**No. R. 1.**

THE INSTITUTION OF
POST OFFICE ELECTRICAL ENGINEERS

# Telephone Relay Research.

BY

**L. H. HARRIS,** M.Sc., M.I.E.E., and
**H. WILLIAMS,** A.C.G.I., A.M.I.E.E.

A PAPER

*Read before the London Centre of the Institution on the 10th January, 1933.*

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[INDEX REFERENCE, I.G.]

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## I.—INTRODUCTION.

The subject of telephone relay design has attracted a great deal of attention recently in connection with the Post Office Engineering Department's efforts to standardise a relay for general use for automatic switching apparatus. Prior to the introduction of automatic working the subject was a comparatively simple one; time adjustments were necessary only in a few special instances; spring loads were small; and, most important of all, only a few contacts were involved in any one call.

The number of contacts involved per call in director areas reaches a very high figure and in certain cases approaches 1000. Failure of any one of most of these contacts results in failure of the call. The failure of each contact once in a thousand operations with the failures following the laws of chance would result in the loss of 63.2% of the total calls if, in each call, one operation of each of a 1000 contacts were involved.

It is obvious therefore that automatic telephone relays have onerous duties to perform and these have, in the main, been carried out up to the present by the Strowger (Automatic Electric Co.) and "knife-edge" (Siemens) types. Other modern varieties are the various "flat" type relays which are characterised by their armatures being parallel to the cores and which have, in general, been designed to carry small spring sets for use in manual exchanges or for similar purposes at low cost of production, and also, the "minor" types which are, in general, miniature Siemens type relays without the elaboration of the knife-edge hinge.

A number of manual types of relay are still in use in the Post Office which are rapidly assuming a museum appearance to those familiar with the automatic types, but they survive by reason of their satisfactory performance of the very light duties imposed on them, and of their cheapness.

Until the question of standardisation arose no precision tests of the magnetic properties of relays had been made by the Engineering Department, and methods of test were not even available. One feature of the standardisation proposals was therefore the development or selection of methods for testing and comparing the performance of various types of relay and for measuring the effect of modifications in design.

## II.—MAGNETIC EFFICIENCY.

1. *Ampère-turn method.*—The foundation of a good relay lies in its magnetic circuit, both economically and from the point of view of performance, *e.g.*, operate capability, stability and slugging properties. Measurements of the magnetic efficiency were made by the Research Section by adopting the method already in use by some manufacturers and finding how the pressure at the armature lifting stud varies with the ampère turns applied to the coil. This was done for a very large number of relays. The tests were carried out with a nominal " zero " residual* armature gap for various stud movements and the operate ampère-turns were taken after the relay had been saturated in the operated condition with 300 ampère-turns. Generally speaking, for normal types of relay, the value of the operate ampère-turns does not greatly depend on the value of the saturate ampère-turns and the above method is much less laborious than completely demagnetising the relay before each reading; moreover, it has been found that the tests can be repeated with great accuracy. The process is complicated in certain relays by parasitical effects, such as pivotting of the armature in a peculiar manner, armature not lying along the poleface when operated, and, most serious of all, bending of the armature during operation. This latter varies from 2.5 mils per 1000 grammes in a Siemens type relay to 16 mils per 1000 grammes in a Strowger type relay. As bending of the armature means that the unoperated air gap is larger than it otherwise need be, this is a source of inefficiency in practice; but, as far as testing accuracy is concerned, most of these troubles are avoided now by arranging a solid back-stop directly behind the armature stud and measuring the stud movement directly by means of a dial gauge.

2. *Allowance for the size of the winding.*—The method of II. 1 provides an Absolute measure of the efficiency of a magnetic circuit. For the purpose of comparing magnetic

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**Note.*—A zero residual gap is a nominal figure as a perfect butt joint cannot be obtained and pressure becomes an important variable. When non-magnetic protection is used on the relay (*e.g.*, zinc) there is also the double thickness of this material (1-2 mils).

circuits it is necessary to take account of the winding space available on the relay. The resistance of a circuit once decided, it is necessary for maximum efficiency to wind as many turns on the core as possible. This is not merely a matter of the volume of the winding space available; and, for comparison purposes, a factor F, which is the relative number of turns which can be wound on a bobbin for a given resistance, is usually employed. The derivation of this factor is given in Appendix I. In the case of the most common types of telephone relay this factor works out, as will be seen from Table I., almost exactly to unity. A "nomograph," from which the winding factor F can be obtained from the dimensions of the coil is given in Fig. 19. This factor, it should be mentioned, is almost independent of the gauges of wire used on the coils being compared, but the type of covering should be the same for both.

TABLE I.

MAIN RELAY DIMENSIONS.

| Type. | Armature Ratio. | Core Diameter. | Outside of Bobbin. | Winding Length. | Winding Factor F. |
|---|---|---|---|---|---|
| | | Inches. | Inches. | Inches. | |
| Siemens and Type 3000 ... ... | 0.92 | 0.354 | 1.0 | 2.4 | 1.0 |
| Strowger ... | 1.4<br>2.25 | 0.378 | 1.04 | 2.7 | 1.03 |
| R.A.T. ... | 0.84 | 0.31 | 0.93 | 2.8 | 1.06 |
| Large Universal | 0.54 | 0.375 | 1.05 | 2.17 | 0.965 |
| Small Universal | 0.54 | 0.25 | 0.78 | 2.18 | 0.993 |
| Danish Relay ... | 0.86 | 0.32 | 0.66 | 2.63 | 0.86 |
| Sterling Minor ... | 0.9 | 0.25 | 0.683 | 2.38 | 0.965 |
| R.B. relay 22 ... | 0.84 | 0.375 | 0.99 | 2.36 | 0.975 |
| R.B. relay 119 ... | 2.2 | 0.31 | 0.725 | 2.03 | 0.82 |
| Stromberg Carlson | 0.84 | 0.37 | 0.945 | 2.45 | 0.98 |
| W.E. Co.— | | | | | |
| Type 30 ... | 1.8 | 0.44 | 1.0 | 1.67 | 0.74 |
| Type 31G ... | 1.28 | 0.375 | 0.75 | 1.45 | 0.625 |
| Type 31H ... | 1.26 | 0.3125 | 0.625 | 1.35 | 0.585 |
| Auto Flat Type | 1.1 | 0.278 | 0.755 | 2.05 | 0.91 |
| W.E. Co. Flat ... | 0.95 | 0.375×0.11 | 0.9 × 0.7 | 1.7 | 0.845 |

3. *Watts method of stating the efficiency.*—Probably the fairest way of comparing the efficiencies of relays is on a basis of watts input against work done and this can be done by plotting armature stud load against operate watts for a

given stud movement, and comparing the watts required to lift a given load. Such curves are used by certain manufacturers and the only available information we have on American relays is of this nature. For the purposes of design, however, these curves are of very little value, for the watts must be calculated on the basis of a fully wound coil which is not always desirable. Moreover, the watts will vary slightly according to the gauge of wire assumed for the calculation and also with the type of covering used. From the point of view of circuit requirements, also, the resistance of the coil is required apart from the number of turns. The ampère-turn curves are therefore used almost exclusively, it being considered that a more informative comparison can be made since the magnetic circuit and the winding can be examined separately. The relative efficiencies of two relays on a power input basis is shown in Appendix II. to be proportional to $\left(\frac{A_2}{F_2}\Big/\frac{A_1}{F_1}\right)^2$ where $F_1$ and $F_2$ are the winding factors and $A_1$ and $A_2$ the ampère-turns required to lift a given load. The relationship between the load/ampère-turn curves and the load/power curves requires, therefore, to be clearly understood, as the former, if used to consider the relative power consumption, tends to understate the difference between the relays.

4. *Relation between force exerted and stud movement.*—The reluctance of the magnetic circuit of a relay will vary as the position of the armature changes, decreasing as the armature moves towards the pole. As the gap decreases, therefore, the flux produced by a definite number of ampère-turns on the core will increase. This means that the force the armature is capable of exerting will also increase as the gap decreases. The curve showing the relation between this force and the armature gap is a very important one in relay design. As the springset lifts from its unoperated position the force necessary to move it will increase. It is necessary, therefore, that the force exerted by the armature should also increase at least as rapidly as the reaction of the springset and, if possible, more quickly, so that the armature does not tend to halt or move very slowly during its stroke. Curves showing the relation between force and gap are therefore useful to the relay designer: they can be obtained experimentally but it

is more usual to get them by cross-plotting from the magnetic efficiency curves. In order to obtain data for a particular type of relay, it is usual to take a family of curves for a large number of armature gaps and from these obtain the curves representing pull against gap for constant ampère turns. It will be noted that these curves refer to the case in which a relay operates while the ampère-turns remain unchanged. Again, these curves, by employing the armature ratio, may be made to apply either to stud movement or gap movement; also the armature residual gap may be allowed for by adding the required residual (referred to the stud) to the required stud movement and treating the result as though it were a stud movement.

A similar set of curves can also be produced for " Release ampère-turns." In this case it is necessary to use, as a base, armature air-gap, the ampère-turns being measured after a saturation value of, say, 600 ampère-turns. Generally speaking, the residual air-gap is the first factor to fix in designing a winding.

## III.—SPRINGSETS.

The number of springs which can be fitted in one pile-up is limited by the available space, the lost motion between push rods, and in some cases by the " buffering " arrangements and the efficiency of the relay. Springsets may be divided into two broad classes, " free " and " buffered." These terms mean, respectively, that the fixed springs (taking a " make " contact say) are either in an unstrained condition when normal, or are tensioned downwards against a buffer.

1. *Springset Characteristics.*—For each springset combination a characteristic curve can be obtained showing the build up of the pressure on the bottom push rod as a function of the movement of the armature stud. It is here that one of the differences between free and buffered springs becomes obvious, for the pressure in the latter case comes on more suddenly, and therefore the curve shows much steeper steps. A similar effect is shown in Fig. 1, which shows the pressure build-up for two break-make contacts both on a normal Siemens type auto relay (the springs of which, although buffered, have a long free end) and the G.P.O. type

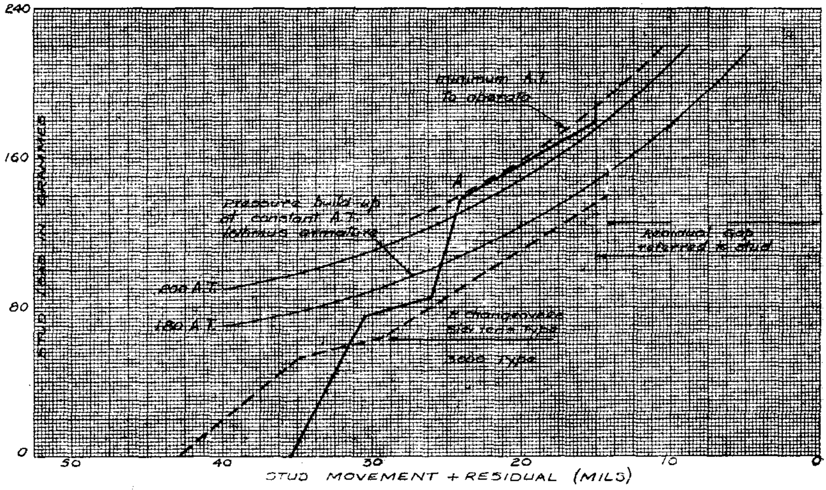


FIG. 1.

3000 relay. This difference is less marked as the number of springs increases.

By superimposing these curves upon the curves showing the relation between magnetic force and stud movement (Para. II. 4), the minimum operating ampère-turns of the relay may be obtained. This has been done in Fig. 1, the relays used being fitted with " isthmus " armatures referred to in Para. VII. 2.

Actually these relays operated at 170 ampère-turns and 197 ampère-turns. Variation of about 10% is expected because the efficiency curves are averages of a number of samples. It should here be noted (although the effect is not well shown in this example) that it may be neither the initial pressure nor the final pressure of the springset which determines whether the relay will fully operate or release. For example, in the figure, " A " is the critical point and the minimum ampère-turns for full operation are shown dotted.

In practice, the operate ampère-turns for the various springsets in use can be tabulated, and these can be used except in special cases. For instance, Table II. gives this information, for the 3000 type relay, regarding pile-ups of " make " contacts.

## TABLE II.

### MINIMUM OPERATE AMPÈRE-TURNS (DEMAGNETISED).

### NORMAL ARMATURE.

### 14 MIL SPRINGS. 20 GRAMMES BUFFER PRESSURE.

| Residual Gap. | Number of " make " pairs. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | |
| 4 mils ... | 50 | 68 | 80 | 92 | 102 | 112 | 130 | Ampere-turns |
| 12 ,, ... | 62 | 83 | 100 | 110 | 125 | 140 | 160 | ,, |
| 20 ,, ... | 80 | 118 | 140 | 160 | 182 | 200 | 240 | ,, |

The shape of the spring pressure characteristics is dependent on the considerations treated briefly from a mathematical point of view in Appendix III.

It is interesting to note from this appendix that, in the case of a change-over springset, the lifting stud pressure, when the relay is operated, is equal to the sum of the normal and make contact pressures and the additional pressure required to move the armature spring from the " break " to the " make " contact, all multiplied by a constant which is a function of the distance between the spring clamping and the lifting pin and between the lifting pin and the contacts.

2. *Some methods of adjustment of springsets.*—The adjustment of the Strowger relay, which has " free " springs, is carried out by " gauging." Considering a " make " contact, the front spring has to " make " or " not make " with definite thicknesses of feeler gauge inserted between the residual screw and the core end. In the case of " break " contacts gauging is also made use of but, in addition, the minimum " non-operate " current is given to ensure contact pressure.

Seven thicknesses of front and back spring (10, 12, 16, 20, 24, 32 and 48 mils) and four thicknesses of mover (10, 12, 16 and 24 mils) have been used to obtain the various requirements. In practice, due to the use of 10-mil springs, tolerances allowed on the nickel silver sheet, armature strain when the relay operates and a variety of other causes, a great deal of trouble has been caused by low contact pressure on

" make " contacts. In this connection Fig. 2 has been developed, and gives the relation between contact pressure and gauging for any thickness of the springs used on Strowger relays.

In the case of Siemens relays the springsets are adjusted to standard contact pressures, fixed armature travels being used. The springs, however, which are of the buffered type, but with free ends of considerable length, are not easily adjusted and this is aggravated in cases of heavy spring piles when the springs are fitted in three blocks. This type of springset, however, possesses a number of advantages, in that the springsets can be changed en bloc; it is suitable for twin contacts, and is generally economical with regard to space.

The Standard Telephone and Cable Co's " universal " relay, utilising free springs and the operating push rod being some distance from the contacts, has been found in practice to be somewhat tedious in adjustment, requiring gauging, contact pressure and current adjustment.

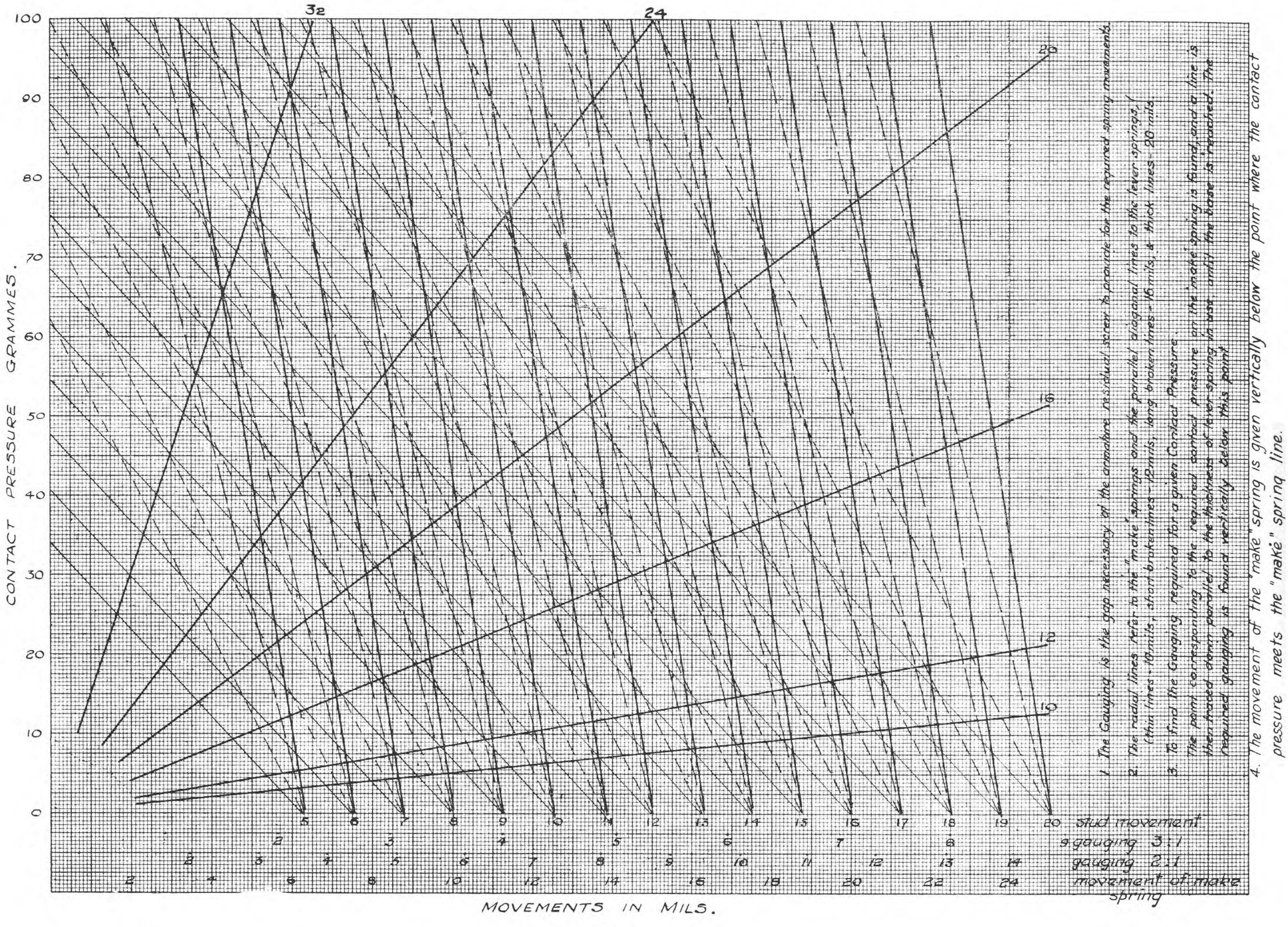
Gauging methods are not favoured as it is our experience that large variations between relays can occur.

In the G.P.O. type 3000 relay the non-moving springs are tensioned against a buffer block with a pressure, measured at the contact. This pressure is allowed to be from 16 to 20 grammes. These springs should move off the block by a distance of 5 mils (gauged by eye) under the contact pressure of the moving spring, the same adjustment for " make " or " break " springs being used. This allows about 7 mils for contact wear. No current adjustment is necessary. Standard travels are used (31 and 43 mils) and fixed residuals (4, 12 and 20 mils) except in a few cases. Only one thickness of spring (14 mils) is being used except in a few special cases where a 12-mil spring will be fitted. The springs are fitted in two pile-ups, ample room being allowed for adjustment. A maximum of 8 moving springs can be mounted on a relay where combinations of makes and breaks are required, but if all break-makes are required only 6 moving springs can be used.

The constructional details and pictures of this relay have been given in *P.O.E.E. Journal*, Volume 24, Part 3. " The Proposed Post Office Standard Telephone Relay for Automatic Exchanges."

## Relays—A.T.M. Co's Strowger Type.

Relation between Contact Pressure and Gauging of Make Springs.



1. The Gauging is the gap necessary of the armature residual screw to provide for the required spring movements.

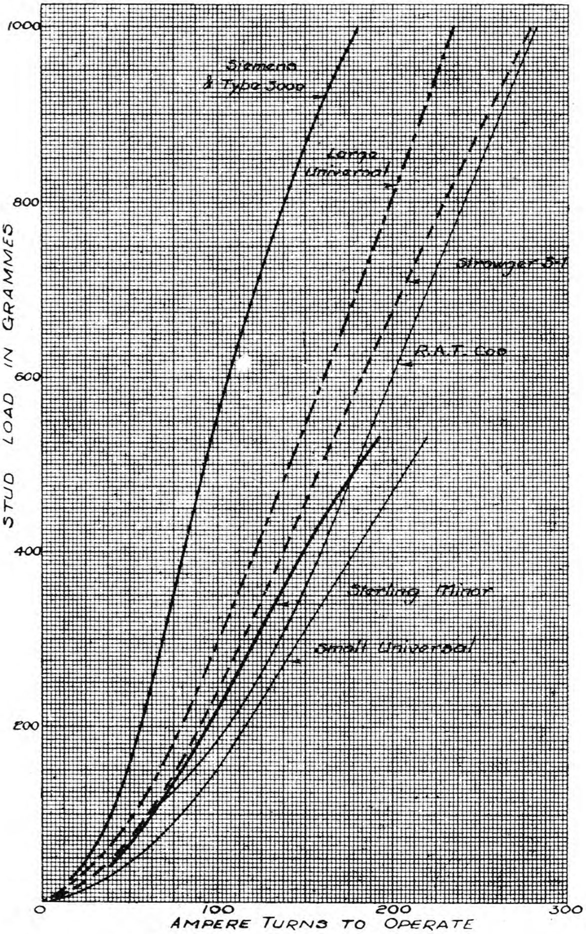
2. The radial lines refer to the "make" springs and the parallel diagonal lines to the lever springs, (thin lines - 10 mils, short broken lines - 12 mils, long broken lines - 16 mils, & thick lines - 20 mils.

