Magnetic Latching Relays Using Glass-Sealed Contacts

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A new type of relay making use of sealed contacts in association with one or more permanent magnets has been developed. The relay is operated and released by selective polar energization of the winding, and remains in the operated or released state following termination of winding energization. The design affords high speed, good sensitivity, circuit flexibility and power economies in various applications.

I. INTRODUCTION

Latching relays or lock-up relays, as they are sometimes called, are becoming important and very useful as switching elements. As a broad definition, a latching or lock-up relay is one whose contacts will remain in the operated state by means of mechanical or magnetic locking or because of reduced energy furnished to the coil or to a separate winding of the coil through a set of auxiliary contacts.

Latching relays take several forms, and some similarities and differences in the characteristics of this family of relays will be described. These relays are usually polar. Their most important characteristic is that they are sensitive, and therefore the relays are usually used where power is at a premium or must be conserved. Since they normally are pulse-operated, much power can be saved when a long period of operation of the relay in its operated state is required.

Many designs of typical armature-operated relays fall into the latching or locking classification of relay. This paper, however, will deal only with magnetic latching types of relays using glass-sealed contacts.

II. SEALED MERCURY CONTACT RELAYS

Although the earliest relays which contained glass-sealed contacts were of the dry reed type, the first sealed-contact relays to go into large scale production in the Bell System were those containing sealed contacts of the mercury-wetted types. These sealed contacts, illustrated in simplified form in Fig. 1, provide a transfer by contacts wetted with mercury. When associated with a coil, magnetic structure and housing, they constitute one form of the well-known Bell System mercury-type relay. If this same structure also includes an adjustable permanent magnet, as shown in Fig. 2, then polar-biased and polar-latching relays result.

The various operating characteristics of this family of relays are shown by a series of staff diagrams in Fig. 3. Here all the function points of these relays are plotted in ampere turns. The crosses are points where the front contacts close or operate, and the circles are points where these contacts open or release. The crosses (X_1 to X_1) also show the variation in sensitivity of all the product, and the circles (O_1 to O_1) show the variation in release of all the product. For an individual relay, operate and non-operate coincide, as do hold and release. The relay shown in staff 1 has no magnet and is a neutral relay since it will operate at the same value of ampere turns for either polarity of coil current, while all the other relays shown are magnet-biased relays. Staffs 2, 3, 4 and 5 are biased polar relays. They are not true polar relays, because they have two sets of function points, the primary points X_1 and O_1 and the secondary points X_2 and O_2. These relays are called polar, however, because the desired function points are obtained only when the correct polarity

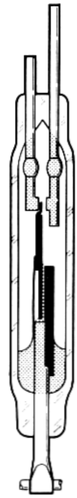

Fig. 1 — Sealed mercury-wetted contacts.

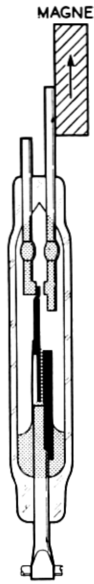

Fig. 2 — Magnet-biased sealed mercury-wetted contacts.

is applied to the relay. All secondary function points of biased polar relays are usually undesirable from a circuit standpoint.

There is one case where a reversal in selection of function points is of advantage. Where a high ratio of release to operate is required, the secondary function points are selected for the wanted operating characteristics of the relay, and the primary function points are avoided by selecting the opposite polarity in the use of the relay.

Since all of these magnetic-biased relays have only one capsule of sealed contacts, it is possible by adjustment of the biasing magnet to reduce the variation in operate X_1 points or the variation in release O_1 points. Practically, the adjusting error allows a reduction in spread of operate or release to about ±5 ampere turns. There thus can be obtained in these relays an adjustment of weak or stiff-controlled operate or weak or stiff-controlled release. Staff 2 shows a relay adjusted to close operate with a weak adjustment. Staff 3 shows a relay adjusted to close operate with a stiff adjustment. Staff 4 shows close release with weak adjustment and staff 5 shows close release with stiff adjustment.

When the magnet is adjusted to cause the hold and release primary function points to occur on negative ampere turns, then we obtain the

