TECHNICAL INSTRUCTION

S. 1

Relays and Uniselectors

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RELAYS AND UNISELECTORS

PART 1: RELAYS

SECTION 1

P.O. TYPE-3000 RELAY

1.1 Introduction

A relay is a device by which an increase or decrease of the current in one electric circuit can be made to perform switching operations in other circuits. Although any of the effects of an electric current can be utilised in the design of a relay, most practical relays are of the electromagnetic type employing a fixed coil and a moving armature. The P.O. Type-3000 relay is of this kind, and much of the general information concerning electromagnetic relays given in this Section also applies to most of the other relays described in the rest of Part 1 of this Instruction.

1.2 General Description

Two typical P.O. Type-3000 relays are shown in Fig. 1.1 and component parts are shown in Fig. 1.2.

The relay consists of a soft-iron core carrying a coil containing many turns of copper wire, the ends of which are brought out to tags on one of the end cheeks of the coil former. The magnetic circuit is extended by an iron yoke, on one end of which the armature is pivoted. The armature carries a non-magnetic stud, known as the *residual* stud, or a corresponding *residual* screw; this prevents complete closure of the magnetic circuit (i.e., it ensures a *residual* gap) when the relay is energised. The switching operations in the controlled circuit are performed by contact springs fixed to the yoke, and the armature is designed to lift the moving or *lever* springs off the fixed or *block* springs by means of insulated pins when the relay operates. The fixed and moving contact springs can be arranged to perform a number of switching operations but the commonest types of contact are those illustrated in Fig. 1.3, namely the *make*, the *break*, the *change-over* (*break-before-make*), and the *make-before-break*. The fixed and moving springs performing any one of these functions are termed *contact units:* a complete assembly of contact units is called a *spring-set* (Fig. 1.2).

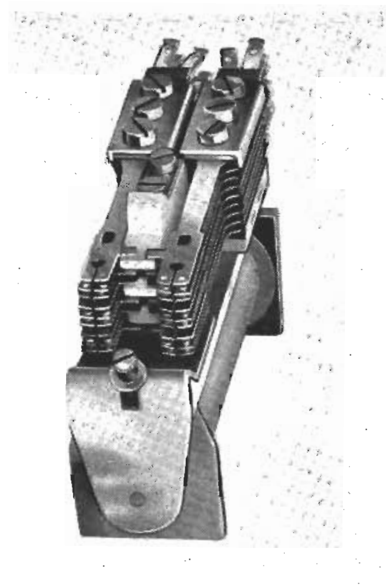
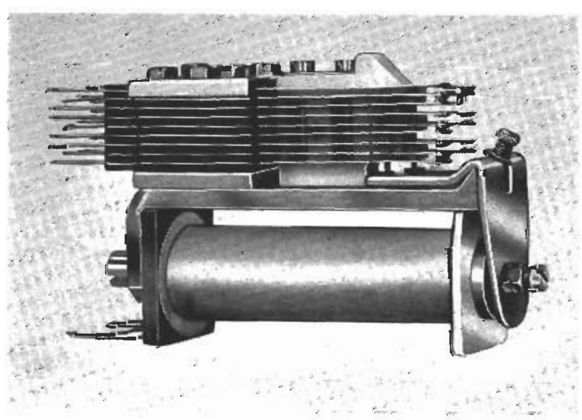


Fig. 1.1. Typical P.O. Type-3000 Relays



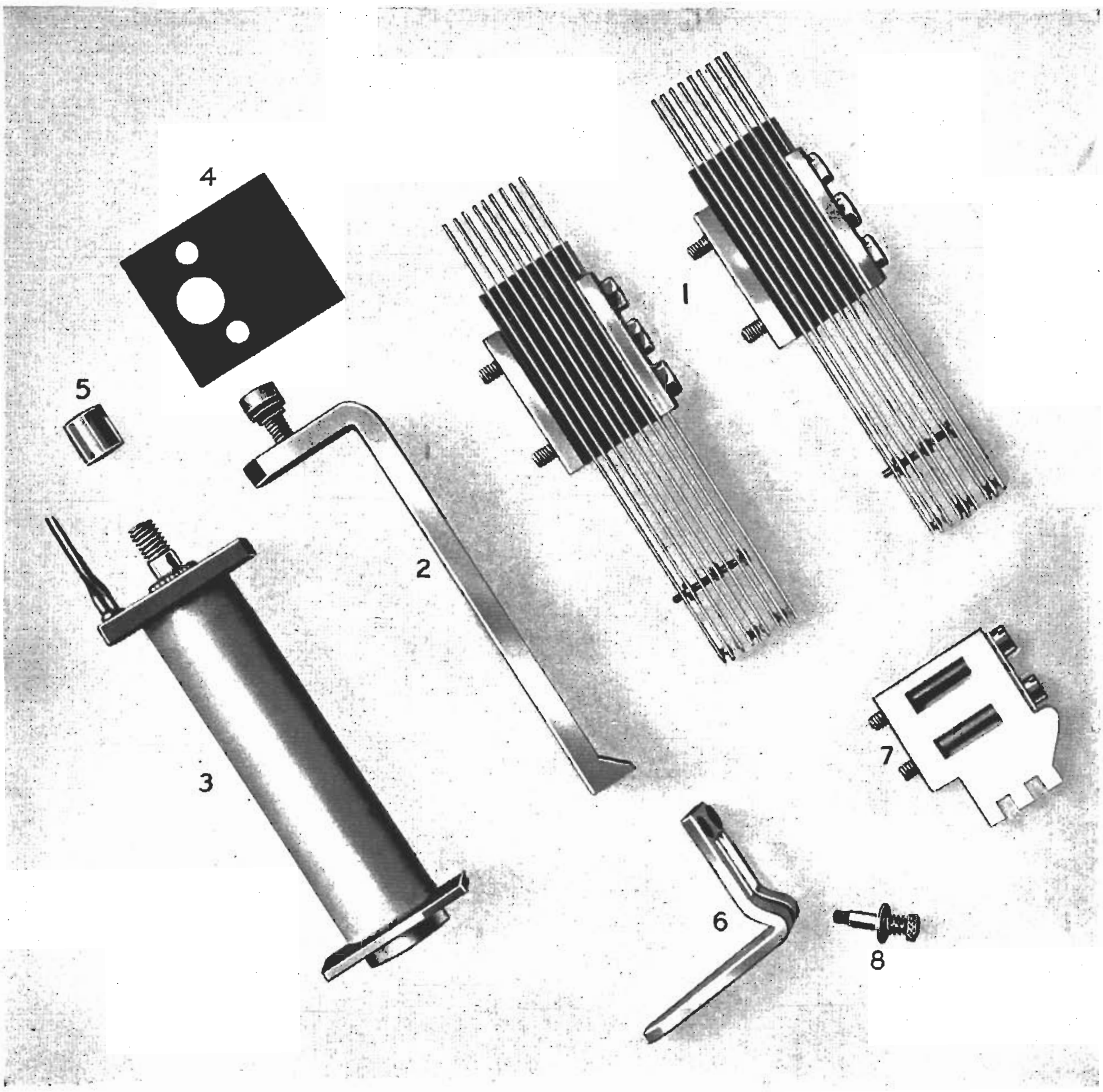


Fig. 1.2. Component Parts of P.O. Type-3000 Relay

1. Spring-sets
2. Yoke
3. Coil-former and Core
4. Insulator
5. Yoke-fastening Nut
6. Armature
7. Buffer Block
8. Armature-retaining Screw

1.3 Magnetic Circuit

The magnetic circuit of the P.O. Type-3000 relay comprises a soft-iron core, the yoke and the armature, as shown in Fig. 1.4. For maximum efficiency the magnetic contact between the core and the yoke, and between the yoke and the armature, must be good, i.e., of low reluctance. This also has the desirable effect of reducing leakage flux, and therefore minimises interference between adjacent relays. To secure good magnetic contact, the core is secured to the yoke by a large-diameter cylindrical iron nut and a low-reluctance contact between the yoke and the armature is obtained by pivoting the armature on a knife edge at the end of the yoke. The armature is held in position by a spring-loaded washer mounted on a bolt which passes through a slot in the armature and screws into the yoke. The length of the bolt is such that the washer and spring apply sufficient pressure between armature and yoke irrespective of the position of the armature. Thus the only air gap in the magnetic circuit is at the essential point between the core (pole-face) and armature and the reluctance of the total magnetic circuit is determined almost exclusively by the dimensions of this gap.

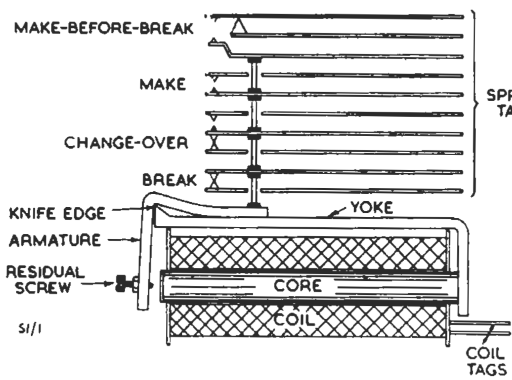


Fig. 1.3. The Commonest Types of Contact-spring Arrangement

Only nine springs are used in any one set

The dimensions of the core and spool are proportioned to give a compromise between maximum area of magnetic path and available winding space. The pole-face is, however, made larger than the core section because, by this means, an increase in tractive pull can be obtained. The reasons for this are made clear in Appendix A where it is shown that the tractive pull is directly proportional to the square of the number of turns and the current, and inversely proportional to the area of the pole-face and the square of the reluctance of the magnetic circuit. If the pole-face area is increased, the reluctance is decreased in approximately the same proportion, but since the pull depends on the square of the reluctance and the first power of the area, a net increase in pull results. For this reason the pole-face of the P.O. Type-3000 relay is larger than the cross-sectional area of the core as shown in Fig. 1.4.

1.4 Winding

The relay winding consists of a number of turns, usually of enamelled copper wire, wound on a former and contained between two end-cheeks,

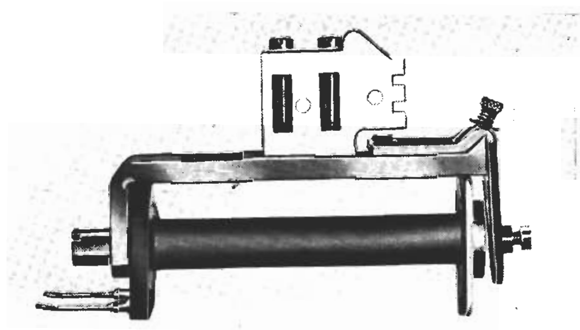


Fig. 1.4. Magnetic Circuit of P.O. Type-3000 Relay

the whole assembly forming an interchangeable unit. The rear winding cheek is of bakelite and carries a number of soldering tags, up to five, on which the ends or tapping points of the winding are terminated. The front cheek may be bakelite but is sometimes of copper for a reason to be given later.

The former may accommodate up to four windings, but where more than two are fitted, the restricted number of soldering tags makes it necessary to common one end of two or more windings. The individual windings may be balanced, and connected either differentially or in series- or parallel-aiding. Sections of non-inductive winding may be used in certain circumstances.

For a given winding space the resistance of a winding depends on the fourth power of the wire diameter and can vary from 0·25 ohm to 50,000 ohms in practical relays.