3. To find the Gauging required for a given Contact Pressure. The point corresponding to the required contact pressure on the 'make' spring is found, and a line is then traced down parallel to the thickness of lever spring in use until the base is reached. The required gauging is found vertically below this point.

4. The movement of the "make" spring is given vertically below the point where the contact pressure meets the "make" spring line.

Fig. 2.

3. *Spring Bounce.*—Spring bounce is a phenomenon which is very troublesome, little understood, except in a few specific instances, and often difficult to remove. Some contacts are exceptionally free from bounce, *e.g.*, the " make " contact of a Strowger type impulsing relay. On the other hand the " make " contacts of relays which receive a heavy current very often bounce, soon after the closing of the contacts, due to the oscillation of the top spring. Contact bounce can also occur due to armature oscillation, *e.g.*, the " break "



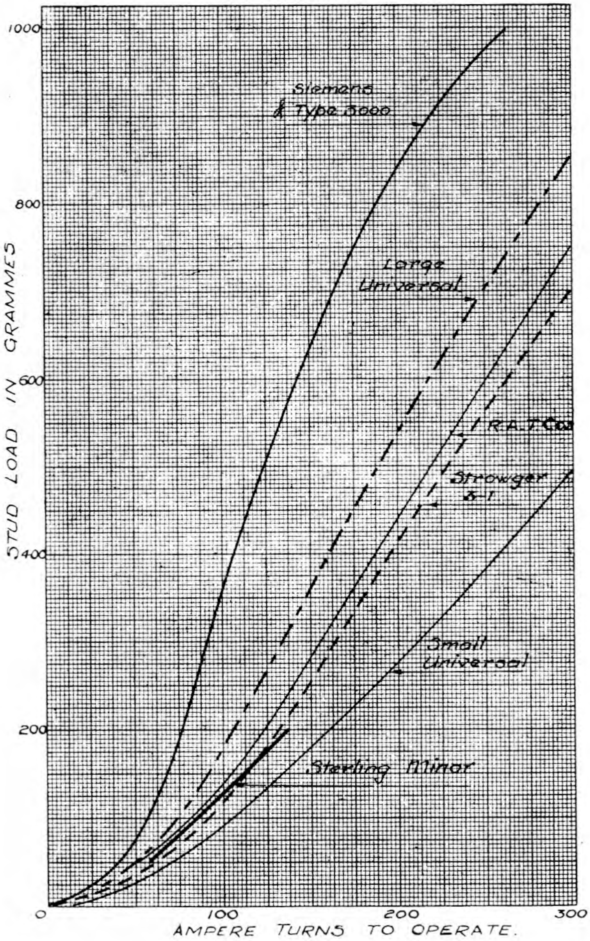
5 MILS STUD MOVEMENT.

FIG. 3.

contact of the Strowger impulsing relay which received attention in the I.P.O.E.E. Paper 118, " Sparking and Arcing at Relay Contacts," A. H. Jacquest and L. H. Harris. Bounce on a " make " contact can sometimes be cleared up by reducing the contact clearance and using a thin moving spring. Reducing the coil current also helps in some cases, but no general cure has yet been found.

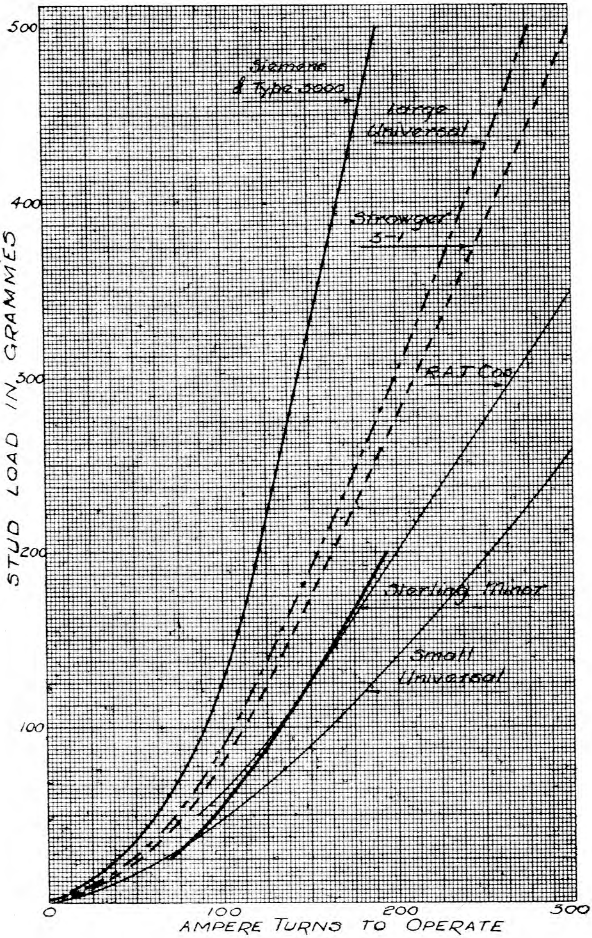
## IV.—COMPARISON OF SOME TYPES OF RELAYS.

1. *English type relays.*—Figs. 3-6 show the magnetic



10 MILS STUD MOVEMENT.

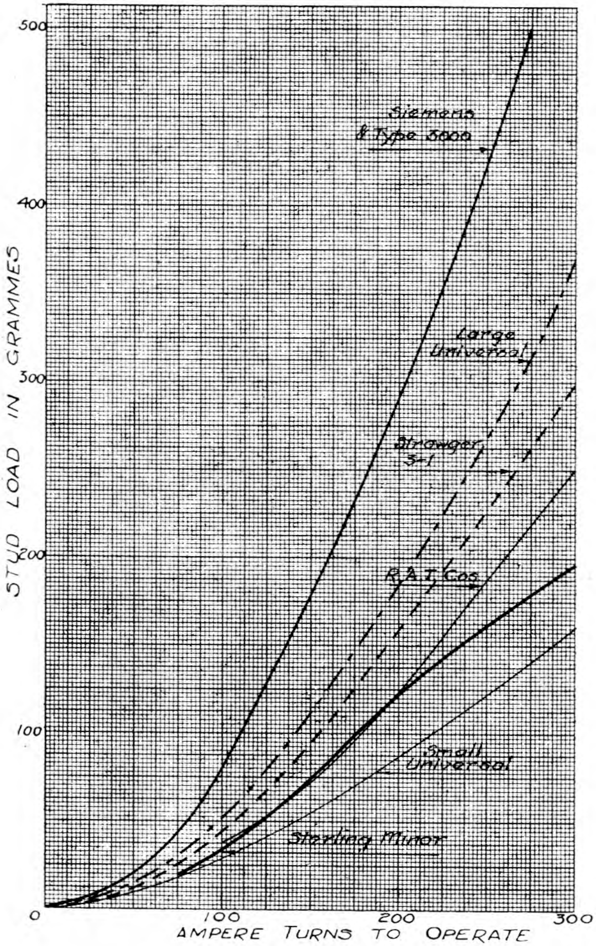
FIG. 4.



20 MILS STUD MOVEMENT.

FIG. 5.

efficiency (ampère-turn) curves for some of the original types of relay tested, and the relative operate capabilities (zero residual gap) of three types which have been used a great deal, namely, Siemens' pendent armature, Strowger (3 : 1 armature) and the Relay Automatic Telephone Co's relay. The large and small "Universal" relays had just been developed by Standard Telephone and Cables, Ltd., and were claimed to save mounting space. The samples of "Universal" relay for which curves are shown were zinc finished. The Sterling



30 Mils Stud Movement.

Fig. 6.

" Minor " relay was a small pendent armature type of relay which was tested mainly to ascertain its suitability to replace certain obsolescent relays (P.O. types 22, 23, and 119), and has since been adopted for this purpose. The magnetic circuits of the relays are shown in Fig. 7.

2. *Foreign type relays.*—In addition to relays of English manufacture the properties of several foreign types of relay were investigated. These included a German relay made by

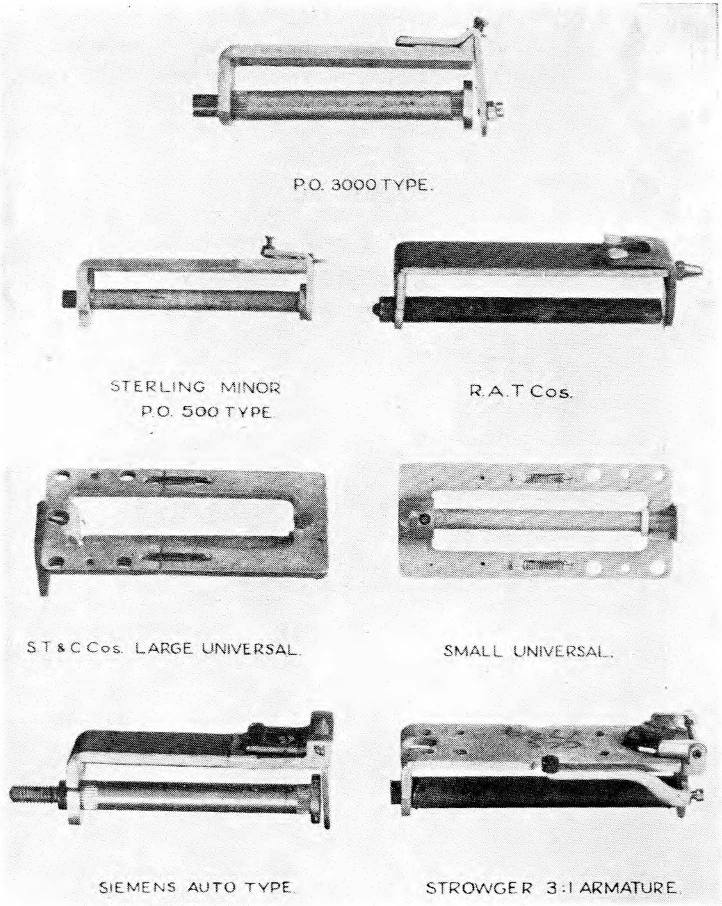


FIG. 7.

Siemens and Halske, a Danish relay by Telefon Fabrik Automatic and a Stromberg Carlson relay. The first two were flat types, the German one being of a particularly cheap construction with a pressed core and armature. The springs on this relay were fitted with twin silver contacts which it is understood are replaceable by means of a special tool. The Stromberg Carlson relay is somewhat similar to Siemens pendent armature type, but has no knife-edge.

In the U.S.A., flat type relays appear to be most generally used and it is understood improved forms are being considered for standardisation. Measurement of the magnetic efficiency is carried out by much the same method as is used by the Post Office Research Section, but the only available results are plotted to a power input basis. Part of a diagram which gives the magnetic capability of various types of American

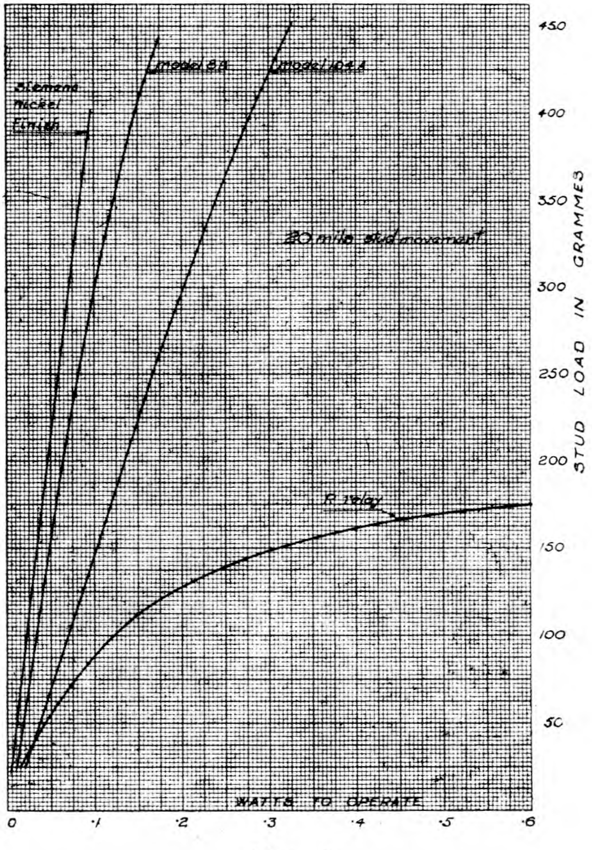


FIG. 8.

relay is reproduced in Fig. 8, together with the corresponding curve for the Siemens' type of magnetic circuit. Neglecting any minor differences that may exist in the method of testing, the curves are comparable on the assumption that the American measurements of the pull and airgap are referred to the lifting stud. This assumption is probably correct and in any case, for the types of relays concerned, would give only a comparatively small error, as the lifting studs are approximately level with the armature air gaps. Judging from the available evidence it will be seen that in no case does an American relay equal the capability of the Siemens' type. Type 104A is described as being the most probable design for standardisation while type 8B is more efficient but also of more complicated construction. The R type, for which a curve is given, appears to be of the same design and dimensions as the Standard Telephones & Cable Co's " E " type which is a very small flat type relay that has been used to some extent by the Post Office.

Curves on an ampère-turn basis for the other types are given in Fig. 10.

It was found that relays with small polefaces and armatures of 1 : 1 (approximate) ratio have curves, which rise very steeply for small values of stud movement. This effect is exhibited by the R.A.T. Co's relay to a marked extent for high values of ampère-turns.

## V.—THE BASIS OF THE P.O. STANDARD (TYPE 3000) RELAY.

It was clear from the commencement of these tests that the magnetic circuit of the Siemens type pendent armature relay was the most efficient one then in existence and it was therefore a satisfactory basis for standardisation. The factors contributing to this efficiency were found to be the corehead, combined with a 1 : 1 (approximate) armature ratio, the low reluctance of the knife-edge hinge, the good heel joint and the nickel finish on the yoke and armature. Other contributory factors were the care taken in manufacture and the small armature strain. A number of experiments were made with a view to simplifying the magnetic circuit and some details may be of interest.

1. *Corehead.*—The corehead is electrically welded under pressure to the rod which forms the core, and is turned to the correct size afterwards. Magnetic efficiency figures were obtained for a Siemens type relay with and without corehead, and it was confirmed that a considerable gain in efficiency results from the larger area of the corehead for large armature gaps due to the lessening of the reluctance of the relay in the unoperated position. Tests were also made on a Strowger type relay fitted with a 1 : 1 (very approximately) armature of the " overlap " type and similar results were obtained as

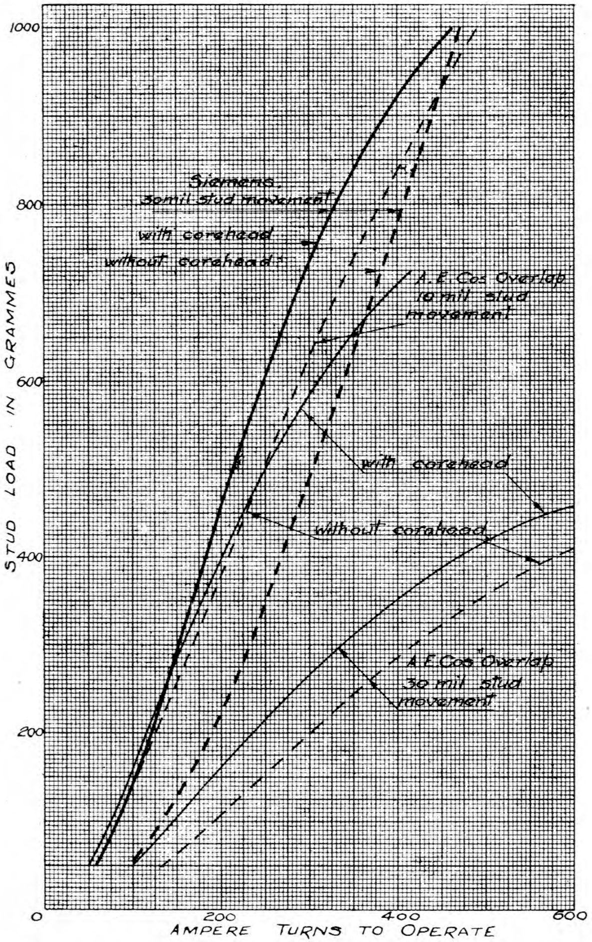


Fig. 9.

shown in Fig. 9. Generally speaking, the effect of a small pole face is to produce high values of flux density in the operated position and hence very heavy pulls in this condition are obtained. The size of the corehead is also bound up with the armature ratio. These tests proved that the corehead could not be dispensed with, in spite of the slight extra winding space which would accrue (if the rest of the relay dimensions were to be adhered to), and the slight saving of cost.

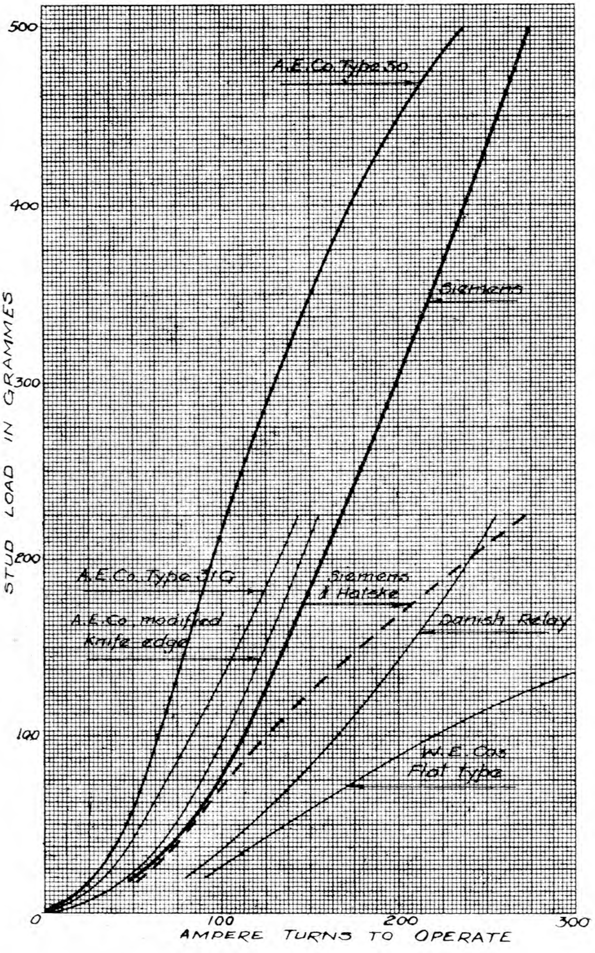
2. *Core fixing.*—The well known method used by Messrs. Siemens and the General Electric Co. for attaching the core to the heelpiece by means of a drive in fit and locking nut is highly efficient, but is said to be expensive. Also the arrangement does not allow of a coil being easily renewed. On the other hand, a bad magnetic joint here cannot be tolerated since the main flux of the relay passes this point and " strangling " would result. It was found, after a number of methods had been tried, that, with nickel finished parts and a cylindrical iron locking nut, no measurable decrease in efficiency occurred when the core end was a loose fit in the heelpiece. This is accounted for by the efficiency of the annular butt joint between the core and the heelpiece when nickel finish is used. This method has been adopted. The relay is secured to the mounting by means of two insulated fixing screws.

3. *Knife-edge armature pivot.*—The knife-edge pivot of the Siemens magnetic circuit possesses the advantages of being almost frictionless and of providing an extremely good magnetic joint, the area of armature overlapping the end of the heelpiece being large. It is produced by welding a piece of rod to the heelpiece and then milling to shape. Some care is necessary in handling the piece after the production of the knife-edge and as the latter also slightly reduces the accessibility of the lower springs tests were made to see whether this manufacturing operation could be avoided. It was found, however, that the combined effect of the altered armature ratio, extra friction and the inferior magnetic joint resulting could not be tolerated.

The freedom from friction at the hinge of the Siemens type relay and the realisation that only a small pressure, correctly applied at the point of minimum movement, was necessary to secure the armature, led to the suggestion of an alternative to the side wings used at present for fixing the armature. This consisted of a spring and washer pressing lightly on the armature at the point of minimum movement and secured to the relay by a screw passing through a clearance hole in the armature. This modification has been adopted and has been found highly satisfactory.

