field and then advance the reeds toward each other until they are closed by the effects of the magnetic field. This has the advantage that the reed separation is determined directly in terms of one of the final switch operating characteristics. It takes full account of the consequences of all of the process variables which might affect this particular characteristic but has the disadvantage of greater operational complexity. Both of these methods of assembly have been used during the development of the switch and it appears that essentially equivalent results in terms of switch performance and yields can be obtained.

A further cause for variability in switch product arises during the sealing of the reeds into the glass envelope. Molten glass has both surface tension and viscosity and since the seals are to be located between the chucks and the free ends of the reeds, differential cooling can cause the surface tension forces to impart displacements to the reeds with respect to their desired final positions. Observations during sealing indicate that the displacements of the reeds may be quite large and erratic and the residual errors of displacement from this cause will be determined by the viscosity of the glass and its permitted rate of cooling.

The process factors mentioned in the preceding paragraphs are important to design because they control the magnitude of the requirements which the designer can place upon the product and therefore have a marked influence on the potential value of the design in terms of circuit application. Process studies are for this reason a very important part of design. Laboratory development must usually be conducted on the basis of making a rather small number of models and it is further limited by the necessary use of hand-operated equipment differing materially in characteristics from the large scale facilities normally acquired for regular manufacture. Recourse must be had to careful design of experiments and to the extensive application of quality control and other statistical methods based on the theory of small samples. Through the use of these methods it has been possible to develop proper reed designs, chucking methods, sealing cycles and gas-filling procedures, and to lay a sound foundation for the design of large scale automatic facilities.

CONTACT INVESTIGATIONS

It is known that some airborne corrosive elements, organic material and dirt have deleterious effects on contacts but it cannot be postulated that therefore the exclusion of air will give rise to ideal contact operating conditions. The volume of gas included in a switch of acceptable size is small and the concentration of contaminants introduced in manufacture could be much higher than that likely to be encountered in large ventilated spaces. Therefore, contact investigations of sealed switches must be based upon completed units containing the materials under study and made by a process sufficiently defined to permit repetition of results. Only then can the effects of materials be differentiated from those of the process and the latter be designed for optimum results.

Early switch designs used reeds made from pure iron and from Perminvar. Although these reeds had been cleaned by heat treatment in hydrogen their brief exposure to air in the course of switch assembly permitted sufficient oxidation to adversely affect their performance as contacts even in switches which were evacuated and filled with hydrogen. This condition was overcome by gold plating the tips of the reeds before heat treatment, and it was the favorable results with such switches that gave rise to the present development. Because they could not be sealed to inexpensive lead glasses, iron and Perminvar reeds had been welded to supports of a nickel-iron alloy specially designed for this purpose. If this material, called 52 alloy, could be used for the reeds the switch structure could be simplified and its cost reduced. Tests showed the alloy to have acceptable magnetic characteristics and a program was initiated to study its properties as a contact material. Perminvar was included in this program to provide a control against previous experience.

As pointed out above, the restoring force of a switch is proportional to the reed travel to contact closure. Since this is only about 0.005 inches, the thickness of contact metal added to the reeds must be small to avoid significant loss of restoring force. This suggests electroplating as the method for applying the contacts and studies were conducted on the basis of such a process step. Contact materials such as gold, rhodium, chromium, etc., and such gases as helium, hydrogen and nitrogen were included in the test program. Switches containing various combinations of these were placed in operating life tests at selected loads up to a half ampere. Early trends showed that there were no significant differences between Perminvar and 52 alloy as the underlying material for the contacts, and that gold plating in combination with either hydrogen or nitrogen gave better results than other combinations. Therefore subsequent interest centered on detailed studies of gold plated 52 alloy reeds in atmospheres of hydrogen and nitrogen and the effects of process upon such combinations.