1.5 Impedance

The inductance of the winding depends on the number of turns and the reluctance of the magnetic circuit (see Appendix A). It is sometimes necessary for a relay to have a high impedance at audio frequencies and this can be achieved by the use of nickel-iron sleeves slipped over the soft-iron core (Fig. 1.5). At frequencies above approximately 300 c/s, alternating fluxes in the soft-iron

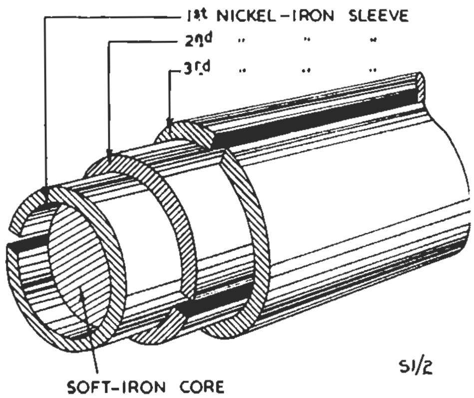


Fig. 1.5. Arrangement of Nickel-iron Sleeves on High-impedance Relays

core are confined, for the most part, to an outer skin of the core about 10 mils (i.e., 0·01 in.) thick, and by fitting longitudinally-gapped sleeves of a low-hysteresis, high-resistance material, such as a 36 per cent nickel-iron alloy, the eddy-current losses can be reduced and the impedance raised. By the use of three of these sleeves of 10-mil thickness, the impedance of the relay can be more than doubled without appreciable effect on the d.c. resistance or the performance of the relay.

1.6 Armature

The armature is an L-shaped pressing with the angle rounded to permit rocking on the knife edge. The method of securing the armature, mentioned on page 1.3, has the advantage over other methods that the armature can easily be removed and replaced without affecting the air gap. The rear limb of the armature contains two Keramot studs and these engage with the non-conducting pins which lift the lever springs when the relay operates. A large rectangular hole is cut in the rear limb to decrease the mass of the armature.

The knife-edge contact between armature and yoke is a low-reluctance joint and gives this type of relay high magnetic efficiency. Because of this, however, the armature will not release until the current has reached a lower value than that for other types of relay. In certain applications, for example when a relay is used in impulse circuits, this low release current may be a disadvantage; in such cases, use is made of an *isthmus armature*, page 1.8.

1.7 Spring-sets

The springs are stamped from sheets of nickel-silver, an alloy of copper (55 per cent), nickel (18 per cent) and zinc (27 per cent) which maintains its elasticity for long periods even in the worst climatic conditions. This material also has the desirable property that springs made from it allow their pressure or *tension* to be readily adjusted by stroking and bending.

In a relay, the fixed and lever springs are separated from each other by strips of insulating material and both springs and insulators are arranged in the form of a stack or *spring-set* which is secured to the yoke at the end remote from the armature by two bolts which pass through the stack but do not make contact with the springs. Most relays are designed to perform a number of switching operations and a number of springs are required. These are arranged in two spring-sets each containing approximately the same number of springs, and the lever springs are moved by brass pins (with insulating sleeves on mains-voltage spring-sets) which engage with the two Keramot studs in the armature. In the P.O. Type-3000 relay a buffer block of insulating material is bolted to the yoke between the two spring-sets; the block is characteristic of this type of relay and performs a number of useful functions which will be described separately.

The tractive pull of the relay is adequate for the satisfactory operation of eight make or break contacts or six change-over contacts or any combination of contacts provided there are not more than nine springs in any one spring-set.

1.8 Contacts and Contact Material

Contacts are domed in shape and are riveted to the free ends of both fixed and moving springs. Each spring is split as shown in Fig. 1.6, and carries twin contacts; this increases reliability in operation for the following reason: with single contacts, particles of dust may cause bad contact and introduce high-resistance connection between two springs; it is improbable that twin contacts would be similarly affected simultaneously; moreover, such a fault on one contact often clears itself with one movement of the relay.

Standard contacts are of either silver or platinum. Experience has shown that the use of silver contacts for programme switching is accompanied by a high fault liability; this is because there is a tendency for a corrosive film to spread over the surface of the contacts, introducing a high resistance which cannot be overcome by the relatively low programme voltages. For this reason, the contacts of BBC programme-switching relays are of platinum.

Current-carrying capacity is another factor which has to be considered in the choice of contact material. It is greater for platinum than for silver and the normal limits are shown in the table below: this applies when no spark quench is fitted across the contacts.

Material	*Mains Voltage Spring-sets*		*Up to 60 V Working*
	AC	*DC*	*DC*
Platinum	0·6 A	0·3 A	1·0 A *
Silver	0·3 A	0·1 A	0·3 A

* *With spark quench if required*

Platinum contacts are also desirable when the relay is used in circuits calling for frequent relay operation, e.g., impulse transmission.

1.9 Contact Bounce

When a relay is energised or de-energised, there is a tendency for the contacts to bounce once or twice before opening or closing permanently. This is undesirable because it may cause arcing at the contacts and sometimes produces circuit faults; in any event, bounce causes unnecessary contact wear and measures are taken to minimise it.

A method commonly used is to arrange for the frequency of resonance of the fixed springs to be different from that of the lever springs; this is done, either by using thicker material for the fixed springs, or by supporting them with additional metal pieces for part of their length to reduce the effective vibrational length. As we have seen, each spring is divided into two tongues by a longitudinal slit and the tendency to bounce is minimised by making the slit in the lever springs longer than in the fixed springs.

There is a second cause of contact bounce, in which the magnetic circuit plays a part. When a relay is energised, the armature does not move with uniform motion; there are pauses and jumps in the motion caused by the lever springs engaging with or disengaging from the fixed springs. Suppose, due to springs disengaging, there is a sudden reduction in the mechanical load on the armature: this causes the armature movement to accelerate and there is a sudden decrease in the air gap between the armature and the core. The resulting decrease in magnetic reluctance causes an increase in tractive pull which tends still further to increase the acceleration of the armature. In a similar way, when the armature meets a sudden increase in load, due to springs engaging, it tends to slow up and

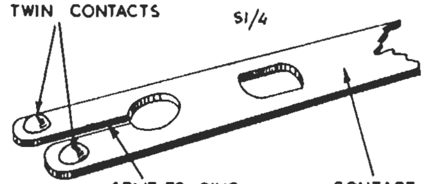


Fig. 1.6. Spring with Twin Contacts

may even momentarily reverse in direction. Any tendency to a reversal produces an increase in the air gap, an increase in reluctance and a decrease in tractive pull. Thus any changes in the velocity of the armature are exaggerated by changes in the reluctance of the magnetic circuit, and this increases any tendency to armature oscillation and contact bounce. The magnetic effect can be minimised by fitting a copper end-plate to the armature end of the coil. This acts to some extent as a slug (see later) and the eddy currents induced in it tend to prevent rapid changes in flux and to minimise contact bounce due to this cause.

1.10 Contact Sequence

In certain relay applications, a particular contact is sometimes required to close or open (when the relay operates) before all the other contacts. This is known as an *X-contact* action and can be obtained by positioning the fixed and lever springs as in Fig. 1.7(*a*). Similarly, certain circuits require a contact which closes or opens after all the other contacts. This is known as a *Y-contact* action and can be obtained by the spring arrangement shown in Fig. 1.7(*b*). It should be noted that only one such contact can be accommodated on one relay, i.e., either one X or one Y. In a relay with either an X- or a Y-contact action, the lever springs need greater travel than in a relay without such actions, and if X-operation is required in a P.O. Type-3000 relay, a thin metal spacer is inserted below the buffer block.

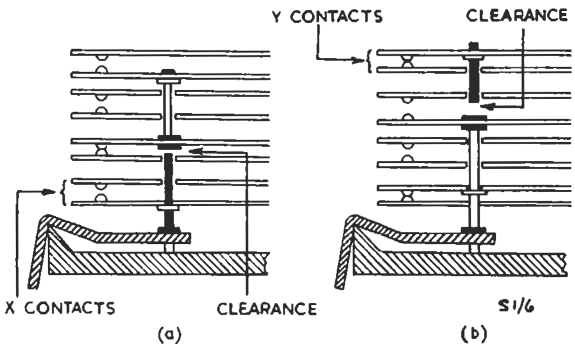


Fig. 1.7. X and Y Contact Action

1.11 Buffer Block

The buffer block is a piece of white moulded insulating material bolted to the yoke between the spring-sets. At the front of the block is a series of notches (Fig. 1.8) positioned so as to form steps with which projections on the fixed springs may engage. The block is primarily intended to maintain correct relative positions of the fixed and lever springs. Provided the springs are kept straight, the buffer block automatically ensures the correct clearances between the contacts and, if the fixed springs are adjusted to have correct pressure on the steps of the buffer block, the contact pressures in operation will be correct. There are five standard types of buffer blocks to cater for the various contact combinations.

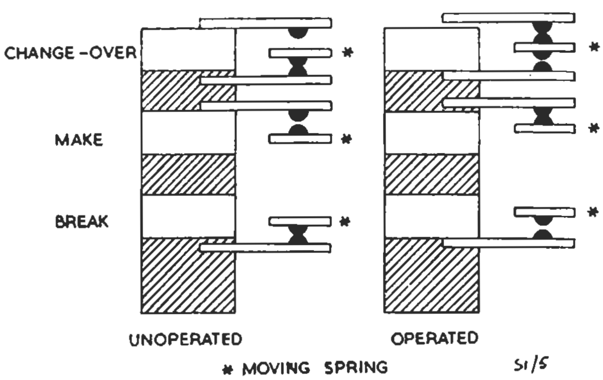


Fig. 1.8. Buffer Block

The block is made of white material so that it forms a light background against which the contacts stand out in sharp relief; this is useful in adjusting spring-sets. The top of the block is shaped so as to guide the relay cover safely over the contact springs and fixing screws.

1.12 Relay Performance

1.12.1 General

Two of the most important properties which must be specified in any statement of relay performance are the currents required for operation and release, and the operate and release lags. The meanings of these and other associated terms must first be defined.

1.12.2 Hold and Release Conditions

If the current in a relay winding is below a certain value, the relay will not operate when the current is first switched on, but if the current is increased, a value will be reached at which the relay operates. The maximum current that can be applied without any of the springs operating is known as the *non-operate* current. The minimum current that will fully operate all the contact springs is known as the *operate* current. After a relay has operated, it is possible to reduce the current appreciably from the operate value without the relay releasing and the minimum current that will hold all the contacts in the operated position is known as the *hold* current. If the current is reduced below the hold value the value at which the relay releases is known as the *release* current.

1.12.3 Operate Lag

Most relay windings have appreciable inductance and the current does not take up the Ohm's law value immediately an e.m.f. is applied. The current takes a finite time to reach its steady value, the rate of increase being high at first but decreasing slowly as the final value is approached. The current growth is illustrated in Fig. 1.9 and follows the exponential law

$$I = I_0 (1 - \varepsilon^{-Rt/L})$$

in which I = current at a time t after switching on, and I_0 = final value of the current. This value is the one given by Ohm's law and, in a relay circuit, is known as the circuit current.

R = total resistance in the circuit

L = total inductance in the circuit

and ε = base of Naperian logarithms = 2·71828 . . .

From this expression it follows that when $t = L/R$ the current has reached $(1 - 1/\varepsilon)$ or 63 per cent of its final value. The quotient L/R is known as the time constant and can be used as a measure of the rate of growth of current in inductive circuits.

The time which elapses between the application of the e.m.f. and operation of the relay is known as the *operate lag*. (Fig. 1.9.)

For a given time constant, the operate lag depends on the ratio of the *operate* to the *circuit* current, and can be reduced by decreasing the operate current or increasing the circuit current. For a given ratio of the operate to circuit current, the operate lag depends on the time constant which, if the resistance is fixed, depends in turn on the inductance of the winding. The inductance necessary in a winding depends on the tractive effort required, both being proportional to the square of the number of turns, and thus the operate lag is dependent on the spring load.