## VI.—MORE RECENT DEVELOPMENTS.

The interest taken by the Post Office in the improvement of relay design also led to various modifications of the Strowger type relay. The Automatic Electric Co. produced a knife-edge nickel finish relay having a carefully designed armature ratio which, combined with a corehead, resulted in the most sensitive telephone relay then known. An ampère-turn efficiency curve for this relay is given in Fig. 10. Following this, several " flat " types of relay having extremely efficient magnetic circuits were developed on a scientific basis by the A.E. Co. One was known as the " 31G " and was a very small relay which could be used as a general purpose



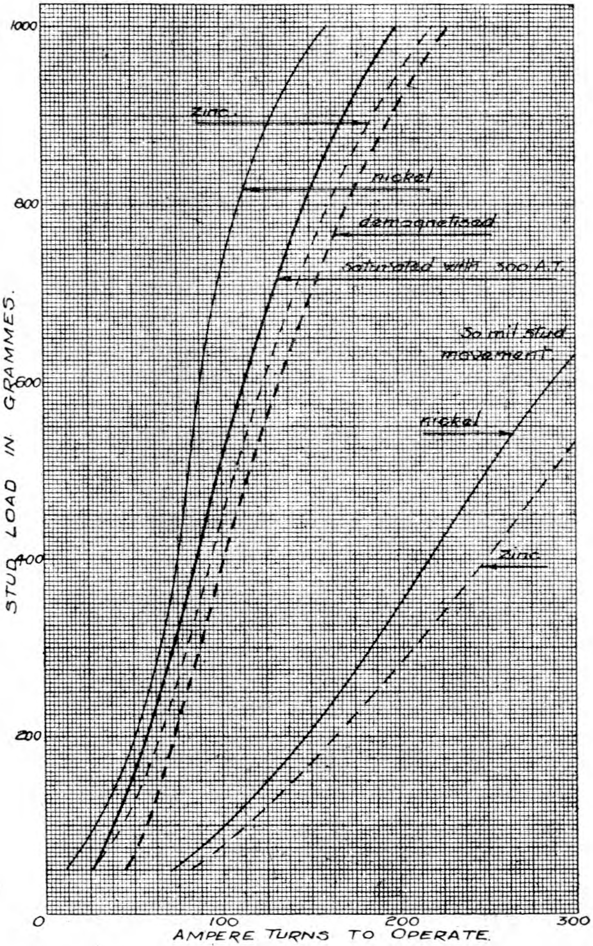
30 MILS STUD MOVEMENT.

FIG. 10.

relay. Quite recently a larger design of relay has been produced by this Company, a curve for which is also given in Fig. 10. (Type 30). This magnetic circuit is by far the most efficient known to us at the moment. Nickel finish is, of course, adopted on all parts (See Para. VII.1.).

## VII.—OTHER CONSIDERATIONS AFFECTING MAGNETIC EFFICIENCY.

1. *Protective coatings.*—Two types of protective coating in very common use are zinc and nickel. It was noticed



5 AND 30 MILS STUD MOVEMENT.

FIG. 11.

when testing a number of Strowger type relays that the nickel-plated specimens were from 5-10% more efficient than the zinc plated specimens. To make a direct comparison, operate efficiency figures were obtained for some Siemens type magnetic circuits. The results are shown in Fig. 11, where the improvement will be seen to be about 20% for small stud movements and 10% for large stud movements. This is attributed to the fact that a non-magnetic coating introduces airgaps into the circuit. Nickel, although not so permeable as soft iron, is much more so than air. It was considered, therefore, that the effect of various types of coating on the magnetic efficiency would be determined by the equivalent airgaps produced by them. As different samples of the same magnetic circuit are liable to vary it was thought that to attempt to assess the effect of the protective coating by testing the magnetic efficiencies, alone, of a number of relays might produce misleading results. A method was devised, therefore, to measure the thicknesses of the various coatings. This was effected by using a small electromagnet with a pointed polepiece, and measuring the force required to separate it from the protected iron. This force was used to estimate the thickness, the magnet being first calibrated by using clean iron and known thicknesses of non-magnetic materials. By this means the equivalent airgaps produced by the various types of coating were estimated. The method has the advantage that a large number of areas on the iron may be explored quickly. For instance, Table III. gives the distribution of zinc plating across the section of the heelpiece, as determined by this method, and shows how the plating builds up at the edges.

## TABLE III.

DISTRIBUTION OF ZINC PLATING.

WIDTH OF IRON = 0.8 INCHES.

| Distance from edge in inches ... ... ... | 0.07 | 0.14 | 0.2 | 0.4 | 0.6 | 0.67 | 0.74 |
|---|---|---|---|---|---|---|---|
| Thickness of plating in mils ... ... ... | 1.5 | 1.25 | 1.0 | 0.65 | 1.0 | 1.25 | 1.32 |

Table IV. gives a list of equivalent airgaps estimated by the above method. The figures refer to the heelpiece, but tests were also made on the armature and core and similar results were obtained. The first column gives the mils of thickness near each edge and also at the centre, on the top of the heelpiece, *i.e.*, where the springset is attached. The second column gives the mils of thickness on the knife-edge. Each figure is the average for six relays.

### TABLE IV.

ESTIMATED EQUIVALENT AIRGAPS (MILS.).

| Coating. | Top of heelpiece. | | | Knife edge. | | |
|---|---|---|---|---|---|---|
| | Edge 1. | Centre. | Edge 2. | Edge 1. | Centre. | Edge 2. |
| **Zinc + lacquer** ... | 1.1 | 0.7 | 1.0 | 1.5 | 1.3 | 1.6 |
| **Zinc** ... ... | 1.3 | 0.5 | 0.85 | 1.2 | 0.9 | 1.1 |
| **Cadmium+lacquer** | 0.8 | 0.8 | 0.8 | 1.4 | 1.4 | 1.4 |
| **Cadmium** ... ... | 0.7 | 0.7 | 0.6 | 1.0 | 0.9 | 1.0 |
| **Cozlettising + lacquer** | 0.5 | 0.45 | 0.4 | 0.4 | 0.5 | 0.5 |
| **Cozlettising** ... | 0.5 | 0.5 | 0.4 | 0.54 | 0.5 | 0.6 |
| *Nickel-Cadmium-Nickel | 0 | 0 | 0 | 0 | 0 | 0 |

* Automatic Electric Co.'s process consisting of a deposition of nickel followed by a " flash " of cadmium and then another coating of nickel. The equivalent airgap produced by this method or by another method in common use, *i.e.*, nickel deposited on a flash of copper, could not be detected. It was noticed that lacquer also had a tendency to collect at the knife edge.

As a check on the above figures the operate efficiencies of one sample of each type were tested. The samples were not well made, but in spite of this it will be seen that the thicker the coating the lower the efficiency.

Flux measurements showed that a larger percentage of the total flux passed through the heel joint when nickel protection was used.

## TABLE V.

### OPERATE EFFICIENCIES OF RELAYS.

### AFTER SATURATION WITH 300 AMPÈRE TURNS.

| | Stud movement 5 mils. | | | | Stud movement 30 mils. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | operate ampère-turns with stud load in grammes of | | | | | | | | |
| | 50 | 100 | 200 | 500 | 20 | 50 | 100 | 200 | 500 |
| Zinc ... ... | 39 | 58.5 | 75 | 120 | 56 | 85 | 120 | 170 | 310 |
| Cadmium + lacquer | 34 | 52 | 75.7 | 125 | 54 | 86 | 121 | 170 | 300 |
| Cadmium ... ... | 30.5 | 47 | 68.5 | 120 | 49 | 82 | 115 | 165 | 295 |
| Cozlettising + lacquer | 34 | 49 | 69.4 | 108 | 52.5 | 81 | 111 | 157 | 268 |
| Cozlettised ... | 31.8 | 45.5 | 63 | 105 | 52 | 78.6 | 110 | 156 | 268 |
| Nickel-Cadmium-Nickel | 23 | 36.5 | 54 | 89.5 | 49.5 | 79 | 110 | 155 | 260 |
| Enamelled and cozlettised | 18 | 33.4 | 45.5 | 74 | 46.5 | 74 | 102.5 | 144 | 256 |
| Nickel on copper | 0 | 25.1 | 43.8 | 77 | 45.5 | 72 | 102.5 | 142.5 | 247 |

The two last samples in Table V. were extremely well made. Also, in the cozlettised and enamelled sample, the knife-edge and core were cozlettised only and all protection was cleaned off at the joint between the core and yoke. Nickel finish has been adopted on all parts of the magnetic circuit of the Type 3000 relay.

2. *The " Isthmus ' armature.*—When the Siemens type of relay is used for impulsing, in order that the relay may follow the input faithfully, the magnetic circuit is degraded by increasing the reluctance of the iron circuit. This is effected by cutting notches in the side of the armature; and the effect is to produce armature saturation at a low value of ampère-turns, thus rendering the lags of the relay less dependent on the ampère-turns (line length, battery voltage, etc.). A relay fitted with such an armature saturates at about 100 ampère-turns, being about 20% less efficient than a normal relay below this figure, and, generally speaking, will not lift more than about 400 grammes at large gaps. This, however, is not of great importance as the load of an impulsing relay, when operated, would not exceed 200 grammes. This is shown in Fig. 1. The release capability curves show that the isthmus armature causes quicker demagnetisation and very small release lags may be obtained without an excessive residual gap.

3. *Relay fitted with a slug or sleeve.*—If a relay is fitted with a slug to produce slow operation or release, the winding

must be concentrated either at the armature or heel end. Tests show that with a front end slug, a loss of the order of 5% in operate efficiency on an ampère-turn basis occurs due to the leakage flux which takes place from the front of the core to the heelpiece. Very little difference can be distinguished if the winding is at the armature end, or if the winding is over a " Sleeve."

4. *Effect of demagnetisation on the operate efficiency.*—To find the difference in the ampère-turns required to operate a relay, after saturation and after demagnetisation, a series of tests was conducted on various relays. The magnetic efficiency of each relay was measured for a definite stud movement from the demagnetised condition and also after saturation with 300 ampère-turns. This effect is greatest at a small stud movement and in Fig. 11 curves are shown for a pendent armature nickel finish relay. The loss in efficiency is practically constant and for this type of relay is equal to that due to a loss of about 20 ampère-turns. The greater the retentivity of the iron the greater this difference becomes.

## VIII.—COMPARISON OF OPERATE AND RELEASE LAGS OF VARIOUS TYPES OF RELAY.

In Table VI. the operate and release lags of the main

TABLE VI.

| Relay. | Operate and release lags in milli-seconds. | | | |
|---|---|---|---|---|
| | Release. | | Operate. | |
| | Load on armature stud. | | | |
| | 400 grammes. | 50 grammes. | 400 grammes. | 50 grammes. |
| Siemens | 20 | 105 | 13 | 5·4 |
| Strowger S.T. & C.Co. No. 3 Armature | 2.8 | 18.2 | 20 | 4·4 |
| A.E.Co. Overlap Armature Nickel Finish | 15·9 | 38 | 21·4 | 5·3 |
| A.E.Co. Extended Overlap Armature Nickel Finish | 13·3 | 46 | 18·4 | 6.2 |
| S.T. & C.Co. Large Universal | 7·3 | 21·4 | 18·7 | 5·1 |
| S.T. & C.Co. Small Universal | 2·5 | 13·7 | 18.6* | 3·3 |
| Siemens & Halske Flat type | 0·7 | 7·5 | 26 | 4·9 |

* Refers to 350 grammes, will not operate with 400 grammes.

types of relay tested are given for 50 and 400 grammes stud load. The measurements in each case were made for a 20 mils stud movement and a 3 mils residual gap with 600 ampère-turns. The superiority of the Siemens type for quick operation on a heavy load and its capability for slow release, when required, without the use of zero residual gap and consequent liability to variation, is indicated.

## IX.—THE TIMING OF RELAYS.

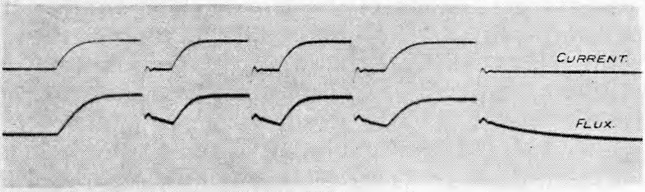
It has been found that under continual operation the residual magnetism tends to build up, until, with other favourable conditions present, a relay may " stick." This may be prevented by providing an adequate minimum residual gap and so avoiding to a great extent the effects of residual magnetism and also " sticking " due to the presence of adhesive lacquers and other substances on the pole faces. Curves have been taken of the residual pull for various values of ampère-turns and residual gap and from these the minimum gap for any springset can be estimated. A number of relays require, for various reasons, accurate and stable timing; and one of the most valuable effects of high magnetic efficiency in a relay is the stability of timing that becomes possible. The air in the magnetic circuit can be concentrated at the armature gap and consequently longer residual gaps can be used. Failure to release is avoided, as the demagnetising effect of the poles is increased, and also the effects of bedding down and wear are less important in their effects on release time lags. The most common device for increasing the time lags of relays is the use of a copper slug or sleeve. This acts as a one-turn secondary with a large time-constant. In the case of release, for example, the ampère-turns are temporarily transferred to it, and the armature remains attracted until sufficient energy has been slowly dissipated for the flux to drop to the releasing value. A sleeve consists of a thin tube (say 3 m.m. thick) over the whole length of the core, in which case the mutual coupling between the winding and sleeve is very close; while a " slug " has the same diameter as the outside of the coil and extends only partly along the core. Greater flexibility is obtained with slugs than with sleeves, since they may be fitted to either end of the core. For instance, a " slow to operate and release " relay is formed by fitting a slug at the front end, whereas a slug at the rear end gives quick operation and slow release.

## Oscillographic Method of Recording Flux.

## Operation of Guard and Series Impulse Control Relays of Strowger Impulsing Circuit.

**Fig. 1.**

OPERATION OF SERIES IMPULSE CONTROL RELAY DURING A TRAIN OF 4 IMPULSES OF INTERRUPTED D.C. (a) RELAY FITTED WITH A SLUG.



(b) RELAY FITTED WITH A SLEEVE.

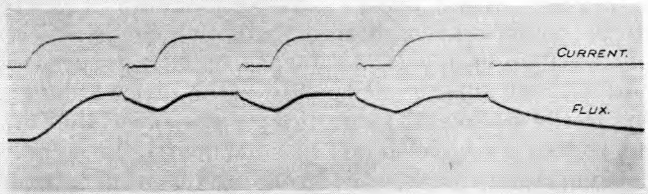
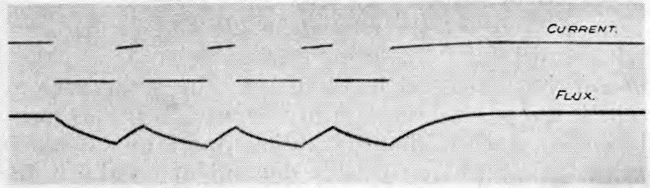


**Fig. 2**

HOLDING OF GUARD RELAY DURING A TRAIN OF 4 IMPULSES OF INTERRUPTED D.C.
(a) RELAY FITTED WITH A SLEEVE.



(b) RELAY FITTED WITH A SLUG.

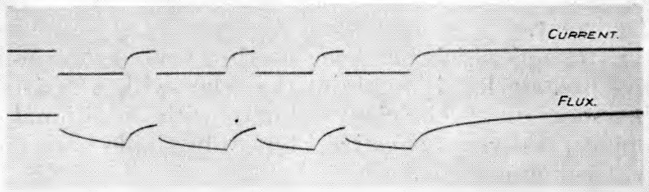


FIG. 12.

A sleeve cannot be easily arranged to give the latter result. Fig. 12, which has been taken from "An Oscillographic Method of Measuring Flux," L. H. Harris, *P.O.E.E. Journal,* Volume 24, Part 3, shows the effect of slugs and sleeves on the flux in the case of the B and C relays of the Strowger switch. All the above effects are dependent on the current in the coil, and to forecast the release time of a relay curves have been taken of the release times for various stud loads, lengths of slug, residual gap, and ampère-turn values. Once the relay is saturated, however, the release time changes very little. Fig. 13 gives a typical set of curves for the Type 3000 relay.

Other methods for obtaining a long release lag under special conditions are (1) to short-circuit a separate winding; (2) to place a resistance or rectifier or barretter across the operating coil; (3) to place a large (sometimes electrolytic) condenser across the operating coil, which is effective in giving very long lags. As far as can be ascertained, the armature speed does not depend on the size of the slug nor on the initial degree of saturation, *i.e.,* once the armature moves it does so at the same, or very nearly the same, speed, independently of the time the armature has been attracted and independently of the current originally flowing in the winding.

Quick release can be obtained by increasing the stud pressure, the residual gap or the reluctance of the magnetic circuit or by decreasing the energising ampère-turns.

For a given coil the operate lag of a relay cannot be varied appreciably by adding series resistance to the circuit or by varying the stud load, unless the relay is near its "limit." Nevertheless, a fully wound relay is not necessarily the best condition for quick operation as the rate of growth of the ampère-turns is dependent on the inductance. Theoretically, the minimum operate time is obtained when the winding is so selected that the operate current is 0.715 of the final current.

A method which has been used to some extent to obtain a long operate lag is to shunt the relay with a resistance of high temperature coefficient which, with additional series resistance, is very effective, but only stable on a constant battery voltage.

## X.—EFFECT OF LINE LENGTH ON LINE (IMPULSING) RELAYS.

The length of line over which an impulsing relay has to operate can have a serious effect on impulse distortion.

3000 TYPE RELAY. 300 AMPERE-TURNS.

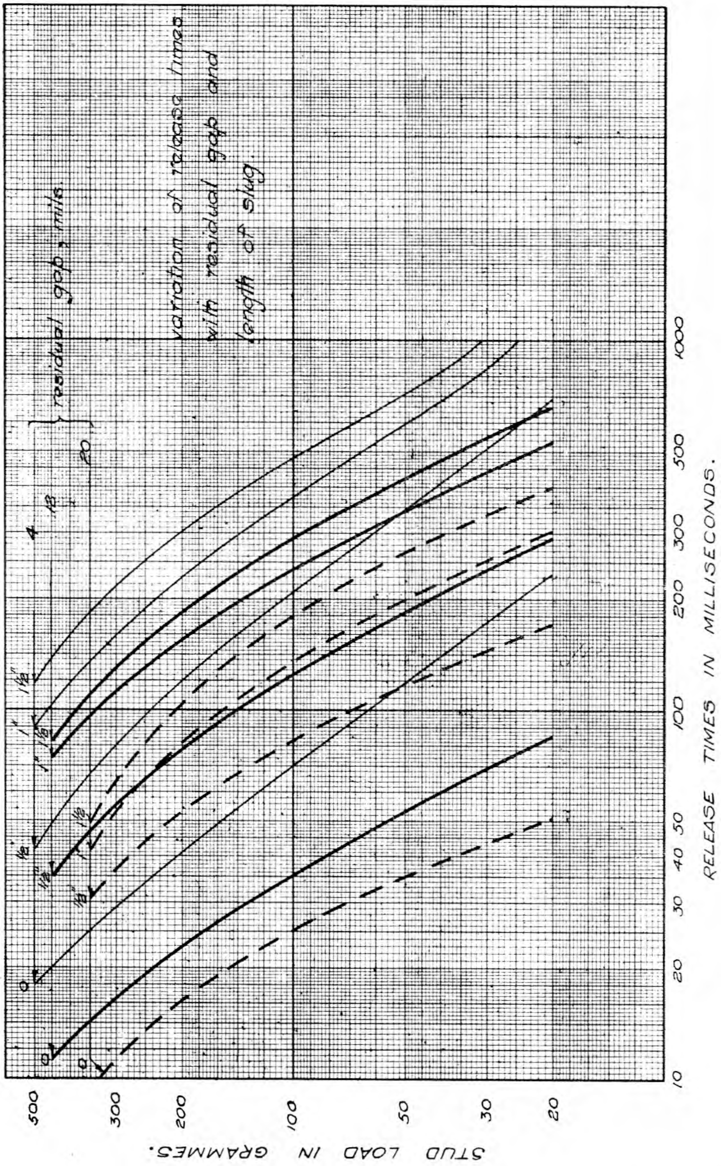


FIG. 13.

Isthmus armatures and similar devices have been used with the Siemens type relay to flatten out the variations due to line length and to produce quick release with light spring loads. If the 2 $\mu$F subscriber's instrument condenser is omitted from the circuit during dialling the release lag gradually falls and the operating lag increases, as the line length is increased, due to reduction in current. Fortunately, the standard subscriber's instrument conditions prevent this occurring, for the 2 $\mu$F condenser across the dial, while not affecting the operate lag to any extent, keeps up the release lag, and thus the make % at the contacts remains constant. This is shown for the Type 3000 relay in Fig. 14. Incidentally, the 2 $\mu$F condenser

3000 TYPE RELAY. 10 I.P.S.

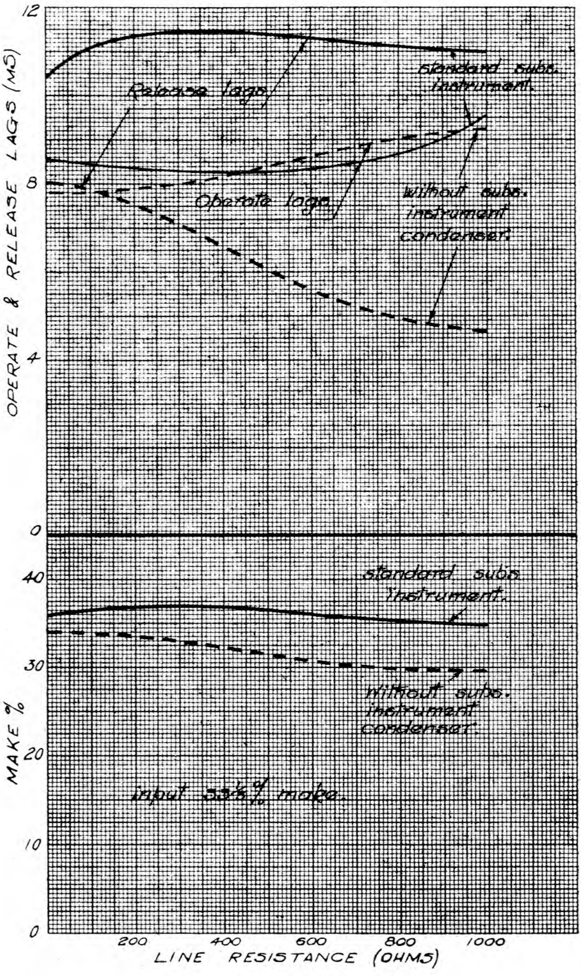


FIG. 14.

cuts down the inductive E.M.F. during dialling from 1000 to 180 volts, while the arrangement of the induction coil windings prevents wear of the interrupter contacts and also bell tinkling during dialling.

