Important Design Factors Influencing Reliability of Relays

By J. R. FRY

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Relays are produced by a large number of manufacturers in this country. When we survey their product, we find that there are many kinds and varieties. They differ widely as to their size, shapes and configurations. Many of these differences are dictated by the requirements of the task they must perform and by the environments under which they must work. Other differences are brought about from considerations of cost and by the design and fabrication techniques the particular manufacturer employs. However, all relays have a common objective. For whatever use they are employed, it is highly desirable that they be reliable. They are expected to function each time they are called upon without failure and over the expected life of the equipments in which they are used. This paper deals with the more important design factors which all relays have in common that greatly influence their reliability of performance. Contact spring pile-up stability and the importance of strength of screws, insulating materials with low cold flow and moisture absorption, and manufacturing procedures and controls to achieve this end are discussed. Coil construction so as to minimize the occurrence of open windings due to corrosion of the wire and breakage of the lead-out wires is dwelt upon. Contact reliability and how it is affected by the material used, its size and shape, the method of actuation, the presence of contaminating vapors, and single versus twin contacts are discussed. The degree by which magnetic materials change their magnetic properties with age and treatments for alleviating this effect are described. The importance of adequate structural design so that the relay will be rugged and remain stable so that its performance is substantially unaffected by wear, shock and vibration is stressed. Methods of test to determine how well the relay meets these objectives are described.

Although a relay is conceptually a simple device, the wide range of conditions under which relays are required to operate, the many different characteristics they must have, and the complete dependence placed upon them in many circuit applications, make them a subject of continuous study.

In the telephone industry, for example, the completion of a single call may bring into play a thousand or more relays. While their principal function is to close electrical contacts, there are many facets to the problem of doing this satisfactorily. Relays are produced by many manufacturers in this country. When we survey their product we find that there are many kinds and varieties. Shapes, sizes and configurations of relays may differ in accordance with the requirements of the tasks they must perform, and the environments under which they may work; other differences may be brought about by cost considerations and by design and fabrication techniques of the manufacturer.

All relays, however they may be used, have one common objective – they must be reliable. They are expected to function each time they are called upon, should do this without failure, and should continue to do so over the expected life of the equipment in which they are used. It is the purpose of this paper to discuss the more important factors that are common to all relays and which have considerable influence on their reliability of performance. The design considerations discussed in this paper are presented in the following order.

(1) Contact Pile-up Stability,
(2) Coil Construction,
(3) Contact Reliability,
(4) Magnetic Stability, and
(5) Structural Stability.

CONTACT SPRING PILEUP STABILITY

Stability of the contact spring pile-up contributes in a large degree to the reliability in performance of the relay. Since contact springs may be assembled into pile-ups of from two springs to a dozen or more, they must be secured so that they will not shift position during the life of the relay, even when it is subjected to relatively large changes in temperature and humidity, and to vibration and shock during shipment, installation, wiring, and under operating conditions. It is also important that the dimensional relations between the contact ends of the springs and the actuating members of the relay do not change appreciably; otherwise, changes in contact separation, contact follow, contact pressure, and operating and releasing current values may cause faulty operation of the relay.

Insulators for securing the springs should be made of materials having low cold flow and moisture absorption characteristics; in telephone relays, the better grades of phenol fibre have been found adequate. They should have generous clamping surfaces, so that when the spring pile-up is clamped under force, high pressures on the insulators are avoided – thus minimizing cold flow and keeping well below the crushing strength of the material.

Pile-up screws, clamping plates, and screw threads should be porportioned such that permanent deformation under any condition does not take place, i.e., the maximum stress does not exceed the elastic limit of the metal. It has been found advantageous to use high tensile strength steel for these parts – a tensile strength of 100,000 lbs per square inch or higher.

In the manufacture of relays, the desired pile-up tightness requires certain procedures and controls. Insulators are baked in an oven at a temperature of about 150°F for a minimum of 24 hours and assembled in the relay while in the dry condition. During assembly, prior to tightening the screws, the pile-up is pressure clamped under a hydraulic or air powered fixture to a controlled force of 1,300 lbs to 3,200 lbs, depending upon the size of the relay; while under this pressure, the screws are tightened using a controlled torque. To assure that the processes and materials are under control, the relay is then tested on a "no-go" basis in a fixture that applies a definite force on the contact springs in a direction to rotate them in the pile-up.

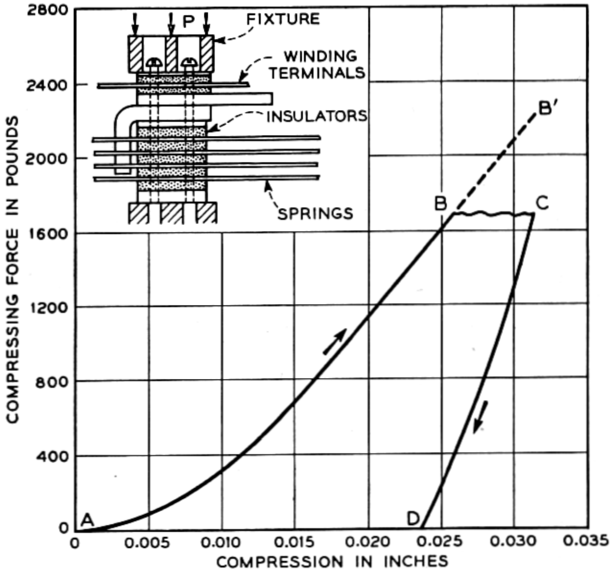

Fig. 1—Compression cycle of a relay contact spring pile-up assembly.

Pressure clamping during manufacture enables the spring pile-up to better maintain its adjustment through cycles of humidity and drying, and to prevent displacement during installation and wiring. The action of a pile-up under this compression is illustrated in Fig. 1. Curve AB represents the application of a 1,700-lb force to the pile-up by a power driven fixture prior to tightening of the pile-up screws. At the start, the relationship is not linear due to "nesting" of the parts, but a linear slope is soon reached, representing the stiffness of the pile-up without the screws. At the point B the two screws are tightened with a controlled torque; further compression takes place, indicated by the jagged line BC. An estimate of the tension put into the screws by this tightening operation can be made by extrapolating the curve AB to the point B^1, vertically above the point C. When the pressure fixture is released, the pile-up tends to expand and follows the line CD. The slope of this line represents the combined stiffness of pile-up parts and screws, which makes it stiffer than the original compression slope. When the pile-up is released, an equilibrium point is reached where the tension in the screws equals the force with which the pile-up tends to expand.