Other effects such as hysteresis and eddy currents can cause lag additional to that described above and an account of these is given later.

1.12.4 Release Lag

When the source of e.m.f. is removed from an inductive circuit, provided there is a conducting path, the current does not fall instantaneously to zero but decays comparatively slowly as indicated in Fig. 1.9. This curve obeys the equation

$$I = I_0 \varepsilon^{-Rt/L}$$

in which I is the current at a time t after the source of e.m.f. is removed. The other symbols have the same meanings as before. Putting $t = L/R$ gives $I = I_0 \varepsilon^{-1}$. Thus the time constant is the interval in which the current decays to $1/\varepsilon$ or 37 per cent of its initial value.

The time which elapses between the removal of the e.m.f. and the subsequent release of the relay is known as the *release lag* (Fig. 1.9).

For a given time constant, the release lag depends on the ratio of the release to the circuit current, and can be reduced by increasing the release current or decreasing the circuit current. Decreasing the circuit current will, however, increase the operate lag. For a given ratio of release current to circuit current the release lag depends on the time constant which, as shown above, is indirectly dependent on the spring load of the relay.

Fig. 1.9 illustrates the decay of current which occurs when a conducting path remains after the e.m.f. has been removed. In most relay applications, the circuit is broken when the e.m.f. is removed and the current then falls very quickly to zero, being maintained possibly for a few milliseconds by an arc at the contacts where the circuit is broken.

Other effects, notably hysteresis and eddy currents, can cause lag additional to that described and an account of these is given later.

1.13 Slugged Relays

The operate and release lags of a relay can be increased by the use of a *slug*, i.e., a mass of low-resistance material closely linked with the magnetic circuit of the relay. When an e.m.f. is applied to the winding, flux begins to grow in the magnetic circuit and eddy currents are induced in the slug. These eddy currents in turn give rise to a magnetomotive force which, in accordance with Lenz's

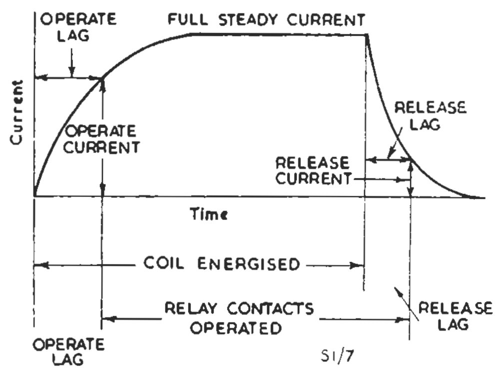


Fig. 1.9. Operate and Release Lags of a Relay

law, opposes the main flux in direction and retards the growth of main flux, thereby delaying operation of the relay. When the e.m.f. is removed from the winding, the resulting collapse of main flux induces eddy currents in the slug, but because the subsidiary flux is now in the same direction as the main flux it retards the collapse and delays the release of the relay.

A slight slugging action is sometimes desired to minimise contact bounce; this can be obtained by fitting a copper end-cheek at the armature end of the bobbin. A greater slugging action can be obtained by fitting copper sleeves over the iron core but under the winding of the coil; it is, however, more usual for the slugs to take the form of hollow copper cylinders which fit over the wound bobbin. Depending on the delay required, these slugs vary in length from $\frac{1}{2}$ in. to $1\frac{1}{2}$ in. and their position on the coil is important: if the slug is situated at the armature end of the core, the operating and release lags are both increased; if it is situated at the opposite end (known as the *heel* end) there is little effect on the operate lag but the release lag is increased to the same extent as before.

The difference in effect of armature-end and heel-end slugs can be understood from Fig. 1.10, which illustrates the paths taken by the eddy-current flux during operation and release of the relay. During operation the flux to the left of an armature-end slug (Fig. 1.10*a*) divides between the iron path through the junction of the yoke with the core and the air gap between the yoke and the core. The reluctance of the air path is very much greater than that of the iron path and most of the flux takes the iron path. There is thus very little flux leakage and the slug exerts maximum effect. If, however, the slug is situated at the heel end of the core, as in Fig. 1.10*b*, the flux on the right of the slug divides between the air gap between the armature and the core and the air gap between yoke and core as before. Although the gap between armature and core has the lower reluctance, the ratio of the two reluctances is less than in Fig. 1.10*a*, and there is appreciable leakage of flux, with the result that the full effect of the slug is not obtained. Thus the operate lag obtained with a heel-ended slug is less than that with an armature-ended slug.

On release of a slugged relay, the eddy-current flux divides between an iron path and an air path irrespective of the position of the slug (Figs. 1.10*c* and 1.10*d*). There is little loss of eddy-current flux and a full release lag is obtained no matter where the slug is situated.

The magnitude of the effect obtained by slugs depends on a number of factors including the size of the slug, the ampere-turns of the winding and the spring load, but reliable operate lags of 100 milliseconds and release lags of 600 milliseconds can be obtained, though not with the same relay. The use of an armature-end slug reduces the tractive pull of a relay but the heel-end slug does not materially effect the pull.

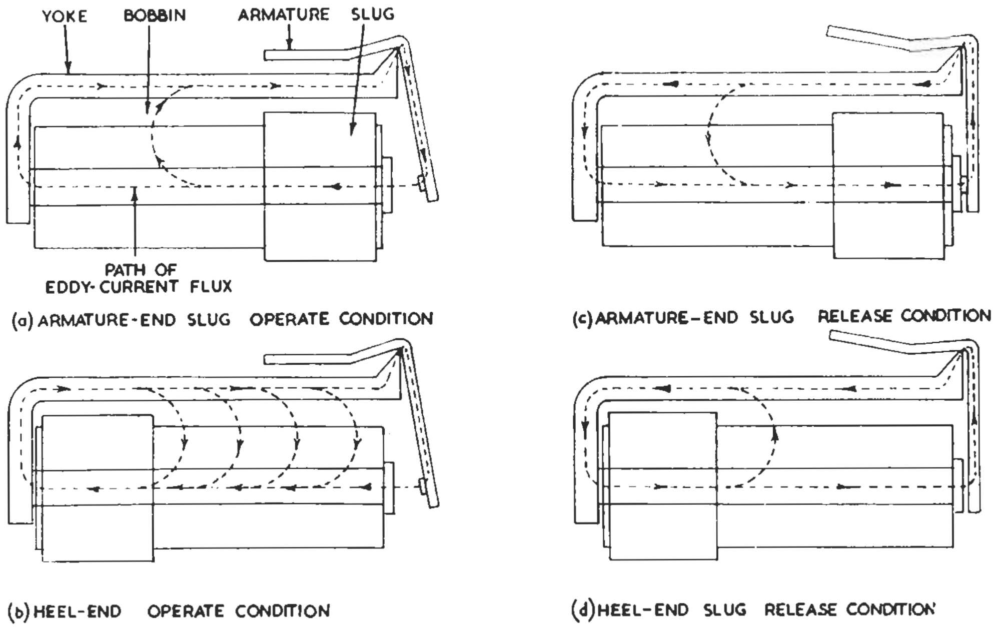


Fig. 1.10. Eddy-current Flux caused by Armature-end and Heel-end Slugs during Operate and Release Conditions

1.14 Isthmus Armature

This type of armature is illustrated in Fig. 1.11. It is of normal construction but two slots, sometimes rectangular (as illustrated) and sometimes V-shaped are cut between the bend and the pole-face so that the cross-sectional area of the flux path is restricted and the reluctance of the magnetic circuit is increased. This increases the operate current, but the effect is slight, because the reluctance of the magnetic circuit, when the relay is in the non-operated condition, is largely determined by the dimensions of the air gap between the armature and the core pole-face.

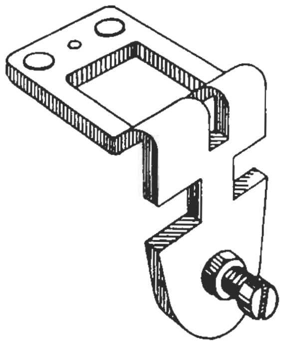


Fig. 1.11. Isthmus Armature

When, however, the relay is operated, this air gap becomes much smaller and the effect of the slots in the armature is more marked; the increase in reluctance due to the isthmus armature is greater than in the non-operated condition and the release current is increased appreciably. Thus the effect of the isthmus armature is to reduce the ratio of operate to release currents and this makes the operating and release times very uniform over a wide range of energising currents.

1.15 Residual Studs and Screws

On all Type-3000 relays a small stud or an adjustable screw and lock-nut is fitted to the centre of the armature to prevent complete closure of the magnetic circuit when the relay is energised. The stud is of non-magnetic material, such as phosphor-bronze, and prevents the armature coming into contact with the core face, thus defeating any tendency for the armature to stick to the core-face when the e.m.f. is removed from the winding. Fixed studs of 4-, 12- or 20-mil length are standard fittings but an alternative fitting is a residual screw which can be adjusted to give any desired clearance between armature and core face within certain limits and can be fixed by means of a lock-nut. This is shown clearly in Fig. 1.3.

The length of the residual stud or screw determines the residual air gap between the armature and the core when the relay is operated and the effect of this air gap on the release lag of a relay is illustrated in Fig. 1.12. The curves show that when the air gap is small, a small change in air gap produces a large change in release lag, particularly if a small slug is used. With larger air gaps, however, the same change in air gap produces a much smaller change in release lag. In many relay applications the release lag must be closely controlled and thus a fairly large air gap and an appreciable residual stud or screw length are desirable.

1.16 Special Applications

1.16.1 Use on Supply Mains

P.O. Type-3000 relays can be designed for use with either a.c. or d.c. mains connected to the coil, to the contacts or to both. The modifications necessary are an improvement in the insulation of the winding, which is normally intended for operation with a 50-volt supply, greater spacing of the springs and larger contacts to carry heavier currents. For making or breaking currents up

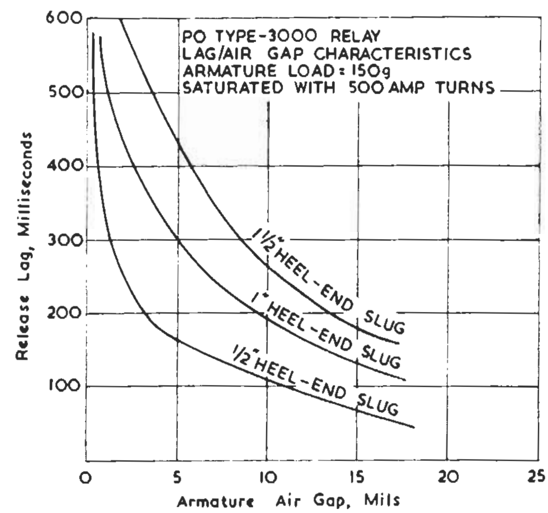


Fig. 1.12. Effect of Residual Stud Lengths on Release Lag

to 0·3 amp a.c. or 0·1 amp d.c., twin silver contacts are satisfactory, but for currents up to 0·6 amp a.c. or 0·3 amp d.c. twin platinum contacts are advisable. For currents up to 8 amps a.c. or d.c. large single contacts of sintered silver-nickel are employed and a spark-quench circuit is necessary for both types of supply if the load is appreciably inductive.

The windings can be designed to give satisfactory operation of the relay with applied d.c. voltages as low as 0·06 volt and as high as 250 volts but some sacrifice in the number of springs may be necessary at very low voltages.