Like ordinary contacts, reed switches are subject to electrical erosion and observations during life tests show that this takes three distinct forms. In one type, a buildup is formed by transfer of material from one reed to the other and eventually the buildup will lock into the pit of the mating contact and the switch will fail to open. A second type of erosion results in the formation of powdery and flaky particles and since these are magnetic they will collect in the contact gap under the influence of the operating flux. Under these conditions the erosion products appear to be brittle and give the impression that they may have been incipient buildups which were broken by the impact of the reeds as the switch closed. The area of erosion is generally large compared to that resulting in an early buildup showing a disposition of the point of contact to wander over the contact surface. The volume of particles in the contact gap is proportional to contact use and it seems likely that quite early in the switch life, if no single predominant buildup has occurred, the electrical contact between the reeds is through these particles which are conducting and are distributed over the contact area rather than by direct contact between the reed surfaces. While some of the particles may be welded to the reed surfaces most of them are loose and under the influence of the gap flux become rearranged at each switch operation. This action may promote distribution of contact wear but can also lead to aggregations which can become welded together and initiate a predominant buildup resulting in ultimate contact locking. It has also been observed that after many operations the volume of particles may become great enough so that their rearrangement will permit them to bridge the gap of the unoperated switch and thus cause contact failure or other malfunctioning. Obviously, this type of erosion is very complex and its consequences are difficult to predict. A third type of erosion occurs in a significant number of switches. Here a buildup takes the form of a puddle-like formation covering an appreciable part of the contact surface with a corresponding shallow depression in the mating contact. Contacts with this type of erosion have much less loose material than contacts of the second type but when they fail it is due to the relatively sudden appearance of a buildup causing locking.

Switches having only the first kind of erosion frequently exhibit short life and are rather uncommon. Those of the second kind are representative of the present state of the art and account for the bulk of the failures observed. Switches having the third kind of erosion give an operating life about ten times as long as those having the second kind. The causes for these differences in contact erosion are not well understood but they appear early in the switch life. For this reason it is suspected that they may be related to such factors as the smoothness and alignment of the reed surfaces, the degree of penetration of the contact material into the underlying reed and process contaminants. These can all affect the reed surfaces and influence the nature of the initial erosion and thereby possibly determine its course through the switch life. The large number of interrelated variables bearing on switch life makes it very difficult to obtain an evaluation through small scale laboratory experiments and there can be no assurance that the same factors will exist in the process for large scale manufacture. For this reason an important part of the continuing program for contact development will be the study of the output from regular manufacture and the effects of variations introduced in the process.

Operating life tests for reed switches have been conducted mostly at one-eighth and one-half ampere resistive or protected inductive loads.

Tests of switches from the early stages of large scale manufacture show that a few of these failed as early as 200 million operations, about half had failed at one billion operations and some were still going at two billion operations. This large spread in the performance of supposedly identical switches does not appear related to the load conditions and therefore must be considered a switch attribute. It is thought that in part it must be due to the fortuitous nature of the second type of erosion described above since both it and the third type of erosion are found in the long life switches and there were no early failures having the third type. In evaluating the behavior of sealed switches it must be remembered that their contacts are not accessible for servicing and for this reason the first failure of a switch must be considered the end of its useful life. On this premise reed switch life in the load range from one eighth to one-half an ampere must be taken as about 200 million operations. For smaller loads longer life may be expected exceeding a billion operations for very small loads. The capabilities discussed are all for 48-volt load circuit conditions.

DESIGN FOR MANUFACTURE

With this background of information it became possible to adopt a switch design and a manufacturing process which would permit a sufficient degree of mechanization to predict acceptable costs. In this design shown in Fig. 6 the reeds are made from 52 alloy wire in the shape of a double-ended paddle with a round section near its middle. The round section provides optimum conditions for minimizing stress concentrations in the metal-to-glass seal. One flat end of the paddle provides the moving reed inside of the switch and the other provides the external electrical connection. Both ends are gold plated, one to act as the elec-

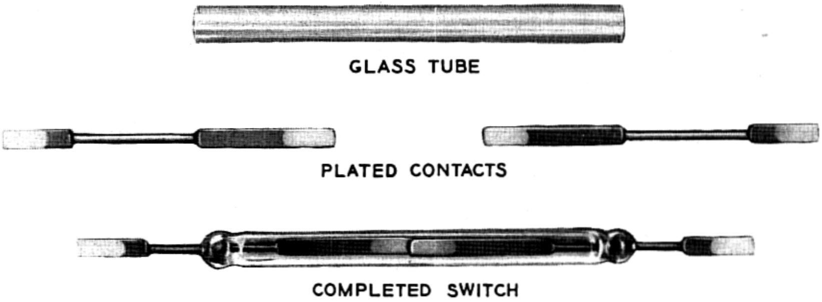

Fig. 6 — Reed switch design suitable for large scale manufacture.