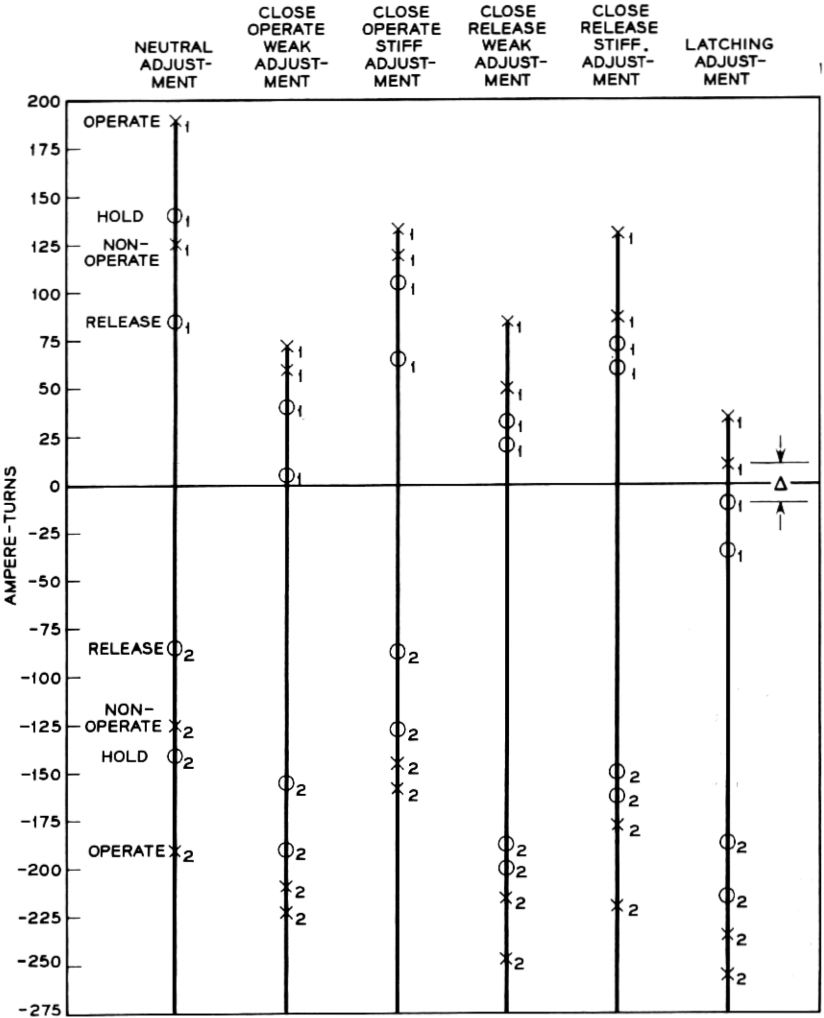

Fig. 3— Static sensitivity characteristics.

latching relay shown by staff 6. This relay will operate on positive pulses, will stay operated or latched when the power is removed and will release on negative pulses and stay released when the power is again removed. In order to be able to adjust a relay to this type of adjustment, the nonoperate function point must be higher than the hold function point and there must exist a margin or delta (Δ) between nonoperate and hold, as is seen to be present with the magnet-biased relays in staffs 2, 3, 4, 5 and 6.

It will be noted, on re-examination of staff 1, that the variation of the operate values of a group of neutral relays overlaps the variation of the release values. Taken as a group, the neutral relays cannot make multiple sealed-contact latching relays because there does not exist a delta or positive difference between the nonoperate and hold function points. If individual magnetic adjustment to each capsule of sealed contacts can be made, or if sealed contacts are selected so as to group them to nearly the same sensitivity, then it becomes possible to make multiple sealed-contact latching relays. The sensitivity of magnetic latching relays of the same typical design of magnetic structure, coil, etc. as illustrated by the relays in Fig. 3 is two to six times better than that of neutral and biased relays of the same family, and since they operate on pulses they permit conservation of holding power.

III. BALANCED POLAR MERCURY RELAYS

There is another family of relays of great interest which uses glass-sealed mercury-wetted contacts. These are of quite a different design, and are even more versatile and sensitive. In this type of relay the sealed contacts are controlled by the precise adjustment of flux from two separately adjusted magnets[1] located on the pole pieces of the sealed contacts, as shown in Fig. 4.

With proper control of the adjustment of these magnets, this type of relay can provide a wide choice of operate values and a wide choice of release values. These choices of adjustments are shown in Fig. 5.

These relays may be adjusted to operate at any value shown on the

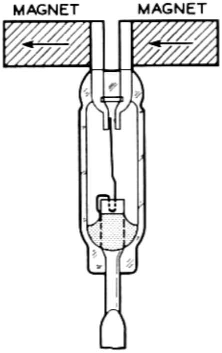

Fig. 4 — Magnet-controlled sealed mercury-wetted contacts.

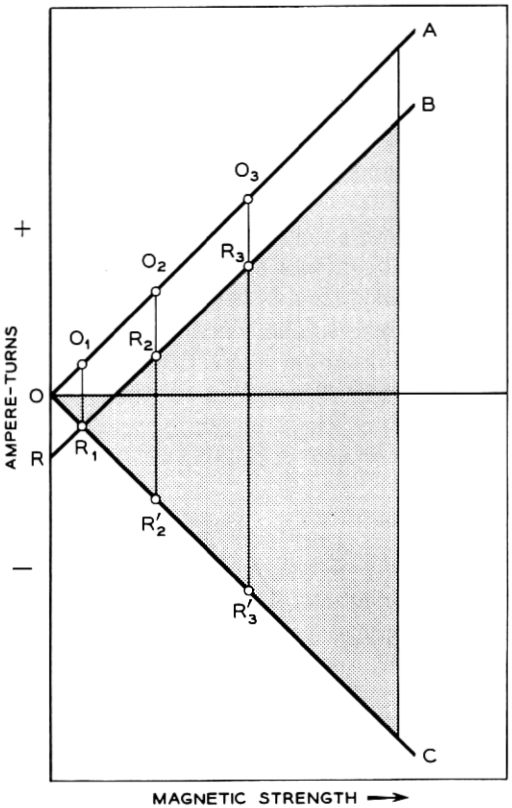

Fig. 5 — Magnet-controlled sealed-contact relay adjustment capability.

line OA and to release at any value shown on a staff directly below the selected operate value in the shaded area of the diagram.