Although special relays with laminated iron cores have been developed for use with a.c. energisation, a standard d.c. relay can be used on a.c., with very little loss of efficiency by connecting a small copper-oxide or selenium rectifier in parallel with the winding and a protective resistor in series with the combination. The action of the circuit may be explained in the following way. During half of each cycle of the applied voltage, the rectifier is non-conducting and current flows through the winding, establishing flux in the core. When the applied voltage falls, the flux begins to collapse and generates a subsidiary e.m.f. which tends to delay the collapse and is in the right direction to drive a current through the rectifier. This induced e.m.f. is large and the rectifier resistance low at the instant when the applied e.m.f. passes through zero. Thus when the applied e.m.f. reverses in polarity, the rectifier resistance is less than that of the relay winding or the series resistor. The p.d. now developed across the relay is very small and most of the power drawn from the a.c. source is dissipated in the series resistor. The relay thus behaves as though it were released with the winding short-circuited. This is equivalent to the use of a very large slug and the armature movement is so slow that before it has started to fall off, the next half-cycle commences, re-establishing flux in the core. The armature is thus held securely during maintenance of the applied e.m.f. and does not oscillate at the mains frequency.

The only disadvantage of this use of relays, apart from the additional rectifier and resistor required in the circuit, is that the relay is a little slower in acting than on d.c. supplies.

1.16.2 High-voltage and Radio-frequency Working

By improving the insulation of the contact springs and reducing their capacitance to each other and to earth, the P.O. Type-3000 relay can be successfully used for switching voltages as high as 3,000 volts and at frequencies up to 20 Mc/s. Considerable modification of the contact spring arrangement is necessary for these special applications, particularly in the special relay designed for aerial switching, but the magnetic circuit and coil are of standard pattern.

1.17 Coding and Specification

P.O. Type-3000 relays used in BBC equipment were originally coded 3/101, 3/102 and so on. At present all such relays which comply with individual P.O. specifications are known by their P.O. numbers. All other relays of this type are known by their manufacturers' code numbers.

A list of Type-3000 relays in current use in BBC equipment, with design and operating data for each relay, is included in the BBC Standards Catalogue.

Type-3000 relays are available in three versions to suit various circuit requirements and the three versions are indicated by different coloured labels as follows:—

White label—a relay with 14-mil thick springs and standard mechanical adjustments.

Green label—a relay with 12-mil thick springs and standard mechanical adjustments.

Red label —a relay with 12, 14, 18, 24 and/or 40-mil thick springs and special mechanical adjustments to suit particular electrical requirements.

The following symbols are used in specifications of relays:—

M—make contact unit
B—break contact unit
C—change-over contact unit, break-before-make
K—change-over contact unit, make-before-break
s—silver contacts
pt—platinum contacts (indicated on the relay by a V-notch cut in the front end of the contact spring)
sn—sintered silver-nickel contacts
x—contact operating before all other contact units
y—contact operating after all other contact units

As an example, if the contacts of a relay are given as 4 C pt; Msy this indicates that the relay has four change-over contacts (break-before-make) in platinum and one silver make contact which operates after all the other contact units.

1.18 Circuit Drawing Code

The code for relays and relay contacts used in circuit drawings is based on the *detached-contact* system which permits contacts to be drawn in the relevant part of the circuit, and not necessarily adjacent to the coil. The coil is drawn as a rectangle, the d.c. resistance of the coil being shown in ohms inside the rectangle.

Each relay is given a functional coding, usually of two or more letters; e.g., MCO = *microphone change-over*.

The number of contact units, indicating the number of possible switching operations, is shown as a denominator of the functional code, thus:

$\frac{\text{MCO}}{4}$ or MCO/4 indicates a microphone change-over relay, performing four switching operations.

Individual contact units are given serial numbers for purposes of circuit identification. Thus: MCO-1, MCO-2, etc. This greatly simplifies circuit description; for example, 'When TB/2 operates, contact TB-1 completes the coil circuit of MCO/4.'

See also *BBC Drawing Office Practice*, page A.2.

SECTION 2

P.O. TYPE-10 RELAY (A.E.I. COMB RELAY)

Although the P.O. Type-3000 relay has given very satisfactory service in many applications since it was introduced in the early thirties, the need has arisen for a relay which will give even longer life in certain instances. Under the direction of the Post Office, therefore, the P.O. Type-10 relay has been designed and developed by A.E.I., who are the successors to Siemens, the firm which designed the P.O. Type-3000 relay for the Post Office.

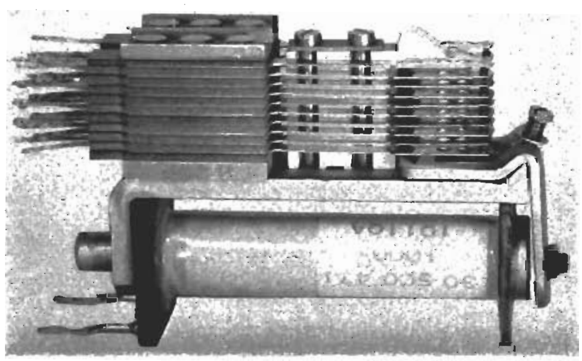


Fig. 2.1. P.O. Type-10 (A.E.I. Comb) Relay

The P.O. Type-10 relay provides for a mechanical life of 100,000,000 operations but retains the basic characteristics, mounting arrangements and design data associated with the 3000-type relay. It can accommodate up to 10 springs per side but has restrictions in design compared with the 3000 type.

In view of its long life and continuity of operation without readjustment it has been adopted in some of the particularly busy switching circuits in the new equipment designed for the extension to Broadcasting House, London.

The major innovation is that the spring-set lifting pins and studs are replaced by a lifting comb of synthetic-resin-bonded paper which bears directly on the metal of the armature, the usual Keramot lifting studs being omitted; a typical comb fitted to a spring-set is shown in Fig. 2.1.

To position the steps nearer the contacts the buffer block has been lengthened, thus assisting the maintenance of effective block clearance by minimising the flexing of the spring between contacts and the spring lug. Improvements have also been made to the armature back-stop, the residual screw, and the seating of the armature on the knife-edge.

SECTION 3

HIGH-SPEED RELAYS

3.1 Introduction

Electromagnetic relays of the type described in Sections 1 and 2 have a minimum operate time of about 5 milliseconds and, when shorter times are required, specially designed high-speed relays must be used. While still using electromagnetic principles, high-speed relays are constructed differently from the conventional type and, when suitably adjusted can operate a break contact in approximately 0·5 millisecond and a succeeding make contact in 1·5 milliseconds after application of the e.m.f. to the coil, while the release lags are even shorter.

To keep the spring load on the armature to a minimum, high-speed relays have only one or two sets of change-over contacts. The single and double contact high-speed relays differ in certain details and will be described separately. *The descriptions which follow are applicable to high-speed relays manufactured by A.E.I. (formerly Siemens Brothers) to whom acknowledgment is made for their permission to use information and illustrations published in their technical journals.*

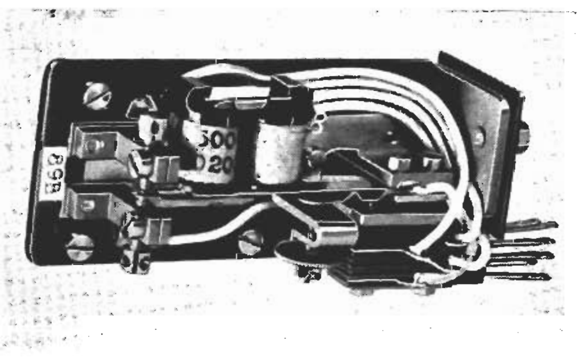


Fig. 3.1. Single-contact High-speed Relay

Other makes of high-speed relays of quite different design are available, some of which have faster operating speeds than those herein described.

3.2 Single-contact Relay

This relay is constructed on a metal base-plate turned up at one end which can be fixed to a P.O. Type-3000 mounting. (Fig. 3.1.)

The moving contacts are of platinum and are carried at one end of a nickel-silver armature spring which is firmly attached to a support piece at one end and, to give rigidity, is channelled for a fraction of its length at the other end. (Fig. 3.2.)

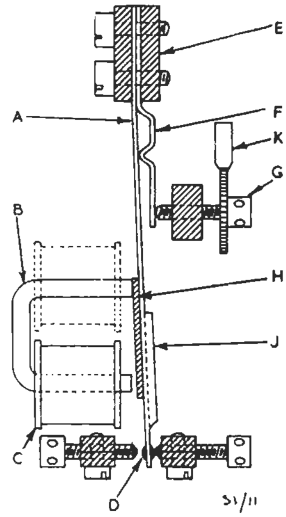


Fig. 3.2. Mechanical Arrangement of Single-contact High-speed Relay

A. Armature Spring
B. Magnetic Yoke
C. Coil
D. Contacts
E. Support Piece
F. Buffer Spring
G. Armature Spring Tension Adjuster
H. Armature
J. Channelling
K. Blade Spring

A short soft-iron armature is welded to the channelled section and is so placed that it can complete the magnetic circuit of a U-shaped yoke, one arm of which carries the energising winding. One end of the armature is permanently in contact with the unwound limb of the yoke but the other end has a small clearance from the wound limb. The moving contact is thus in electrical contact with the yoke and the design of the relay must be such that the yoke is not earthed to the relay frame. A second spring, known as the buffer spring, is also attached to the support piece and at approximately its middle point has a V-shaped bend which bears against the armature spring. The other end of the buffer spring is in contact with an adjustable screw known as the armature-spring tension adjuster. The pressure applied by this screw to the buffer spring can be resolved into two components: one ensures firm contact between the armature and the unwound limb of the yoke, the other tends to swing the armature about the yoke in an anticlockwise direction (Fig. 3.2) and increases the pressure between the break contacts. The design is such that the setting of the armature-spring tension adjuster which gives correct pressure between the break contacts also gives a suitable pressure between the armature and the unwound limb of the yoke.

The adjusting screw has a capstan head which can be rotated by a tommy pin and, to avoid backlash, the screw is supported in two threaded holes in a U-shaped member. There is no locking device but the screw carries a knurled wheel engaged by the end of a small blade spring, which acts as a brake to prevent unwanted movement of the screw.

In addition to the armature-spring tension adjuster there are two further adjustments. The fixed contacts are not mounted on fixed springs as in standard relays but are secured to the ends of capstan-headed screws. The threads for these screws are formed in slots in fixed members and, to make adjustment permanent, these slots can be closed to grip the screws by tightening two locking screws.

3.3 Double-contact Relay

The single-contact high-speed relay has many applications and is widely used but its sensitivity is limited by the small size of the coils which are necessarily of low impedance. Moreover the relay is unsuitable when two quick-acting change-over contacts are required. To meet this need the double-contact high-speed relay was introduced: it has two change-over contacts and the coils are much larger than in the single-contact type.

The double-contact relay has a magnetic circuit similar to that of the single-contact type but the yoke is larger and of greater cross-section to permit the use of two parallel armature springs (Fig. 3.3). Since both armatures are in contact with the magnet yoke, they are insulated from the armature springs by thin sheets of mica to prevent electrical connection between the two sets of moving contacts. Single domed contacts made of platinum are used and the make and break contacts are riveted to the ends of fixed contact springs of 28-mil nickel-silver. Each armature spring is of 10-mil nickel-silver and, together with the associated fixed springs, forms a spring-set, two of which are mounted on the relay frame as in standard relays. As with the single-contact type, the relay can be fitted to a Type-3000 mounting.