A series of measurements on a typical relay pile-up screw and clamp plate assembly is shown in Fig. 2 to illustrate the stress-strain relationship when a force is applied axially to put the screws under tension. As force is applied, Hooke's law is followed up to the point A; strain is proportional to the stress and no permanent deformation takes place. Beyond point A the elastic limit of the metal is exceeded and permanent deformation begins. When a point B is reached, somewhere below the breaking point of the screw, and the force is released, a permanent deformation results. Note that, in Fig. 2, the high strength screw will permit a higher screw tension without deformation – and its resultant looseness of the pile-up – than will the lower strength screw.

Analytical methods are available for estimating the range of screw tensions that exist during the life of the relay. By taking into account the known cold flow characteristics of the insulators with the relay in the dry state, a minimum value can be estimated. It should be of sufficient value to hold the springs securely in place. By considering the conditions that obtain in the humid state, maximum value of tension can be predicted, which should not exceed the strength characteristics of the materials used.

To determine how well the design objectives for stability are being realized, accelerated laboratory tests are made upon the relay, and from these results predictions can be made as to its performance during its life. In the telephone system, relays are generally subjected to repeated cycles of alternate humid and dry environments over the years. Humid conditions exist during the summer season, followed by a dry exposure during the winter months when the central offices are heated. Experience has shown that a relay exposed for six days to 90 per cent relative humidity at 85°F will be comparable to those observed in service in humid localities. Although the six day exposure is admittedly an accelerated test, the dimensional changes produced are approximately the same as those caused by the accumulating effect of fluctuating humidity during the entire season. Similarly, a period of six days exposure to 120°F produces the same effect of drying as that which occurs during the heating season.

By making careful measurements on an adjusted relay of such important parameters as operate current, releasing current, contact separation, contact spring tension, armature back tension, stud gaps, etc., and then subjecting the relay to repeated cycles of humid and dry conditions, repeating the measurements after each exposure and noting the changes, a good appraisal of the relay can be made. A repetition of the test will reproduce the same pattern of results as the first cycle unless permanent deformation of the materials in the relay has taken place.

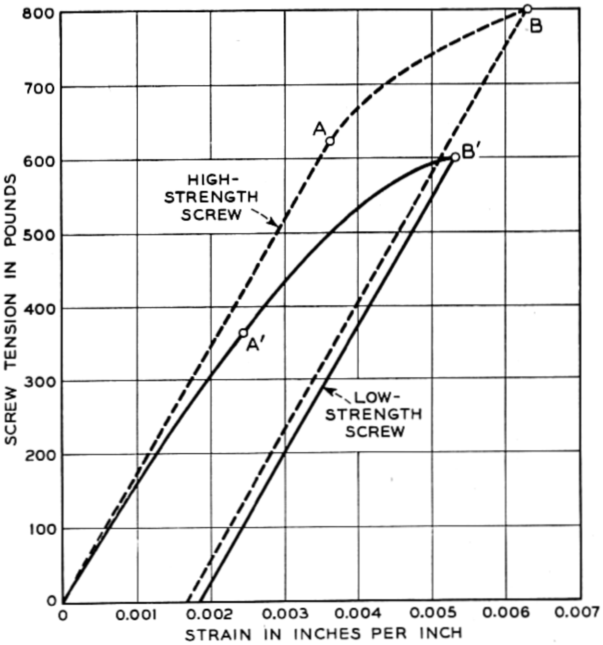

Fig. 2—Strength of relay pile-up screws.

COIL CONSTRUCTION

If, for any reason, the winding of a relay should become open during its life, usefulness of the relay ceases. One of the most prevalent causes for failure of this kind can be due to so-called corrosion of the wire. This is not corrosion in the ordinary sense of the word, but is caused by an electrolytic action within the coil when an electrical potential is applied to the winding. This action can take place only in the presence of moisture. If there are any active impurities in the insulating materials intimately associated with the copper wire, an electrolyte is formed and disintegration of the wire proceeds to the point where failure may occur. This trouble is accentuated with coils using small diameter wires, because with the smaller cross-section of copper, failure of the section will occur in a shorter period of time.

There are two methods of approach to minimize corrosion failure. One is to thoroughly dry the coils, and in this condition seal them in a potting compound, which prevents the entrance of any moisture into the coil, or enclose the coil in a hermetically sealed chamber. For relays this is an expensive and cumbersome way to overcome corrosion troubles. The second and more practical method is to use, in the construction of the coil, insulating materials that are chemically inert and free from corrosion promoting impurities.

For many years, studies were made with a view towards eliminating the occasional corrosion failures of fine wire windings which occurred under unfavorable atmospheric and circuit conditions. Although improvements were effected by the use of the better grades of phenol fibre for spoolheads and waxed varnished papers for core and winding insulation, an entirely satisfactory coil was not achieved until the use of cellulose acetate insulation was adopted. This material, in thin sheet form, can be applied to spool-wound coils, where the coils are wound individually, and the so-called "filled" coils, where a multiple number are wound simultaneously on automatic winding machines. The coils are wound on a mandrel, as many as twelve individual coils per mandrel, with a thin sheet of insulation between the layers of wire. The "stick" of coils is wound so as to leave a small separation between coils to provide insulation at the ends of the coils and to permit cutting the stick into individual coils, after which they are assembled to relay cores using conveyor assembly methods. This results in not only a more economical coil, but in a higher quality coil as well. The thin sheet of insulation between the layers of wire, generally not provided on the spool wound type of construction, eliminates the occurrence of short-circuited turns.

