

July 25, 1950

E. R. MORTON ET AL

2,516,790

SLOW-ACTING QUICK-RELEASE RELAY

Filed Feb. 24, 1947

4 Sheets-Sheet 1

FIG. 1

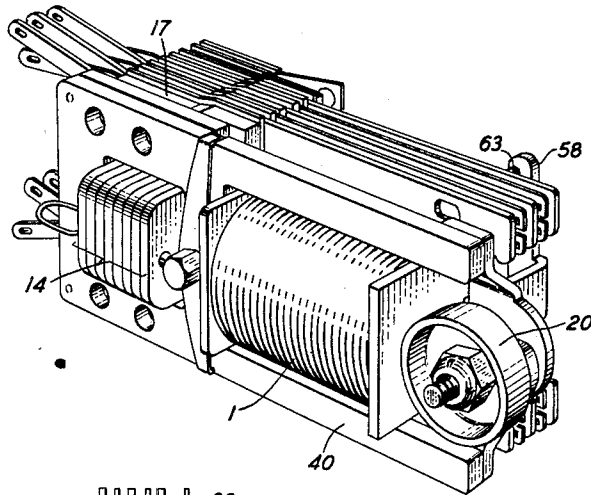


FIG. 2

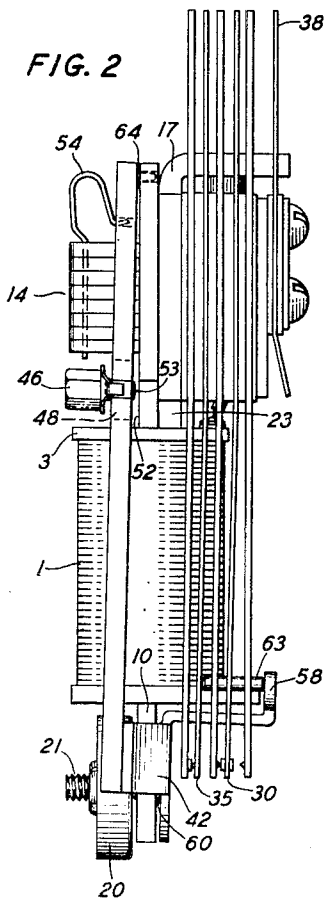
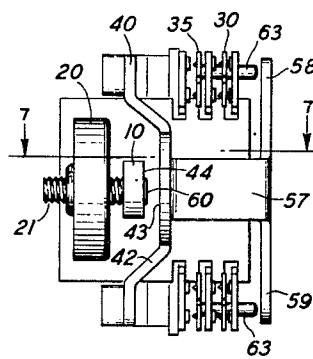