## XI.—FLUX AND INDUCTANCE MEASUREMENTS.

1. *Flux.*—Although a knowledge of the flux and dimensions of a relay does not enable the magnetic efficiency of a

TABLE VII.

| Relay. | Ampere-turns. | Flux in lines. | | | |
|---|---|---|---|---|---|
| | | In gap. | | Total. | |
| | | Operated | Unoperated. | Operated | Unoperated. |
| Siemens Nickel Finish | 100 | 4100 | 2010 | 5550 | 3100 |
| | 300 | 6475 | 5140 | 8940 | 8275 |
| | 600 | 7250 | 6350 | 10150 | 10160 |
| | 1000 | 7750 | 6950 | 10950 | 11250 |
| Small Universal Zinc Finish | 100 | 1740 | 540 | 2090 | 1300 |
| | 300 | 3625 | 1700 | 4400 | 3950 |
| | 600 | 4110 | 2275 | 5000 | 5125 |
| | 1000 | 4460 | 2600 | 5450 | 5650 |
| | 1400 | 4525 | 2725 | 5825 | 6000 |
| Large Universal Zinc Finish | 100 | 2940 | 1130 | 3475 | 1975 |
| | 300 | 7000 | 3825 | 8500 | 6600 |
| | 600 | 9125 | 6050 | 11200 | 10550 |
| | 1000 | 10000 | 7100 | 12400 | 12100 |
| R.A.T.Co.'s Zinc Finish | 100 | 1550 | 400 | 2000 | 1050 |
| | 300 | 4250 | 1350 | 5600 | 3800 |
| | 600 | 5225 | 2500 | 7290 | 6675 |
| | 1000 | 5825 | 3300 | 8090 | 8075 |
| Strowger A.E.Co.'s No. 3 armature Nickel Finish | 100 | 2600 | 950 | 3275 | 2025 |
| | 300 | 5650 | 2950 | 7400 | 5700 |
| | 600 | 7400 | 5000 | 9725 | 9250 |
| | 1000 | 8400 | 6150 | 11250 | 11360 |
| Ditto Zinc Finish | 100 | 1775 | 925 | 2450 | 1950 |
| | 600 | 7150 | 4750 | 9940 | 8975 |
| Strowger No. 2 armature Nickel Finish | 100 | 1780 | 950 | 2510 | 1880 |
| | 300 | 4780 | 2850 | 6710 | 5540 |
| | 600 | 6850 | 4625 | 9725 | 9075 |
| | 1000 | 7825 | 6000 | 11525 | 11210 |
| A.E.Co.'s Manual Type Nickel Finish | 100 | 1400 | 900 | 2475 | 2110 |
| | 600 | 4700 | 3625 | 8075 | 7900 |
| Siemens & Halske Flat Type | 100 | 1925 | 1075 | 4375 | 3510 |
| | 300 | 2700 | 2275 | 6000 | 5850 |
| | 600 | 2800 | 2600 | 6650 | 6600 |
| | 1000 | 2975 | 2800 | 7300 | 7300 |

relay to be numerically forecasted with any degree of accuracy, owing to irregularities such as the important effect of uneven distribution of the flux over the pole face, the amount of flux in the various types of relay is of general interest. Particulars are given in Table VII.

TABLE VIII.

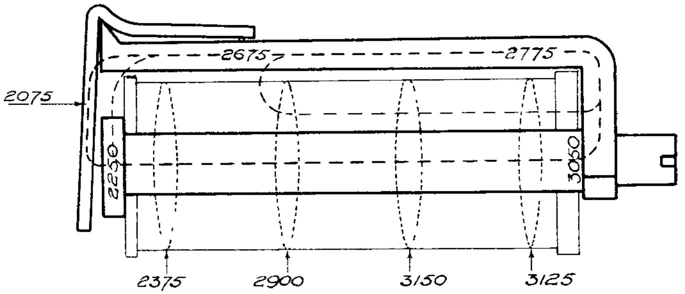
| Relay. | Ratio of gap flux to total flux. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 100 A.T. | | 300 A.T. | | 600 A.T. | | 1000 A.T. | | Average. | |
| | O | U | O | U | O | U | O | U | O | U |
| Siemens Nickel Finish | 0.74 | 0.65 | 0.72 | 0.62 | 0.71 | 0.62 | 0.71 | 0.62 | 0.72 | 0.63 |
| Small Universal Zinc Finish | 0.83 | 0.42 | 0.83 | 0.43 | 0.82 | 0.44 | 0.82 | 0.46 | 0.83 | 0.44 |
| Large ditto | 0.85 | 0.57 | 0.82 | 0.58 | 0.81 | 0.57 | 0.81 | 0.59 | 0.82 | 0.58 |
| R.A.T.Co.'s Zinc Finish | 0.77 | 0.38 | 0.76 | 0.36 | 0.72 | 0.38 | 0.72 | 0.41 | 0.74 | 0.38 |
| Strowger A.E.Co.'s No. 3 armature Nickel Finish | 0.80 | 0.47 | 0.76 | 0.52 | 0.76 | 0.54 | 0.75 | 0.54 | 0.77 | 0.52 |
| Ditto, Zinc Finish | 0.72 | 0.48 | — | — | 0.72 | 0.53 | — | — | 0.72 | 0.50 |
| Strowger A.E.Co. No. 2 armature Nickel Finish | 0.71 | 0.50 | 0.71 | 0.51 | 0.70 | 0.51 | 0.68 | 0.54 | 0.70 | 0.52 |
| A.E.Co.'s Manual Type Nickel Finish | 0.57 | 0.43 | — | — | 0.58 | 0.46 | — | — | 0.58 | 0.45 |
| Siemens & Halske Flat type | 0.44 | 0.31 | 0.46 | 0.40 | 0.42 | 0.39 | 0.41 | 0.38 | 0.43 | 0.37 |

O = Operated. U = Unoperated.

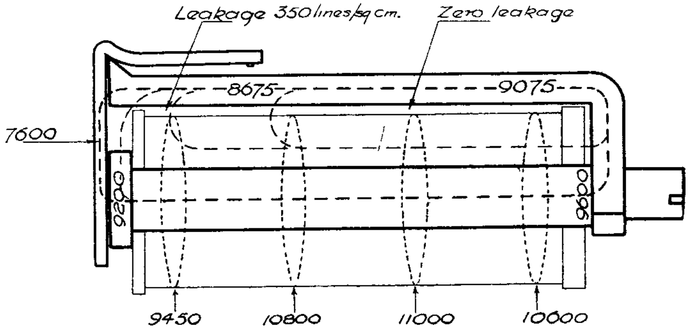
In Table VII. the values of the flux at the centre of the coil and at the armature air gap with 100, 300, 600 and 1000 ampère-turns for both the operated (3 mils residual) and unoperated conditions are given. The figures confirm, in general, that with large values of ampère-turns the maximum total flux is dependent chiefly on the cross-section of the iron circuit of the relay, while with small values of ampère-turns the flux is very largely dependent on the amount of air in the magnetic circuit. The large values of flux in the gap of the Siemens type relay are specially noticeable both in the operated and unoperated condition.

The useful flux in a relay is that passing in the air gap and it is of interest therefore to compare the gap flux with total flux in a relay. Table VIII. shows the ratio of gap flux to total flux for 100, 300, 600 and 1000 ampère-turns for the operated and unoperated conditions and also for the average of the four values of ampère-turns (since this ratio does not vary greatly with ampère-turns). The following points are of interest. The proportion of flux in the gap of

FLUX DISTRIBUTION. (MAXWELLS).



UNOPERATED, 100 A.T.



OPERATED, 600 A.T.

FIG. 15.

the Siemens relay is larger in the unoperated condition than with the other types. The proportion of flux in the gap of the "Universal" type is larger in the operated condition than with other types, due to the higher reluctance of the leakage paths from core to armature and yoke arising from the method of construction. The proportion of flux in the unoperated condition is much lower, due to the necessarily large air gap with the "Universal" type of relay and is lower with the small than with the large "Universal" as the poleface area in the latter is relatively larger.

2. *Flux distribution in a Siemens type relay.*—It is of interest to see how the flux varies in the magnetic circuit of a relay. Table IX. shows the flux in various cross-sections of the iron circuit of a Siemens relay, when the armature is operated (zero gap) and unoperated (30 mils gap). This is shown pictorially in Fig. 15. Generally speaking, the point carrying most flux is the point where the core joins the heelpiece, and the most leakage takes place between the poleface end of the core and the yoke: in fact this is one effect which limits the size of the poleface. Table X. shows the manner in which the flux density varies over the poleface. With a large number of ampère-turns the distribution is more uniform than with, say, 100 ampère-turns, since the flux in the latter case is markedly concentrated towards the edge nearest the yoke.

### TABLE IX.

FLUX IN MAXWELLS.

| | Centre of Coil. | | Poleface. | | Armature. | | Heelpiece. | | Leakage between poleface and heelpiece. |
|---|---|---|---|---|---|---|---|---|---|
| | O | U | O | U | O | U | O | U | O |
| 100 A.T. | 6300 | 3200 | 5700 | 2200 | 5600 | 2000 | 5400 | 2700 | Not taken |
| 1000 A.T. | 12000 | 12000 | 9750 | 8700 | 7800 | 7400 | 9400 | 9300 | 376 lines/ sq.cm. |

O = Operated. U = Unoperated.

### TABLE X.

FLUX DISTRIBUTION OVER THE POLEFACE.
LINES/ SQUARE CENTIMETRE.

| | 100 A.T. | 1000 A.T. |
|---|---|---|
| Upper edge | 2,320 | 6,500 |
| Centre | 1,160 | 5,300 |
| Lower edge | 1,010 | 3,500 |

The above figures are referred to the demagnetised condition. The residual flux is of the order of 300 lines in the unoperated condition and 1000 lines operated.

3. *Inductance measurements*.—Measurements of the D.C. inductance of the various types of relay were made to confirm that the values were in line with the flux measurements and that no peculiarities were present with any particular type. In Table XI. the inductance of the main types tested is given for zero and 3 mils residual gaps (operated condition) for 300 ampère-turns. In each case the relays were wound to 10,000 turns, except in the case of the small " Universal " type which was wound to 5000 turns. The calculated values of the inductance are also given for the 3 mils residual case, firstly, as obtained from the total flux; secondly, as obtained from the operated gap flux, and also the average of these two values. It will be seen that this average value is approximately that obtained by measurement and confirms that the mean flux linking the turns is not very different from the average of the flux at the coil centre and at the poleface.

In the course of these measurements a new form of Maxwell D.C. inductance bridge was devised which also enabled the time-constant of the iron, considered as a closed secondary circuit, to be measured. This is described in *P.O.E.E. Journal,* Vol. 23, Part 1, " An Improved Form of Maxwell D.C. Inductance Bridge," L. H. Harris and H. Williams. Table XII. shows the results of some measurements of this kind on an Automatic Electric Co's No. 3 armature, nickel finish, relay, for various values of current and armature gap; inductance variation is also shown in this table. The predetermination of relay lags from the time constants of the circuits and of the eddy currents in the iron is considered in a paper on "The Principles of Relay Timeing," by Dr. Turney, J.I.E.E., Vol. 66, April, 1928, p. 341.

### TABLE XI.

| Type of Relay and Residual Gap. | | Inductance in Henrys. | | | |
|---|---|---|---|---|---|
| | | Calculated from | | | Measured. |
| | | Total flux. | Gap flux. | Mean. | |
| Siemens | Zero | — | — | — | 22.1 |
| | 3 mils | 29.8 | 21.6 | 25.7 | 24.7 |
| A.E.Co.'s Extended | Zero | — | — | — | 19.8 |
| Nickel Overlap | 3 mils | 25.7 | 18.7 | 22.2 | 22.1 |
| A.E.Co. 3 : 1 Nickel | Zero | — | — | — | 22.5 |
| | 3 mils | 24.7 | 18.8 | 21.75 | 21.7 |
| R.A.T. Co.'s | 1½ mils | 18.7 | 14.2 | 16.4 | 14.9<br>(3 mils) |
| Large Universal | 3 mils | 28.3 | 23.3 | 25.8 | 25.8 |
| Small Universal 5000 Turns | 3 mils | 3.67* | 3.02* | 3.35* | 3.22* |

* To compare this type with the other types these figures should be multiplied by 4 as there were 5000 turns on these samples.

### TABLE XII.

| Armature air gap. | 10 mA. | | 30 mA. | | 60 mA. | |
|---|---|---|---|---|---|---|
| | $L_1$ | $\frac{L_2}{R_2}$ | $L_1$ | $\frac{L_2}{R_2}$ | $L_1$ | $\frac{L_2}{R_2}$ |
| 0 mils | 28 | 7.6 | 22.3 | 2.85 | 15.65 | 0.83 |
| 10 ,, | 20.1 | 4.68 | 19 | 2.45 | 14.7 | 1.25 |
| 20 ,, | 16.5 | 3.5 | 16.4 | 2.1 | 13.4 | 1.17 |
| 30 ,, | 15.4 | 3.2 | 15.8 | 2.34 | 12.8 | 1.08 |

$L_1$ = winding inductance in henrys.

$\frac{L_2}{R_2}$ = time-constant of eddy current paths.

## XII.—INTERFERENCE BETWEEN ADJACENT RELAYS.

As the magnetic characteristics of a relay are always affected to some extent by the proximity of other relays, tests were made to compare this effect for the various types. A number of ways of measuring this are possible and were tried in order to determine the most satisfactory method of comparison and to obtain information on this effect generally.

In the first instance, the field strength in the vicinity of the relays was measured and tests were also made of the flux induced in a second relay due to energisation of an interfering relay.

In the following paragraphs, position A refers to the case where the relays are mounted with the heelpieces adjacent in the same plane; position B to the case where the heelpieces are parallel, with the coils adjacent between them; position C refers to the case for " Universal " type relays mounted in a row where the heelpieces are parallel, with the coil of one relay adjacent to the heelpiece of the next; position D is the same as C, but whereas in C the " interfering " relay has its own armature between it and the core of the " interfered with " relay, in D the " interfering " relay has its core adjacent to the armature of the " interfered with " relay.

The spacing in inches between mounting centres used for the various types is as follows:—

| | Position. | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Siemens ... ... | $1\frac{1}{32}$ | $1\frac{23}{64}$ | | |
| Strowger ... ... | $1\frac{1}{4}$ | $1\frac{1}{16}$ | | |
| R.A.T. ... ... | 1.0 | $1\frac{3}{4}$ | | |
| Small Universal ... | 1.7 | | 0.81 | 0.81 |
| Large Universal ... | 2.0 | | 1.1 | 1.1 |
| Small Universal mounted above a Large Universal ... ... | $1\frac{27}{32}$ | | | |
| Siemens & Halske flat type ... ... | 3 cms. | | 4 cms. | 4 cms. |

The effects indicated by the foregoing flux measurements were borne out by tests on the effect of interference on minimum operating and release currents, and showed, in general, that interference under condition A (heelpieces in the same plane adjacent) is greater than under condition B, and

### Table XIII.

RESIDUAL GAP 3 MILS IN EACH CASE EXCEPT THAT OF THE R.A.T.CO.'S RELAYS WHICH HAD 1½ MILS RESIDUAL. INTERFERING RELAY WAS ENERGISED WITH 600 AMPERE TURNS IN EACH CASE.

| | | Effect on the release A.T. of relays of interference from a second relay. Stud pressure = 100 grammes in all cases. | | | |
|---|---|---|---|---|---|
| Type of Relay. | Arrangement. | Release A.T. without interference. | Release A.T. with interference. | Release A.T. with direction of interference reversed. | Average effect of interference for the two directions in A.T. |
| Siemens | A | 4.95 | 5.8 | 4.5 | 0.65 |
| Strowger No. 3 zinc A.E.Co. | A | 51.4 | 61 | 45 | 8 |
| Ditto, A.E.Co. nickel | A | 55 | 63 | 47 | 8 |
| Strowger No. 2 armature A.E. Co. zinc | A | 29.7 | 36 | 19 | 8.5 |
| Ditto, nickel | A | 21.3 | 22 | 18.4 | 1.7 |
| A.E.Co. Manual Zinc | A | 66.3 | 75 | 65 | 5 |
| Ditto, nickel | A | 31.2 | 34 | 28 | 3 |
| R.A.T.Co. | A | 3.2 | 15.1 | Necessary to reduce interfering A.T. to 440 to release. | 11.9 in one direction Sticks in other. |
| Large Universal S.T. & C. | C | 37.5 | 40 | 33 | 3.5 |
| Ditto | D | 28.1 | 60 | 5.2 | 27.4 |
| Small Universal S.T. & C. | D | 74 | 110 | 48 | 31 |
| Large interfering with Small Universal | A | 74.7 | 122 | 35 | 44 |
| Siemens & Halske flat | D | 21.3 | 24.15 | 17.7 | 3.2 |
| | C | 19.6 | 21.9 | 18.3 | 1.8 |
| | A | 19.1 | 24.4 | 15.1 | 4.65 |

that the effect on operation is less than on release, the figures in the latter case reaching high values in some instances. Measurements of the effect of interference on the operate and release time lags gave similar results to those obtained in the current tests. In order to eliminate errors due to variation of springsets and to make the tests strictly comparative, further interference tests were made under the release condition for arrangement A, with the springs removed and a load of 100 grammes on the armature stud. The results of this test are given in Table XIII., the effect of interference in this case being given in ampère-turns, as it was found that this was of the same order for any value of load. For example, the variation in the effect of interference on the release current between two Automatic Electric Co's Strowger relays (No. 2 armature, zinc finish, 3 mils residual gap, arrangement A) expressed in ampère-turns, is only from 4 to 10 ampère-turns as the load on the armature stud varies from 20 to 1000 grammes, being fairly constant up to 500 grammes.

1. *Comparison of methods of measuring liability to interference.*—While the tests of field strength and induced flux are of interest, it is evident from a comparison of the results that neither the field strength in the vicinity of a relay nor the flux induced in a de-energised relay by a second interfering relay can be taken as a reliable measure of the liability to interference. The general indications are the same, but their interpretation quantitatively would be difficult and involve questions of armature ratio, poleface area and the manner in which the flux is distributed over the poleface. The percentage change in flux due to an interfering relay gives more representative results, but still tends to give an under-estimate of the effect on the operate and release currents and time lags. In the later tests, for the purpose of simplification, arrangement A only was used, as this was generally a worse condition as regards interference than arrangement B, while the use of a definite load instead of springs made for further simplification. The effect of interference at release being greatest and also most important in practice, this condition only was tested and the results expressed in ampère-turns to give an Absolute measure. As the effects of interference on the operate and release currents are reflected in the time lags, it is considered that the above method gives a simple comprehensive measure of the liability to interference of any type of electromagnetic relay.

2. *Liability to interference of various types of relay.*—Using Table XIII. for the comparison of the various relays, it will be seen that with the Siemens type of relay the interference is very small (less than one ampère-turn) while with the " Universal " type it is very large. The Strowger types tested varied from 1.7 to 8.5 ampère-turns. A large number of tests have also been made with the G.P.O. type 3000 relay, to find the effect of interference on an impulsing (isthmus armature) relay. This effect has been found to be negligible. When an isthmus armature relay interferes with a slow release relay, the release lag of the latter may vary about 10%.

The large amount of interference in the case of the " Universal " type of relay was due to the proximity of the air gap of the " interfered with " relay to the core of the " interfering " relay (particularly in the case of arrangement D), the construction and method of mounting of this type of relay being such that the leakage path *via* a second relay is comparable with the leakage path to its own armature and heelpiece. In the more usual methods of construction, *e.g.*, Siemens and Strowger types, the leakage is confined to a much greater extent to the heelpiece of the relay itself. The screening effect of the armature in the latter two types also appears to decrease the liability to interference as compared with the flat types, while the excellence of the magnetic circuit in the case of the Siemens type is a further reason for the particularly small figures obtained in that case.

A photograph of the leakage flux, as displayed by iron filings, is shown in Fig. 16, which shows three " Large Universal " relays, the centre one of which is energised The large amount of stray flux from the centre relay to the armature of one adjoining relay is well shown.

## XIII.—HEATING OF RELAYS.

Some tests have been conducted on the heating of relay windings. By placing thermo-couples at a number of points in the winding the distribution of temperature has been determined. The curves agree with the well-known ones for field coils, magnets, etc. For instance, in some tests of a relay wound with single silk covered wire, absorbing 9.45 watts in a full winding, the temperature half-way along the

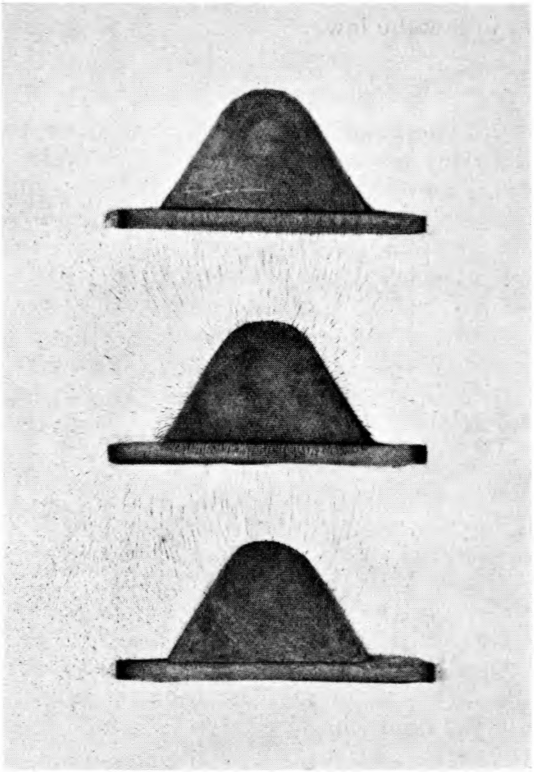


FIG. 16.

core was 106°C. On the outside of the coil the temperature was 114°C. The hottest point occurred about two-thirds the distance from the core to the outside of the coil. Taking the temperatures along the core, the temperature of the heel end is about 10° lower than that of the armature end. A point which is not always realised is that the inner part of the winding, due to the conduction of the iron, is at a lower temperature than the outer. The maximum temperature is about 5% greater than the average temperature.