The degree of improvement obtained by the use of cellulose acetate over the materials formerly used is shown in Fig. 3.[1] This is the result of an accelerated corrosion test adopted as a means of obtaining data on proposed constructions, using as a basis for comparison, the performance, in this test, of the earlier spool wound construction. The latter had given satisfactory service in the field, only occasional failures occurring under the most severe circuit and atmospheric conditions. This test is made with double or triple wound coils since these represent the most

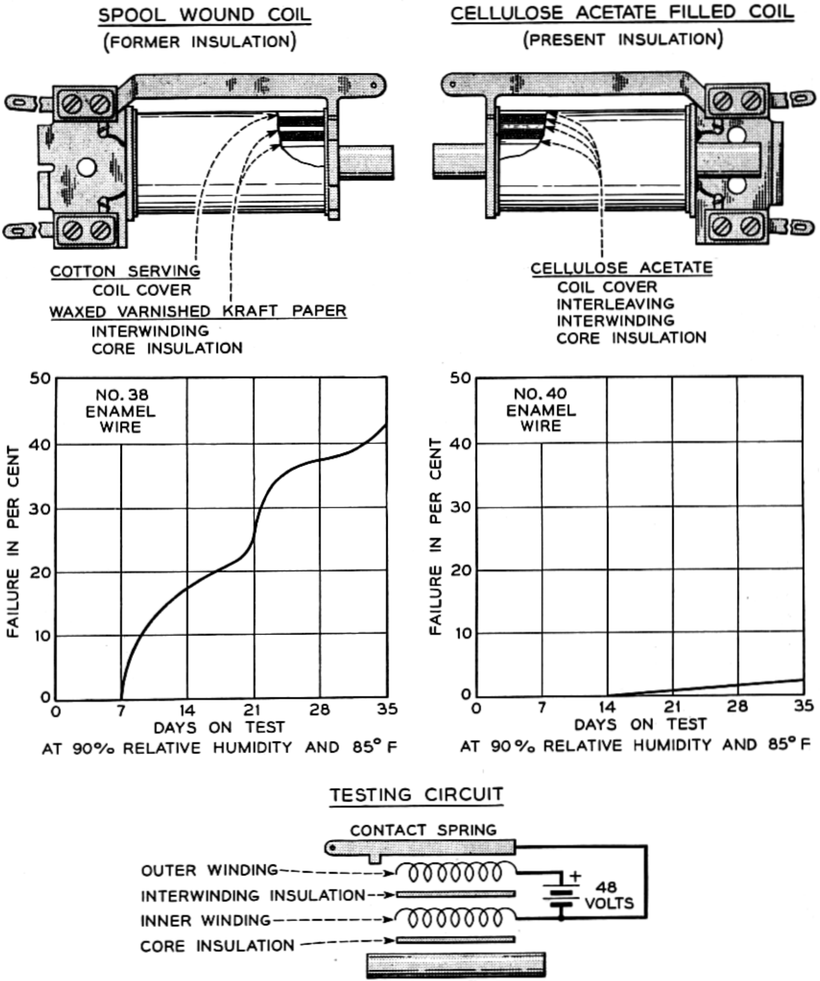

Fig. 3—Corrosion tests on relay windings.

serious conditions. A group of coils are subjected to 90 per cent relative humidity at 85°F with negative potential applied to the inner winding and positive potential to the outer winding. No current flows in the windings. Depending upon the type of apparatus in which the coil is used, other parts of the structure may be made positive or negative to simulate actual service conditions. When electrolytic action takes place, copper is always eaten away from the positive electrode. Consequently in practice where there is a choice, it is better to keep the winding negative with respect to its surroundings. During a 35 to 40 day period, continuity checks are made periodically using a Wheatstone Bridge having a battery supply of $1\frac{1}{2}$ volts in a series with 10,000 ohms. This method of test does not provide high enough voltage nor permit flow of sufficient current to establish continuity through a minute length where the wire may be corroded through, nor does it cause a reduced section of wire to burn out. In other words, this method of test does not restore continuity in a corroded through section nor does it destroy metallic continuity. Thus more consistent results are obtained than if higher voltages or currents were to be used. The marked superiority of the cellulose acetate insulated coil is apparent, and experience with its use in service has shown that corrosion failures have been eliminated.

From time to time the question arises as to how the cellulose acetate insulated coil compares with coils vacuum impregnated with a varnish and employing other types of insulation for use in equipment for the Armed Services where atmospheric conditions are more severe than those ordinarily encountered in the telephone plant. Frequently specifications for these applications require impregnation of the windings. Tests have shown that impregnation will extend the life of a coil employing inferior materials, but that corrosion will take place in a shorter period than where cellulose acetate is used throughout without impregnation.

Results of such tests are shown in Fig. 4 where the various groups of coils were kept in a humidity chamber at 95 per cent relative humidity. The temperature within the chamber was raised and lowered between limits of 85° and 150°F in cycles so as to produce severe condensation on the coils. Each cycle, plotted as abscissae represents 24 hours of exposure. The top two curves IIIA and IIIB show the failure rates of two groups of coils constructed exactly alike except that one group was impregnated while the other was not. They were cellulose acetate filled coils, but used lead-out wires insulated with commercial grades of braided cotton. The two curves IIA and IIB represent the results on two groups of spool wound coils having cellulose acetate core and interwinding insulation, but provided with vincellatate muslin covers and red-rope paper

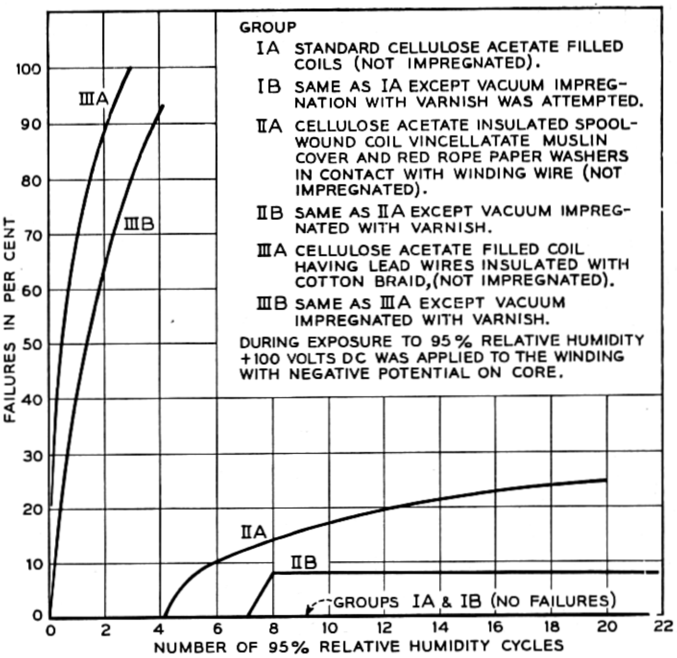

Fig. 4—Corrosion comparison of impregnated and non-impregnated relay coils.

winding washers. Likewise, one group was impregnated while the other was not. Fifth and sixth groups of coils having cellulose acetate insulation throughout with and without impregnation were exposed and there were no failures at the end of the test. This shows that the corrosive effects of impure materials can be retarded, but not overcome by resorting to impregnation. In general, impregnation of relay coils is not desirable because of the risk of contaminating the vital working surfaces of the relay.