trical contact and the other to provide for ease of soldering an external connection to the switch. The final design also had to avoid the use of metal tubulations if cost objectives were to be met, and the methods for pumping and filling used in the vacuum tube art were considered too expensive. Novel methods were explored. One of these was to enclose

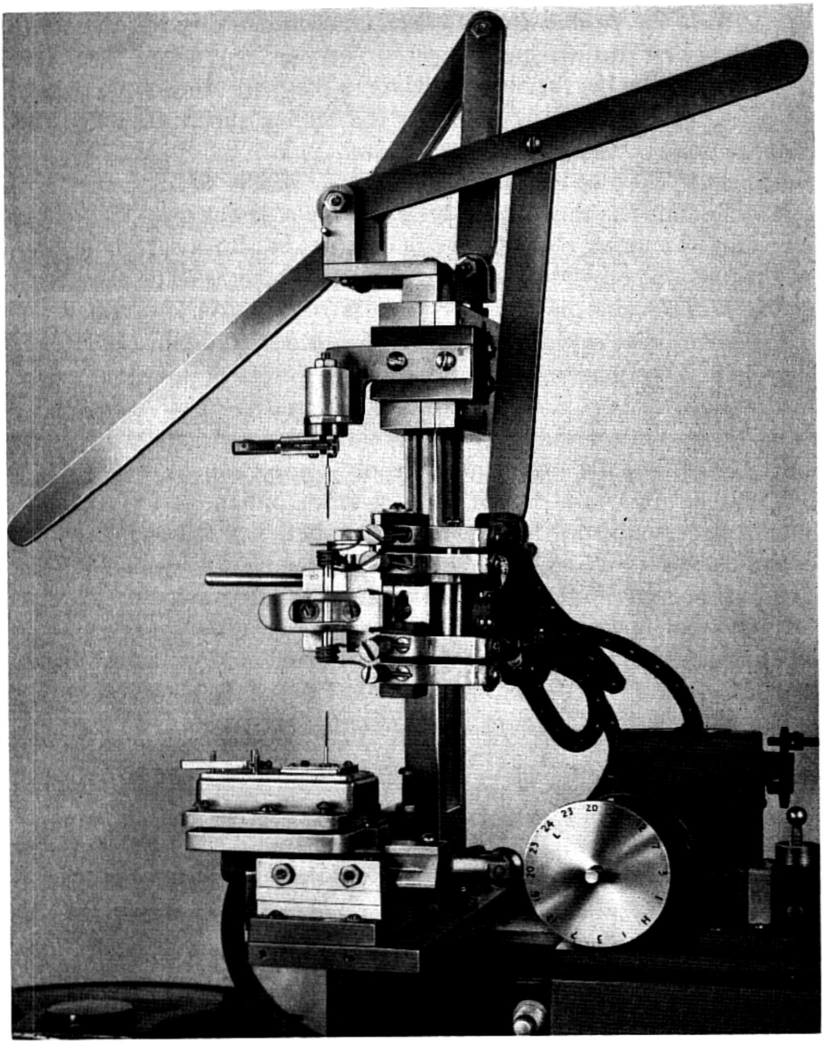

Fig. 7 — Laboratory facility for the semiautomatic assembly and flush-filling of reed switches.

the entire switch assembly machine in the atmosphere desired for switch filling. This method received considerable experimental study and it was concluded that the problems of switch cleanliness in the presence of machine lubricants and other contaminants would be difficult to solve. The means selected was to mount the reeds and the glass envelope in the proper position for sealing and then displace the air in the envelope by flushing with the desired gas. Extensive experiments were required to design means for introducing the gas so that aspirator effects would not draw in air during the flushing process and the whole technique of glass sealing had to be revised to allow for the cooling effects of the flowing gas as the seals were closing. Fig. 7 shows the laboratory setup for this development. The two heater coils are clearly visible and between them a clip for holding the glass tube. Above the upper heater is seen the chuck for holding the upper reed. At the bottom is the chuck for holding the lower reed and it provides the means for introducing the gas including a chamber for assuring its lamellar flow. It is mounted on a track and under control of a servo motor may be moved to obtain the desired switch gap. The upper chuck and the sealing heaters are mounted on vertical slides so that after the reeds and glass tube have been loaded the reeds can be inserted in the glass tube by operation of the levers shown. After this the machine operation is programmed by auxiliary facilities. The air is flushed from the glass tube while the servo establishes the desired switch gap. The upper heat coil is then energized and when this seal has been effected the velocity of gas flow is lowered and the lower seal is made. Aside from their value in supplying requirements for final machine design these automatic features were an absolute necessity in providing a sufficient degree of process stability to permit significant conclusions to be drawn from small lots of switches intended to display the effects of specific design or process changes.