FIG. 3



INVENTORS: E. R. MORTON
H. M. STOLLER
BY P. C. Smith

ATTORNEY

July 25, 1950

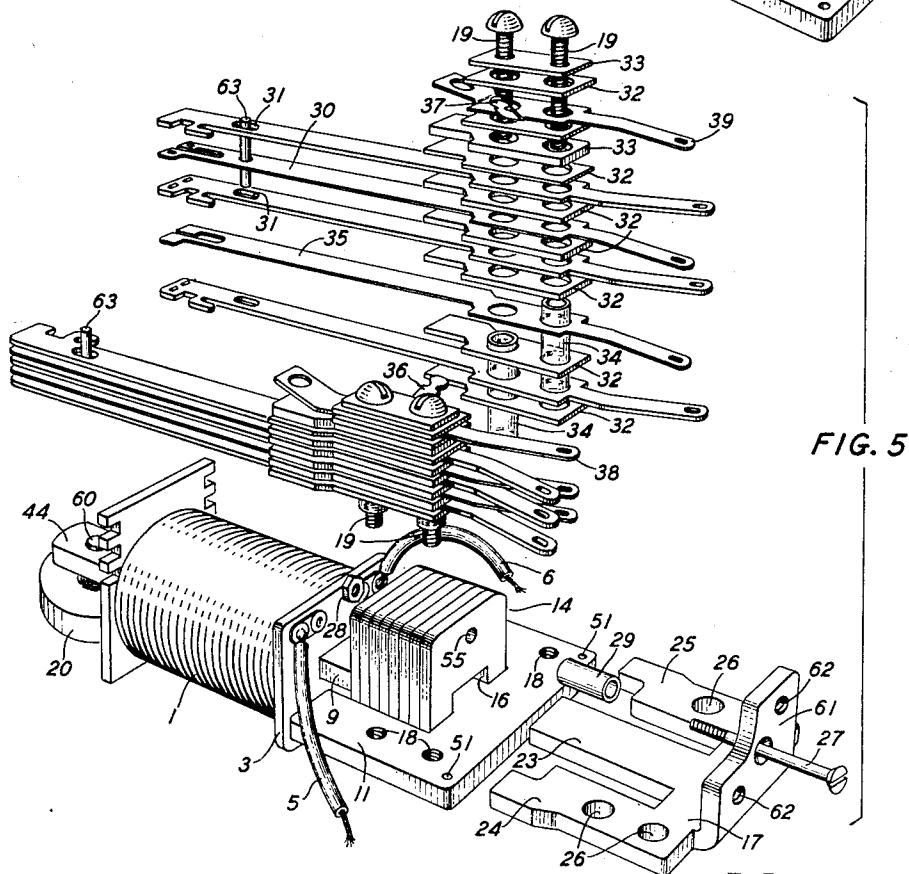
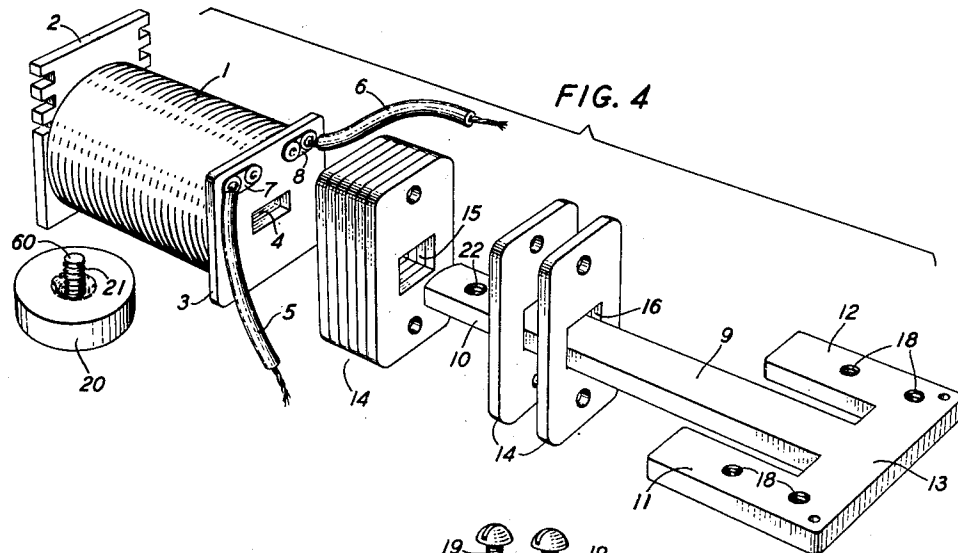
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INVENTORS: E. R. MORTON
H. M. STOLLER
BY P. C. Smith