In the normal operation of a relay when the circuit through its winding is opened, a transient voltage, which may reach hundreds of volts is generated across the winding terminals by the collapsing flux. If the insulation between the lead-out wires or between the lead-out wires and the end turns of the winding is not adequate, electrical breakdown causes arcing and repeated operation of the relay may cause ultimate disintegration of the wire and consequent failure of the relay. It is important, therefore, to design the coil so that lead-out wires under all conditions are properly spaced, and to provide adequate insulation between those portions of the winding where high voltages can exist. A test has been devised for use during manufacture which will detect an incipient failure of this kind. By pulsing the relay in its normal fashion the self-generated coil voltage on breaking the circuit can be observed on a cathode ray tube; any deviation in this voltage caused by momentary breakdown or shorted turns can be detected readily.

Another source of coil failure is lead breakage, caused principally by fatigue of the small copper wires. Copper has a low fatigue strength and if it is subjected to repeated bending strains, eventually it will break. As the relay operates and releases, impact of the armature against the core and backstop causes shock and vibration of the coil; coil construction therefore needs to be such that strains are not imposed upon the fine wire by this motion.

On spool wound coils, being individually wound, the fine winding wires can be reinforced by stranded lead-out wires for connecting to the relay terminals. Besides, the coil is generally wound tightly on the relay core. These factors, to a large extent, preclude lead breakage. With the cellulose acetate filled coil it is desirable to bring the winding wire directly to terminals on the terminal spoolhead to which the end of the coil is later bonded. Since the filled coil must slide loosely over the core for assembly reasons, it can have a small lateral motion at the non-terminal end. To eliminate this movement a "motion limiting" washer has been provided to fit snugly over the core and which is bonded to this end of the coil.[2] The washer and the way it is used is illustrated in Fig. 5. In assembly, the thin cellulose acetate faced phenol fibre washer and the non-terminal spoolhead are forced over the knurl on the core and the washer is bonded to the end of the coil. The tight fit of the washer on the knurl is the feature that prevents lateral movement of the coil. There is always some slight shrinkage of the cellulose acetate filled coil in the

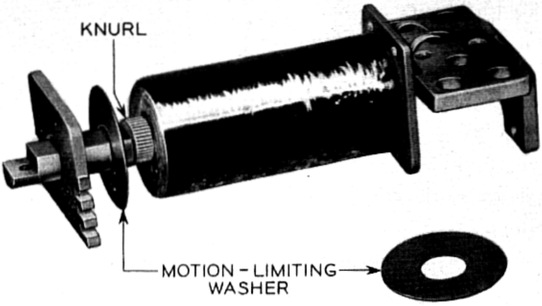

Fig. 5—Relay coil employing a motion limiting washer to prevent lead breakage.

longitudinal direction, but the washer can move with the coil, although eliminating lateral movement. Use of this washer has practically eliminated fatigue lead breakage.

CONTACT RELIABILITY

Since the opening and closing of contacts are the prime objectives of a relay, it is extremely important that the contacts themselves are made reliable. To realize these objectives, several factors should be taken into consideration. First is the contact material. While much could be said regarding the behavior of contact metals, space does not permit more than a brief treatment. The contact should maintain reasonably low resistance and under the environment in which it is used, be able to withstand the erosion. Electrical resistivity of most metals is low enough to be satisfactory from the resistance standpoint, but unfortunately, most of them develop tarnish or corrosion films when exposed to the atmosphere, thus increasing the contact resistance and rendering them unsuitable for a contact. These metals are sometimes referred to as "base" metals, and include aluminum, brass, bronze, copper, chromium, nickel and stainless steel. There is a much smaller group of metals known as "noble" or precious metals, such as platinum, palladium, gold and iridium. These are relatively free from the tendency to tarnish and will maintain low contact resistance. Alloys of these metals and certain alloys in which silver is included are widely used in the telephone plant. Pure silver is also used and is attractive because of its low cost; however, it has a tendency to form high resistance tarnish films and therefore has limitations in its use. It is employed in signaling circuits where the contact makes or breaks current. Its contact resistance remains low because the films that form on the silver are broken down or destroyed by the arc. It is not employed in circuits carrying voice currents on account of its tendency to introduce noise.

Enough metal must be provided to give satisfactory life. Each time a contact makes and breaks an electrical circuit, a small part of the metal may be lost, so that life may be considered roughly proportional to the volume of metal available for erosion. The pair of contacts must have sufficient height to provide enough contact spring clearance to allow for spring adjustment and to insure that the springs will not touch during the normal operation of the relay. At least one contact of a pair must be large enough, that is, present a sufficiently large target area, to insure full registration of the contacts with normal manufacturing variations of the position of the contacts on the springs and with the variations in alignment of the springs during assembly.[3]

In the early days of relay design, contacts were attached to the springs by riveting. In fact, many of the relays manufactured abroad today are made in this manner. In this country, during the past 30 years or more, spot welding has largely replaced the riveted construction. This was done for economy reasons. Spot welded contacts, unless carefully controlled during manufacture, may not be so reliably attached as the riveted contacts and the likelihood of the contacts dropping off during the life of the relay may be greater. It has been found in welding the millions of contacts required in the telephone system that close control is required in several factors affecting the quality of welds obtained with any given material. Important factors are cleanliness of the welding surfaces, pressure between electrodes, welding current and the time during which the current is applied. In order to insure that these factors are at all times under control, and since the consequences are rather grave when poor quality welds are produced, it has been found desirable to institute frequent inspectons of the quality of welds at each welding machine on a sampling basis. Periodically a small number of contacts are subjected to a destructive test in which the force required to shear off the contact is measured. In this manner, any deterioration in the quality of welds can be detected early, and corrective measures can be applied.