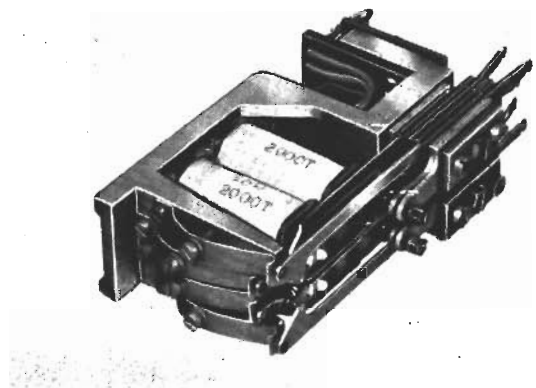


Fig. 3.3. Double-contact High-speed Relay

Because of the slightly greater armature mass of the double-contact relay, its operating lags are slightly larger than those of the single-contact type. The break contacts open approximately 1 millisecond and the make contacts close approximately 2 milliseconds after the application of the e.m.f. to the coils. On removal of the e.m.f. the make contacts open in less than 0·5 millisecond and the break contacts close in less than 1·5 milliseconds.

3.4 Relay Coils

High-speed relays are manufactured with a single untapped coil, with a single tapped coil or with two separate untapped coils and the connections to the coils are brought out to two, three or four tags respectively. In the two-coil type each limb of the yoke is fitted with a coil as shown by the dotted lines in Fig. 3.2.

3.5 Coding and Specification

High-speed relays used in BBC equipment normally comply with a P.O. specification and have been allocated a P.O. code number, by which they are also known in the Corporation. Design and operating data for each of these relays are given in the BBC Standards Catalogue. The manufacturer's code is used for high-speed relays which have not been made to an individual P.O. specification and have therefore not been allocated a P.O. code.

3.6 Miniature High-speed Relay

3.6.1 Introduction

This miniature relay was designed to meet a wartime need for a small relay with a performance equal to that of the single- or double-contact high-speed types but capable of withstanding very great humidity as well as very large and very rapid changes in atmospheric temperature and pressure. In addition it was required to operate satisfactorily in dust clouds and totally immersed in water. To this end the relay is hermetically sealed in a steel can. The relay is sometimes known as the tropic-seal type and is given the code number 96.

3.6.2 Construction

The construction of the relay is shown in Figs. 3.4 and 3.5; it has a frame somewhat resembling a letter G and containing a U-shaped soft-iron yoke, each limb of which carries a bobbin wound on a former. A spring-set consisting of three nickel-silver springs is secured to the frame by two bolts, the springs being insulated from each other and from the frame by bakelite or neoprene washers. The inner and outer of these springs are the fixed springs and carry platinum make and break contacts at their free ends. The ends rest under tension against ceramic buffer blocks secured to the ends of screws which enter tapped holes in the relay frame and carry lock nuts.

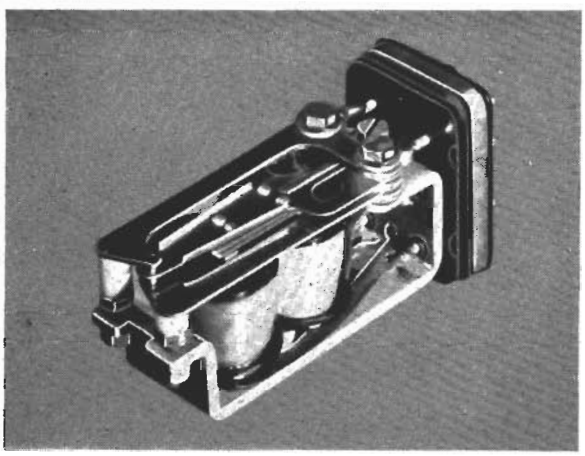


Fig. 3.4. View of Unsealed Relay

The centre or moving spring carries an armature which, as in the other high-speed relays, is in contact with one limb of the yoke and pivots about it, as a fulcrum, when the relay operates. The adjustment of the relay is such that a residual air gap is obtained between the armature and the other yoke face. Near the fulcrum the moving spring divides into three prongs, the outer two of which are held, together with the fixed springs, by the two fixing bolts already mentioned. The centre prong is channelled for a fraction of its length to give rigidity and the end is forked to engage

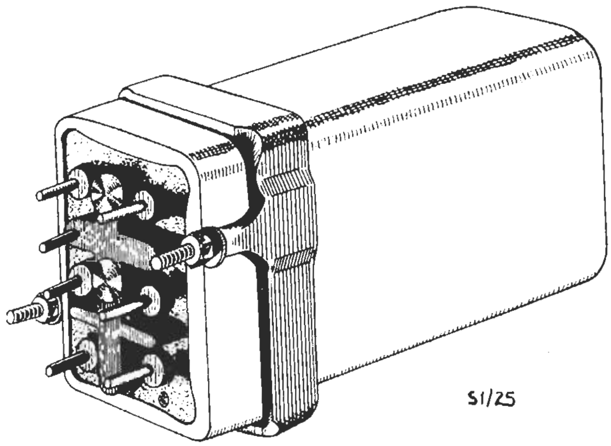


Fig. 3.5. General View of Sealed Miniature High-speed Relay

with an adjusting screw carried in a tapped hole in the frame and provided with a locknut. This screw is the armature-spring tension adjuster and, in conjunction with the make- and break-contact adjusting screws, provides a means of tensioning the springs and setting the contact-spring opening.

3.6.3 Method of Connection and Sealing

The connections to the springs and the two coils are brought out to seven thick pins which pass through a bakelite plate bolted to the relay frame. The pins have enlargements on the far side of the plate and these enter countersunk holes in a rubber gasket shaped like a tray and placed next to the inner bakelite plate. Finally the pins pass through an outer bakelite plate with countersunk holes for the pins and with edges bevelled to fit inside the rubber gasket. To give adequate mechanical strength this outer bakelite plate is ribbed and has bosses surrounding the pins. Before sealing, the relay and can are thoroughly dried, when the relay is placed in the can, the pin end is supported firmly by the inner bakelite plate which rests firmly against a well-defined shoulder in the can, the other end of the relay being held firmly by a bakelite support moulding which is secured to the relay frame by a single bolt and is a good fit at the top of the can (Fig. 3.6). Pressure is now applied to the outer bakelite plate and the edges of the can are turned over to grip the plate. This pressure causes the pin enlargements to force the rubber gasket into the countersunk holes in the outer bakelite plate, and also causes the gasket to spread outwards against the sides of the can, thus hermetically sealing the relay in the can.

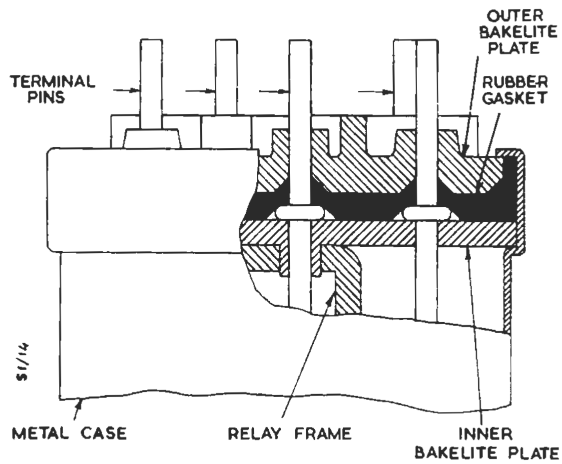


Fig. 3.6. Method of Sealing Miniature High-speed Relay

The dimensions of the can are $2\frac{1}{8}$ in. by $1\frac{1}{16}$ in. by $\frac{3}{4}$ in. and the relay is secured to a chassis or mounting plate by means of a rectangular ring which slips over the can and butts against the shoulder. Two threaded stems attached to the ring project beyond the edge of the can to enter holes in the mounting plate and are secured by nuts on the far side, the relay pins projecting through an aperture in the mounting plate.

The operating and release lags are of the same order as for the single-contact high-speed type and are slightly better than for the double-contact high-speed type.

The break contact operates approximately 0·5 millisecond and the make contact approximately 1·0 millisecond after application of the e.m.f. to the coil. On removal of the e.m.f., the make contact opens after less than 0·5 millisecond and the break contact closes after less than 1·5 milliseconds.

SECTION 4

THERMAL RELAYS

4.1 Introduction

The relays so far described make use of the magnetic effect of an electric current and by suitable design can be made to give operate lags up to 100 milliseconds and release lags up to 600 milliseconds. There are, however, certain relay applications requiring lags of several seconds; for these applications thermal relays are particularly well suited. These relays operate by virtue of the heating effect of an electric current and can give reliable lags up to 40 seconds.

Thermal relays make use of bimetal, which is made by riveting together two strips of dissimilar metals. The metals are chosen to have differing coefficients of expansion and, because of this, a bimetal strip bends into an arc when heated. Early bimetal strips were made of nickel and brass but more recent ones are constructed of two dissimilar steel alloys. In all-steel bimetal strips it is almost impossible to detect the junction between the two constituents.

4.2 Mechanical Construction

In its simplest form a thermal relay consists of a coil of wire wound over a bimetal strip 18 mils thick but insulated from it by a thin sheet of mica. When a current is passed through the coil the heat developed causes the strip to bend and operate contacts. Simple change-over contacts are commonly employed.

A disadvantage of this simple arrangement is that the operate time varies appreciably (as much as 25 per cent) with normal day-to-day variations in ambient temperature. This can be minimised by use of a second, compensating, bimetal strip mounted parallel to and coupled to the first strip but arranged to bend in the opposite direction (Fig. 4.1). In this way any tendency for the first strip to bend as a result of fluctuations in ambient temperature is largely balanced out by a tendency of the second strip to bend in the opposite direction. The heat developed in the winding on the first strip must not be communicated to the compensating strip and the link between the strips must be of non-heat-conducting material. For convenience in mounting, thermal relays are usually constructed in a similar way to a spring-set, and are attached to the yoke of a standard relay as shown in Fig. 4.1. The thermal relay can thus be supported on a standard relay mounting plate; moreover, the advantages of the buffer block are also obtained.

The delay introduced by the relay depends on the power dissipated in the heater coil and varies from 36 seconds for 1 watt to 2·5 seconds for 20

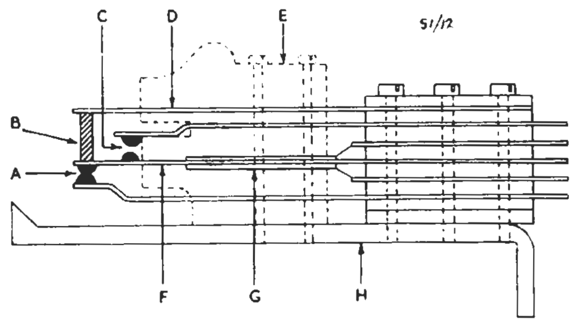


Fig. 4.1. Simple Thermal Relay

A. Break Contacts
B. Heat Insulator
C. Make Contacts
D. Compensating Strip
E. Buffer Block
F. Bimetal Strip
G. Heating Coil
H. Standard Relay Yoke

watts. For a relay designed to work at a given voltage, the delay depends on the resistance of the heater coil. The release lag is between 15 and 20 seconds and is independent of the operate lag.

4.3 Thermal Relay with Fleeting Action

The simple type of thermal relay described above has the disadvantage that the contacts close and open comparatively slowly, and arcing may occur with consequent damage to the contacts if heavy currents or inductive circuits are controlled. To overcome this, a thermal relay with a snap or fleeting action has been developed.

This relay employs a bowed spring, known as the fleeting spring, which is firmly fixed at one end and, to allow some freedom of movement, is held by a spring at the other end. When the relay is not operated, this fleeting spring applies pressure between the break contacts. When the bimetal strip is heated, it applies pressure to the centre of the fleeting spring and straightens it. Further movement of the strip causes the fleeting spring to flick over very quickly to bowed formation in the opposite direction, completing the make-contact circuit. The fleeting spring lies between the limbs of a U-shaped piece attached to the end of the bimetal strip and, when the relay is de-energised, the fleeting spring is again straightened and snaps back to its original position to give a very quick break action. The bimetal strip is compensated for variations in ambient temperature by a second strip in the same way as the simple thermal relay.