A relay adjusted to operate at O_2 or O_3 and to release at R_2 or R_3 respectively is a biased polar relay. It should be noted that it has only these primary function points, there being no secondary function points. A relay adjusted to operate at O_1 and to release at R_1 is a polar latching relay. It also has no secondary function points.

If similar types of sealed dry contacts were to be manufactured, the same kind of neutral, biased or latching relays could be made. However, a complete study and understanding of the behavior of dry contacts would be required before they could be used. This is necessary because sealed mercury-wetted contacts obviously do not require high contact forces in order to produce good electrical connections, whereas sealed dry contacts do. Some of the questions which must be answered are: What effect do these various adjustments have on contact force and chatter? Can adequate margins be obtained to assure reliable contact performance under both normal conditions and environmental conditions such as shock and vibration?

IV. SEALED DRY CONTACT RELAYS

The invention and development work on sealed dry contacts, which preceded the sealed mercury-wetted contacts, were the basis of many experimental and many paper relay designs. Of necessity, in order to find large-scale application, such sealed contacts must be inexpensive to manufacture, and thus their construction must be suitable for automation. Such a sealed contact (Fig. 6) was developed and it was shown[2] in 1955 that, in addition to a neutral relay with this simple sealed make contact, magnetic latching relays with makes, breaks or transfers could be produced. It was also shown that the sealed dry contacts would be functionally suited for all types of multicontact relays.

With multicontact relays, the spread of the function points of the sealed contact product must be taken into account before the design of magnetic latching relays can be attempted. The distribution of the function points of the dry sealed contacts is shown in staff 1 of Fig. 7. It will be noted that this distribution appears to be ideally suited for magnetic latching relays because there exists a large delta or spread between the nonoperate and hold functions. This spread makes it possible for these sealed contacts to be utilized without selection or separate adjustment, and also for some of the available margins to be used to absorb variables encountered in adjusting more than one enclosed contact with a single biasing magnet, thus simplifying the design of the latching multicontact relay.

When adjusted, a magnetic latching relay must have good margins against nonoperate and hold conditions at zero coil flux. This is to prevent the sealed contacts from falsely operating or releasing when the relay is subjected to vibration and shock. Because of the normal differences in sensitivity of the sealed contacts, and because of the unequal distribution of flux from the magnet to the sealed contacts, these relays must be carefully designed and precisely adjusted.

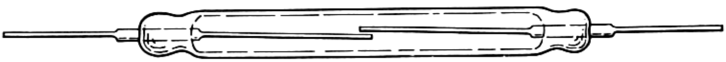

Fig. 6 — Sealed dry contacts.

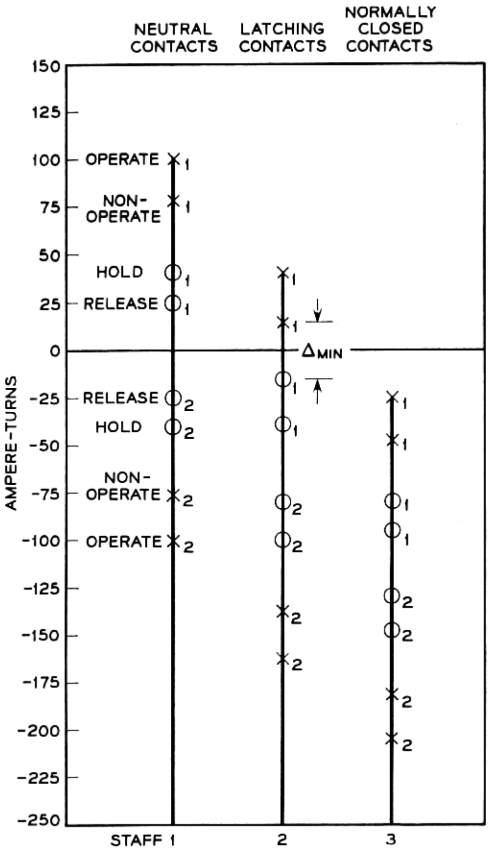

Fig. 7 — Typical characteristics of neutral and magnetic-biased relay.

Another important consideration is to obtain a design in which the secondary function points of Fig. 7 are, if possible, spread from the primary operating function points. In this way reclosure will be prevented when the release current is maximum in any given circuit. It has been found experimentally that the secondary function points can be spread by proper design of the permanent magnet and the magnetic return paths. A typical design is seen in Fig. 8. Here, four sealed contacts are grouped together so that, the glass envelopes being cylindrical, a space exists in the center of the group. The permanent magnet is then placed in this space at a position near the gaps of the reeds. A near-maximum volume of magnetic material is achieved by making the magnet square in cross section.