The final rise in temperature was found to be proportional to the number of watts dissipated, and for ordinary telephone relays 10 watts will produce 100°C rise in temperature. It was also found that the power required for a given rise in temperature was proportional to the weight of a fully wound relay and to follow the law

$$\text{Watts} = \frac{T}{3880}(186 + M)$$

where T is the required rise in temperature and M is the weight of the relay in grammes.

It was also found that a relay carrying a "slug" would dissipate approximately the same number of watts for a given rise in temperature as a fully wound relay.

A problem which often presents itself is to find the resistance of a relay when cold, to give, say, 100°C rise in temperature when a voltage E is applied to it. The weight of the fully wound relay gives the watts (W) which the relay will stand for the given temperature rise (T), or W can be found by trial. The resistance when hot, therefore, is $R_t = \frac{E^2}{W}$.

Assuming the resistance at 16°C, is required,

$$R_{16} = \frac{R_t}{1 + \frac{T}{250}}$$

The time taken for a relay to reach a steady temperature also depends on its weight. The following figures give a rough idea of the times, in minutes:—

| *Weight: grammes.* | *Time: minutes.* |
|---|---|
| 190 | 60 |
| 110 | 38 |
| 85 | 25 |

The silk covering on the wire turns grey at about 150°C and brown at 180°C. A coil should, therefore, stand a rise in temperature of about 100°C without damage.

From a number of other tests it appears that the above results are applicable to other types of insulation, *e.g.*, enamel.

Enamel insulation will not stand such severe heating conditions as single silk insulation.

## XIV.—RINGING RELAYS.

These can be divided into two common types—

(*a*) Those in which the vibration of the armature is prevented by making the latter with high mechanical inertia, and (*b*) Ordinary D.C. relays in association with a metal rectifier.

In the Post Office type (*a*) is sub-divided into relays Nos. 56A and 56B, which are single make, vertical mounting relays with heavy ⊓ shaped armatures; relays Nos. 100 and 176A, which are large horizontal mounting relays with heavy "slab" armatures and relays Nos. 76A, 153A and 195A, which are smaller horizontal mounting relays with "slab" armatures.

The contact pressures obtained in practice are from 1 to 10 grammes except with the small "slab" type which have an inclined plane device for lifting the springs, resulting in 15 to 50 grammes pressure. The relays 56A and 56B are the most sensitive and operate with 15,000 to 18,000 ohms in series on 75 volt 16$\frac{2}{3}$ p.p.s. A.C.

The limitations of these relays are (*a*) insufficient margin and contact pressure in cases requiring great sensitivity and (*b*) inability to operate any but the smallest spring combinations with good contact pressure, even where ample power can be applied. These limitations have probably had a cramping influence on circuit design, but where ample power is available and the number of springs small the small "slab" type give satisfactory performance. Their cost is also much less than the large "slab" and ⊓ armature types.

D.C. relays fitted with a rectifier shunt extend the aforementioned limits very considerably and further have the advantage that D.C. locking features can be employed satisfactorily owing to the uni-directional nature of the flux. Their use, however, requires more care than is necessary with the inertia type of relay for the following additional points must be remembered:—

(*a*) Appreciable loss results if they are connected directly across talking circuits.

(*b*) They must not be connected to the A.C. supply without series resistance or reactance to limit the current in the rectifier.

(*c*) The rectifier must be connected with correct polarity where locking is required or where D.C. as well as A.C. operation is required.

(*d*) They must not be connected directly across a polarised bell as the latter will fail.

Their action depends equally on the effect of the by-passing of alternate half waves by the rectifier in keeping the relay flux uni-directional and on the provision through the rectifier of a path for a circulating current which ensures the slow decay of the magnetic energy of the effective half cycles. Where ample ringing power is available there is no difficulty in obtaining satisfactory operation of any high resistance D.C. relay, say, of the Strowger or pendent armature type, even with considerable spring loads, by shunting them with suitable rectifiers. For example, the Post Office's relay No. 130A, 2000 ohms, carrying three change-over springsets and with average contact pressures of 40 grammes operates satisfactorily on 60 volts, 16⅔ p.p.s., A.C., in series with 4,000 to 7,000 ohms. Similarly, a relay of the new standard type fully wound to 2,000 ohms was found to operate through 11,000 ohms with two 5-spring springsets (20 grammes pressure) or through 19,000 ohms with one 5-spring springset. No difficulty exists, therefore, in selecting suitable relays for use in conjunction with a rectifier in any case not requiring high sensitivity. For cases requiring high sensitivity it was found that a Siemens automatic type relay, wound to 3000 ohms and carrying a single make or break springset, with 10 grammes contact pressure, approached twice the sensitivity of the most sensitive of the inertia type of ringing relay. Quicker operation and more consistent time lags are further advantages of the rectifier shunt relays.

In general, D.C. relays do not hold in over the non-operate half wave when connected in series with a rectifier, but, if used in conjunction with a D.C. locking winding, satisfactory operation is obtained because of the halved speed of armature vibration and the uni-directional nature of the flux. Some sensitivity is lost as compared to the shunt method of connection, but it is a useful feature since the minor objections previously stated regarding the transmission losses, etc., are avoided.

The use of a relay in series with a rectifier for operating a separate locking relay is a very unsatisfactory arrangement, nor can a series rectifier be used if a condenser is in circuit, as the latter merely charges up and prevents the passage of further current.

Westinghouse Rectifiers type 1-12-1 have been found most suitable for use with ringing relays. They have been tested as regards breakdown by transient voltage and current surges with the conclusion that they will withstand these at least as well as the condensers, contacts, wiring, etc., of normal telephone equipment.

## OSCILLOGRAPHIC METHOD OF RECORDING FLUX. OPERATION ON 3 CYCLES OF RINGING CURRENT OF A RELAY WITH A D.C. LOCKING WINDING. EFFECT OF A RECTIFIER SHUNT.

FIG. 1
NO RECTIFIER.

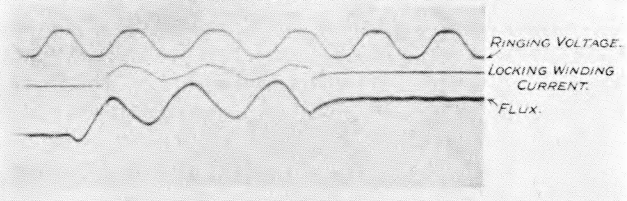


FIG 2
NO RECTIFIER.

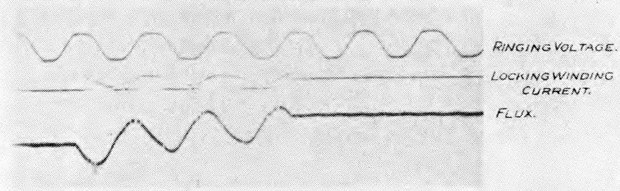


FIG. 3
WITH RECTIFIER.

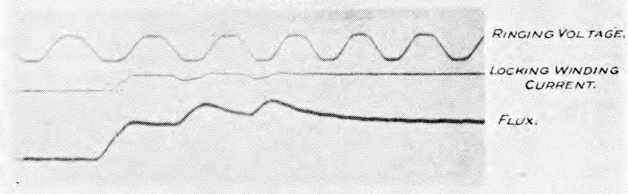


FIG. 4
WITH RECTIFIER REVERSED.

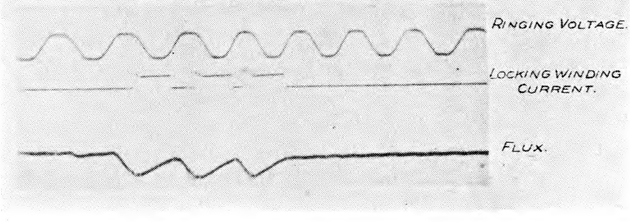


FIG. 17.

Perhaps the most interesting feature of this method of operation from ringing current is the ability of rectifier shunt relays with light contacts to operate on low voltage ringing supplies in one cycle and to lock on three or four volts from a local supply. This feature seems to show possibilities of new applications.

Fig. 17 shows some oscillograms of the flux in ringing relays provided with a D.C. locking winding under various conditions when three cycles of 16⅔ p.p.s. A.C. is applied to the operating winding. The first record shows the operation without a rectifier when the point in the cycle at which switching occurred was favourable to quick locking. The second record shows the prolonged contact chatter due to switching at an unfavourable moment, while the third record shows the improved operation which is consistently obtained by shunting the relay with a rectifier correctly connected as regards polarity with respect to the sense of the ampère-turns of the locking winding. The fourth record shows the effect of incorrect connection of the rectifier which results in failure to lock. The cyclic variations in the locking winding are due to transformer action from the A.C. in the operating winding.

## XV.—CONTACTS.

1. *Contact metals for magnet circuits.*—A number of metals have been tried for impulsing contacts breaking the 1-amp selector vertical magnet circuit. An alloy of 10% iridium and 90% platinum has given the best results so far (> 70 millions). Other metals which have given good results are palladium (25 millions); 10% gold, and 90% platinum (10 millions); and 60% copper and 40% palladium (12 millions). The last-named has been used to some extent in America for certain purposes. Tungsten gives an exceedingly long life, but is adversely affected by a most intractable high resistance compound which forms on the surfaces and is therefore only suitable where heavy contact pressure is available. All the above take a 1 $\mu$F + 200-ohm quench circuit which, in the absence of high resistance tendencies, is the sign of a wear-resisting contact metal. (See I.P.O.E.E. Paper No. 118). Silver, having an arcing limit of about 0.45 ampere gives a life of about 2.5 millions with a 1 $\mu$F + 200-ohm quench and about 9.0 millions with a 1 $\mu$F + 10-ohm quench. The average life for platinum is about 40 millions and P.G.S. No. 1 contact metal (6% Pt – 70% Au – 24% Ag), 3 millions (1 $\mu$F + 10 ohms). Metals which are useless for the above purpose are "staybrite," phosphor bronze, "$\mu$ metal" and

nickel. Molybdenum, although it has a high melting-point, is subject to high-resistance faults, resulting in severe arcing. An alloy used on the continent to some extent (70% Ag – 25% Pd – 5% Co) gives a life of about 2 millions.

The following table, supplied by Mr. Rudeforth, sum-

TABLE XIV.

| Contact Metal. | Quench. | | Average Life in Millions of Impulses. | Remarks. |
|---|---|---|---|---|
| | Capacity $\mu$F. | Resistance Ohms. | | |
| Pt | 1 | 200 | 40 | |
| Pd | 1 | 200 | 25 | |
| Ag | 1 | 200 | 2.5 | |
| | 1 | 10 | 9.0 | |
| Wo | 1 | 200 | Exceedingly Great | Subject to High Resistance. |
| Mo | 1 | 200 | Approximately 3 | ,, |
| Ni | 1 | 100 | 0.4 | ,, |
| Pt = 10% Ir | 1 | 200 | 70 | |
| 60% Cu = 40% Pd | 1 | 200 | 12.1 | |
| Ag = 10% Au | 1 | 10 | 7.2 | |
| Au = 10% Ag | 1 | 10 | 3.8 | |
| Pd = 10% Ag | 1 | 200 | 5.2 | |
| Ag = 10% Pd | 1 | 10 | 2.5 | |
| Pt = 10% Au | 1 | 200 | 10.2 | |
| Au = 10% Pt | 1 | 10 | 4.3 | |
| Ag = 7% Pt | 1 | 10 | 4.1 | |
| Ag = 15% Pt | 1 | 10 | 3.8 | |
| Ag = 5% Pd | 1 | 10 | 2.2 | |
| 6% Pt = 70% Au = 24% Ag or "P.G.S." | 1 | 10 | Approximately 3 | |
| 70% Ag = 25% Pd = 5% Co | 1 | 10 | 2.1 | |
| 18% Cr = 8% Ni = 74% Fe or "Staybrite" | 1 | 200 | 0.2 | Subject to High Resistance. |
| 80% Au = 10% Ni = 10% Mo | 1 | 200 | 0.73 | |
| Phosphor Bronze | 1 | 100 | Tests Stopped at 0.2 Million Impulses. | Subject to High Resistance. |
| "*u* Metal" (Ni = Fe = Cu) | — | — | — | Useless. |

The above figures refer to normal size hemispherical contacts.

marises the results of tests on contacts made of various metals, when impulsing the 46-ohm vertical magnets and 4-ohm C relays of final selectors.

An important effect present with P.G.S. contacts and probably with other similar contact metals is that of the variation of the effectiveness of the quench circuit with the cleanliness of the point of contact. Unless this effect is taken into consideration there appear large discrepancies between the results of life tests made under impulsing (not necessarily continuous) and occasional operating conditions. It seems that the less frequent the operation the less the self-cleaning effect of sparking, the less effective the quench circuit and the shorter the life in terms of the number of operations.

2. "*Dry*" *contacts.*—This name has been used for contacts which carry speech currents only and have not, as is more commonly the case in practice, direct current superimposed on them.

Such contacts are susceptible to high resistance faults which, however, are due to the small voltages associated with attenuated speech and not to their alternating nature.

A disconnection at contacts which carry direct current usually means that the full exchange battery voltage is present across the faulty contacts and extraordinary conditions would have to be present for the voltage across the fault to be sufficiently low to cause the type of fault introduced by "dry" contacts. The effect, as it applies to contacts in telephone switching circuits, is as follows. When the voltage between two contacts subject to this type of fault is increased from zero, the current passing is at first only a minute fraction of the current to be expected from the E and R values of the circuit. Increasing the voltage further, the current also increases but still remains practically negligible. When, however, the increasing voltage reaches a certain point the contacts "cohere" and the current jumps to its full E/R value. On reducing the voltage after cohesion, the current decreases proportionately with the voltage unless the contact be subjected to a jar or vibration, when "decohesion" takes place and the current drops to a negligible value.

It appears that no full explanation covering all cases of this phenomenon has been given, but it seems that thermal effects, introducing back E.M.F's at the contacts, predominate.

An examination of this effect determined that base metal contacts such as brass, german silver and phosphor bronze switch banks and wipers, even with double contacts, were extremely susceptible to disconnections when the alternating potential across the fault was of the order of 0.05 volt and that an increase to 0.2 or even 0.5 volt was necessary to cause cohesion.

Relay contacts of P.G.S. or platinum were found much less prone to trouble, but the evidence was such as to support the principle of eliminating " dry " contacts which it is believed Messrs. Siemens have followed for many years.

The use of a high resistance to provide a D.C. leak path was found to effect an improvement and has been resorted to in some instances, either as a means of avoiding faults on the first " make " of contacts or for counteracting the effects of vibration on contacts that " make " under battery voltage conditions (*via* a condenser, for example) and later carry speech currents only.

It is considered that insufficient attention has been given to this effect in the case of trunk cables and telephone repeaters.

3. *Dust faults on relay contacts.*—Most of the information available on the subject of relay contacts is relative to the wear-resisting properties of various metals under various conditions of working, and the liability to faults has often been a secondary consideration. In practice, the majority of contacts are not called upon to resist wear, for it is estimated that 30-40% of the total contacts in an automatic exchange normally neither "make" nor "break" current. This condition is also the commonest in practice, for the remaining 60-70% of the contacts are split up between those that " make " current only, those that " break " current only, those that " make " and " break " current and those that transfer current from one path to another. An examination of fault return schedules obtained from automatic exchanges has indicated that faults are not appreciably (if any) less frequent with the former condition than with the others.

While, therefore, the question of wear influences the liability to faults in some cases, *e.g.*, where the wear affects the adjustment of the relay or where the sparking tends to affect the contact surface, either adversely or favourably, in the majority of cases the question of liability to faults is a separate problem.

An extensive investigation into this subject has recently been made by the Research Section and a brief summary of the results and conclusions obtained follows.

Apart from contact faults due to maladjustment or to wear preventing the contacts from meeting, it is considered that any cases of disconnection due to other causes than dust (whether visible or not) are so rare that they can be neglected. The occasional faults of the type which are difficult to remove are considered to be due to dust embedded in the contact surface.

The use of well fitting covers greatly reduces the fault liability. The design of relays should be such as to prevent the generation of dust by wear of the moving parts. Ebonite lifting studs were proved to be a source of dust faults in certain cases with both pendent armature and Strowger type relays.

Relay springs in the vertical plane have a much smaller fault liability than those in the horizontal plane. In this connection some subsidiary tests, made by weighing the amount of dust deposited under various degrees of screening, indicated that the proximity of horizontal springs would have to be much closer than it is for any appreciable screening of the contacts by the top spring to exist.

Fault liability decreases with increase of contact pressure. Plotting the number of faults against pressure gives a curve of a hyperbolic nature. Insufficient pressure exists in many cases in practice. Where it is impossible to give a reasonable pressure in practice, the dust fault liability can be kept low by having very small follow. Twin contacts give a much smaller fault liability than single contacts. Test results show the ratio to be at least 1 to 10.

Contact pressure should be obtained by means of stiff springs and small follow rather than by flexible springs and large follow. Evidence of this, however, has only been obtained for buffered springs. The effects of rub are inseparable, in practical cases, from the effects of disturbance of dust by spring movement. If the effect of rub is beneficial in itself it appeared from the tests to be more than offset by the additional spring movement and dust disturbance necessary to obtain it.

This conclusion was taken into consideration in connection with the design of the G.P.O. standard relay, and was of interest later when a comparison was made between the existing Siemens automatic type relay and the G.P.O. 3000 type relay. In this test, in order that the number of faults should be sufficient to enable some conclusions to be obtained, the comparison was made mainly using springs fitted with single contacts in each case, but a smaller number of the new type of relay fitted with the normal twin contacts were also tested to ensure that no peculiarities were overlooked.

All the relays were fitted with 18 springs, *i.e.*, six break-make combinations, mounted in the vertical plane.

The results are given in Table XV., from which it will be seen that the ratio of fault liability obtained with the proposed standard relay as compared with the existing Siemens type, is as 1 to 2¾ for single contacts and as 1 to 11.4 for twin contacts on the proposed standard relay. The average contact pressures were 14.5 grammes "make" and 14.7 grammes "break" for the Siemens type relays and 18.6 grammes "make" and 21.6 grammes "break" for the new type of relay. The increased pressure with the standard relay is considered to account only partially for the decreased fault liability of the latter type. It will be noticed that the fault liability for the "break" contacts of the existing type is much less than for the "make" contacts (ratio 1 to 6). In the case of the proposed standard relay this effect is not present, the fault liability for "make" and "break" contacts being about equal and equal to that of the "break" springs of the existing type relay. This provides convincing evidence that the nature of the movement of the springs has a direct bearing on the liability to dust faults, for, in the case of the existing type of relay, the average "make" follow was 17.2 mils, and the "break" follow 7.8 mils, while with the proposed type the figures were 9.4 and 6.8 mils, respectively. Some light may be thrown on this by Fig. 18 which shows the movement of the "make" springs of the type 3000 relay and the Siemens auto type relay. The smaller oscillation of the former is noticeable. The "make" and "break" follow naturally tend to be equal with the proposed standard type, due to the symmetrical method of buffering the "make" and "break" springs.