Because of the additional work the bimetal strip has to do, the lag of a fleeting-action relay is longer than that of a simple relay dissipating the same power. For fleeting-action relays the operate lag varies from 50 seconds for 2·5 watts to 3 seconds for 20 watts. The release lag is from 15 to 20 seconds.

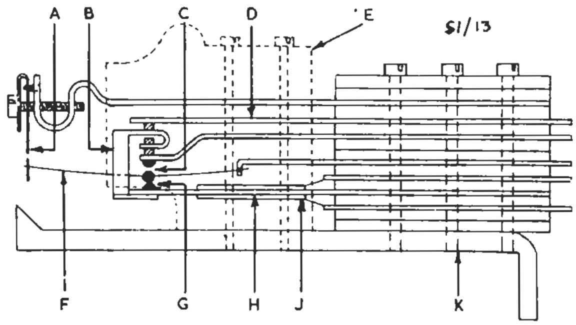


Fig. 4.2. Thermal Relay with Fleeting Action

A. Support Spring
B. Link Connecting Bimetal Strip with Compensating Strip
C. Make Contacts
D. Compensating Strip
E. Buffer Block
F. Fleeting Spring
G. Break Contacts
H. Bimetal Strip
J. Heating Coil
K. Standard Relay Yoke

SECTION 5

MULTIPLE RELAYS

5.1 Introduction

In many applications of relays, for example in computers and registers, the considerable number of contact actions available in the P.O. Type-3000 relay are not required and space can be saved by using a simpler type. The A.E.I. (Siemens) Relay Unit Type 140 has been developed for such purposes. It consists of four simple relays built into a unit of the same size and suitable for fitting on the same drillings as the Type-3000 relay.

This type of relay has been used in equipment at Bush House, but experience has shown that in the complicated switching circuits required for BBC purposes there is no overall advantage in employing it in preference to normal single relays. In future BBC installations, therefore, it is proposed to retain the single relay as standard for all normal purposes.

5.2 General Description

The general construction of the individual relays and the unit of four is shown in Fig. 5.1.

The core, yoke and armature of each relay form a flat rectangle, each item being essentially a flat pressing. The core is an L-shaped blank, the longer limb carrying the coil spool. The shorter limb projects laterally beyond the edge of the front spool cheek to form a pole face to attract the armature. The rear end of the core is fixed to the yoke by means of two screws.

In addition to having lugs for mounting the relay, the yoke has a lateral projection complementary to, and in the same plane as, the pole face of the core. The space between the pole face and the yoke is bridged by a flat armature riveted to a flat thin hinge spring, thus completing the rectangular magnetic circuit.

The contact springs are fitted with twin contacts and are approximately the same size as those used on the P.O. Type-3000 relay. They are built into self-contained spring-set units which are attached to the yoke of the relay by means of two screws. Due to the simple build-up it has been found that the conventional type of buffer block can be eliminated. Contact combinations normally accommodated are one change-over contact (break before make) or two make contacts (silver or platinum). In the latter case the contact pair nearer the armature closes later and opens earlier than the other pair.

The springs are tensioned towards the operated position but are held at normal by means of a separate bias spring provided to hold the armature in the unoperated position. This bias spring is secured to the end of the core by a single screw and is guarded from accidental damage by a small protection detail. The armature is fitted with a 4-mil residual as used in the standard Type-3000 relay.

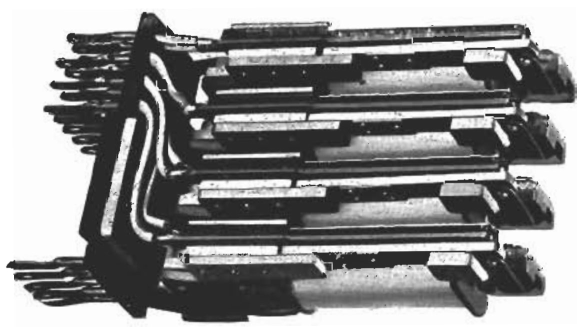


Fig. 5.1. A.E.I. (Siemens) Relay Unit Type 140

Buffer action is provided by tensioning the springs against each other via small insulating studs fixed to the appropriate springs. One of these springs is of greater thickness, and its insulating stud projects through the spring to form a back stop for the armature.

The armature operates the contact springs by means of an insulating stud fixed to one of the lower springs. Contact pressures of 11 to 15 grammes are maintained throughout.

The four relays comprising a Relay Unit Type 140 are mounted on a bracket which is provided with a tag plate, and the complete unit can be mounted in the same way as a Type-3000 relay so that fixings and tag positions are similar. Up to 25 tags are provided for terminating external wiring.

SECTION 6

MINIATURE RELAYS

6.1 Introduction

A type of miniature relay which was originally introduced for simple switching operations in aircraft radio equipment is the S.T. & C. Midget Relay. It has been found to be suitable for similar applications in BBC equipment, for example, in television apparatus and Type-B Studio Equipment. It is robust in construction, extremely small and of light weight and is designed to give the highest possible reliability under exacting conditions of service.

It is available in two types, namely, sealed and open, for light, medium and heavy duty operation.

6.2 Hermetically Sealed Relay (Fig. 6.1)

In its hermetically-sealed form the S.T. & C. Midget Relay is fully tropicalised and cannot become maladjusted and is unaffected by changes in atmospheric pressure or humidity. It is filled with dry air at normal atmospheric pressure, and both the winding and the contact springs are terminated on glass-to-metal seals of a type specially designed to give robustness and good insulating properties. Insulation is better than 1,000 megohms and withstands a flash test of 1,000 volts a.c. and is suitable for working up to 300 volts d.c. or a.c. (r.m.s.).

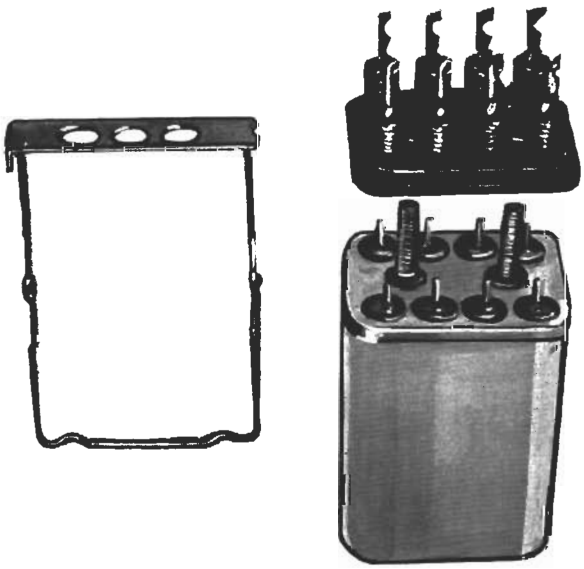


Fig. 6.1. S.T. & C. Hermetically-sealed Relay

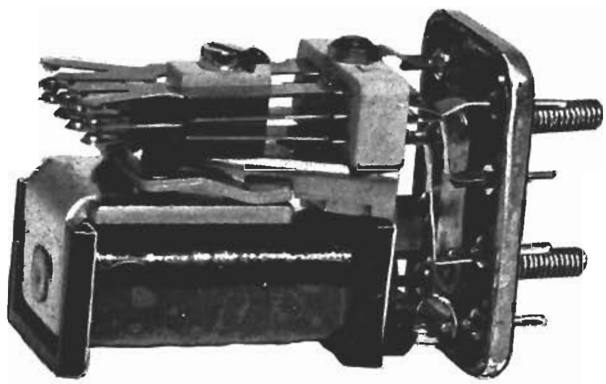


Fig. 6.2. S.T. & C. Open Type Miniature Relay

Relays are available with coils suitable for d.c. supplies of 1, 3, 6, 12, 24, 33 and 48 volts.

The *light duty* relay is fitted with twin contacts of a precious metal suitable for switching video-frequency and radio-frequency circuits at a low power level, as well as handling normal switching currents up to 2 amps in a non-inductive circuit. It carries two change-over contacts.

The *medium duty* relay is fitted with single contacts of a special alloy and carries two change-over contacts suitable for switching non-inductive loads up to 3 amps.

The *heavy duty* relay is fitted with single contacts of the same type as the medium duty relay, but carries a single make contact only suitable for switching non-inductive loads up to 10 amps.

A list of the relays used in BBC equipment, with operating data, is given in the BBC Standards Catalogue.

6.3 Open Type Relay (Fig. 6.2)

This type of relay is intended for use in equipments which are themselves hermetically sealed. The general construction is identical with that of the sealed relay, but without the container.

6.4 Method of Mounting

The open type relay is fitted with a single 6 B.A. stud for mounting, and the sealed relay is fitted with two 6 B.A. studs with the exception of the medium type which has one 4 B.A. (nearest the winding terminations) and one 6 B.A. to ensure non-reversibility when used with a special socket. This special socket has been designed for the sealed type relay where plug-in facilities are desired, and the medium duty type is non-reversible in this socket but this non-reversible feature does not apply to other sealed relays.

SECTION 7

LOCKING OR LATCHING RELAYS

7.1 Introduction

In large studio centres such as Broadcasting House, London, relays used in switching circuits are often required to remain in the operated condition when the energising current is removed and to release only when a release switch is closed momentarily.

This function can be performed by using a pair of relays whose armatures are mechanically interlocked so that one armature with its associated spring-sets locks in position when operated and is released mechanically when the other armature is operated. Release and change-over can be effected electrically only when the other armature is operated by a pulse of current momentarily energising its coil.

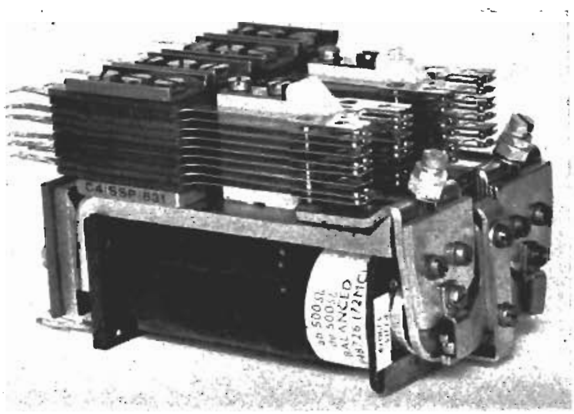


Fig. 7.1. G.E.C. Interlock Relay

Another method is to use a single relay with two coils and a special remanent core having high retentivity. Momentary current through one coil operates the relay, which remains in this condition until the core flux is cancelled by momentarily passing current through a release winding arranged to produce a flux in the opposite direction.

Relays of both types are used in the equipment for the extension to Broadcasting House, London, and are described below.

7.2 G.E.C. Interlock Relay

In this device a pair of relays of the standard P.O. 3000-type have their armatures mechanically linked by a G.E.C. Type-IR1101 relay interlock. (Fig. 7.1.) The interlocking mechanism automatically ensures that only one armature at a time can be in the operated position and can only be released electrically when the other relay of the pair is momentarily energised. If the armature is operated or de-operated manually it will lock in position. Spring adjustments are as for standard P.O. 3000-type relays.

7.3 S.T. & C. Latching Relay

This also consists of a pair of P.O. 3000-type relays yoked together and provided with a latch mechanism. (Fig. 7.2.)