ATTORNEY

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4 Sheets-Sheet 3

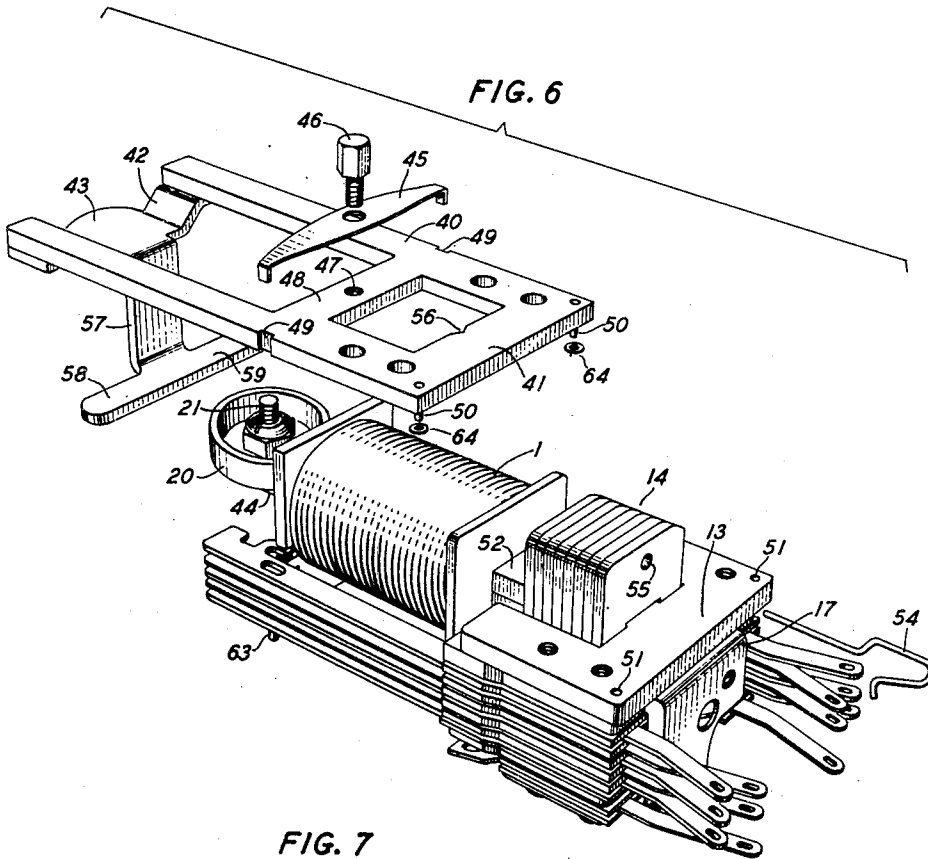
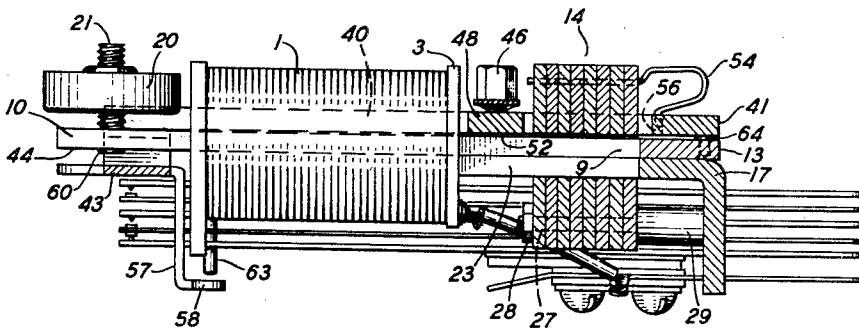


FIG. 7



INVENTORS: *E. R. MORTON*
H. M. STOLLER
BY *P. C. Smith*
ATTORNEY

July 25, 1950

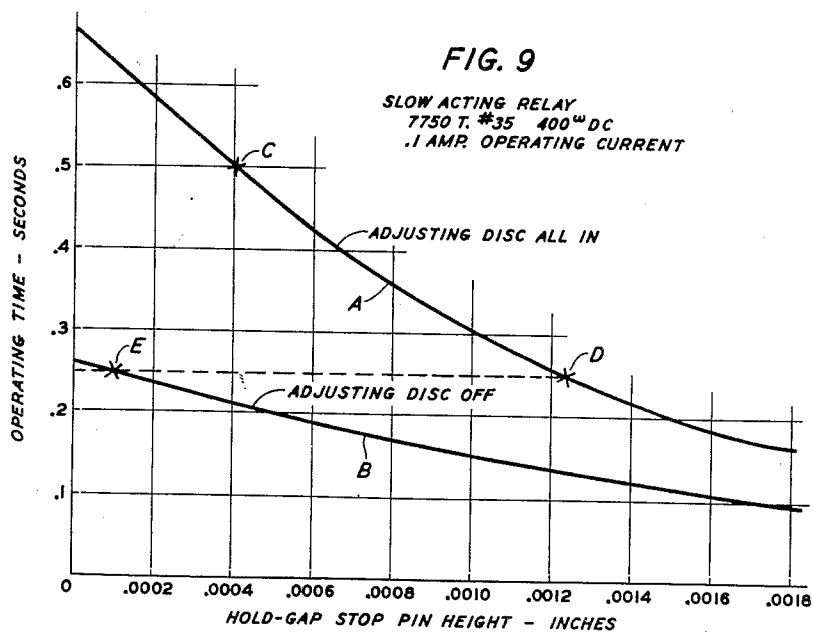
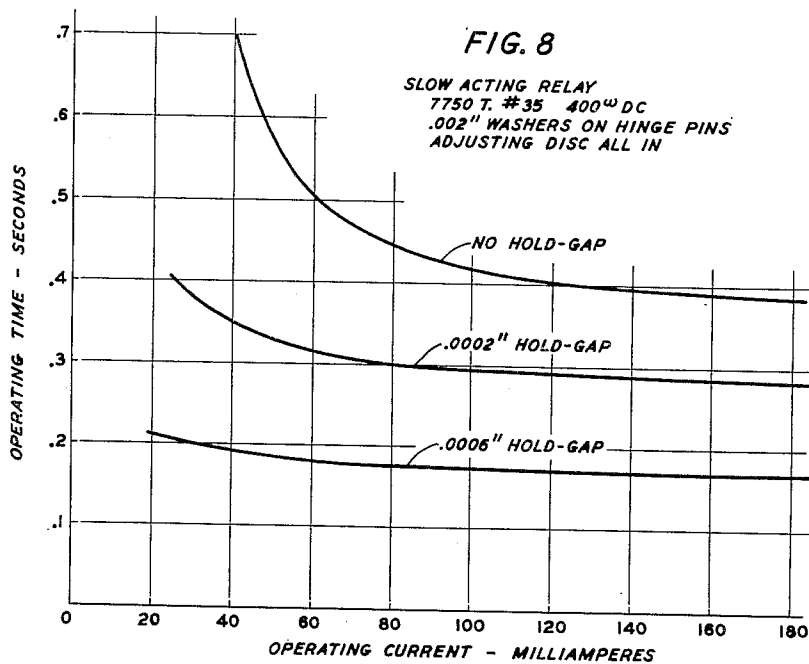
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SLOW-ACTING QUICK-RELEASE RELAY