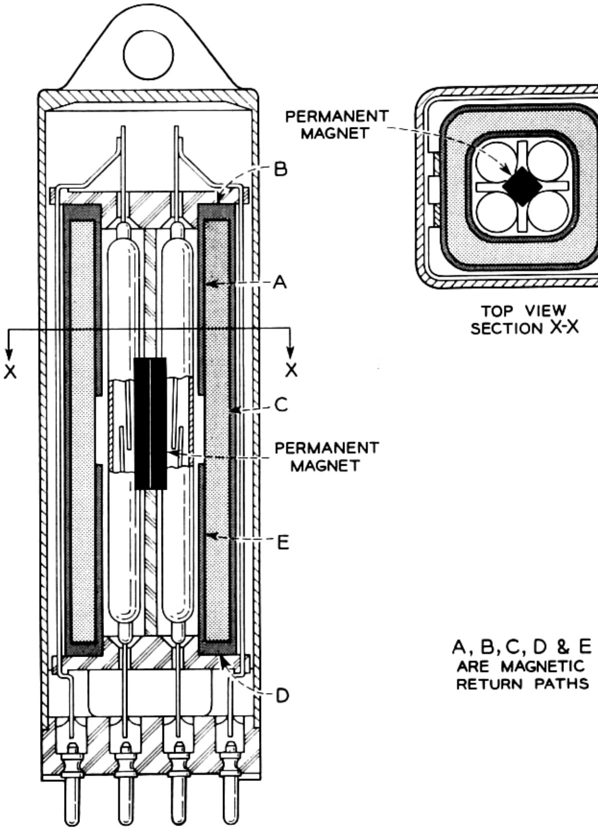

Fig. 8 — Typical four-contact relay design.

The precise adjustment of the magnet is accomplished by magnetizing it to saturation and then demagnetizing it while it is in place in the relay. The finished relay is adjusted by means of a servo-type adjusting set, which first magnetizes the magnet fully and then automatically demagnetizes it in small steps until all sealed contacts respond to the predetermined sensitivity selected for the relay and checked for by the servo-adjusting machine.

This basic design, incorporating one to four sealed contacts, will provide a relay with one, two, three or four contacts of either the neutral type or the magnetic latching type in the same size and same over-all structure, and with a minimum of parts. A single magnet might also be used in this manner for controlling more than four sealed contacts, but, when it is desired to have magnetic latching relays with more than four sealed contacts, a second or third group of four, each with its own magnet, is used to assure good symmetry. A larger relay of this type, incorporating 12 sealed contacts, is shown in Fig. 9.

Figs. 8 and 9 are composite views showing typical construction of both a magnetic latching relay and a companion neutral type. The neutral relay omits the permanent magnet, but incorporates magnetic return paths.

Typical neutral relays operate in a range of 65 to 120 ampere turns when equipped with one to 12 sealed contacts. The magnetic latching counterpart operates in an analogous range from 45 to 90 ampere turns. Depending on the power applied and the number of sealed contacts,

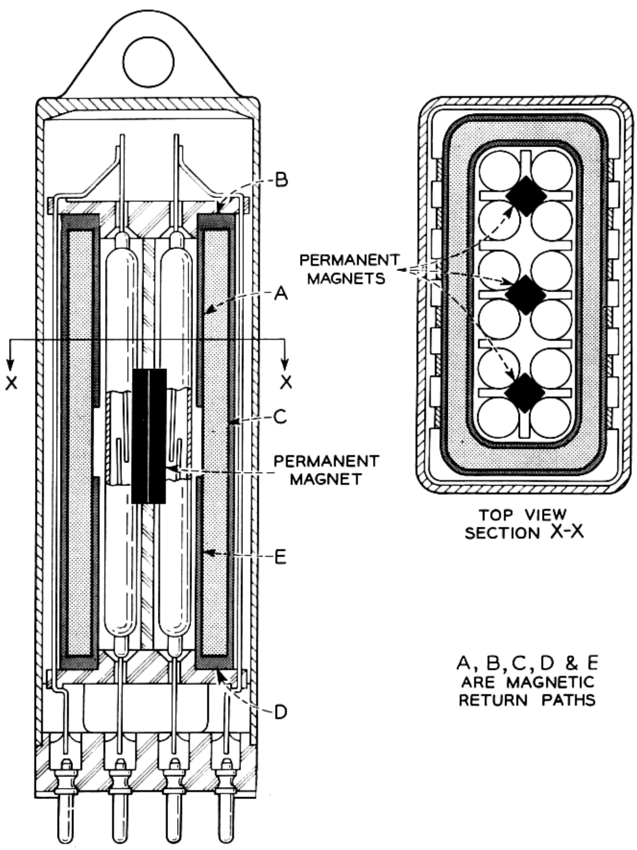

Fig. 9 — Twelve-contact relay design.

speeds of between 2 and 5 milliseconds can be obtained with the one to four sealed contact relays and speeds between 4 and 10 milliseconds on the larger 12 sealed-contact relays. Operating times of the magnetic latching relays are about one-half those of the neutral relays for the same power. Since they require no holding power, they may be pulse operated and released, as discussed in the next sections.