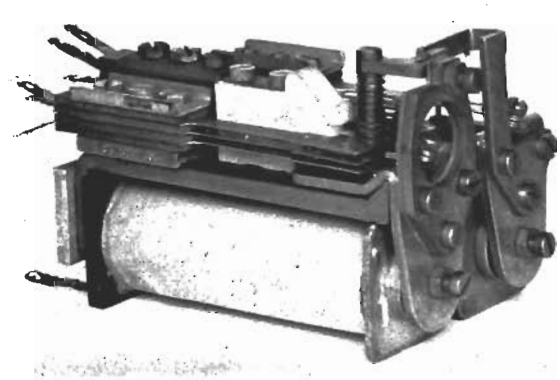


Fig. 7.2. S.T. & C. Latching Relay

When the coil of the lock unit is energised its armature is mechanically latched in position and is released when the coil of the release unit is energised. If the armature is operated manually it will lock in position. The type for normal use is coded 4619, but a tropically finished version, coded 4624, is available and is insulated for 600 volts working maximum, with contacts suitable for currents up to about 5 amps. Type 4619 can be fitted with spring-sets as for P.O. 3000-type relays but spring-sets on type 4624 are limited to make or break contact actions with a maximum of six contact units and with a maximum of twelve springs.

7.4 Type-3000 Remanent Relay

This relay is of the single type and differs from the P.O. Type-3000 relay only in respect of the core and armature. A special remanent core with high retentivity is used to hold the armature in the operated position when the operating current is removed, and the armature is not fitted with a residual stud. A double-wound coil is fitted to operate and release the relay on the same polarity supply. The release winding has fewer turns than the operate winding to minimise the risk of the release voltage producing excessive flux in the reverse direction and thereby tending to re-operate the relay.

When circuit conditions are such that this danger exists with a particular relay, a make or ' suicide ' contact can be wired in series with the release winding to cut off the release voltage immediately the relay releases.

APPENDIX A

TRACTIVE PULL OF A MAGNETIC RELAY

The force between the armature and the pole face in a magnetic relay is given by

$$\text{tractive pull} = \frac{B^2 A}{8\pi} \text{ dynes*} \quad \ldots \quad \ldots \quad (1)$$

where
B = flux density in the air gap in lines per sq cm
A = area of pole facc in sq cm
To calculate the pull, the flux density must be known; this may be evaluated as shown below.

The magnetomotive force F due to a winding of N total turns carrying a current I amperes is given by

$$F = \frac{4\pi NI}{10} \text{ gilberts}$$
$$= 1{\cdot}25NI \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$
$$= 1{\cdot}25 \times \text{ampere-turns}$$

The flux produced by this force in a magnetic circuit depends on the magnetic resistance or reluctance of the circuit. If the magnetic circuit is composed entirely of one medium, the reluctance is given by

$$S = \frac{l}{A\mu}$$

where l = length of the flux path in cm
A = area of the flux path in sq cm
μ = permeability of the medium.

The flux path may, however, contain a number of sections of different lengths, area or permeability. For example, the magnetic circuit of a relay includes an iron and an air path. In such cases the effective reluctance is given by

$$S = \frac{l_1}{A_1\mu_1} + \frac{l_2}{A_2\mu_2} + \text{etc.}$$

where the suffix 1 applies to the first medium, suffix 2 to the second, etc.

The flux ϕ is given by the quotient of the magnetomotive force and the reluctance thus

$$\phi = \frac{F}{S} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

* For proof of this expression reference should be made to any standard textbook on magnetism, for example S. G. Starling, *Electricity and Magnetism*.

and the flux density B is obtained from this by dividing by the cross-sectional area of the magnetic circuit

$$\therefore B = \frac{\phi}{A} = \frac{F}{SA}$$

Substituting for F from (2)

$$B = \frac{1{\cdot}25NI}{SA}$$

and, from expression (1), the tractive pull is given by

$$\text{tractive pull} = \frac{B^2 A}{8\pi} \text{ dynes}$$
$$= \left(\frac{1{\cdot}25NI}{SA}\right)^2 \cdot \frac{A}{8\pi} \text{ dynes}$$
$$= \left(\frac{1{\cdot}25NI}{SA}\right)^2 \cdot \frac{A}{8\pi} \cdot \frac{1}{981} \text{ gm}$$
$$= \frac{6{\cdot}4N^2I^2}{10^5 S^2 A} \text{ gm} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Thus the tractive pull is directly proportional to the square of the number of turns and the square of the current is inversely proportional to the pole-face area and the square of the reluctance.

For a given relay in which N, A and S are fixed, the pull depends only on the square of the current.

For a given number of turns and current, an increase in tractive pull can be obtained by increasing the area of the pole-face. This decreases the reluctance in approximately the same ratio as the increase in area but the pull depends on the first power of A and the square of S and thus a net gain in pull results.

Thc flux obtained in a relay is always less than the calculated amount because of loss due to leakage. This loss is undesirable not only because it reduces the tractive pull but also because it may cause interference between adjacent relays. To minimise the loss, air gaps in the magnetic circuit are avoided except at the essential point between armature and pole-face, and the magnetic joints between armature and yoke and between yoke and core are made as good, i.e., as low-reluctance, as possible. By this means the loss can usually be kept to 20 or 30 per cent of the total lines.

PART 2: UNISELECTORS

SECTION 21

MOTOR UNISELECTOR

21.1 Introduction

In automatic telephone exchanges some form of rotary switch is required which will select a particular outlet that has been *marked* by associated circuits controlled by dialled impulses or by other means. The A.E.I. (Siemens) High Speed Motor Uniselector Type 1400 was developed for this purpose in conjunction with the A.E.I. Digit Switch which is used to convert dialled impulses into a marking signal. It is used by the BBC for both telephone and programme switching at large programme centres, but the switching circuits used in BBC equipment normally employ punching keys or multi-way switches to mark the uniselectors directly or via relays instead of using dialled impulses and Digit Switches as in automatic telephone systems.

21.2 General Description

In the A.E.I. High Speed Motor Uniselector which is illustrated in Fig. 21.1, a unidirectional motion, i.e., the wipers rotating in one plane, with individual motor drive, has been adopted in preference to a bi-motional action incorporating ratchet and pawl drive as used in earlier switches for automatic telephone systems.

It has a contact bank with either 8 or 16 arcs each having 50 contacts available for allocation, arranged in unbroken sequence, and a drive and arresting mechanism capable of selecting any outlet up to the fiftieth within the normal inter-digital pause of standard dials. Thus up to 50 sixteen-wire outlets can be obtained, or 200 four-wire outlets.

Double contact of wipers on segments and of wiper feeds on wiper disks is provided, and the unidirectional motion of the wipers ensures that all contacts are cleaned and that dirt swept off early segments is not deposited on later segments.

Very little maintenance is required and the fault liability is almost as low as that of standard telephone relays.

21.3 Motor

The wipers of the uniselector are driven by a small 50-volt d.c. motor, which runs at 3,000 r.p.m., via an intermediate gear, the ratio being such that 90 degrees rotation of the rotor moves the wipers one step, i.e. 3½ degrees. Thus at normal speed 200 steps are covered per second. The motor consists of an unwound rotor with two main poles and two subsidiary poles mounted between two stator coils disposed at 90 degrees to each other, and a spring-set operated by a cam on the rotor to control energisation of the stator coils in the correct sequence. Maximum speed is restricted to 240 steps per second by fitting copper washers over the stator cores.

Lubrication is provided by an oil-saturated wick in the hollow rotor spindle, and the intermediate idler gear is lubricated similarly.

21.4 Wiper Assembly

The drive from the idler gear is transmitted to the wipers by means of a 104-tooth gear wheel incorporated in the wiper assembly which also comprises the wipers and their associated feeder disks and the necessary insulating and spacing washers.

Each wiper consists of a central blade 0·016 in. thick with a pair of 0·008-in. tips attached to it. Electrical connection is made to the wipers via the disk associated with each wiper and the feeder springs mounted on the contact bank. The feeders are offset to avoid passage of the wipers over the feeder spring blades.

A number disk on the end of the wiper assembly, in conjunction with a pointer on the bank, enables the outlet on which the wipers are at rest to be seen at a glance.

21.5 Latch

A latch is provided to hold the wipers stationary on the bank contacts when the switch is at rest, and to stop the switch on any desired outlet when the wipers reach this outlet.

Operation of the latch is effected by a start contact in the associated control circuit and takes place within 20 milliseconds of completing the latch circuit. Release of the latch is effected

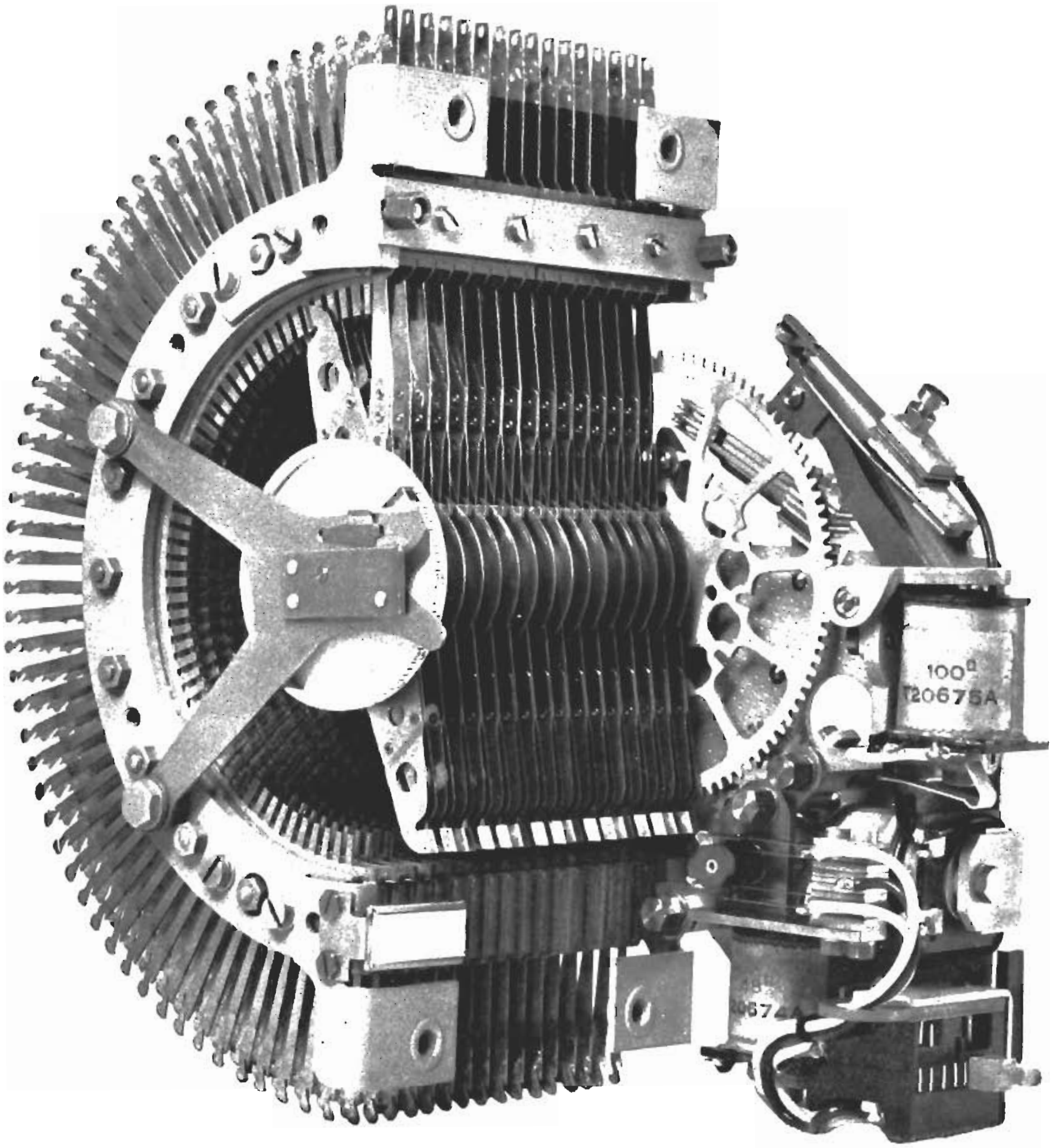


Fig. 21.1. A.E.I. (Siemens) High-speed Motor Uniselector

(a) by a high speed relay in the control circuit which has responded to the ' testing in ' condition on the required bank contact or (b) by the ' homing ' spring-set which operates when the wiper assembly reaches its ' home ' position.