One type of failure sometimes experienced with relays is contact locking.[4] When a contact is closed by the operation of the relay it may become mechanically locked to the contact member with which it is engaged and fail to open when the relay is released. As a result of arcing as the contact closes and opens an electrical circuit there is a transfer of metal from one contact to the other. This building up and wearing away leaves both contacts roughened. If the opening and closing motion were along a perpendicular to the face of the contacts, this roughening would ordinarily have little effect. But with a slight sliding or rocking motion at the contacts after they come into engagement, small projections on one contact may lock mechanically in a cavity on the other and thus prevent the contacts from opening when they should. When contacts have locked, measurements have shown that forces in excess of 100 grams may be required to separate them.

This kind of failure can be avoided by employing an improved method of spring actuation.[5] This is illustrated in Fig. 6. At the top of the figure is a stud actuated contact spring assembly. The spring carrying the moving contact is tensioned away from the fixed contact member and exerts a force to hold the armature against the backstop when the relay is unoperated. A stud, moved by the armature, presses against the moving contact spring a short distance back of the contact to close the contact when the relay is operated. As will be noticed, the further deflection of the contact spring necessary to obtain the required contact force after closure, causes the moving contact to slide and rock slightly on the fixed contact. For the reasons previously mentioned such a contact is prone to lock when the conditions are favorable.

Now, the bottom of the figure shows a card actuated contact spring arrangement. Here a phenol fibre card is employed to operate the contact instead of a stud. The moving contact spring itself is pretensioned against the fixed contact to give the desired contact force. The card is held by two card springs that are tensioned away from the fixed contact in a slightly greater amount than the moving contact spring is tensioned toward it. As a result, when the relay is unoperated, the card holds the make contact away from the fixed contact. When the relay operates, the armature pressing against the top of the card pushes it toward the fixed contact and allows the contact to close. It is quite apparent that with this actuation the moving contact engages the fixed contact without

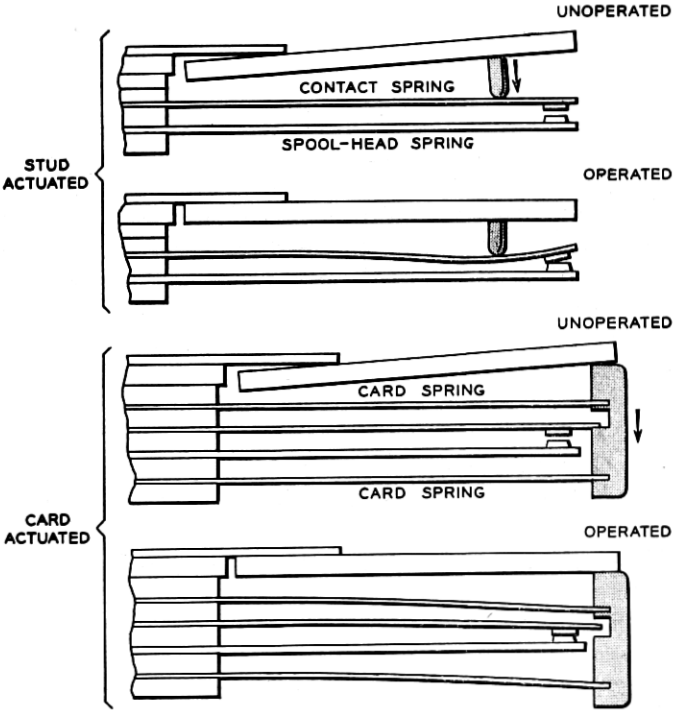

Fig. 6—Two methods of contact spring actuation and their influence on contact locking.

sliding or rocking on it and the tendency to lock is thus largely avoided. The likelihood of locking is further decreased because the restoring force is greater and is applied closer to the contact, and because of the impact of the card on the spring when the relay releases. With the contact closed there is clearance between the contact spring and the bottom of the slot in the card, and thus when the card hits the spring in opening, it is already moving and has acquired kinetic energy. This energy is available on impact to overcome any locks which may have occurred.

Recent studies have shown that erosion of electrical contacts on closure is due almost entirely to an arc occurring, in most cases, before the contacts touch.[6] When there is no arc there is no erosion. It has also been observed that the occurrence of an arc between the approaching contacts is influenced by operation in the presence of various organic vapors; for example, benzene derivatives.[7] The effect of such operation is to permit arcing on lower currents than is the case with clean contacts and results in increased erosion rates. This is true for noble metal contacts, and when so exposed they are said to have become "activated". A metal surface which has been activated by organic vapor remains active indefinitely if there is no arcing at the surfaces. With continued operation and accompanying arcing, the activating material is burned away, and the surface returns to the inactive condition, provided no contaminating vapor is present.

Some materials used in relays may give off organic vapors which can aggravate the arcing at the contacts. A series of experiments has been made by placing various materials under test in a small glass enclosure and proceeding to find if, and at what elevated temperature, vapor from the materials will give rise to arcing on "make", with contacts that are operating within the enclosure. The materials tested varied widely in their effects upon arcing at the relay contacts. In the solid organic group, they ranged from polystyrene, which produced arcing at room temperature, to teflon, which did not cause arcing until heated above 200°C.

The precise correlation between the results of these tests and the changes in erosion rates, which occur when these materials are used in the relay construction, has not yet been established. However, they may be used as an aid in the choice of such materials. Cases have come to our attention both in the laboratory and the field where the erosion rates of relay contacts operating in confined chambers were many fold those which occurred when the relays were operated in the open. This was at least partially ascribed to the presence of contaminating materials known to be present.

Another type of failure that is quite generally experienced in relay operation is "open" contacts due to small insulating particles present in the atmosphere becoming trapped between the contacts. This causes high resistance or open circuit and consequent circuit failure. Many attempts have been and are being made to reduce "open" contact troubles. Examples are filtering the air supply to the central office, enclosing the relay equipments in closed cabinets, pressurizing the enclosing cabinets, covering smaller groups of contacts by independent covers, employing twin contacts rather than single contacts, and enclosing the relay or its contacts in a hermetically sealed chamber. Even going to the extreme of completely isolating the relay from its surroundings is not a complete answer. There is always the possibility of failure by wear particles generated within the enclosure by the relay actuation.