The question of dust disturbance is allied with that of the subdivision of covers. Any arrangement of subdivision of covers on groups of relays (which decreases the number of times each relay is exposed) would be beneficial, but, unless

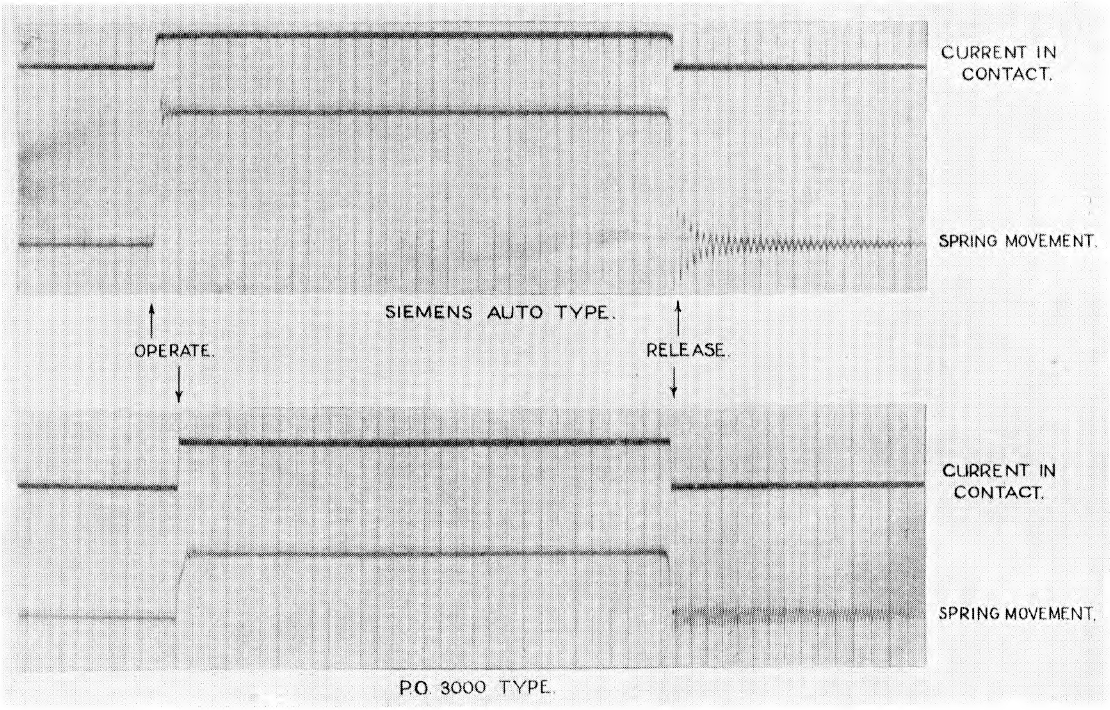


FIG. 18.

great care were taken in the grouping of relays in practice, the clearing of a fault would necessitate the removal of more than one cover and additional jerking of apparatus would probably offset any advantage obtained. Comparison of the fault liability of the various groups of relays tested indicated a tendency for the fault liability per contact to be greater for relays carrying a large number of springs than for those carrying a small number, and also that close spacing of relays gave a greater fault liability than open spacing. Both of these tendencies would be accounted for by the inter-spring or relay interference of disturbed dust.

Fault liability is not very greatly affected by the current conditions of the circuit, but sparking appears to give a decreased fault liability. Tests under the most common practical conditions of " no make or break of current " give average results, and it is not, in general, necessary to test other current conditions in order to compare fault liability of relay groups.

4. *Silver contacts.*—During some tests initiated to determine the effect of the hardness of the contact metal on the fault liability, an inherent small fault liability of pure silver as compared with platinum or P.G.S. was discovered. It has been stated that the oxides of silver are conductive, but no evidence to support this is available, although experimental work on the point has been carried out both at Dollis Hill and in America. The low cost of silver, together with the example of German practice, has added further weight to the experimental results, and the general use of twin silver contacts is therefore receiving serious consideration. The value of raw material for the contacts of a 10,000-line director exchange, fully equipped, using P.G.S. and platinum, is of the order of £2000 for single contacts, and the proposal recommended by the authors is to replace the P.G.S. alloy contacts by pure silver, retaining platinum for those contacts where it is used at present.

Tests show that the range of humidity in exchanges does not appear likely to affect the fault liability.

Apparatus which is connected to battery attracts a great deal more dust than apparatus which is disconnected; further, dust is attracted to under surfaces as well as to upper horizontal surfaces. Application of battery to apparatus only during essential periods has resulted in the laboratory in a large decrease in dust faults (ratio 4.7 to 1). This appears to have practical possibilities, while the general principle of electrostatic precipitation of dust (*e.g.*, filters) seems worth examination.

The shape of the contacts affects the dust fault liability.

Concentration of pressure and minimum amount of horizontal area in the immediate vicinity of the point of contact appear desirable, but with springs in the vertical plane insufficient evidence has been obtained to justify change from dome-shaped contacts which are considered best from the point of view of wear, and need no particular polarity. Some tests were made of a modified dome-shaped contact designed to combine the advantages of concentrated pressure with those mentioned above for dome-shaped contacts. In this case the contacts, which had the upper part of the domes slightly ridged, were mounted on the springs with the ridges on each pair of contacts at right angles. Some benefit resulted as regards dust fault liability, but not such as to justify any recommendation for changes in existing shapes.

5. *Cleaning of Apparatus.*—Throughout the tests it was noticed that the fault liability of contacts immediately tended to increase on relay springs being touched for any reason. On several occasions faults occurred following (not always immediately) an apparently negligible irregularity such as, for example, pushing up a relay armature once by hand. Cleaning a fault-free relay group by thoroughly brushing the contacts with a dry brush or with a brush moistened with carbon-tetra-chloride or with a contact cleaner or by flicking the springs, almost invariably produced faults. It was found that relays so dusted, even when the bulk of faults produced by cleaning had been cleared, remained susceptible to faults for a settling-down period which might, under exchange conditions, be serious, since such a tendency could then be quite easily missed on test. This agrees, so far as is known, with exchange experience, for it is believed that periodic cleaning of selectors has proved troublesome due to the subsequent increase in dust faults. In the present tests, a very large amount of dust was present, and yet a satisfactory fault liablility was obtained where the conditions were such as to produce little disturbance of dust, and it is considered that as regards apparatus which requires little attention (and, therefore, is subject to little dust disturbance) the intervals between cleaning should be made very long, for example, several years. In the case of apparatus requiring more attention and subject to more dust disturbance, the cleaning should be extremely thorough and special attention should be given to the routine testing of apparatus recently cleaned to cover the settling-down period which appears consistently to follow even through cleaning.

6. *Removal of Faults.*—Comparative tests of the increased liability on cleaning contacts by means of (*a*) brushing with a dry brush (*b*) brushing with a brush moistened with carbon-tetra-chloride (*c*) flicking the springs and (*d*) using a contact cleaner, were made by cleaning groups of contacts by these respective methods and recording resulting faults. The over-all result of these tests indicated that the careful use of a contact cleaner was preferable to the other methods, since it was found that the removal of the fault was more certain and the tendency to produce faults on adjacent contacts was less. The flicking of springs, by raising them about $\frac{1}{8}''$ and letting go, has been recommended and, while it is agreed that this method usually removes the fault on the contact flicked, it has been found that it increases the fault liability on adjacent contacts. For example, evidence was obtained that, if a group of relays carrying a number of change-over springsets are flicked on the " normal " contacts, a much increased fault liability follows on the " make " contacts. This increased fault liability is much less if a contact cleaner is carefully used, but the tendency still remains and great care is necessary. It was found that few faults could not be removed by a thin smooth steel contact cleaner drawn gently between the contacts under their own pressure. In a few cases only was additional pressure and the use of a cleaner with a slightly roughened surface necessary.

The use of paper for making disconnections when testing is a practice which still exists in exchanges; this is an almost certain source of faults.

Any design or arrangement of apparatus or any maintenance instruction which tends to prevent or confine dust disturbance in the vicinity of relay contacts, due to their operating movement or to their maintenance, will have the effect of reducing dust fault liability.

In conclusion, something should be said to account for the many omissions in this paper. Some types of relay, such as split phase ringing and thermal relays and lag devices, have been omitted entirely. This is because the authors have confined themselves to work of which they have a first-hand knowledge. Similarly, the relative merits of the various types of springset, from the point of view of ease of adjustment under exchange conditions, have been left to others. We think, however, that the designers of the springset of the type G.P.O. 3000 relay in its original form are to be congratulated on its simplicity in this respect.

## TABLE XV.

(COMPARISONS OF SIEMENS AND PROPOSED STANDARD TYPES OF RELAY.)

TOTAL OPERATIONS = 1,134,000.

| Type of relay. | Contacts. | No. of relays tested | No. of relays on which faults occurred. | No. of contacts tested. | | No. of contacts affected | |
|---|---|---|---|---|---|---|---|
| | | | | Make | Break | Make | Break |
| Existing Siemens type. | Single P.G.S. | 22 | 22 | 132 | 132 | 103 | 30 |
| Proposed standard type. | Single P.G.S. | 18 | 18 | 108 | 108 | 32 | 38 |
| | Twin P.G.S. | 6 | 3 | 36 | 36 | 1 | 2 |

| No. of faults. | | | No. of contacts cleaned. | | Operations per fault per contact | | |
|---|---|---|---|---|---|---|---|
| Total | Make | Break | Make Contacts. | Make Contacts. | All Contacts | Make Contacts. | Break Contacts |
| 373 | 321 (17.2) | 52 (7.8) | 20 | 1 | 800,000 | 470,000 | 2,900,000 |
| 112 | 59 (9.4) | 53 (6.8) | 3 | 0 | 2,200,000 | 2,100,000 | 2,300,000 |
| 9 | 6 | 3 | 0 | 0 | 9,100,000 | 6,800,000 | 13,600,000 |

The figures in brackets give the "follow" of the springs in mils.

It is considered that the merits of any type of telephone relay can be quickly ascertained by laboratory tests on the lines given in this paper and that the resulting information exceeds many times that obtained by trying out a few relay groups in an exchange where the results are difficult to interpret and sometimes even more difficult to believe. In neither case do the effects of time show themselves, but the effects of wear can be ascertained in the laboratory in a few weeks by a test which can incidentally be used to determine the dust fault liability of the springsets.

The opportunity is taken to thank Messrs. G. P. Belcher and S. Clipstone, of the Research Section Staff, for the able assistance they have given with the experimental work described in this paper.

## APPENDIX I.

### *Calculation of the Winding Space of a Relay.*

The number of turns upon a bobbin and its winding resistance can be calculated with reasonable accuracy by making several simple assumptions. Several factors, it will be recognised, will vary, which may make slight errors in practice, such as:

(1) The specific resistance of the copper.
(2) The diameter of a certain gauge of wire will vary between limits.
(3) All manufacturers do not put exactly the same thicknesses of insulation on their wires.
(4) The bedding factor of wires has been assumed to be unity, *i.e.*, there is assumed to be no airspace between adjacent layers or adjacent turns. This is very nearly true for small wires.

All the following calculations have been based on the London Electric Wire Company's wire tables.

For a circular bobbin and core

Let L = winding length.
C = core diameter + core insulation.
D = outside winding diameter.
= outside diameter of bobbin less allowance for insulation.

$$\triangle = \frac{D - C}{2} = \text{winding depth.}$$

$\rho$ = Specific resistance of copper.
= .626 microhms per in$^3$ at 0°C and .677 microhms per in$^3$ at 20°C, for these calculations.

The problem may be treated in two ways.

1. Suppose the bobbin to be wound with wire the copper diameter of which is $d_2$ and the diameter of which outside the insulation is $d_1$. Each wire may be assumed to take up a square of space, side $d_1$, and therefore the number of turns on the relay is

$$T = L \frac{(D - C)}{2d_1^2} \qquad \text{.....(1)}$$

The length of a mean turn of the wire is $\frac{\pi}{2}$ (D + C) and the total length of wire on the bobbins is $\frac{\pi}{2}$ (D + C) × $L\,\frac{(D - C)}{2d_1^2}$. The resistance of the wire is therefore

$$R = \rho L\,\frac{(D + C)\,(D - C)}{d_1^2 d^2_2} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $\rho$ is the specific resistance of copper at the temperature of winding.

2. Assuming that turns of an upper layer bed down into the spaces between turns in a lower layer, the number of turns on the relay becomes

$$T = L\,\frac{(D - C)}{\sqrt{3}\,d_1^2} \text{ very nearly} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\text{or} \quad \frac{\sqrt{3}T}{2} = L\,\frac{(D - C)}{2d_1^2} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Under these conditions the distance between layers is $\frac{\sqrt{3}}{2}\,d_1$ and the resistance becomes

$$R = \frac{2\,\rho L(D + C)\,(D - C)}{\sqrt{3}\,d_1^2 d_2^2} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$\text{or} \quad \frac{\sqrt{3}}{2}\,R = \frac{\rho L\,(D + C)\,(D - C)}{d_1^2 d_1^2} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

It is thus possible to get about 15% more turns and resistance for each gauge if the wires bed down.

In practice method 1 has been found to give most accurate results and calculations and curves are based upon it.

3.—*Bobbin with a rectangular (approx.) core.*

Where a bobbin has a rectangular core, the edges are usually rounded and it has been found that the following approximations lead to practical results.

The core is assumed to be a rectangle length $b$, with semi-circular ends, of diameter $d$. The outside of the bobbin is then also a rectangle length $b$ with semi-circular ends of diameter D. The number of turns upon the bobbin then becomes

$$T = L \cdot \frac{D - d}{2d_1^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

and the resistance

$$R = \frac{\rho \cdot L\,(D - d)\,\{4b + \pi\,(D + d)\}}{\pi\, d_1^2 d_2^2} \quad \ldots\ldots\ldots\ldots (8)$$

4. *Winding Factor.*

A formula may now be derived which will give the turns for a given resistance independent of the diameter of the wire. In order to do this, let $d_2 = rd_1$

Then from (2) above

$$d_1^2 = \sqrt{\frac{\rho L\,(D + C)\,(D - C)}{r^2 R}}$$

substituting this in (1) above, the turns for a given resistance

$$T_R = \frac{r}{2}\sqrt{\frac{R}{\rho}}\sqrt{\frac{\Delta\, L}{C + \Delta}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

If the resistance is fixed, therefore, the expression $\sqrt{\frac{\Delta\, L}{C + \Delta}}$ when calculated for various relays gives the relative number of turns which may be wound in each relay to give a definite resistance. It can therefore be used as a Winding Space Factor for comparing winding spaces. The assumption made is that the ratio copper diameter to copper + insulation is the same for the wire on each relay.

This ratio will obviously depend on the gauge of wire used in each and also upon the type of insulation upon the wire. Supposing one type of relay had to be fully wound with 39 s.w.g., another with 40 and another with 41 to obtain the same given resistance in each case. Table I. shows the error in assuming this ratio to be a constant for various types of covering.

It will be noticed that the space factor for these small wires is considerably greater for enamelled wires than for single or double silk covered wires, and also that an error of about 3% can be introduced by assuming " $r$ " a constant for double silk covered wires.

For a rectangular core this factor becomes

$$F = \sqrt{\frac{(D - d)\,L \cdot \pi}{4b + \pi\,(D + d)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

## TABLE I.

| Gauge. | Enamel. | | | Single silk. | | | Double silk | | |
|---|---|---|---|---|---|---|---|---|---|
| | $d_1$ | $d_2$ | $r$ | $d_1$ | $d_2$ | $r$ | $d_1$ | $d_2$ | $r$ |
| 39 | 0.006 | 0.0052 | 0.867 | 0.0065 | 0.0052 | 0.8 | 0.0077 | 0.0052 | 0.675 |
| 40 | 0.0055 | 0.0048 | 0.874 | 0.0061 | 0.0048 | 0.788 | 0.0073 | 0.0048 | 0.658 |
| 41 | 0.005 | 0.0044 | 0.88 | 0.0056 | 0.0044 | 0.786 | 0.0066 | 0.0044 | 0.667 |

*Correction if Relay has a Slug.*

It will be noticed that the turns for a given resistance on a relay are proportional to the square root of the length. If therefore a relay bobbin is only wound partly along its length due, say, to having a slug at one end, the number of turns on it for a given resistance may be found by obtaining the number of turns to wind the relay fully and multiplying by $\sqrt{\frac{L_S}{L}}$ where $L_S$ is the winding length of the relay with the slug on and L is the normal winding length of the bobbin.

If the bobbin is not fully wound or if there is a sleeve over the core, the number of turns for a given resistance may be obtained by calculating the new winding factor F. The turns for the given resistance should then be obtained from the curves for a fully wound relay and multiplied by the ratio of the new winding factor to the old one.

It is evident that any modification to a relay which has the effect of increasing the winding factor will not necessarily increase the efficiency in proportion to this factor, but will usually have a lesser effect owing to the reluctance of the magnetic circuit not being in general independent of the modification to the winding space. For instance, increasing the length of a relay from $L_1$ to $L_2$ will increase the winding factor in the ratio of $\sqrt{\frac{L_2}{L_1}}$. Actually, however, the length of the iron circuit has also been increased and other things being kept constant the efficiency will not be increased in this ratio, particularly for the case of heavy loads or high values of ampère-turns where the iron becomes saturated.

*Derivation of Figures Nos.* 19, 20, 21 *and* 22.

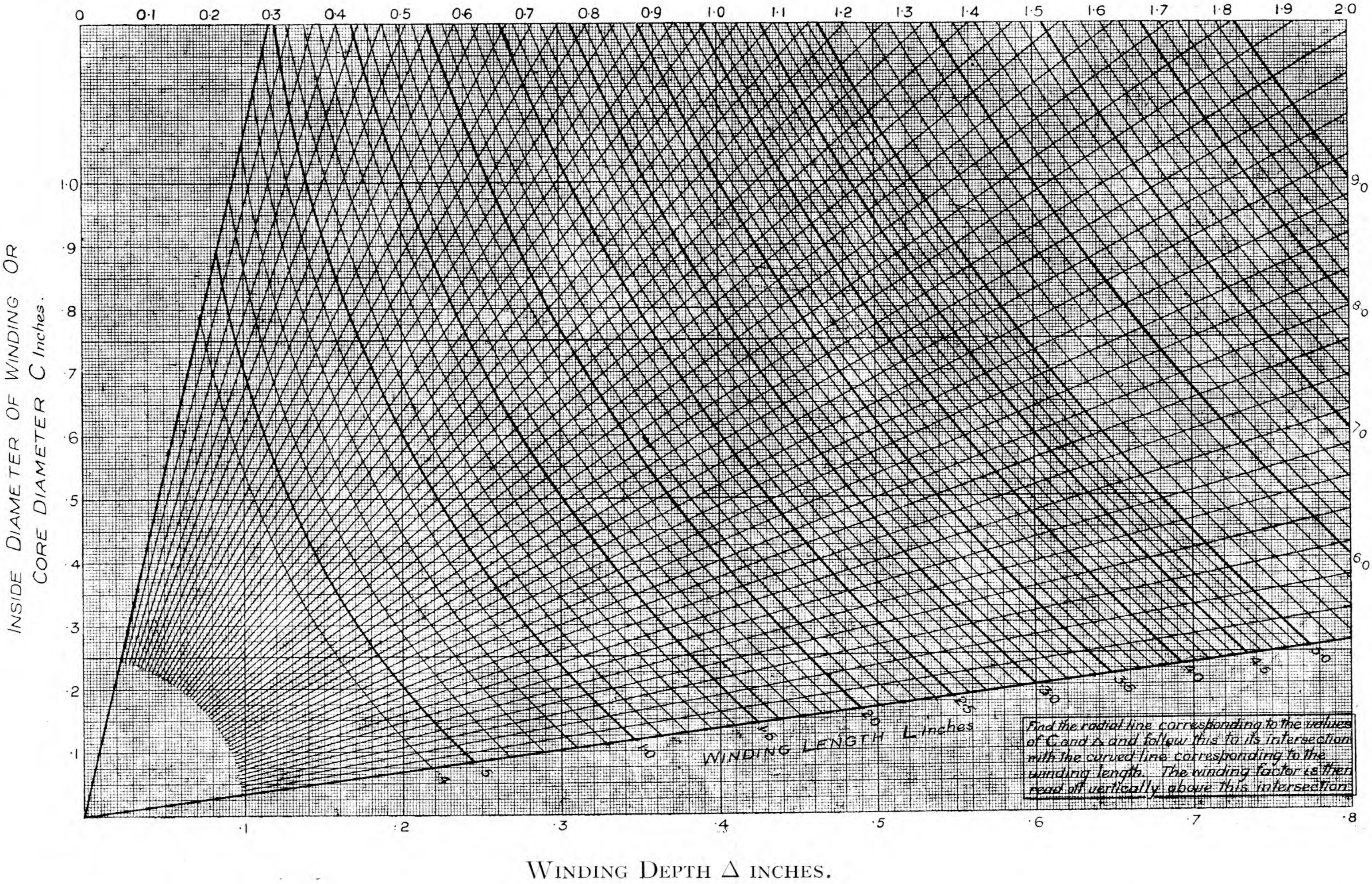
From equation (1) $T = \frac{L(D - C)}{2d_1^2}$, it will be seen that it is possible to correlate these quantities (winding length and depth, number of turns and $d_1^2$) in a diagram. The scale corresponding to $d_1^2$ can conveniently be marked off in gauges and alternative scales provided for various types of insulation.

Similarly for equation (2) $R = \frac{\rho L(D^2 - C^2)}{d_1^2 d_2^2}$. It is necessary in this case, however, as there are too many variables, to rearrange the equation thus; $\frac{R}{L} = \frac{\rho(D^2 - C^2)}{d_1^2 d_2^2}$

# Relays—Winding Space.

## Determination of Winding Factor from Dimensions.

$$\text{Winding Factor} = \sqrt{\frac{\Delta L}{C + \Delta}}$$



Find the radial line corresponding to the values of C and Δ and follow this to its intersection with the curved line corresponding to the winding length. The winding factor is then read off vertically above this intersection.

Fig. 19.

The maximum number of turns that can be wound on a bobbin for any given resistance can be taken as a measure of the available winding space. The number of turns for any given resistance is proportional to $\sqrt{\frac{\Delta L}{C + \Delta}}$ where Δ is the winding depth and C the inside winding diameter. This factor can therefore be used for directly comparing the winding space of various types of relay or sizes of bobbin.

For the calculation of actual turns and resistance from gauge of wire and dimensions of coil see Figs. 20 and 21.