21.6 ' Homing ' or ' Off-normal ' Spring-set

The only mechanically operated spring-set employed consists of 1 make and 1 break action. The break action is employed to stop the switch on the ' home ' contact and is operated by a cam on the wiper assembly as the wipers leave the fifty-second outlet, thus disconnecting the latch magnet circuit and causing the wipers to stop on the home outlet.

The make contact is used for indicating to the control circuit that the switch has reached the home contact.

21.7 Bank

The bank has 52 segments in each arc and may have 16 or 8 arcs of contacts according to requirements, giving a total capacity of 832 or 416 outlets respectively. Normally only 50 of the 52 segments per arc are available for allocation to groups of circuits, the first segment being used for the ' home ' position and the fifty-second being left disconnected or omitted.

The contacts are normally of nickel silver as are the wipers and feeders. The width of each contact is 0·070 in. and the gap between adjacent contacts in the same arc is 0·050 in.

For special applications where small a.c. signals without superimposed d.c. are switched, e.g., in programme circuits, the contacts are rhodium plated.

The wiring ends of the contacts are of such a length that a special type of flat multiple cable may be mounted between the rows when several switches have their banks commoned together.

Provision is made for mounting at one side an arc of 26 terminals for terminating various facilities such as ringing tone so that they may be cross connected to any part of the bank.

The feeder assembly is bolted to the bank and individual feeders are of similar construction to the wipers with a pair of flexible tips at the end.

21.8 Electrical Data

The supply voltage may vary between 46 volts and 52 volts. Spark quenching arrangements are fitted to each of the three coils and consist of a resistor and capacitor in series connected between the positive side of the coil and earth. The total current consumption when running is of the order of 0·8 amp of which 0·5 amp is taken by the latch coil.

In a typical circuit shown in Fig. 21.2 operation commences when the start contacts in the control circuit make and operate the latch magnet. The latch is released and closes a contact which operates the motor circuit and the switch begins to drive. On arrival at the outlet marked by the control circuit the corresponding high speed relay operates

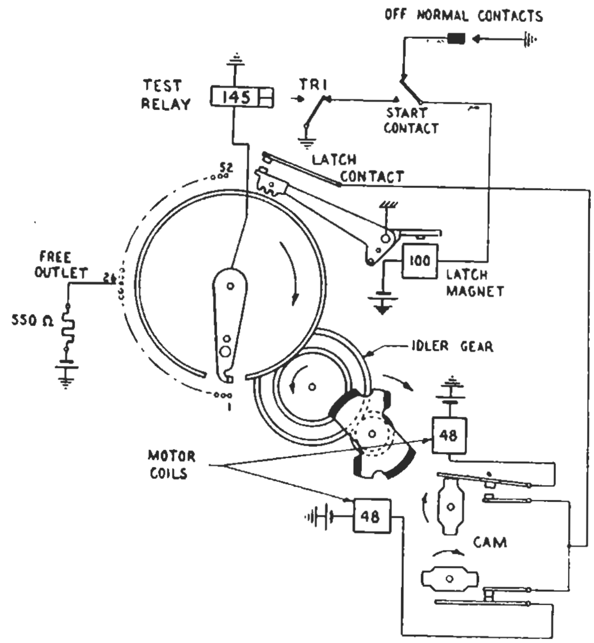


Fig. 21.2. Typical Circuit

The two actions of rotor cam and rotor blades are shown separated for clarity

and releases the latch and stops the switch on the marked outlet. Restoration of the start contacts re-operates the latch via the off-normal contacts until the wipers leave the fifty-second outlet when the homing spring-set operates and releases the latch and brings the wipers to rest on the first outlet of the bank.

Imperfect contact may result if the wipers carry only small a.c. signals without the ' wetting ' action of a superimposed d.c. voltage which is normally present in the speech signals at telephone exchanges. In some applications of the selector, therefore, provision has to be made for a d.c. ' wetting ' potential. This is avoided in BBC programme circuit switching by rhodium plating the bank and wiper contacts concerned.

SECTION 22

RATCHET-DRIVEN UNISELECTOR

22.1 Introduction

The facilities provided by the High Speed Motor Uniselector are not required for simple switching operations such as those which can be carried out by a switch which is responsive to dialled pulses and has only a small number of outlets. The A.E.I. (Siemens) ratchet-driven Digit Switch Type 1700 was developed to register dialled pulses for marking associated High Speed Motor Uniselectors which carry out the high speed hunting functions required in an automatic telephone exchange. This digit switch can also be employed for switching directly a small number of programme circuits using punching keys to control it.

22.2 General Description

The digit switch is a ratchet-driven uniselector with a bank having 8 arcs of 12 contacts giving a total of 96 outlets (Figs. 22.1, 22.2, 22.3).

The complete switch fits into the space occupied by four standard P.O. relays and it can, therefore, be mounted in a relay set with the relays of associated circuits.

22.3 Magnet and Armature Assembly

The magnet and armature assembly of the digit switch form a single unit secured to the frame by two screws. There is no knife edge in the magnetic circuit, the armature being located by a hinge which incorporates a hollow spindle containing an oil-soaked wick.

The phosphor-bronze pawl is held against the bronze ratchet by a stainless steel flat spring. Armature restoration is effected by a flat spring with a single adjusting screw.

The interrupter spring-set which is used to self-drive the switch engages directly with the armature via an insulating stud. The interrupter springs are of nickel-silver with tungsten contacts.

22.4 Wiper Assembly

Integral with the ratchet is a rigid brass tube or sleeve over which the complete wiper assembly is slid and clamped to it in the correct position relative to the bank contacts. The ratchet and sleeve assembly rotates on a rigid stainless steel spindle which projects from the frame of the mechanism.

Each wiper comprises two cruciform nickel silver blades, suitably set at the tips and spot welded together, thus giving a rigid centre blade with a pair of flexible tips.

There are no wiper disks to give electrical connection to the wipers as in the Motor Uniselector, their place being taken by a small continuous arc of nickel-silver at each end of each arc of contacts on the bank.

A wiper number disk, in conjunction with a pointer attached to the frame, shows the outlet on which the wipers are at rest.

The normal combination of wipers is three bridging wipers (i.e., one contact makes before the previous one breaks) and five non-bridging wipers.

When used in BBC programme circuits the wiper contacts are rhodium plated.

22.5 Bank

The bank has 8 arcs of 12 contacts (10 plus ‘ normal ’ and ‘ eleventh ’ outlet) giving a total of 96 outlets. The contacts are normally of nickel-silver, like the wipers and feeder segments, but when the switch is used in BBC programme circuits they are rhodium plated.

At the end of the bank remote from the mechanism is a ninth row of contacts which do not project into the wiper field. These are for the termination of local services such as busy tone, for subsequent cross connection to the bank contacts.

Each arc of contacts has at each end a small continuous arc of nickel-silver, the two small arcs being connected electrically to each other and to an 8-way terminal block at the rear of the switch. This arrangement provides electrical connection to the wipers in successive contact with the feeder arcs and takes the place of the more conventional wiper disks.

22.6 Electrical Data

The nominal supply voltage is 50 volts d.c., the permissible range being 46 volts to 52 volts.

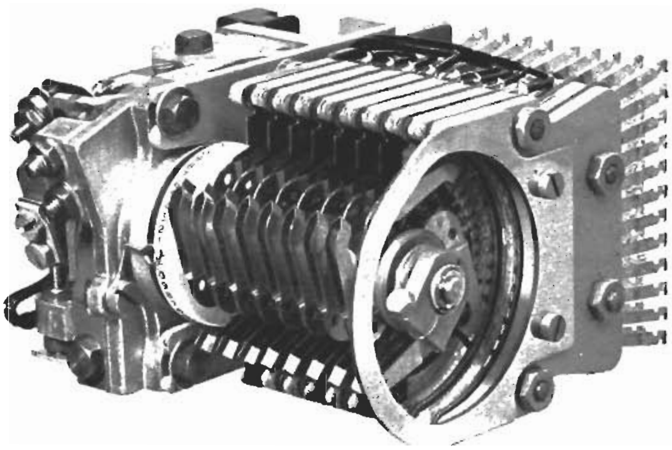


Fig. 22.1. Digit Switch showing Wiper Assembly and Bank

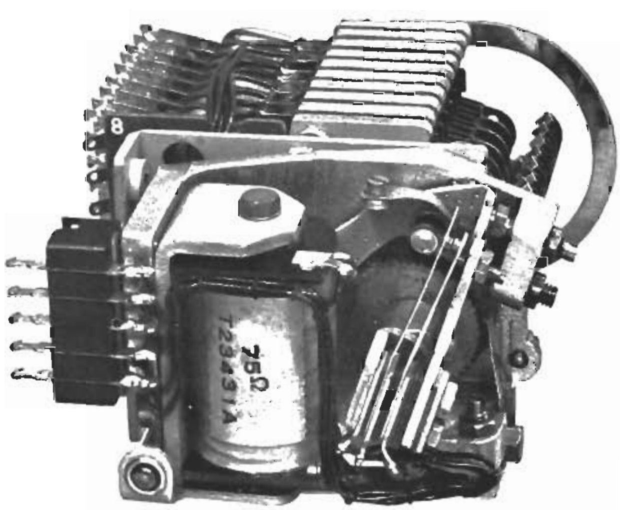


Fig. 22.2. Digit Switch showing Drive and Interrupter

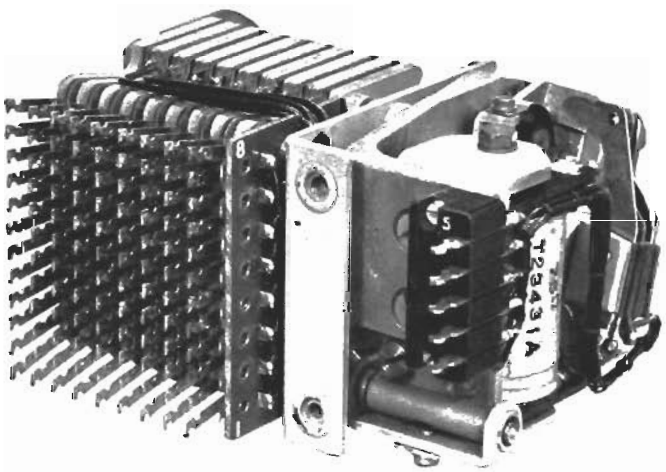


Fig. 22.3. Digit Switch showing Bank Wiring Field

The d.c. resistance of the coil is 75 ohms. The minimum current for complete operation of the armature is approximately 0·4 amp and the maximum current at which the armature releases is approximately 0·09 amp.

The time for complete operation of the armature is approximately 20 milliseconds and the release time is of the order of 3 milliseconds.

When self-driving, the speed of the switch is approximately 60 steps per second, the current consumption being then about 0·2 amp; the corresponding consumption when driven at 10 steps per second (67 per cent make pulses) is approximately 0·3 amp.

Spark quenching arrangements are provided by a 200-ohm resistor in series with a 1-microfarad capacitor connected between the positive side of the magnet coil and earth.

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