The most widely employed method to reduce dust failures in the telephone plant is the use of twin contacts in combination with some of the above mentioned types of enclosures. If the incidence of dust failures followed the laws of probability, then elementary considerations would lead us to predict that if single contacts failed at the rate of once in 1,000 operations, the simultaneous failure of the two such contacts comprising the twin would be once in 1,000,000 operations. This is the so-called "square" law. However there are a number of reasons why this is not realized in practice and why the figure of merit for the twin contact is very much less than that indicated by the "square" law. In the first place, when foreign matter becomes lodged on a contact, it seldom falls out on the first subsequent operation, but will require a number of operations before it cleans itself; in fact, it may remain inoperative indefinitely. When this happens to one of the twin contacts, during this period of time, the twin contact is no better than the single contact. In practice, twin contacts are generally used with the same total force as the single contact, being nominally divided equally between the two contacts. This reduction in force per contact on the twin contacts is of considerable importance in reducing its effectiveness. Relay designs employing twin contacts that have been used in the past do not have complete mechanical independence of the two members to which the contacts are attached. Foreign material or protrusions under one contact can adversely influence the performance of its mate. In a new design of relay which is about to go into production, the design criterion that twin contacts to be most effective should be completely and mutually independent has been met. Laboratory tests and field experience obtained to date show a marked improvement over the former designs in regard to the incidence of open contact failures.

Tests have been made repeatedly in the laboratory for comparing the performance of twin contacts with single contacts, and arriving at a figure of merit. Data have also been collected from relays in service in the telephone plant on the basis of numbers of found open troubles on both types of contacts. As might be expected the results varied widely, with the twin contact being superior by a factor of anywhere from 3 to 100 with perhaps 10 as a reasonable figure.

MAGNETIC STABILITY

Magnetic materials in relays have been found to change in their magnetic characteristics with time and temperatures to which they are subjected in their normal usage. This effect is known as aging. The direction of the change is such as to decrease the permeability and increase the coercive force of the material. The degree of change in certain applications, such as relays in marginal and time delay circuits, may be so large as to be of serious concern.

A high grade of magnetic iron which has been extensively used in the telephone system has been found to age considerably under conditions simulating operation in the plant. Aging of iron is attributed to the precipitation of impurities such as carbon, nitrogen, and oxygen. The solubility of these elements decreases with decreasing temperature. When iron is cooled from a high temperature, impurities, such as carbides and nitrides, do not have sufficient time to precipitate completely, so a supersaturated solid solution is produced. Consequently the impurities tend to continue to precipitate slowly at low temperatures where the diffusion rate is extremely slow, and internal strains are produced which affect the magnetic properties.[8]

It has been found that if these parts are annealed in atmospheres of dry hydrogen instead of the ordinary "pot" anneal, this aging effect is greatly reduced. Not only is the aging effect reduced to where it is of no great engineering importance, but the magnetic properties of the material are improved. The maximum permeability is increased and the coercive force is decreased both by a factor of about two. The use of relays in critical applications is thus greatly enhanced.

The degree by which magnetic materials change by aging may be determined readily by laboratory tests. Long time aging effects can be simulated by baking ring samples of the material or the relays at 100°C for several hundred hours and measuring the magnetic properties of the ring specimens or the operating characteristics of the relays before and after aging. For "pot" annealed magnetic iron the effect of such aging is to decrease the maximum permeability by about 50 per cent and to approximately double the coercive force. When the iron is hydrogen annealed, the corresponding changes caused by aging will be about a 15 per cent decrease in maximum permeability and 15 to 20 per cent increase in coercive force.

The improvement in aging effect on relay performance obtained by the hydrogen treatment is illustrated in Fig. 7.[2] This was obtained on a design of relay having a closely coupled magnetic circuit for use in time delay circuits. The ordinates show the change in residual grams; hours of aging are plotted as abscissae. Residual grams represent the force with which the armature is held attracted to the core by the residual flux remaining in the magnetic circuit after the electrical circuit through its winding is opened. This force is a measure of the coercive force of the magnetic material. As was noted, the effect of aging is to increase the coercive force and hence the residual grams. For this relay, a change in residual grams will cause a change in the delay time of the relay under a given adjustment and is therefore important.

How hydrogen annealing improves the pull characteristics of a relay is shown in Fig. 8. This was taken on a relay designed for sensitive and marginal circuit applications. The curves show the grams pull, plotted as ordinates, produced on the relay armature at a given air gap by various values of ampere turns on the relay plotted as abscissae. The ability of the hydrogen treated relay to operate given loads on considerably smaller currents is obvious. This improvement is due to the higher permeabilities obtained by the hydrogen anneal.

There are other magnetic materials available for use in relays and in which the aging effect is practically non-existent or is considerably smaller than that just described. Several kinds of nickel-iron alloys known as permalloy are widely used in the telephone system where their

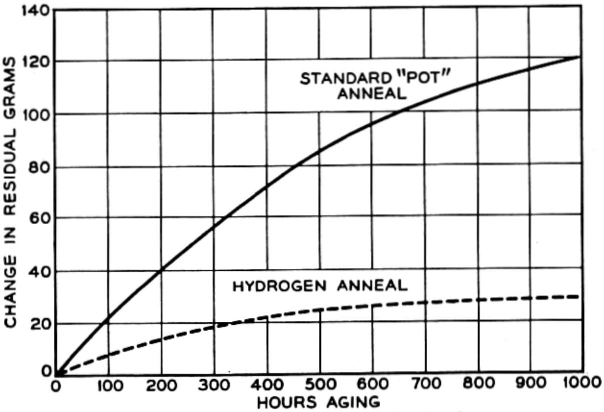

Fig. 7—Improvement in aging effect by hydrogen anneal.

excellent magnetic properties are needed in difficult applications. They are substantially non-aging. Low silicon-iron alloys are being more widely employed. They have good magnetic properties and the aging effect is small. Where the intrinsically inferior magnetic properties of low carbon steel alloys, such as SAE 1010, can be tolerated they are used. While initially they have poorer magnetic characteristics than magnetic iron, their aging effect is considerably smaller.