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4 Sheets-Sheet 4



INVENTORS: E. R. MORTON
H. M. STOLLER
BY P. C. Smith

ATTORNEY

UNITED STATES PATENT OFFICE

2,516,790

SLOW-ACTING QUICK-RELEASE RELAY

Edmund R. Morton, Brooklyn, N. Y., and Hugh M. Stoller, Mountain Lakes, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application February 24, 1947, Serial No. 730,360

11 Claims. (Cl. 175—372)

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This invention relates to electromagnetic relays and specifically to improvement of those of the slow-to-operate type.

There has been for some time an unsatisfied demand for a slow-operating relay of the electromagnetic type which is characterized by a controllable operating time delay of the order of one-half of a second or less. There has been no such relay structure in the art which would meet the requirements of space, cost, efficiency and reliability prescribed for such a relay for telephone switching application. It has been an almost universal practice to employ slow-releasing relays, with associated additional relays and circuits, or condenser-resistance time delay networks with vacuum tubes for fast relays, to accomplish indirectly the desired slow-to-operate effect.

In Reissue Patent 14,834 to J. Erickson, dated April 6, 1920, is disclosed an electromagnetic relay structure which is exemplary of the slow-to-operate variety found in the prior art. Even in view of this type of disclosure, which unquestionably embodies qualities of a slow-operating relay, it has been considered advisable by those skilled in the art of telephone switching to favor complicated circuits and additional relays to accomplish the desired slow-to-operate function. Disclosures such as the above are not considered as embodying necessary qualifications of efficiency, space requirements, low manufacturing cost and reliability of operation and control to permit their employment in lieu of the relatively complicated arrangements in current use.

Disclosure to the art of a single satisfactory relay which will preclude further necessity of employing the aforementioned undesirable arrangements presently employed is a substantial contribution to the advancement of such art. Such a contribution represents the solution to what has been considered as a deficiency in the art, unsatisfied prior to the advent of the present invention.

The present invention rests in mechanical, electrical and magnetic characteristics of an electromagnetic relay structure whereby the relay can accomplish controlled results heretofore realized only by the use of a plurality of relays cooperating with external electrical circuits as heretofore mentioned.