V. RELAY PERFORMANCE CHARACTERISTICS

In addition to flexibility, compactness and low unit cost, the relay characteristics sought by a circuit designer usually fall into the following pattern:

(a) fast operate and release times;
(b) good sensitivity or ability to work on low power;
(c) high reliability and long life;
(d) good contact force;
(e) low contact resistance.

The glass-sealed dry contact magnetic latching relay meets all of the above objectives with good working margins when used within its prescribed limits. A review will now be presented of the relay's performance, together with an analysis of some of the problems peculiar to this design of relay that require special consideration regarding the application and use.

Sealed-contact magnetic latching relays may be used with all contacts normally open or with all contacts normally closed. When the winding is energized by a current of appropriate polarity, magnitude and duration, the open contacts will close or the closed contacts will open. Upon removal of the winding energization, the contacts of these relays remain in their closed or open states respectively. In the usual circuit application of conventional neutral relays the expression "operate" generally refers to energizing a relay to cause its open contacts to close or its closed contacts to open and "release" refers to de-energizing the winding to cause the contacts to restore to their normal state. Since "operate" and "release" of the magnetic latching relays are both accomplished by energizing the relay winding with current of proper polarity, the customary reference to operate and release tends to become confusing if applied to describing the dynamic characteristics associated with the closing of open contacts and the opening of closed contacts. For the sake of clarity, therefore, the following discussion will be concerned only with relays intended for use with the contacts normally open, so that "operate" will refer to the act of closing the contacts and "release" to the opening of the contacts.

5.1 *Operate Case*

When the winding is energized to operate the relay, sufficient flux must be produced to cause the reeds to come together. With relays having only one sealed contact, there is no problem, since all of the coil flux is available to attract this single pair of reeds together. However, when more than one sealed contact is to be operated by the coil flux, we have a somewhat different situation. If the coil current in a multiple-contact relay is gradually increased, the contacts will close sequentially, depending on the relative contact sensitivities and the distribution of the available flux. It is necessary therefore to raise the coil current enough to produce sufficient flux to close the last remaining open contact. In ac-

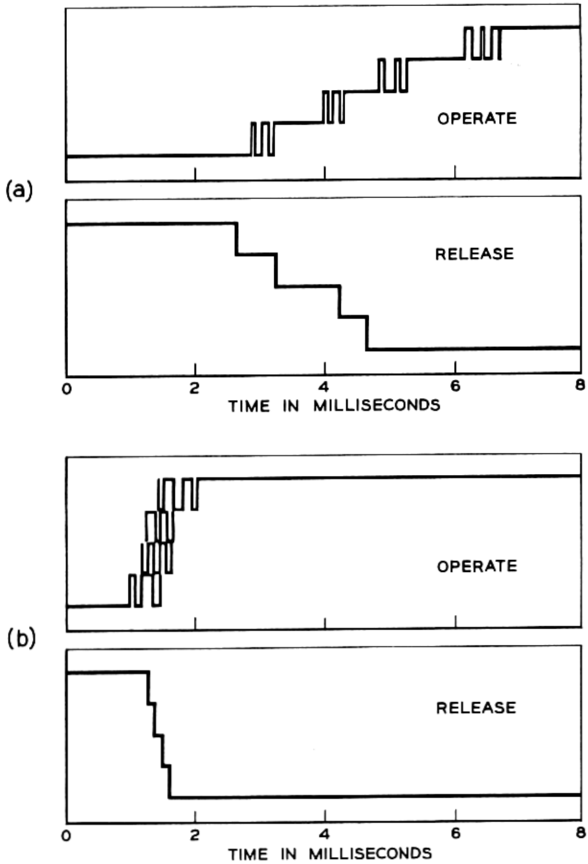

Fig. 10 — Typical sequential action of the four contacts in a magnetic latching relay: (a) low power energization; (b) high power energization.