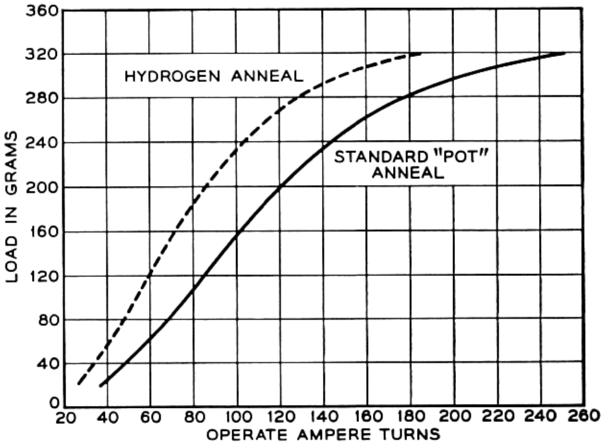

Fig. 8—Improvement in relay performance by hydrogen anneal.

STRUCTURAL STABILITY

Response of a relay depends upon the value of the magnetic force of attraction produced between the armature and core when the coil is energized, and upon the magnitude of the mechanical forces acting upon the armature. To keep the response constant during the life of the relay, it is essential that the relationships between these two forces be not changed. The force of attraction varies approximately inversely with the square of the length of the air-gap between the armature and core. Since this distance is usually small, any small change will have a relatively large effect on the pull. The core and armature, together with their associated members, should be of stable design and secured in such fashion that their dimensional relationships remain unchanged when the relay is subjected to shock, vibrations, and stresses incident to attaching the relay to its mounting. The design of the structure and the thermal coefficients of expansion of the materials used should be such that deformation does not take place when the temperature is varied throughout the operating range.

Moving parts, such as the armature and its suspension, together with the associated actuating members and springs, should move freely under all conditions without binding or friction. Since friction is inherently a variable quantity and difficult to control, it should be kept as small as possible, otherwise it will be a cause for instability. If the friction component is an appreciable part of the total load, the relay will be unsatisfactory, particularly for marginal operation. The friction part of the load on the moving system of a relay can be determined readily by an improved measuring technique which automatically plots the force required to move the armature, and its displacement, as it moves from its unoperated to its operated position. This is illustrated in Fig. 9. The top curve is the force required to move the armature and operate its associated contact springs as it moves from its back-stop to its fully operated position. The lower curve is the force acting on the armature that allows it to restore to its unoperated position. The vertical displacement between the two curves represents double the friction. Since friction always opposes motion, it adds to the force required to operate the relay and detracts from the force releasing the relay. If the ideal of no friction were obtained the two curves would coincide. When

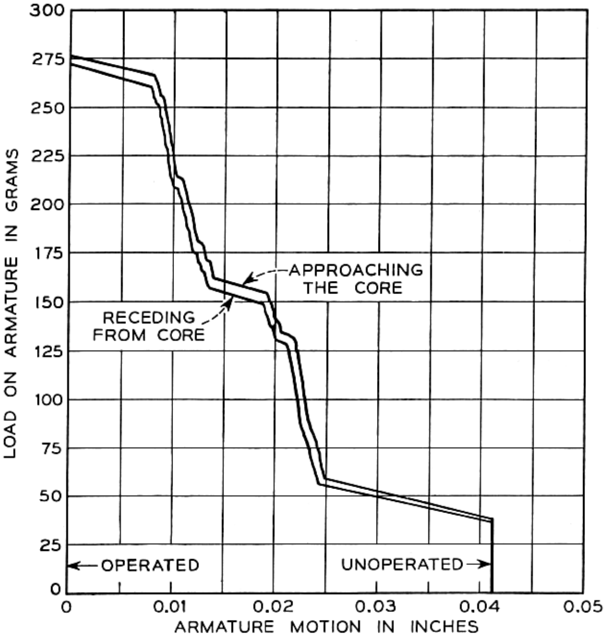

Fig. 9—Mechanical load of a relay and its friction component.

the displacement and hence the friction is large, aside from the fact that it is indicative of a rapid rate of wear, the relay would be unstable.

While the wear of the relay parts can be minimized by good design, it cannot be eliminated entirely, especially for relays required to operate a very large number of times during their life. For telephone relays the design objective is for a 40-year life. The effects of wear on performance to a great extent can ofttimes be counteracted by ingenious design. Fig. 10 is an illustration of such a case.[5] The diagram on the left shows a moving system of a relay in which the contact springs are stud actuated. The moving springs are tensioned toward the armature and exert a force tending to open the contacts. When the armature operates, the stud presses the moving springs into engagement with the stationary springs. There is no contact force when engagement is first made and further flexing of the spring is necessary to build up the contact force to the desired value when the armature reaches its fully operated position. As the contacts and studs wear, it is apparent that the contact force and consequently the load on the armature decreases rapidly. The stud wear becomes cumulative in its effect on the outside pair of springs as more springs are added to the pile-up.

The diagram to the right shows a moving system of a relay using what is called "lift-off" card actuation. The moving springs are ten-

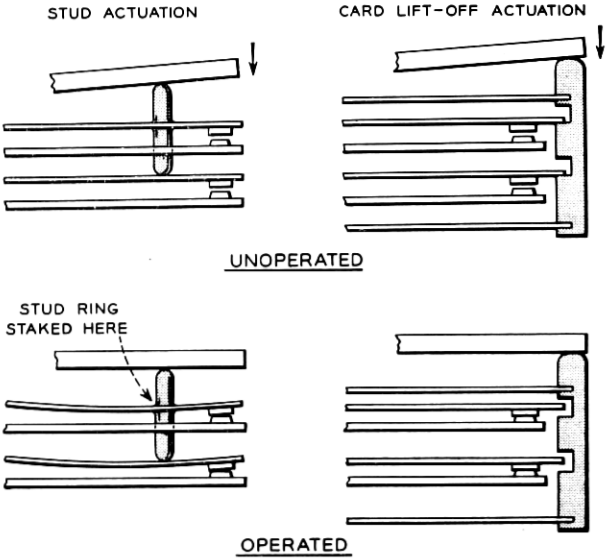

Fig. 10—Two moving systems of relays in relation to the effects of wear on their performance.

sioned, before assembly, toward the stationary spring by an amount necessary to give the desired contact force. Two supplementary springs are provided to support the card and tensioned to restore the armature and contact springs to their unoperated position. Upon operation, the motion of the card permits the contacts to close, and when engagement of the contacts occurs, the contact force reaches its predetermined value very rapidly. Further motion of the card, provided for by the width of the slot in the card, allows for wear of the contact and card without appreciably affecting the contact force or the load on the armature.