The embodiment of the invention disclosed herein is an electromagnetic relay of flat type construction and of the multiple contact spring variety employing to some extent the electromagnetic delay principle disclosed by Erickson,

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above. The core and armature are hinged through a path of low magnetic reluctance. This is known as the hinge gap. There are two other operating armature-core air-gaps located on opposite faces of the flat core at different distances from the hinge. Located on the core between the hinge gap and the one of the other gaps nearer thereto, known as the hold gap, is a short-circuited electrical winding, shown as a copper slug of high electrical conductivity. Located on the core between the hold gap and the main operating gap is an energizing winding. The reluctances of the hinge gap and hold gap, when the relay is unoperated, are low by virtue of the construction of cooperating parts thereof. The reluctance of the furthestmost air-gap, hereafter known as the main gap, under the same conditions is relatively large since it is normally open while the hinge gap and hold gap are normally closed. Since the hold gap and main gap are on opposite faces of said core and since they are located at different distances from the hinge, they will produce opposing moments on the armature when the magnetic circuit is energized. The relative magnitudes of said moments at instants during the transient period following energization of the operating winding are determined by the resistivity of the slug, the reluctance of the magnetic circuits involved and the moment arms represented by the respective distances said air-gaps are removed from the armature hinge.

The latter parameters, for the most part, determine the operating time element or constant of the relay structure. The exemplary embodiment disclosed herein allows these opposing moments, when acting on the armature, to dictate a controllable and reliable time element on operation in the order of one-half of a second or less. Other constructional features, to be explained later, permit the operating time element to be substantially independent of ampere-turns energization and spring loading within capability limits of the relay.

One feature of this invention is the realization of an armature hinge arrangement of controllable and somewhat critical low magnetic reluctance. The critical nature of this reluctance pertains to specific embodiments and not to the scope of the invention as will be herein-after discussed.

A second feature is an operating or main armature air-gap, of relatively high reluctance when the armature is unoperated, opposing a holding or auxiliary armature air-gap, of controllable low magnetic reluctance, said two air-

gaps located at different distances from the armature hinge.

Another feature of this invention is unloaded initial movement of the armature upon operation of same in order to achieve a time element independent of spring loading.

A fourth feature of particular importance is an electromagnetic relay structure comprising a core of magnetic material carrying an operating winding and a short-circuited winding, said windings being mutually spaced apart on said core, and an armature of magnetic material hinged to said core, different portions of said armature forming with said core two air-gap paths, one of which occurs at the core space between said windings and the other of which occurs remote from said space.

Still another feature of this invention is the provision of a steady-state flux as well as a transient flux in the hold gap between windings, whereby the available reliable time element of the relay is increased beyond the limits available in the prior art.

A further feature is an electromagnetic relay structure of the type outlined previously, the operating time delay of which is substantially independent of ampere-turns energization available within capability limits of the structure.

An important cumulative feature is a combination of the above features, with others, to produce a reliable, efficient and easily manufactured relay structure, characterized by the operating qualifications heretofore briefly explained and not possessed by disclosures of the prior art.

The following is a general description of the drawings forming a part of this disclosure:

Fig. 1 is a perspective view of an electromagnetic relay embodying features which constitute the invention. This relay normally operates in the position shown wherein the armature rests substantially in a vertical plane and moves horizontally when attracted or released. The relay disclosed is capable on the other hand of operating in any desired position. The relay is here shown unoperated;

Fig. 2 is a top view of the relay of Fig. 1 and shown in an operated status;

Fig. 3 presents an end elevation of Fig. 2 typifying an unoperated status of the relay;

Figs. 4, 5 and 6 constitute a progression of assembly stages shown in exploded perspective;

Figs. 4 and 5 illustrate assembly stages associated particularly with the right side of the relay of Fig. 1;

Fig. 6 is concerned with assembly stages pertinent to the left side of the relay of Fig. 1;

Fig. 7 is a partially sectionalized view similar to Fig. 2 and taken along the line 7—7 of Fig. 3. For ease of presentation the relay of Fig. 7 has been rotated 90 degrees from the position of the relay shown in Fig. 2. Fig. 7 illustrates an unoperated status of the relay; and

Figs. 8 and 9 are curves of the data from laboratory tests on samples of this relay. These curves will be explained after a complete description of the construction and operation of this structure is set forth.

The important features of this relay structure can best be described by reference to the assembly views of Figs. 4, 5 and 6, reserving the remaining figures for general comment and description of specific aspects of operation or relative positions of important parts during operation. The same reference numerals refer to the same parts in all figures.

Reference numeral 1 represents a winding assembled between non-magnetic insulating spoolheads 2 and 3 and retaining a rectangular axial opening 4 therethrough. The two ends of the winding 1 terminate in leads 5 and 6 attached to terminal lugs 7 and 8 fixed in spoolhead 3.