II — REED RELAYS

The combination of a reed switch and an operating coil constitutes a relay and in contrast to other relays no magnetic core, armature or contact carrying springs are required. The design of switch developed provides a simple make contact. However, as will be described below, break and transfer functions and other worth while features can be obtained by associating a permanent magnet with a make contact reed switch.

RELAYS WITHOUT MAGNETS (NEUTRAL)

If a single switch is placed in an operating coil and the current through the coil is increased there will be a definite value of ampere turns at which

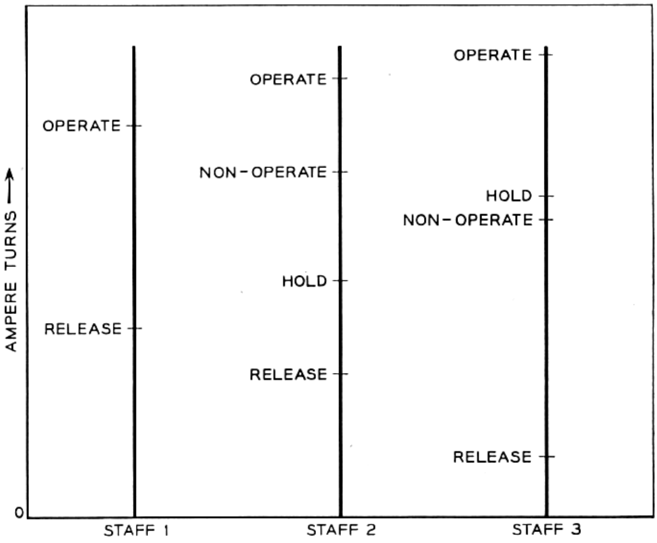

Fig. 8 — Comparison of the operating characteristics of a single reed relay with that of the relay type universe of which it is a sample.

the switch will close. When the current is then decreased, there will be another definite value at which the switch will open. These are called the operate and release values of that switch and are shown on Staff 1 of Fig. 8 where the ordinates are operating coil ampere turns. Sealed switches are not adjustable and their individual operating values are subject to manufacturing tolerances. In consequence, if a succession of switches are measured in the same operating coil the results are as indicated on Staff 2. As the coil current is increased from zero there will be an ampere turn value at which the most sensitive switch will just fail to close; this is called the non-operate value of that relay design and is the highest ampere turn value at which no relay will operate. As the ampere turn value is further increased a value will be found just sufficient to assure that all switches will close; this is called the operate value of the relay. If the coil current is then decreased, a value will be found below which one or more switches will open; this is called the hold value of the relay and the still lower point at which all switches will just have opened is called the release value of the relay. The difference between operate and non-operate and that between hold and release represent the manufacturing spread in the nominal operate and release values of a given relay design. These four characteristics are important to circuit designers and considerable development effort is justified to obtain good margin between hold and non-operate. Staff 3 shows the consequences of a lower grade of design and process where the spread is so great that the hold value is higher than the non-operate value. Such a product would require selection of switches for relays specifying these parameters and this would not be tolerable as the basis for wide application.

If two switches are placed in the same operating coil the events are more complicated. As the current through the coil is increased, the more sensitive switch will close first and provide a magnetic shunt across the second switch which therefore will require more ampere turns to close than would otherwise be needed. Upon decreasing the ampere turns after operating both switches, it would be expected that the switch with the higher restoring force would open first. This may or may not be the case depending upon the relative closed gap reluctances of the switches. The result is an increase in the dispersion of the operating characteristics of the relay and difficulty in specifying the sequence of operation of the switches. As an example of this effect, for two similar designs we find the following results in ampere turns:

	Single Switch Relay		Two Switch Relay	
	Average	Tolerance	Average	Tolerance
Operate	79	±16	92	±22
Release	25	±12	33	±17

MAGNET BIASED RELAYS

By suitable association of a permanent magnet with a reed relay the operating characteristics become radically altered from those otherwise obtainable. Referring to Fig. 9 the axes are ampere turns, the ordinates representing those due to the operating coil and the abscissa those due to the permanent magnet. The polarity of the permanent magnet is assumed to be aiding the operating winding in the direction taken as positive and the curves depict events as the strength of the magnet is varied.