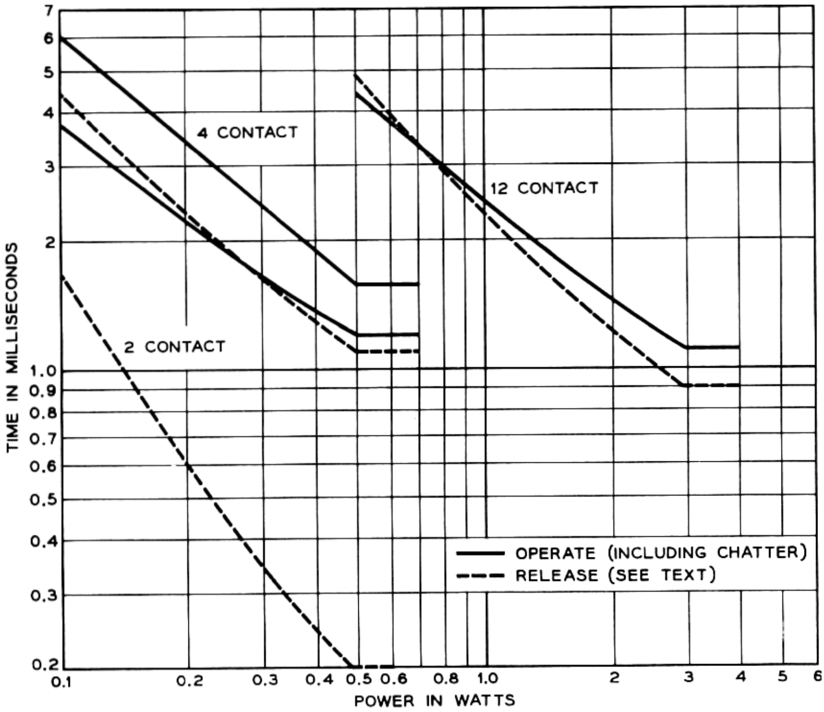

Fig. 11 — Relay function times at optimum G_c .

tual operational use and with suitably designed relays to meet short operate times, the rate of flux rise is sufficient to impart the necessary acceleration to all the reeds, and this minimizes but may not entirely eliminate the sequential contact closing in a multiple contact relay. This action is illustrated in Fig. 10: When the contacts close they chatter briefly.

The operate time as defined in this paper is the elapsed time from the start of coil energization to the closure of the last contact, to the end of chatter. It is a function of the coil constant G_c* and the total coil circuit power. Where short operate times are desired, the relay design aim is to optimize G_c for the particular circuit and power requirements. Fig. 11 illustrates the range of operate times measured to the end of chatter, for a 2-, a 4- and a 12-contact magnetic latching relay at various power levels and corresponding optimum G_c.

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* $G_c = N^2/R$, where N is the number of turns in winding and R is the total coil and series circuit resistance.[3]

On this same figure is illustrated the release time at corresponding optimum G_c and power levels. For applications requiring relay operation from current pulses of discrete short duration it is good engineering practice to employ operate pulse durations adequate to provide margin over the indicated times. Depending on the number of contacts in the relay, the relay adjustment and the circuit power, and assuming optimum G_c, such relays typically, can be operated from pulses of from 2 to 7 milliseconds.

5.2 *Release Case*

The release behavior of magnetic latching relays is affected by a number of factors which must be considered when the relays are to be used under conditions subject to wide variation of voltage, circuit resistance and temperature. Since the magnitude of the release current pulse, its duration and the shape of its trailing edge have a bearing on the consistent release performance of the relays, this area was carefully explored to establish the relay working limits. For this purpose, relays with sealed contacts chosen to represent the maximum, minimum and average sensitivities encountered within the specified manufacturing tolerances of the sealed contacts were assembled. They were put together in such combinations as to cause the relays to exhibit the possible functional irregularities to be found when the relays were subjected to worst circuit and ambient conditions.

In Fig. 7, staff 2, it is shown that the relays can be caused to operate under two conditions of coil energization. In the first, or normal, case, the polarity of the coil current is such that the permanent magnet flux and coil flux are additive. When the relay is released the polarity of the coil current produces a flux which ideally should just cancel the permanent magnet flux, thus allowing the contacts to open. Under a variety of circuit applications, the release current could possibly be appreciably higher in magnitude than the operate current, though of opposite polarity, and the relay would release satisfactorily. However, if the associated circuit conditions are such that the release current can be considerably higher than normal, the release coil flux may then be so high that it will not only cancel the permanent magnet flux but the net difference flux could be high enough to hold one or more contacts closed. In this case, although there is a flux reversal in the reeds the reversal occurs so rapidly that the contacts do not open. This is the secondary operate point illustrated in Fig. 7, and its possibility must be considered if the relays require sensitive adjustments and are likely to be applied under conditions involving wide variations in voltage, variations in external circuit resistance, low ambient temperatures or fortuitous circuit trouble that might produce very high release current.

The application of a release pulse causes the reed contacts to open and, being undamped cantilevers, they vibrate at their natural frequency of about 840 cycles per second, alternately moving close together and away from each other during the decay of their mechanical oscillation, as long as the release current is maintained in the coil winding. However, if the release current is terminated too quickly, while the amplitude of the reed oscillation is large, the flux from the associated permanent magnets may be sufficient to reclose one or more contacts as the vibrating reeds come close together. Some may reclose momentarily while others may reclose permanently, depending on the relative sensitivities of the contacts. Normally, when the reeds are at rest the gap reluctance is so high that the permanent magnet cannot by itself close the contacts. However, on the small gaps that occur alternately as the reeds vibrate, the gap reluctance may be low enough to cause contact reclosures under limiting conditions. During one time constant of the damped mechanical oscillation decrement there is a region of critical points in time at which these irregularities could occur, as illustrated in Fig. 12.