The core 9 is of flat E-shaped construction having its middle leg 10 longer than the two outside legs 11 and 12, all of which legs are integral with a core crosspiece 13. The middle leg 10 of core 9 is of dimensions suitable for a snug fit into the axial hole 4 through coil 1 and spoolheads 2 and 3. Numeral 14 indicates numerous copper plate-like sections adapted to encircle the leg 10 of core 9 by means of rectangular holes 15 substantially centrally located in said plates 14. When properly assembled on the leg 10 of core 9 the copper slug pieces 14 are closely packed and assume the position shown in Fig. 5. The holes 15 in these plates 14, when the leg 10 of core 9 rests snugly along the bottoms of said holes 15 as in Fig. 5, expose unfilled portions 16, which portions accommodate leg 23 of frame mounting piece 17, hereinafter described.

The tapped holes 18 on core 9 are adapted to receive the bolts 19 which fasten the spring pile-up assemblies to the frame of said relay as hereinafter explained.

Numeral 20 designates a disc of magnetic material threaded to engage the stud 21 which is staked in hole 22 of core leg 10 to form a stop pin 23 for the armature main air-gap as will be mentioned later. The disc 20 is adjustable on stud 21 when the latter is fixed to the core leg 10 and may be removed entirely if desired.

The frame mounting piece 17 has a middle leg 23 thereof and two outside legs 24 and 25 and in addition an angle extension 26 with holes 27 therein adapted for mounting said relay. The leg 23 engages with a snug fit into the holes 16 through the copper slug pieces 14 as shown. The holes 26 in the outside legs 24 and 25 of frame piece 17 fit the bushings 28 and the complete assembly is held together by the spring pile-up bolts 19. The bolt 27 and nut 28 clamp the slug pieces 14 together and against the spacing bushing 29 which is positioned between the frame piece 17 and the slug pieces 14. In Figs. 2 and 7 it is seen that the position of winding 1 on leg 10 of core 9 is such that spoolhead 3 is fixed against the end of the leg 23 of frame piece 17.

Fig. 5 illustrates the nature of the spring pile-up assemblies. Insulator stud 30 is staked to spring 31 and passes through clearance holes 32 to thereby actuate contact springs 33 and 35 when stud 30 is moved by the armature of the relay. Springs 30 and 35 are somewhat thinner than are the other springs in the pile-up. Numeral 32 designates insulator strips. The parts numbered 33 are clamping plates and 34 indicates insulator sleeves adapted to fit over bolts 19, which sleeves extend over a sufficient length of the bolts 19 to insulate the contact springs therefrom. The spring pile-ups are fastened to the relay assembly by means of bolts 19 engaging tapped holes 18 in the core 9, the sleeves 34 fitting holes 26 of frame piece 17. The leads 5 and 6 from the winding 1 are soldered respectively to lugs 36 and 37 on respective winding terminals 38 and 39 of the two spring pile-ups.

The assembly stages of Figs. 4 and 5 produce a structure which is shown intact in the lower portion of Fig. 6 except that in Fig. 6 the assembled structure of Figs. 4 and 5 is turned over

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to expose the side thereof pertinent to the final assembly stage about to be described.

With reference to Fig. 6 the piece designated 40 is the armature of this relay. It is of H-shaped flat construction having one end bridged by an integral piece 41 and the other end bridged by a U-shaped piece 42, the face 43 of which cooperates with the face 44 of the core leg 10. This face 44 of core leg 10 is most clearly shown in Fig. 5 and indicated in Figs. 3 and 7. A spring member 45 is adapted to yieldingly apply pressure to adjusting screw 46 to hold it in adjusted position in armature 40. Screw 46 is adapted to engage tapped hole 47 in crosspiece 48 of armature 40. Spring 45 is positioned in notches 49 in the edges of armature 40. The purpose of this adjusting arrangement will be apparent from subsequent description of the operation of this relay.

Pins 50 on armature crosspiece 41 are adapted to engage holes 51 of the core crosspiece 13, with non-magnetic washers 64 interposed therebetween. The washers 64 may be in the order of thickness of .002 inch in order to provide a definite location of the hinge axis in spite of surface roughness or lack of flatness of mating core and armature surfaces. The armature crosspiece 43 is adjacent the core leg 10 at the area 52 of Fig. 6. The adjustment of screw 46 shown in Fig. 7 allows the armature crosspiece 48 to be adjusted as to its separation from the cooperating surface of leg 10 at area 52. The adjustment of screw 46 in Fig. 2 will permit the armature crosspiece 48 to approach the core leg 10 at area 52 only until the end 53 of screw 46 touches core leg 10. The screw 46 is thus an air-gap adjustment, at the hold gap area 52, for the unoperated status of the relay. The use of washers 64 at the pin hinge insures three-point contact between the armature and the core to give stable seating in spite of manufacturing variations in the flatness of mating surfaces.