On the staff of ordinates for zero flux from the permanent magnet are shown the four operating parameters for the particular relay design. It should be noticed that these are repeated in mirror image fashion for negative coil ampere turns. In other words, if there is no permanent magnet the closure and opening of the switch depends only on the magnitude of the coil flux and is independent of its direction. As the strength of the permanent magnet is increased from zero, less coil flux will be needed to close the switch and the four relay parameters will behave as shown by the curves. To illustrate, if the magnet strength were 10 ampere turns the coil operate ampere turns would be reduced from 110 to 100 and the release ampere turns from 20 to 10 ampere turns. If negative coil flux were applied for this condition it would take 120 ampere turns to close the switch compared with 110 ampere turns for the case of no permanent magnet. Therefore, increasing the magnet strength increases the sensitivity of the relay and provides additional margin against operation by unwanted negative current. As the strength is increased further a point will be reached where it is equal to the release value of the relay design. Beyond this point some of the relays will fail to release on coil open circuit. This limit, indicated by the dashed ordinate A gives the

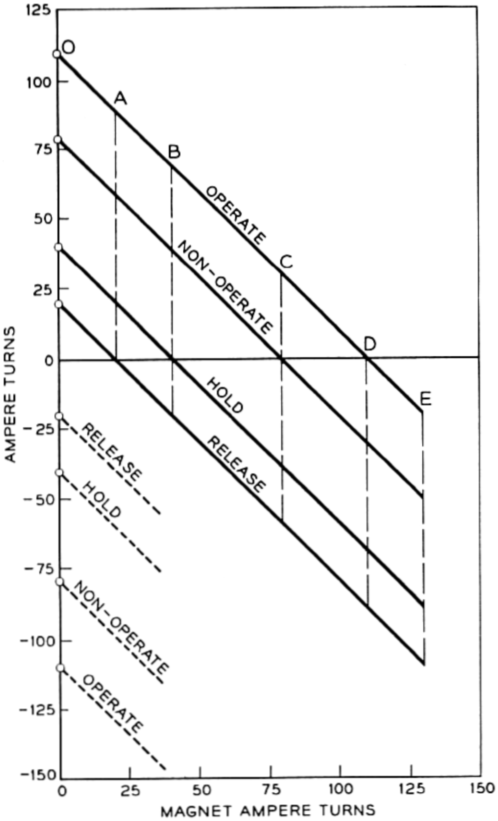

Fig. 9 — Typical operating characteristics of a magnet biased reed relay.

useful range for magnet bias as a means for increasing relay sensitivity. In the operating range from 0 to A there is the additional possibility that by adjusting the magnet strength the spreads in the operate or release characteristics of the relay can be reduced. However, both of these values cannot be controlled simultaneously.

In the operating region between A and B some of the relays will release on coil open circuit and others not. This operating region would require selection of switches and is only useful for special applications.

PULSE OPERATION

The operating region between B and C is of great interest. Any relay in this region when operated will remain operated and will require reversed coil current to be released. Due to the high speed of the switch, operation can be accomplished by pulses of a few milliseconds and no holding power will be required to keep the switch closed. Likewise the switch can be released by a negative pulse. In this region the switch can perform either the make or the break function as desired and the pulses may be symmetrical or assymmetrical in either direction. This is also the most sensitive operating region of the relay.

NORMALLY CLOSED OR BREAK OPERATION

Further increases in the magnet bias in the region from C to D yields another region of uncertainty. Operation here would be with negative coil current which should cause the relay contacts to open but some relays would fail to reclose on open circuit.

The region beyond D is again generally useful and here the operation is that of a normally closed contact which opens on negative coil current. When the magnet strength becomes equal to the sum of the operate and release ampere turns of the switch design the relay is a break relay with the same sensitivity as a neutral make relay. The additional cost of a break relay will be that of the magnet and its adjustment.