Consistently reliable release performance is obtained when the release pulse is maintained for a time sufficient to allow the mechanical oscillation to drop to safe limits. This time (typically 5 to 30 milliseconds) will vary from one relay application to another, depending on the number of contacts in the relay, its adjustment, the circuit power and the character of any electrical paths in shunt with the relay coil circuit. The latter may affect the trailing edge of the release pulse. If the release current decay is oscillatory the fortuitous phasing of the mechanical reed oscillation and the reverse current transient may enhance reclosures. Steep current decays cause the contacts to come immediately under the influence of the full permanent magnet flux during the time of large reed oscillation, when the reeds can come close to each other. By choosing proper values of resistance and capacitance connected in series and bridged across the contacts that de-energize the relay, this effect may be minimized in a given application by effectively damping the coil current transient.

5.3 *Contact Characteristics*

5.3.1 *Contact Force*

Consistent and reliable performance of any relay demands that when its contacts are closed they must press together with sufficient force

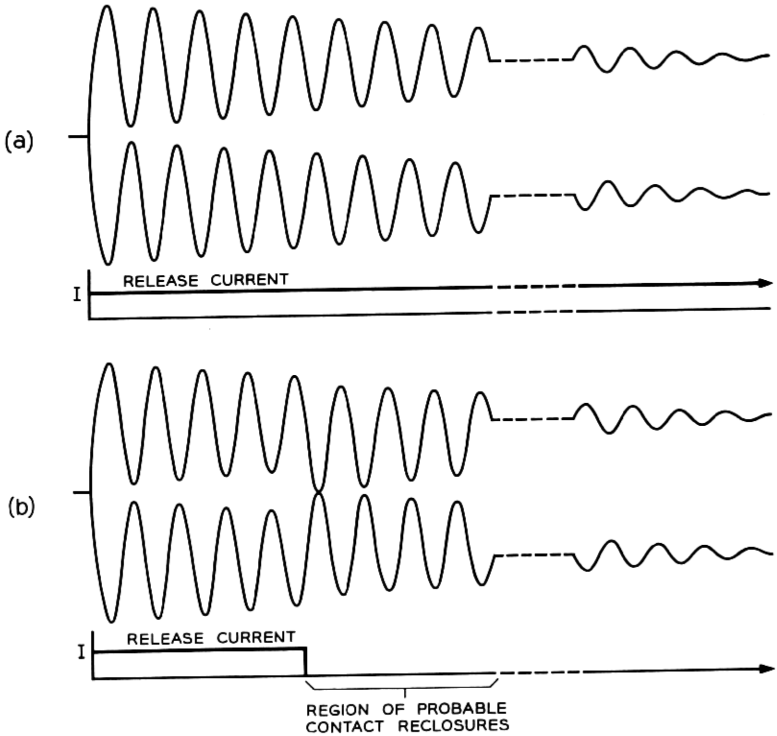

Fig. 12 — Reed motion for (a) long and (b) short release pulse.

not only to have low contact resistance, but also to withstand environmental vibration, to avoid any modulation of current flowing through the contacts that might produce excessive noise in a talking circuit. The contact force of a sealed contact is a function of the reed magnetization and of the inherent sealed contact sensitivity. For a given applied magnetomotive force, a sealed contact that has inherently a high NI-hold value will have a lower contact force than one with a low NI-hold value, because of differences in the force/displacement ratios between the two sealed contact units. Fig. 13 illustrates the relative contact forces for maximum, average and minimum hold value sealed contacts at various levels of hold NI in a test coil containing a single sealed contact.

When a permanent magnet is associated with one or more sealed contacts, the contact forces are no longer a function of the coil NI, because, with zero coil current, the contacts are held closed by the flux

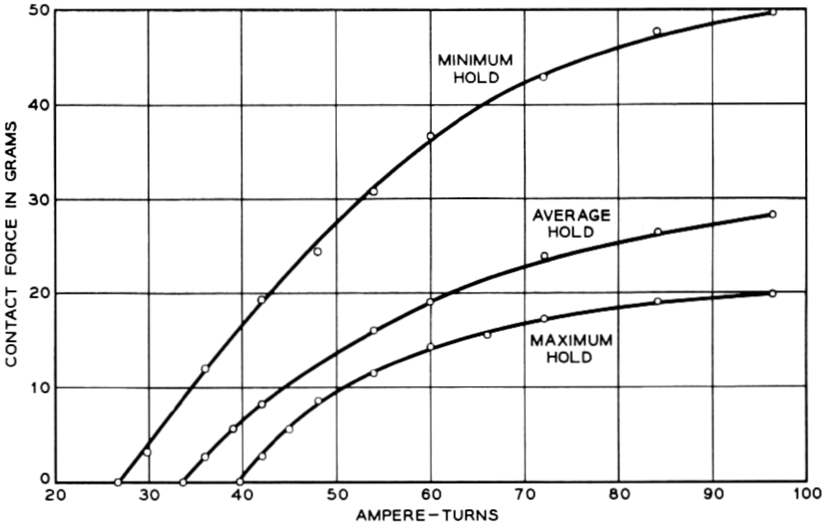

Fig. 13 — Contact force vs. ampere-turns.