## RELAYS—WINDING SPACE.

## RELATION BETWEEN DIMENSIONS, TURNS, TYPE OF INSULATION AND GAUGE OF WIRE.

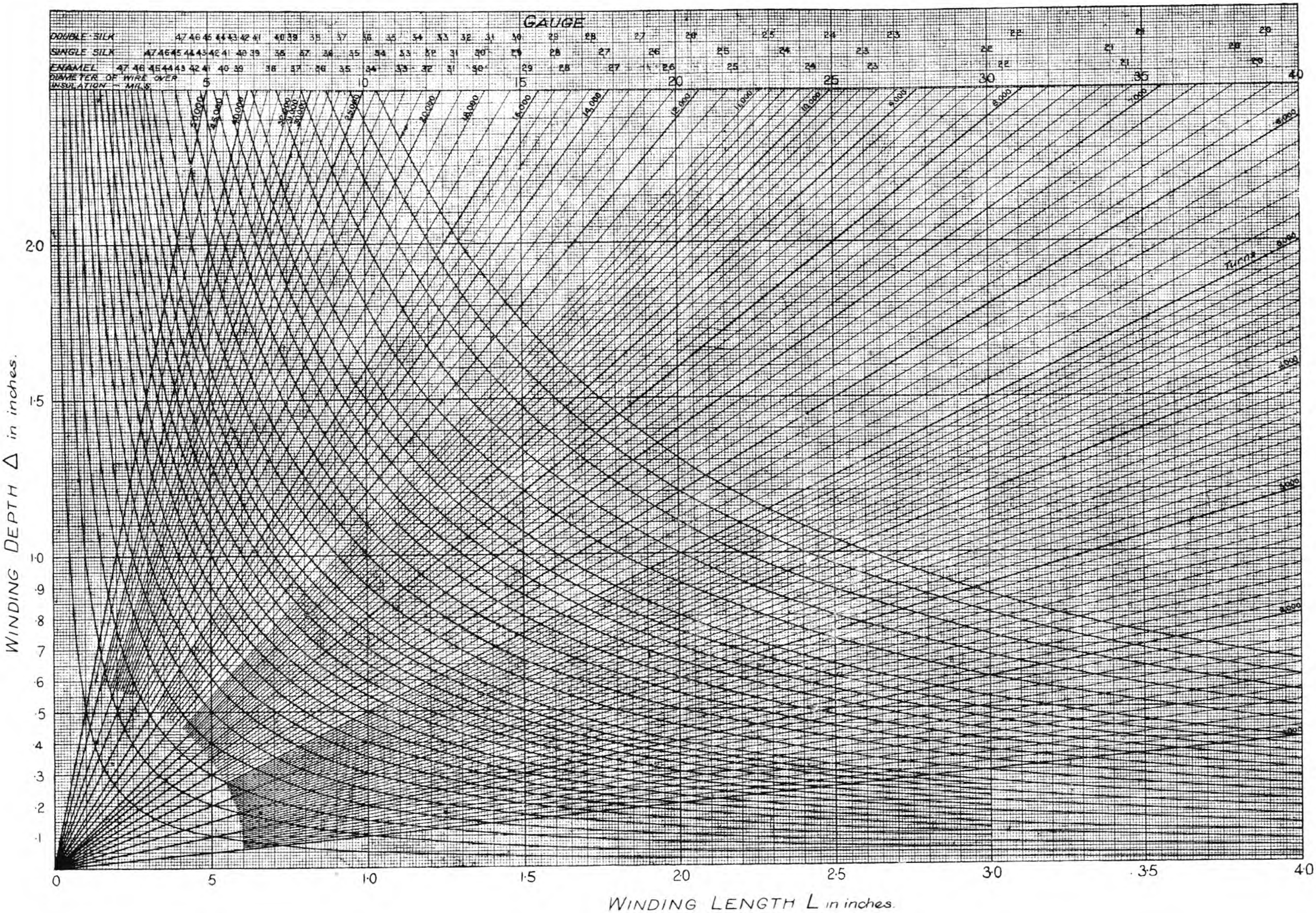


FIG. 20.

DETERMINATION OF GAUGE OF WIRE.

Find the curve corresponding to L and Δ and follow it to the point of intersection with the radial line corresponding to the number of turns. The gauge of wire for the type of insulation to be used is then read off vertically above this point of intersection.

Inverse processes can be used, *e.g.*, for determining the number of turns when the gauge is known.

For the determination of the resistance see Fig. 21.

For the comparison of winding space, *e.g.*, of various types of relay, see Fig. 19.

and to construct the diagram, correlating Resistance per inch of winding length, inside and outside winding diameters and $d_1^2 d_2^2$. Here again $d_1^2 d_2^2$ is fixed if the gauge and insulation

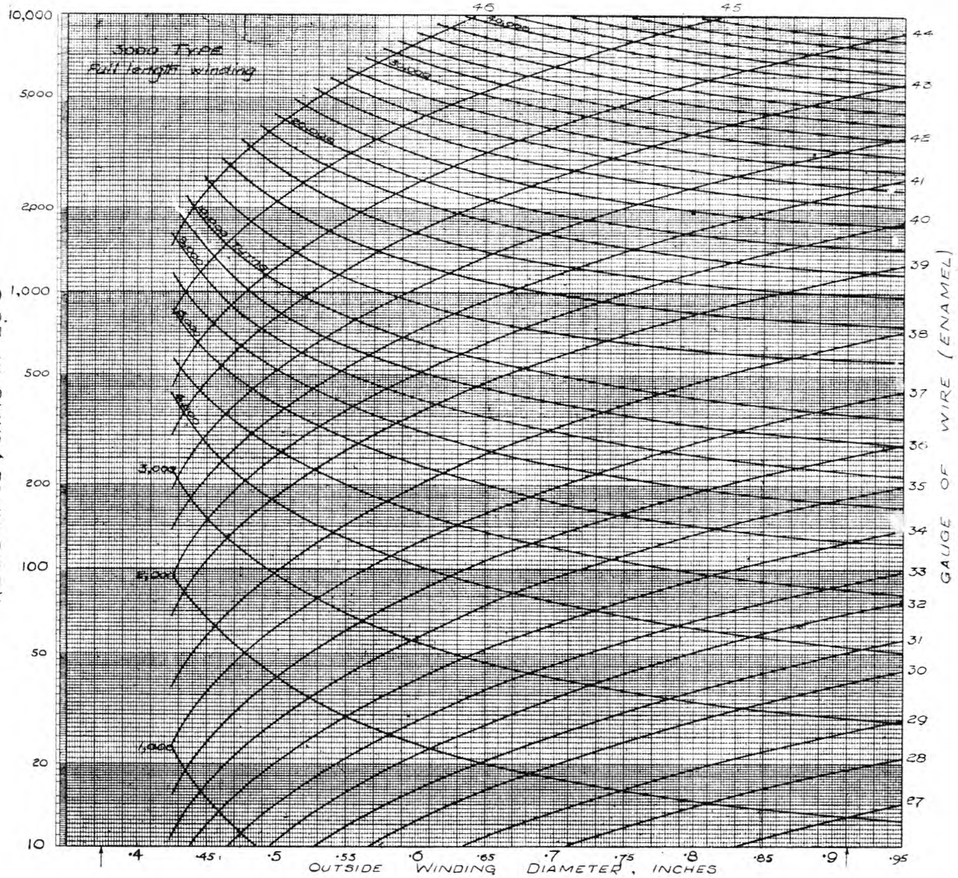


FIG. 22.

are given and this scale can be calibrated directly in gauges for any type of insulation.

Fig. 19 has similarly been derived from the formula F, relative winding space $= \sqrt{\dfrac{\triangle L}{C + \triangle}}$.

The resistances in the above curves are at 20°C. The law relating resistance and temperature has been taken as follows $R_t = R_0\,(1 + .00426\,t)$.

Where $R_0$ = resistance at 0°C
$R_t$ = resistance at $t$°C

The following diagrams provide convenient means of dealing with questions of the winding space and design of relay windings.

Fig. 19 enables the winding space factor for an ordinary relay to be read off from the bobbin dimensions.

Fig. 20 gives the gauge and insulation of wire and number of turns for any winding dimensions.

Fig. 21 gives the Resistance per inch of winding length, gauge and insulation of wire for any winding dimensions.

Fig. 22 gives for a full length winding of the type 3000 relay the relation between winding diameter, turns and resistance for various gauges of wire. This enables double or sandwich windings to be easily and quickly designed.

## APPENDIX II.

### *Capability Curves in terms of Power Input.*

If it is required to compare magnetic efficiencies of relays on a power basis, tests are first made by the ampère-turn method. The number of watts corresponding to the ampère-turns must then be carefully calculated, assuming a fully wound relay, having first decided upon a resistance R. Let the turns corresponding to this resistance be T. Then if A ampère-turns are required to operate the relay

$$\text{Watts} = \left(\frac{A}{T}\right)^2 \times R$$

From (1) and (2) of Appendix 1.

$$= \frac{4\rho \cdot A^2}{L} \; \frac{(D + C)}{(D - C)} \; \frac{d_1^2}{d_2^2} \quad \ldots\ldots\ldots\ldots (11)$$

$$= 4\rho \cdot A^2 \; \frac{C + \triangle}{\triangle L} \cdot \frac{d_1^2}{d_2^2} \quad \ldots\ldots\ldots\ldots (12)$$

It becomes obvious from these expressions that the watts depend to a small extent on the gauge of wire and also on the covering in use.

The relative magnetic efficiency ($n$) on an ampère-turn input basis of a relay 1 to a relay 2, is evidently

$$\frac{n_1}{n_2} = \frac{A_2}{F_2} \Big/ \frac{A_1}{F_1} \quad \ldots\ldots\ldots\ldots (13)$$

From (12) above substituting for $\dfrac{\triangle L}{C + \triangle} = F^2$ the efficiencies become, in terms of power input

$$\frac{n_1}{n_2} = \left(\frac{A_2}{F_2} \Big/ \frac{A_1}{F_1}\right)^2$$

assuming $r$, the space factor to be constant.

This expression is the square of the former one and it follows that a load/power curve is equivalent to a curve plotted between load and a function which is proportional to the square of, the ampère-turns divided by the winding factor.

# APPENDIX III.

## *A Note on the Relationship between the Pressure at the Contacts and the Pressure at the Lifting Stud.*

It is sometimes convenient to consider the load at the armature stud in terms of the contact pressures with which it is related. The relationship is not usually obvious owing to the cantilever action of the springs and the following notes were made in an endeavour to simplify its consideration :—

(1) Let the distance from the clamping insulation of a spring to a point of support (armature stud or buffer) be L cms. and the distance from this point to the contacts be $l$ cms. Then with a stud (or buffer) pressure of W grammes and providing the contacts are free, the deflection (from the undistorted or free position of the spring) at W will be

$$D_w = \frac{WL^3}{3EI}$$

The slope at this point will be $\frac{WL^2}{2EI}$ and the deflection $d$ at the contacts (also with regard to the free position of the spring) will therefore be given by

$$d_w = \frac{W}{EI}\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right)$$

The deflection at the contacts will therefore be the same as if the spring were rigid and pivotted at $\frac{L}{3}$ cms. from the clamping insulation.

(2) Similarly with a load P at the contacts and no other support the total deflection at the contacts from the free position will be $\frac{P(L + l)^3}{3EI} = d_p$ and at L cms. from the clamping insulation the deflection will be

$$\frac{P}{EI}\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right) = D_p$$

(3) From these expressions the relationship between W, P, $d$ and D for the case when W and P are acting simultaneously can be obtained by superposition giving—

$$d = \frac{1}{EI}\left[ W\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right) - \frac{P(L + l)^3}{3}\right]$$

and $$D = \frac{1}{EI}\left[\frac{WL^3}{3} - P\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right)\right]$$

(4) Considering a change-over springset, let $W_m$ be the armature stud pressure on the moving spring in the operated position

$P_n$ be the contact pressure in the normal position.
$P_m$ be the contact pressure in the make position.
$d_n$ be the normal deflection of the moving spring contact due to $P_n$.
$d_t$ be the travel of the moving contact.

If, as is commonly the case, the pressure on the armature stud is zero in the unoperated position then

$$dn = P_n \frac{(L + l)^3}{3EI}$$

In the operated position the total deflection of the moving contacts is $d_t + d_n = d$

From 3 above

$$d = \frac{1}{EI}\left[ W_m \left(\frac{L^3}{3} + \frac{L^2 l}{2}\right) - P_m \frac{(L + l)^3}{3}\right]$$

$$\therefore \quad W_m = \frac{EI\, d + P_m \dfrac{(L + l)^3}{3}}{\left(\dfrac{L^3}{3} + \dfrac{L^2 l}{2}\right)}$$

but $$EI = P_n \frac{(L + l)^3}{3d_n}$$

$$\therefore \quad W_m = \frac{P_n \dfrac{(L + l)^3 d}{3d_n} + P_m \dfrac{(L + l)^3}{3}}{\dfrac{L^3}{3} + \dfrac{L^2 l}{2}}$$

$$= \left( P_n \frac{d}{d_n} + P_m \right) k \text{ where } k = \frac{(L + l)^3}{3\left(\dfrac{L^3}{3} + \dfrac{L^2 l}{2}\right)}$$

$$= \left( P_n + P_m + P_n \right) \frac{d_t}{d_n} \; k$$

But $\frac{P_n}{d_n}$ is the force at the contacts per unit deflection

$$= \frac{3EI}{(L + l)^3} = k^1 \text{ say}$$

Therefore $W_m = (P_n + P_m + k^1 d_t)\,k$.

In other words, the load on the armature stud in the make position is equal to the normal contact pressure, plus the make contact pressure, plus the additional force required to move the spring from the normal to the make contacts, all multiplied by a constant which is a function of L and $l$.

This constant is the ratio of load at contacts to load at stud.

The value of $k$ for various ratios of L to $l$ is given in the following table :—

| L | $l$ | $k = \frac{(L + l)^3}{3\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right)}$ | $k'' = \frac{L^3}{3\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right)}$ |
|---|---|---|---|
| 10 | 1 | 1.16 | 0.87 |
| 5 | 1 | 1.33 | 0.77 |
| 2 | 1 | 1.93 | 0.57 |
| 1 | 1 | 3.2 | 0.4 |

(5) The make or break springs can be treated in a similar manner.

The deflection $D_b$ of a spring at the buffer when the contacts of the spring are unmade is $D_b = \frac{W_b L^3}{3EI}$ where $W_b$ is the pressure of the buffer on the spring and L is the distance from the clamping insulation to the buffer. This remains constant where the make of the contact increases the buffer pressure, as is commonly the case with " break " springs. With the contacts made the deflection at the buffer $D_m$ is therefore $D_b = D_m = \frac{1}{EI}\left[\frac{W_{bm} L^3}{3} - P_n\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right)\right]$

$= \frac{W_b L^3}{3EI}$ where $W_{bm}$ is the buffer pressure when the contacts are made and $l$ the distance from the buffer to the contacts. It follows that :—

$$W_{bm} = W_b + P_n/k'' \text{ where } k'' = \frac{L^3}{\left(\frac{L^3}{3} + \frac{L^2 l}{2}\right)}$$

If buffered in such a way that the make of the contact decreases the load on the buffer, as is commonly the case for a make spring, then $W_{bm} = W_b - P_m/k''$. In this case as the moving spring operates $W_{bm}$ usually becomes zero and the conditions are simplified. It will be noticed that the value of $k''$ corresponds to the ratio of $\frac{D}{d}$ obtained in (1).

It is not thought that the above notes are of practical value except to give, when studying the question of relay springs, a clearer idea of the effects of bending on the relative contact and stud pressures.

# NOTES ON THE DISCUSSION.

Mr. J. HEDLEY:—

I am sure you will all agree that we have had presented to us to night a paper which is full of valuable information, and Messrs. Harris and Williams deserve the thanks of this Institution.

For many years the introduction of telephone relays generally was somewhat haphazard, and it has only been during the last few years that real study has taken place in order to evolve a relay which will be satisfactory from a magnetic circuit point of view, prevention of interference from one relay to another, ease of adjustment, and with all the various improvements which Messrs. Harris and Williams have brought to our notice this evening.

It might be inferred from some of the slides that there is perhaps a better relay from an operating or magnetic circuit point of view than the standard relay which the Post Office have adopted. It might also be inferred from the concluding remarks made by the author that trials in exchanges are not necessary.

I do not wish to minimise the work that has been done in connection with relay research, which is exceedingly valuable, but I do say this: that the outstanding feature in my opinion which has led the Post Office to adopt the type 3000 relay is the fact that it is easy to adjust. It is not only easy to adjust, but the method of adjustment can be specified definitely and is such that every skilled workman will follow the same method of adjustment. It has also been shown in the paper that under working conditions the number of faults is much less on the P.O. standard relay. To obtain such information experiments in the field are essential. I think the buffer block which Messrs. Ray and Biddlecombe introduced, when they studied this question of a standard relay for the Post Office, is largely responsible for the reduction in faults for with its existence it is possible to test and ensure that a specified pressure on the relay springs of, say, 20 grammes, is available.

With existing types of relays, dirty contacts have always been a source of trouble. This is mainly due to the difficulty during maintenance in obtaining good contact pressure.

With the introduction of twin contacts, reliability of good contact pressure and other improvements embodied in the P.O. standard 3000 type relay, it is hoped that dirty contact trouble will be eliminated.

Mr. F. I. RAY:—

It is a very great pleasure to open this discussion to-night, as it gives me an opportunity of expressing my great appreciation of the research work carried out by the authors, work which was of the utmost importance in connection with the design of the 3000 type relay.

In 1929 Mr. Biddlecombe and I were entrusted with the task of studying the relay problem, and of producing within a period of three months a standard relay to be manufactured by all contractors for future telephone exchange equipment. But for the assistance of the authors of this paper, the task would have been well nigh impossible. As it was, we were able to see our way clearly at the end of the allotted span and to give a definite recommendation after four months.

As stated by the authors on page 3, when we commenced this work we found that no officer was employed by the Post Office wholly on investigating relay problems, and there was no organised accumulation of relay design data. Mr. Biddlecombe and I had, therefore, to turn for assistance to the Research Section, where we were fortunate in receiving permission to co-operate directly with the authors of this paper, co-operation which was of the utmost assistance to us.

The first problem was to decide upon the most efficient form of magnetic circuit. One might well ask why it is necessary for telephone relays to have such an efficient magnetic circuit. Any modern type of relay will produce a pull on the armature of several hundred grammes. Why strain after perfection?

To answer this question it is necessary to refer briefly to the three chief objectives of any relay designer, viz., to obtain a relay with a high contact pressure, a long residual air gap and freedom from flux interference between adjacent relays.

Considering contact pressure, the authors have pointed out that the "fault liability—contact pressure" curve is hyperbolic. With infinite pressure there would be no contact faults, while with zero pressure there would be infinite contact faults. The turning point of this hyperbolic curve is in the neighbourhood of 20 grammes, *i.e.*, with pressures below 20 grammes the fault liability rises very rapidly. In the early automatic exchanges there are many relays with contact pressures of 10 grammes, or even less, and it was felt that this fact could not but have an adverse affect upon the quality of the service which was being given. With a more efficient magnetic circuit, it is possible to increase the minimum contact pressure, and for the 3000 type relay a minimum of 20 grammes was recommended.

The residual air gap is an important factor in determining the release lag of the relay. With certain existing types of relays, residual air gaps of 1½ mils are specified, and it will be realised that a departure of half a mil one way or the other will make a considerable difference to the release lag of such relays. With a more efficient magnetic circuit a longer air gap may be used, and thus greater stability of release lags may be obtained. With the 3000 type relay, a minimum of 4 mils has been adopted for the length of the residual air gap.

We now come to the third point, flux leakage between adjacent relays. It has been argued that leakage flux is an advantage because it enables a clever designer to assist the operation of one relay by means of leakage flux from a neighbouring relay, *i.e.*, to get more than a pint out of a pint pot. A case in point occurred recently, when it was found necessary to increase the time period between impulse trains sent out by directors or senders. The duration of this period is governed largely by the release lag of the SA. Relay, and as the contact pressure and residual air gap of this relay had already been reduced to the limits of safety, the connections to the SA. Relay were reversed, in order that it may benefit by the flux leakage from adjacent relays and thus take a little longer to release. From this example, it will be seen that advantage can be made of leakage flux between relays, but, on the other hand, it is very easy for this leakage flux to cause adverse effects. For example, the C.C.I. Decoding Relays were influenced by adjacent relays and had to be moved. An even more subtle case occurred in connection with a 1st Code Selector Circuit, in which a testing relay received current at each step of the " A " Digit Finder. By flux leakage these current pulses were transferred to another relay, whose coil was associated with a subscriber's line, and the subscriber, therefore, heard these current pulses, interpreted them as dial tone, and commenced prematurely to dial. A fault of this character is difficult to detect in the laboratory, since the experimental arrangement of the relays on the relay plate may not be the same as that adopted in the final shop production.

The tests that were made by the authors showed that the Siemens type magnetic circuit was so much better than any competitive design that we decided that it was not much good going ahead in the comparatively limited time with the object of producing anything better. Another factor which influenced this decision was the very striking manner in which the Siemens type of relay maintained the accuracy of its release lag. We made some tests on final selectors and found that, after 800,000 operations, the releasing lag of this type of relay had increased only 5.4%, compared with an increase of 72% to 91% obtained with relays of competitive design. This striking difference is attributed very largely to the fact that the armature strikes the core directly, whereas in competitive designs the blow is an oblique one and, therefore, produces much greater wear.

A very important service rendered by the authors at this time was the demonstration of the improvement which may be obtained by using a nickel finish as the protective covering of the metal parts constituting the magnetic circuit. This point is clearly brought out by the authors in this paper.