TRANSFER RELAY

The transfer function can be performed by using a make and a break relay with simultaneous excitation of their windings and suitable connections to their switches.

RELAY DESIGN

The design of a relay includes a packaging problem. Heretofore this has been based upon using the relay core as a central stucture to which

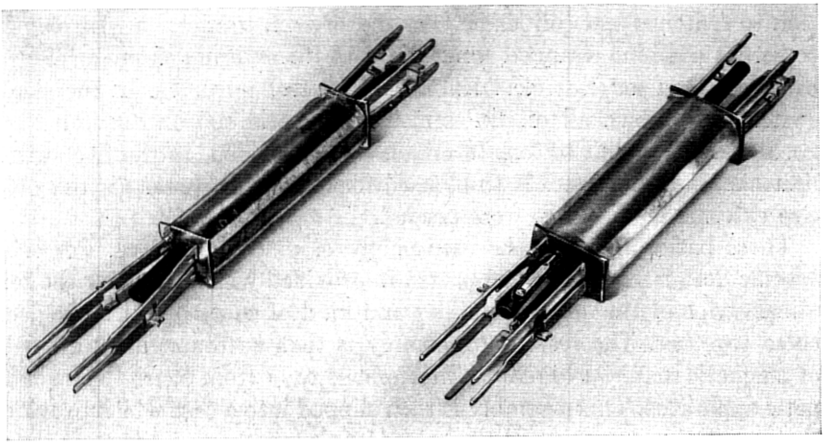

Fig. 10 — Models showing the construction of basic relay units. These may be used singly or in assemblies.

was attached the operating windings, armature, contact springs, covers and the means for mounting this assembly. Reed switch relays having no magnetic cores must use other means to provide a method for mounting.

In the case of reed switch relays a new design requirement arises from the needs of the maintenance personnel in the operating telephone plant. Over the years, maintenance personnel tracing circuit troubles have been aided by visually determining the state of operation of relays and other electromechanical devices. Additionally, by having access to the contacts they could as desired isolate portions of circuits by "toothpicking" individual contacts to cause them to remain open or closed regardless of the operating state of the relay. Because the reed switch magnetic gap and contacts are inside of the operating coil neither of these well established techniques can be used and the relay designer must provide other means for maintenance.

One design approach to the reed relay rests upon the concept of a basic building block composed of a coil containing 1, 2, 4, 6 or 10 switches. The inside dimensions of the coil and its shape conforms to the number of switches to be used and applications requring an odd number of switches can use the next higher even sized building block. Fig. 10 shows two of these basic units, one for a single switch, the other for two. Shown in the picture are the terminals which take the form of metal strips projecting beyond the switch ends. These terminals are held in position on the outside of the coil by acetate spoolheads and locked by acetate sheeting. Each terminal is shaped to provide means for making connection to switches and coil leads. One end of each terminal is also shaped to accept machine wrapped connections to the external circuit while the other end can serve as electrical access for test purposes. In the single switch unit shown all of the connections to the coil and switch were needed in the circuit so four terminals were provided. In the two switch unit one of the switches is to be used for locking purposes so that only five external connections were needed.

These basic units may be used singly or in combinations. For each specific design simple molded parts are provided which slip over the terminal strips of the desired number and kind of subassemblies and lock them together. The resulting assembly is then surrounded by a shield of magnetic material to reduce interference to or from other electromagnetic apparatus. This assembly is then slipped into a case which provides the means for mounting the whole. Here again new design principles have been applied as seen in Fig. 11. The four corners of the case are extended and provided with detents and the case is suitably slit to control the compliance of the corners. To mount this assembly it is simply pushed into suitable holes in a mounting plate. After passing through the holes the detents lock the assembly into position. This method of mounting eliminates the need for mounting screws and the space they would occupy and permits the fullest realization of the inherent compact-