supplied by the permanent magnet. Since the permanent magnet strength is adjusted after the relays are completely assembled, it is difficult to know precisely the individual closed reed contact magnetization and the corresponding contact force. However, since contact resistance is a function of contact force, estimates have been derived for the contact force in a magnetic latching relay by graphical analysis of the NI hold versus contact force and the NI hold versus contact resistance parameters of sealed contacts in a neutral-type relay structure and relating these parameters to experimental measurements of contact resistance in magnetic latching relays.

The measurements involved progressively increasing the current in the relay winding in a direction that tends to cause the magnetically latching relay to release. At discrete levels of coil NI, contact resistance measurements were made up to the point where the contacts opened. Then the hold NI for neutral and for magnetically latched relays were related to the common parameter, contact resistance. Fig. 14 illustrates the change in contact resistance of a test universe of sealed contacts tested individually in a test coil, as the coil NI was varied.

From this study it was concluded that under the normal circuit hold condition of zero coil current, the contact force of a sealed contact in a 12 contact magnetic latching relay, for example would be about 13 grams.

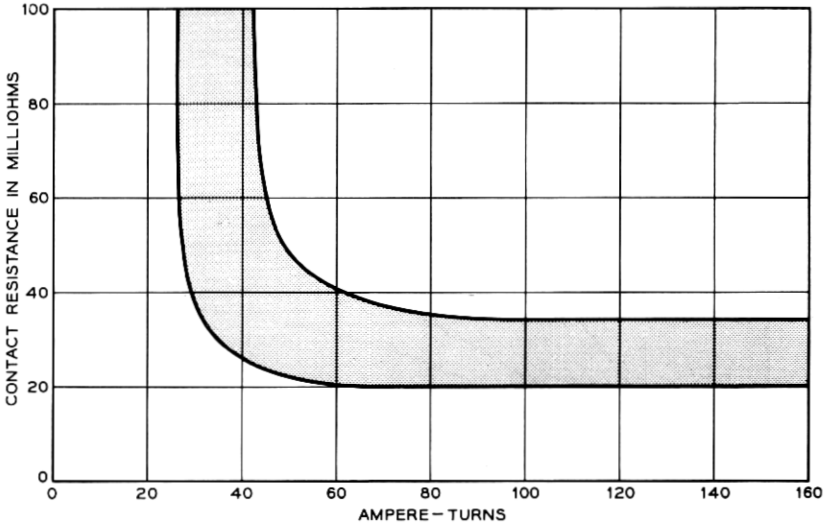

Fig. 14 — Contact resistance vs. ampere-turns.

Contact forces of this order are considered adequate to meet normal central office environmental conditions.

5.3.2 *Vibration*

The zero current hold feature of magnetic latching relays makes them very attractive for applications in equipments to be mounted at locations remote from the central office. In such applications, since the equip ments and relays may be subjected to vibration, it is necessary to have assurance of a margin of safety against vibration. Studies were conducted to determine the degree of vibration that was likely to momentarily close open contacts, momentarily open closed contacts and the levels at which it was possible to cause noise at closed contacts in a talking circuit.

Employing a biasing current technique similar to that used for the contact force and contact resistance studies, shake-table tests were made

Table I — Margins

	4-Contact Relay	12-Contact Relay
Against false contact closures	88%	93%
Against false contact opens	94	93
Against excessive noise	59	56

with four- and 12-contact magnetic latching relays over a range of 0 to 60 cycles at peak-to-peak amplitudes of 0.005 to 0.020 inch. Typical of conservative design for switching application are the margins obtained under the vibration condition of 10 cycles per second at peak-to-peak amplitude of 0.012 inch, as given in Table I. The margins are expressed as a percentage of the nonoperate test and of the hold test values. They indicate that, under the vibration condition imposed on the four-contact relay, for example, a current in a direction tending to operate the relay that was 88 per cent of the specified nonoperate test value was required to induce false contact closures; a current in a direction tending to release the relay that was 94 per cent of the specified test hold value was required to induce false contact opens; a similar current that was 59 per cent of the specified test hold value was required to cause excessive contact noise. The noise measurements were made with the contacts carrying 100 milliamperes DC in the subscriber set talking path of a simulated intraoffice trunk with HA1 receiver weighting. Noise was measured directly across the HA1 receiver with a 2B noise measuring set. Noise levels above 17 dba were considered excessive.

VI. SUMMARY

This paper has reviewed and compared magnet-biased relays generally, and has described specifically the design and performance of a new type of magnetic latching relay that makes use of sealed reed contacts.

VII. ACKNOWLEDGMENTS

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