When considering relay design, I should like to emphasise the importance of simplicity in adjustment. It is a lamentable fact that cheapness in first cost can usually be obtained by introducing complexity in design. One has only to consider the Strowger Switch and the Strowger Automatic Telephone System to see how simplicity can be sacrificed to a decrease in first costs, and I rather fear that the development of the 3000 type relay is following the same path. The original proposal was a simple relay with a maximum of three moving springs at each side, a relay particularly easy to adjust. Since then it has suffered many vicissitudes in order to meet the requirements of the circuit designer, and I fear it is losing this attractive feature of simplicity. I would suggest that simplicity has a very definite cash value, even though this value is difficult to evaluate, and I hope this factor will be taken into consideration in the future development of this type of relay.

The authors' investigation into contact faults has elicited three interesting points.

(1) That silver is a better contact material than the present P.G.S. alloy.
(2) That electro-static action plays an important part in the dust problem.
(3) That the best way to maintain relays is to leave them severely alone as long as possible.

Mr. T. O. K. WYLIE :—

The previous speaker has made reference to the low contact pressure common in automatic exchanges, and I think this is a very big argument for a relay having a good magnetic circuit. Further, with the non-supported springs, in order to ensure a minimum contact pressure of 15 grammes, let us say, it becomes necessary to provide for lifting a contact pressure in excess of 30 grammes merely as a result of the variations in the actual thickness of the spring contact material used, so that immediately we come to a supported type of spring, such as the 3000 type, we have to a large extent reduced the necessary manufacturing tolerances which should be required.

It will be noticed in connection with sleeved relays that an oscillograph shows that current rise is practically instantaneous, whereas with the slugged relay a much less rapid rise is obtained. A rather interesting point arose in that connection recently, where it was found that a contact which was controlling a sleeve B relay was frequently failing. This was undoubtedly attributable to the fact that contacts seldom reached their static condition instantaneously and therefore as the current rose practically instantaneously, arcing at the moment of closing or opening the contact was considerably more severe than in the case where the slugged coil was fitted.

The authors give some figures of ampère-turns required with the 3000 type relay and we have in the laboratory, for purely practical purposes, taken a number of tests on these lines, with different types of springs. It may be of interest to know that the figures taken are of the same order as those obtained by the authors. We have taken similar tests in connection with the A.E. type of relay and we required approximately 100% more ampère-turns to get the same nominal contact pressures. This may be somewhat exaggerated because the turns are " nominal turns " of manufacturers. I believe it is the practice at the moment, of certain manufacturers to wind definitely on a turn basis, whereas others wind on a resistance basis without paying very much regard to turns.

Mr. R. W. **Palmer** :—

In the greater part of the paper prominence is given to the aspect of capital cost, but on the question of relay contacts the following figures may be of interest. Taking contacts in a typical director exchange, the capital cost of all the platinum contacts is about £500, but the total maintenance cost expended on those relays is at least £2,500 for a 25 year period, so I feel that in the research on the life of contacts the question of fault liability is of even greater importance than the saving of capital costs and I think it would be of value if we could have more information on this subject.

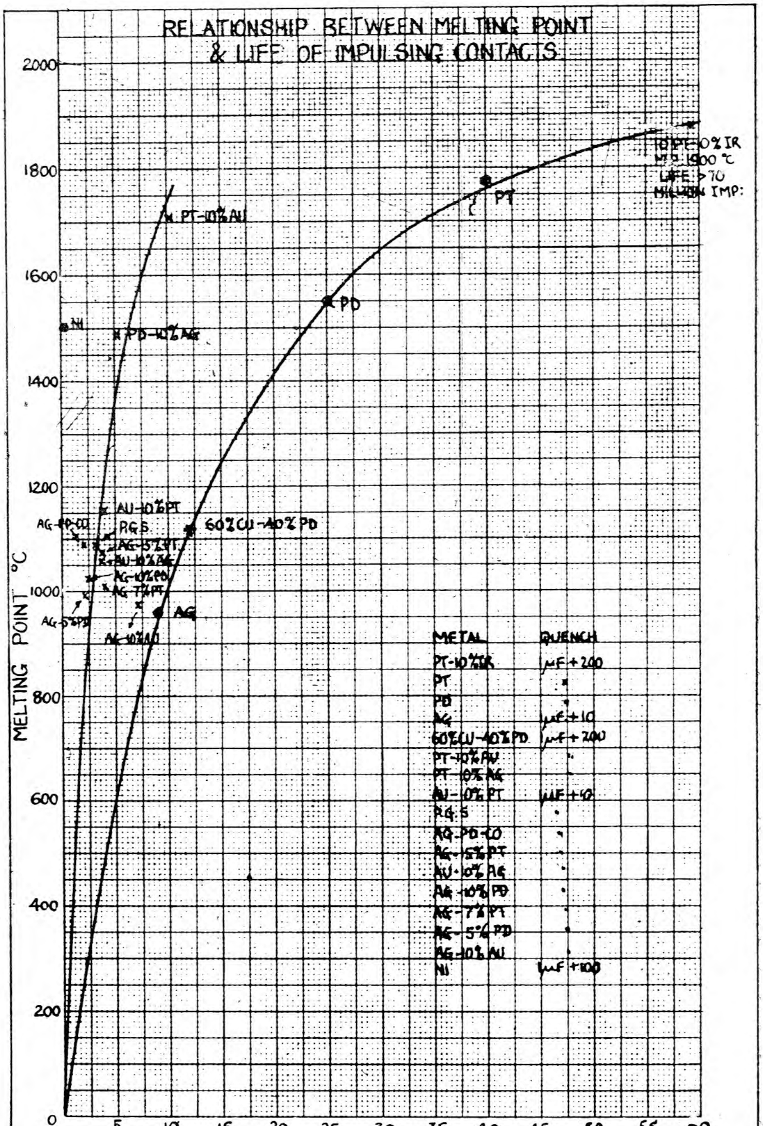
Turning to " light duty " contacts, I rather wondered why the tests on such materials as silver, included the operation of magnet circuits. When such a test is first started it should be fairly obvious that silver is not going to supersede platinum, and it seems that such tests should be confined to platinum or a similar substitute.

I would like to ask a question concerning " dry " contacts. If a contact is required in a circuit carrying no D.C. current, is it sufficient to discharge a condenser through that contact in order to reduce the coherer effect? Some solution of that kind would certainly help in the design of impulsing repeaters where the condenser surges are superimposed on the impulses that are repeated.

Mr. H. J. **Gregory** :—

One cannot help admiring the very thorough way in which this investigation on the Telephone Relay has been carried out. The magnetic circuit, winding, springsets and contacts have all been examined in great detail so that it is not surprising that an exceptionally good relay has been the result.

There is only one statement in the paper that I wish to criticise. On page 42 it is stated that enamel wire does not stand up to such severe heating conditions as single silk covered wire. Enamel insulation on wire has been greatly improved during recent years and a good quality enamel may perhaps stand heat without damage better than silk.



| METAL | QUENCH |
|---|---|
| PT-10% IR | μF + 200 |
| PT | . |
| PD | . |
| AG | μF + 10 |
| 60% CU-40% PD | μF + 200 |
| PT-10% AU | . |
| PT-10% AG | . |
| AU-10% PT | μF + 10 |
| RG.5 | . |
| AG-PD-CO | . |
| AG-5% PT | . |
| AU-10% AG | . |
| AG-10% PD | . |
| AG-7% PT | . |
| AG-5% PD | . |
| AG-10% AU | . |
| NI | μF + 100 |

FIG. 23.

Table XIV. gives a list of contact metals with their average life in a magnet circuit. Now the melting point of these metals will be one of the principal factors in determining their life and in the graph the melting point of each metal is plotted against its life in millions of impulses (Fig. 23). The points for the elements Ag, Pd and Pt lie along the graph, but Ni being a base metal although with a high melting point is useless. All the alloys except Cu-Pd and Pt-Ir are very much to the left. The possibility of finding an alloy with a life approaching that of Pt is therefore rather remote, unless an alloy of Pt with a metal of higher melting point such as Ir is used. This alloy of Pt containing 10% Ir has a life at least twice that of Pt and as its cost is not appreciably more than Pt, it is worth considering as a substitute for Pt.

The small fault liability of pure silver compared with P.G.S. or Pt is still under investigation and its behaviour in bad industrial atmospheres is being studied. The possibility of using standard or commercial silver instead of pure silver is also being tried.

A further point that requires investigation is the mechanical properties required of Ni-silver for springsets. A machine has been constructed at Dollis Hill which will measure the fatigue elastic limit, *i.e.*, the stress at which samples of Ni-silver take up permanent set on repeated bending. It is hoped that a specification for Ni-silver can thereby be obtained which will ensure greater uniformity and reliability.

In regard to contact bounce, the authors state that no general cure has yet been found. Does one infer from this that the copper coil cheek on the standard relay is of no use?

Now having produced a relay with such a small fault liability, the next step should be to improve the conditions under which it has to work in order to obtain its full benefit. This means some reconsideration of the present type of ventilating system. Tests made by the Research Section at Temple Bar three or four years ago showed that the efficiency of the ventilating system there was about 20%, *i.e.*, only 1/5th of the dirt is removed from the air blown into the exchange. (See curve in Fig. 24). With this forced ventilation about three times the quantity of air enters an auto exchange compared with a manual exchange of similar size but with natural ventilation. It follows that much more dirt enters the auto

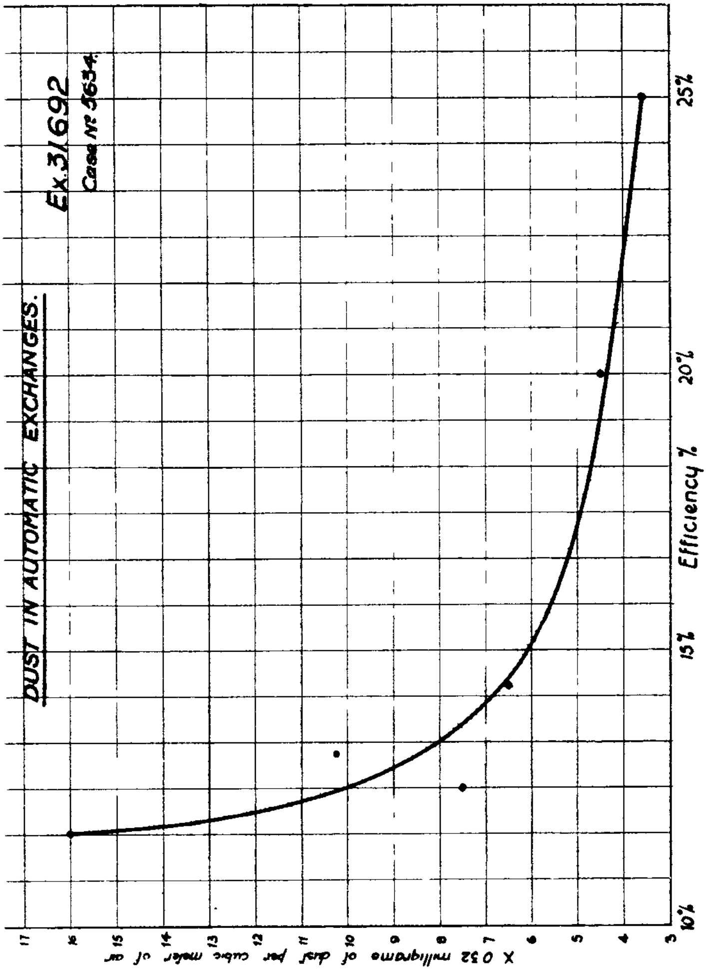


FIG. 24.

exchange and this is oily dirt too and consequently a greater menace.

According to Technical Instructions the important factors in ventilation are movement of air, humidity and temperature. It is suggested therefore that some partially enclosed ventilating system should be tried so that only a fraction of the quantity of air and consequently dirt from the outside atmosphere need be admitted. The maintenance of the auto apparatus should then be an easier problem.

Mr. W. H. GRINSTED :—

I think we should all be very grateful indeed to the authors for publishing the result of their research in this paper. If one thinks of the conditions existing some ten years ago and of the welter of different opinions that existed then with regard to desirable and undesirable features in relays, one realises, I think, the value of work of this kind. The authors have done a great deal to sort out the wheat from the chaff, and sound practice is now gradually emerging.

I am not quite sure what the authors had in mind in including Table II. on page 9; perhaps I have misunderstood it, but I suspect it may have been included with a view to helping people in the design of relays. There is a suggestion that if you provide the number of ampère-turns specified in that table you will have a perfectly satisfactory relay. I should like to suggest that a little more care is necessary. I do not see any reference to a factor of safety to cover manufacturing variations or departures from precise adjustment in maintenance. Then, again, it seems to me that the table must have been based on a comparatively small number of specially made up samples, which of course is not a sound basis for mass production. It is necessary to base data of that kind on the commercial product. As a matter of fact the table would apply reasonably well to the P.O. type 3000 relay, but it would be unwise to base specifications on it and expect manufacturers to turn out relays commercially to satisfy the figures quoted in that table.

On page 47 the authors refer to silver contacts. I should like to ask whether the results apply to a single contact and on what type of relay. We have been making a number of investigations on the use of twin silver contacts and we have found that the twin contact with 1 $\mu$F and 200$\Omega$ quench has withstood 9½ million impulses and is still in good order. We should estimate the working life of this combination at about 10 million impulses, which is considerably greater than the authors quote and corresponds more nearly with their results with the 10$\Omega$ quench. Even that of course does not approach the life of platinum or iridium contacts.

There is one aspect of the paper which, I think, is a good example of the process of sorting the wheat from the chaff. It seems to be generally accepted throughout the paper that pressure adjustment is preferable to current adjustment. That was certain, sooner or later, to be recognised. If one considers the duty of a relay in an automatic exchange, it is altogether different from that of a telegraph relay. The service is entirely dependent on the reliability of the contact operation and usually there is plenty of current available so that the right process in adjustment is undoubtedly to begin with contact adjustment and finish up with the current tests. The current tests then serve as a check on the correct assembly and performance. The adjustment of spring tensions to comply with specified currents on the other hand offers opportunities of covering up defects.

There is also some very interesting information with regard to the effects of dust. The authors point out that it is important to avoid disturbing dust in the proximity of contacts, and that is in full accord with our experience. All our investigation and experience go to show that it is dust which is disturbed which causes contact trouble, and it seems to me that that is a very strong argument for not including the mechanisms of selectors under the same cover as the relays.

Then there are some interesting remarks with regard to the subdivision of covers. In connection with that I might be allowed to go back and refer to some of our very early equipment on which relay covers common to a plate of twenty relays were used. We had the misfortune not to be able to complete the covers in time and we took what now appears to be the awful step of installing the equipment with nothing more than brown paper over the relays. The resulting dirty contact trouble can be better imagined than described. Repeated cleaning effected little improvement until we put a sub cover over each relay under the common cover; that finally mastered the trouble. We have adopted the practice of not including more than 100 contacts under one cover, otherwise in clearing one fault there is a serious risk of bringing about further faults on account of exposure. Too many covers may also be undesirable, however, as the authors point out. The covers should be arranged so that each includes those elements that need to be inspected in conjunction in the case of a fault.

As to the question of dust precipitation and the effect of electrical tensions on relay faults, we have suspected that the trouble exists and have searched for it very carefully among detailed exchange records, but we have never been able to find any proof of its reality. We have also made a number of tests in the laboratory, but the authors must allow me to congratulate them on being the first, as far as I know, to obtain evidence in that way. I should like to ask them if the potential they used is 50v or higher. I must say I did not altogether expect to find the effect in exchange records, as they are distorted by the importance of the trouble which a dirty contact may cause.

On page 42 the formula giving temperatures is interesting. Does the weight of the relay referred to there include the spool, or the spool and the polepiece, or the spool, polepiece, armature and springsets? The authors seem to suggest 10 watts as the maximum permissible loading. We have always worked to seven, calculated on the cold resistance. I am not sure whether the 10 referred to is calculated on the resistance hot or on the resistance cold.

One other point refers to the permissible rise of temperature. 130°C. is suggested and the authors say that the silk covering turns grey at 150° and brown at 180°. Will the relay maintain its adjustments if it is repeatedly subjected to 100°C.?

Mr. R. St. G. Terry :—

In the first place, I am glad to observe the adoption of a general formula for comparing different sizes of coil. This is identical with one used by ourselves in discussions with the Department, and is exceedingly useful. It is gratifying that the authors have given it their blessing.

My second remark applies to the graphs shown in Fig. 1. These are of great use in designing relays for difficult applications, and have been used by my Company for, I think, about seven years. Their utility to us has been such that I am sure wider publication will be of value.

With regard to the question of how relays should be adjusted, I see there is reference to their being adjusted to "gauging" and current. This method is, of course, employed, but it should be remembered that the real basis of such adjustment is that advocated by Mr. Grinsted. The designer chooses values of current and gauging primarily to ensure correct contact functioning and, moreover, these tests are supplemented where necessary by actual pressure measurements. In these latter cases, the current tests are a repetition of the mechanical tests giving the additional assurance that the magnet is sound. Actually, there are a considerable number of relays of this type in use on which the current tests are omitted with satisfactory results. I think, however, that the best general method is to apply complete mechanical adjustments followed by current tests.

In connection with the tables on interference, the Universal relays referred to there, were some of the earliest samples, which differ from any regularly manufactured. The later ones are provided with a magnetic bridge over the hinge, which has the effect of reducing interference to a practically negligible amount, and increasing the efficiency slightly.

In considering the results of efficiency comparisons, one is apt to assume that the highest is necessarily the best. High efficiency is not, however, essential and introduces timing difficulties on fast relays. To give some idea as to how much efficiency is essential, I can perhaps state that the Universal relay has been used to engineer a complete London director exchange, using a minimum contact pressure of 20 grammes. Actually, there were about half a dozen exceptions to the latter rule, perhaps the smallest number in any existing exchange.

In connection with the table on contact material, I was interested to notice the results with platinum iridium. Since a considerable number of relays having these contacts are now being installed, there will be an opportunity of watching service performance.

One further point is the question of finish. The authors have stressed the important effect of this on efficiency. Usually, it is resistance to corrosion that decides the choice of a finish. Are we to assume that the authors have satisfied themselves on this point?

In conclusion, I should like to thank the authors for the thoroughness of the paper, and to state from the point of view of a designer that a good deal of the paper will be of daily use.

AUTHORS' REPLY:—

It was not intended to convey, as Mr. Hedley suggests, that actual exchange tests of a new type of relay were entirely unnecessary, but rather that these should be regarded as a wind up to laboratory tests and that no new type of relay should be installed in an exchange unless it had survived the onerous efficiency, wear and stability tests that can only be carried out in a laboratory. It is considered that ease of adjustment is of secondary importance to stability of adjustment in the sense that prevention is better than cure.

While we agree with Mr. Ray that 20 grammes is a good figure to take for minimum contact pressure, the authors do not quite agree that this is because of any turning point in the fault pressure curve. For example, extensive tests indicate that whatever point in the curve is taken, there is always the same relative advantage to be gained by increasing the pressure.

It is interesting to know that Mr. Wylie's views and experience agree with the authors' as regards buffered springs, the magnetic efficiency of the 3000 type and Strowger type relays and the effect of sleeves on the rate of current rise and contact wear. In reply to Mr. Palmer, tests of silver for impulsing contacts were made because this is a condition under which many metals have been tested and useful comparisons can be made. Also, it is understood that in Germany replaceable silver contacts are used for impulsing. As regards " dry " contacts, the discharge of a condenser invariably causes the contacts to cohere but, as stated in the paper, a leak path is beneficial in preventing decoherence due to vibration.

Mr. Gregory differs from the authors in his opinion of the relative merits of silk and enamel covered wires from the point of view of withstanding high temperatures. The tests on which the opinion is based were made on modern enamel wire under the conditions imposed by a relay winding. It seems that further information is desirable on this question.

The effect of the copper spool cheek used on the type 3000 relay has been proved to have little if any effect on the " bounce " of the relay contacts. It reduces the impedance of the relay to speech currents by about 25% and increases the operate and release lags of the relay to an extent which is important in the case of impulsing or other quick operating relays. Mr. Gregory's remarks on contact metals and the ventilation of exchanges are important contributions to the discussion, but do not call for a reply.

Table II., referred to by Mr. Grinsted, gives the minimum operating ampère-turns of the relays. It is considered that a factor of safety of 1.5 should suffice to cover manufacturing variations.

In reply to Mr. Grinsted's query in regard to silver contacts, the life given in Table XIV. refers to single, hemispherical contacts on Strowger type relays. The voltage used in the electrostatic tests was −50v. The weight referred to in the formula connecting temperature, power input and weight is that of a complete relay with an average springset in a loose (selector) cover.

It is agreed that 7 watts is a good practical figure to take for a Siemens type relay. The 10 watts refers to 100°C temperature rise and allows no margin.

No information is available on the question of the variation of relay adjustment with temperature.

In reply to Mr. Terry's remark that high efficiency is not essential and introduces timing difficulties on fast relays; unless the magnetic circuit of each relay is to be designed for the particular job it is called upon to do, *i.e.*, from the point of view of timing and spring load, then high efficiency is essential in order to obtain stability of timing of slow relays. A good, self-contained magnetic circuit without air gaps, except the armature air gap, having been decided upon to provide this stability, an isthmus armature can be provided to meet impulsing conditions. Clearly a compromise is necessary to meet all conditions, but a deliberate arrangement of this kind is surely preferable to the use of an inefficient magnetic circuit.

As regards the adoption of nickel finish, the authors are satisfied that this at least meets the requirements of the English climate.

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Birch & Whittington, 10, Station Road, Epsom