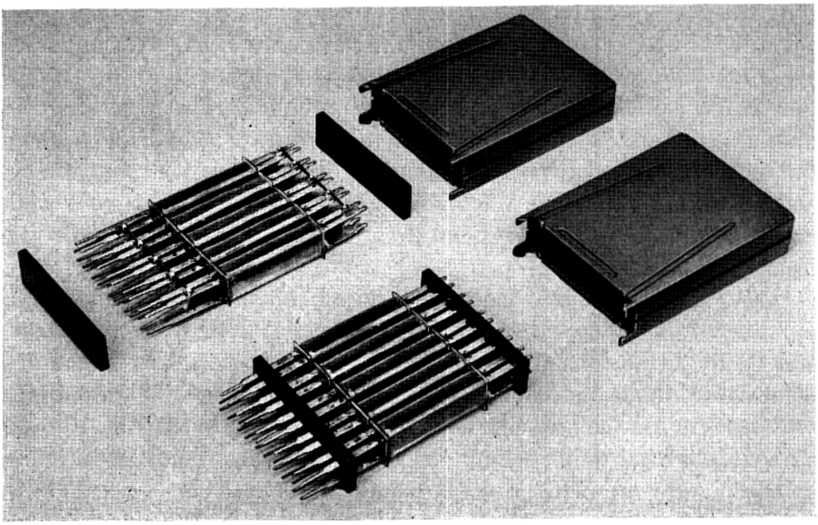

Fig. 11 — A digit register which is an assembly of five relay units each containing two reed switches. A digit is stored by operating two of the relays on the basis of a 2 out of 5 code.

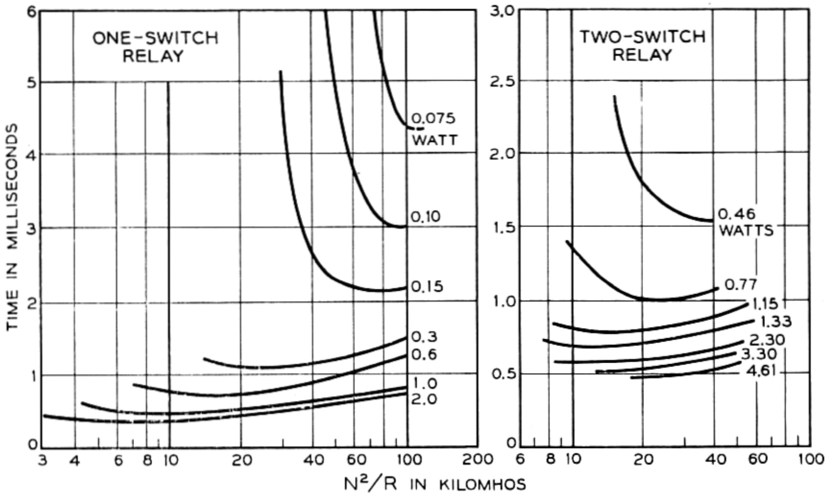

Fig. 12 — Operating speed of typical reed relays versus operating coil design constant N^2/R.*

ness of reed relays. Fig. 11 shows the details of an assembly of five relays each containing two switches. This is a digit register for use in storing a digit by the operation of two of the five relays. This register occupies about three square inches of panel space and performs the same functions as five standard relays requiring about ten square inches of space. It appears possible to plan the building blocks so that the height of relay assemblies will permit two rows on a standard 2″ mounting plate. By spreading the relays in two rows the resulting presentation of terminals avoids wiring congestion. The wiring terminals of the relay are at the mounting end while the test terminals are at the free end. This gives access to the relay test points from the equipment aisles and testing from the wiring sides of frames is avoided. By molding grooves in the end insulators and providing soldering lugs on the terminals means for strapping between coils and switches is made possible inside of the relay assembly at less cost than could be done in the course of equipment wiring. Wiring straps can be seen in the illustration and these further reduce wiring congestion on the equipment frames.

The operating speed versus relay coil design constant is shown for various circuit power inputs in Fig. 12 for one and two switch relays of the basic design described above. These characteristics compare very

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* M. A. Logan, Estimation and Control of the Operate Time of Relays, B.S.T.J., **33** pp. 144–186, Jan., 1954.

favorably with those of other types of relays now used in the telephone plant.

At this writing a number of relays and relay assemblies have been designed for use with reed switches and several are already in manufacture by the Western Electric Company which is also producing the reed switches. All of these are of the neutral type without permanent magnet bias. Applications of these relays are conservative and are made in circuits where the contacts make or break only moderate loads. Further development of the contacts, coupled with field experince will permit gradual broadening of use but even so millions of these switches will be required during the next few years.

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