The effect of this wear on the contact force is shown in Fig. 11 for both types of actuation. For the stud actuated relay, as the contact and stud wear continues, the contact force decreases very rapidly. After 0.010 inch wear only about 6 grams remains out of an original 26 grams. This is accounted for by the fact that the combined stiffness of the moving spring in engagement with the stationary spring is 2 grams per 0.001 inch deflection. This requires 0.013 inch contact follow to establish a contact force of 26 grams when the relay is adjusted initially. For the card "lift-off" actuated relay where the moving spring had been pretensioned to give a contact force of 25 grams initially, after 0.010 inch wear of the contacts, the contact force will have decreased about 1 gram. This is because the stiffness of the moving spring is about 0.1 gram per 0.001 inch deflection. Card wear does not affect the contact force so long as it is provided for by the width of the slot in the card.

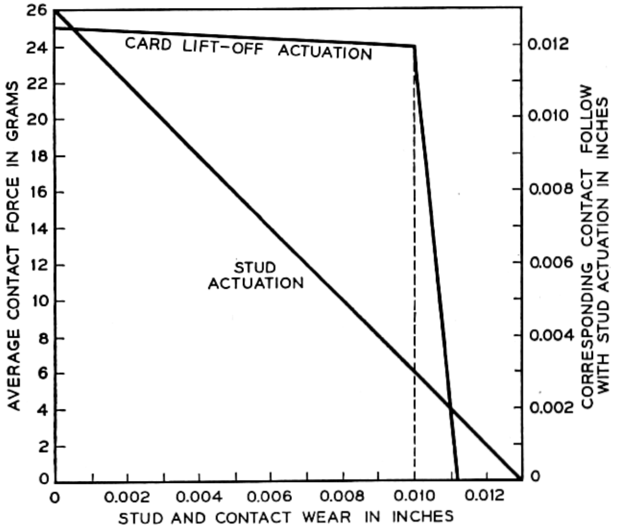

Fig. 11—Comparison of effects of wear on contact pressure of a relay.

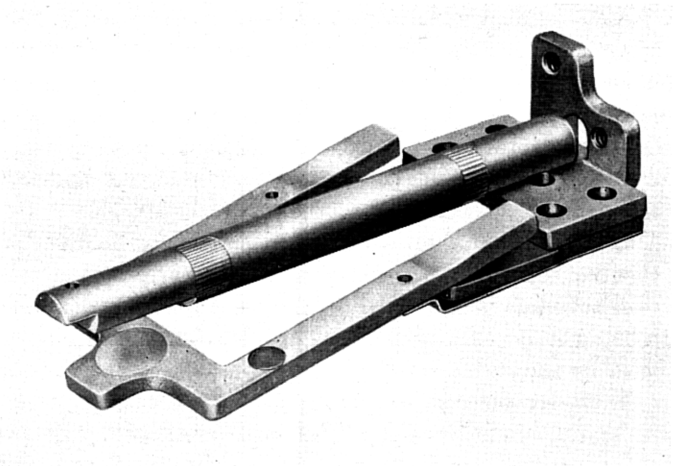

Fig. 12—Magnetic circuit of a relay having embossed pole faces.

Another instance where the effects of mechanical variations upon its performance have been largely nullified by design, is in the design of slow release copper sleeve relays. To make most effective use of the copper sleeve, which causes the delayed action, it is desirable to provide as low a reluctance as possible of the magnetic circuit when the relay is in the operated position. Instead of providing small non-magnetic separators in the air-gap between armature and the core as is usually

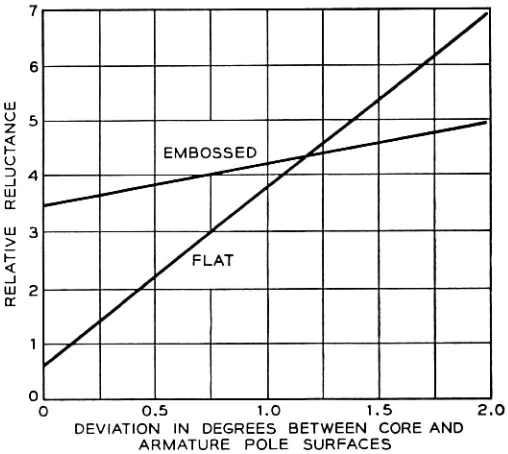

Fig. 13—Comparison of flat and embossed pole surfaces and their magnetic closed circuit reluctance with misalignment.

done with the ordinary quick-to-release relays, for slow release relays the armature is allowed to contact the core, finish to finish. When plane flat pole face surfaces are provided, it is expensive and difficult to insure in commercial practice that precise and uniform alignment of the pole face surfaces will obtain. Variations in the alignment of these two surfaces will cause variations in the closed magnetic circuit reluctance and consequently on the release time of the relay.

In Fig. 12 is shown a design where the necessity for holding the alignment of core and armature so precisely is not so great.[9] A spherical surface of rather large radius is embossed on the front end of the armature, so that with commercial variations in alignment, the armature always presents a point on the surface of a sphere for contacting the flat surface of the core. Similarly, the legs of the armature where they pivot on the front ends of the hinge bracket are likewise embossed. The results of the effects of these structural differences on the closed circuit reluctance are shown in Fig. 13 for a design with flat surfaces and one with embossed surfaces. While it is true that with perfect alignment the relay with flat surfaces will give longer release times, it is apparent that as variations in alignment occur from time to time and from relay to relay, it will have larger variations in performance than the relay with the embossed surfaces. This is a feature which has proven of great value in the manufacture of slow release relays of reasonable time precision.

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