Spring member 54 of Fig. 6 is inserted into the holes 55 in the slug pieces 14 and engages yieldingly in a notch 56 in the inner edge of the armature crosspiece 41, as shown in Fig. 7. This spring 54 at all times forces the crosspiece 41 of the armature into contact with the washers 64 and core crosspiece 13 and acts as an armature return spring to normally retain the armature in the positions shown in Figs. 3 and 7.

The offset projection 57 of the armature U-shaped crosspiece 42 has integral therewith two laterally disposed ears 58 and 59 which, after assembly as in Figs. 1, 2, 3 and 7, are adapted to actuate the contact spring operating studs 63. The insulator studs 63 in turn connect or disconnect cooperating pairs of contact springs which may in turn control external circuits or apparatus.

The disc 20 on the free end of the core leg 10 may have numerous adjusted positions when on end of the core leg, two of which are represented by respective Figs. 2 and 3. In Fig. 2 the adjustment is shown as positioning the disc 20 close to the surface of the end of core leg 10 and in Fig. 3, removed therefrom. The purpose of this adjustment is set forth hereinafter. The tip 60 of stud 21, on which disc 20 is threaded as illustrated in Figs. 3 and 7, acts as an operated stop for surface 43 of armature crosspiece 42.

An electromagnetic relay of the above type depends for its functioning on the effectiveness of short-circuited turns to divert the flux into one of

two parallel magnetic paths. By a well-known principle, for example as disclosed by Erickson's patent, short-circuited turns on a magnetic core, during the transient period following energization of said core by an energizing winding, will contain induced currents as a result of the increasing flux linking said turns. This current will set up a magnetomotive force in opposition to that which caused the induced current and thereby tend to limit the rate of build-up of the flux through the core section encircled by the turns. After a time lag the flux reaches a maximum steady value and the counter-magnetomotive force of such a group of short-circuited turns will disappear.

If, at such time as the short-circuited turns are effecting a counter-magnetomotive force on the normal or low reluctance path of the flux, there is an alternate magnetic path available, the flux will be diverted therethrough.

In the embodiment of the invention described herein, and in particular in Figs. 4 and 6 of the drawing, an energizing winding 1 is positioned on a core 9, upon which core 9 is also positioned a series of short-circuited turns represented by the copper slugs 14. These two structures are separated on the core 9 by a portion of the core indicated as area 52. The armature 40 is hinged to core 9 by means of pins 50 of armature crosspiece 41 unequivocally positioned in holes 51 of core crosspiece 13. This connection, along with the interposed washers 64, constitutes the armature hinge or hinge gap. The spring 54, which assists in holding the armature 40 in its unoperated position, insures that the surface of armature crosspiece 41 is held close to the surface of core crosspiece 13 in a magnetic path of low reluctance. When assembled, as per Fig. 7, the armature crosspiece 48 appears opposite to the core leg 10 at area 52, the hold gap, and the surface 43 of the free end 42 of the armature 40 is seen to cooperate with the adjacent free end surface 44 of core leg 10 at the main air-gap.

The copper slugs 14 are so positioned that the hinge gap and hold gap are in parallel in a series magnetic circuit with the core, the main gap and the armature. The slugs 14 are effective to limit the rate of change of flux through the core portion encircled thereby.

When unoperated the relay assumes a status exemplified by Fig. 3 or 7. The hinge and hold gaps are closed except for the amount determined by the adjusted position of the end 53 of screw 46 at the hold gap area 52 and except for the spacing in the hinge gap caused by washers 64. The main gap, free end areas 43 and 44 respectively of armature and core, is a relatively large air-gap. Under these conditions, when the winding is energized to create flux in the core, the slugs 14 will produce a magnetomotive force in opposition to that which produced the flux and this counter-magnetomotive force will prevent the flux from returning to the core via the hinge gap. The hold gap, at area 52, prevents the path of least effective reluctance at this time and consequently is traversed by the increasing flux. The main air-gap will transmit part of the flux, the rest returning to the hold gap by air leakage from disc 20 whenever said disc is present on the structure.

Initially the hold gap is closed, or nearly so, is of small flux path area and contains substantially the total flux. The main air-gap is open, is of relatively large area and contains only part

of the total flux. The forces represented by these conditions at the two air-gaps are large for the hold gap and small for the main gap. The hold gap moment about the armature hinge axis will be larger than the main gap moment and will hold the armature unoperated.

As the flux approaches a steady-state the counter-magnetomotive force produced by the copper slugs 14 decreases, allowing most of the flux to traverse the desired final path through the hinge gap. The loss of flux by the hold gap to the hinge path represents a loss of holding moment by the hold gap and at a predetermined time, depending on various adjustments, the ratio between the main gap moment and hold gap moment will have increased to a value at which the main gap will predominate. At this time the main gap force will attract the armature to its operated position to effect closure of cooperating contacts of the relay spring pile-ups.

It should be noted that in the case of the Erickson type of structure the flux in the hold gap approaches zero as a final value. In the structure of the present invention the hold gap flux approaches a definite lower limit, dependent on the ratio of hold gap and hinge gap reluctances.

The difference set forth in the latter paragraph above permits the attainment in the case of the present invention of longer time elements, or a smaller and cheaper structure for a given time element, with a given degree of reliability. This will be elucidated in the following discussion.

The induced current in the copper slug is a maximum an instant after the closure of the main or operating winding circuit and thereafter reduces in amplitude logarithmically with time. The maximum time element rating of such a structure is therefore dependent on the minimum practicable slug current to which it is reliably feasible to work. The holding force moment produced by this current, in addition to that moment produced by the return spring, balances the main gap force moment about the hinge axis. In order to obtain consistent and reliable performance from any given design the hold gap moment due to the slug current must be adequately large relative to the other moments in the structure. Therefore any feature of the design which will increase the holding force per ampere of current in the slug will increase the practicable time rating of the structure.

In the Erickson structure the holding flux is proportional to the slug current and the holding force is proportional to the square of the flux or current. Therefore as the slug current becomes small the holding force becomes very small, and thus a minimum practicable cut-off value is soon reached.

In the structure disclosed herein the flux across the hold gap is composed of two parts: The first part is due to slug current; the second part is a final value which persists after the slug current has reduced to zero (assuming that the armature were held unoperated) and is due to the magnetomotive force across the rear hinge gap. It is to be understood that the latter remark refers to the existence of a finite ratio of hold gap reluctance to hinge gap reluctance under these conditions. To be more specific, under steady flux conditions when the armature is unoperated the flux in the hold gap will be a finite amount, a proportion of the total flux determined by the ratio of the hold gap reluctance to hinge gap reluctance under these conditions. The logarithmic decay of the hold gap flux therefore ap-

proaches an appreciable finite asymptote instead of a zero asymptote as in prior art. It is this simple concept which we have discovered which enables a relay structure as disclosed herein to possess some of the superior operating qualities aforementioned.

It will be appreciated, from an understanding of the above discussion and description, that the control afforded of the flux condition in the relay structure is realized without the necessity of any polarization of the magnetic structure, as is commonly found in so-called polar relays. The latter relays employ a polarizing flux, usually produced by a permanent magnet or the equivalent, to effect in the magnetic structure a flux condition independent of the energizing or controlling flux produced by operating current. Wherever in the claims the descriptive term "unpolarized" is used, it is intended to mean not polarized in the sense that so-called "polar" relays are polarized, as above indicated.

The pull at the hold gap is proportional to the square of the total flux effective therein so that if the first part of the flux mentioned in the above paragraph is $\Delta\Phi$ and the second part is Φ the pull is proportional to $(\Phi + \Delta\Phi)^2$.

$$(\Phi + \Delta\Phi)^2 = \Phi^2 + 2\Delta\Phi \cdot \Phi + \Delta\Phi^2 = \Phi^2 + 2\Delta\Phi \cdot \Phi$$

since $\Delta\Phi^2$ is negligible when compared to the other terms of the equation.

Since Φ is independent of time the term Φ^2 can be balanced by pull developed at the main gap by a proper selection of the lever or moment arms involved. Thus the net pull due to slug current is proportional to the term $2\Delta\Phi \cdot \Phi$ where $\Delta\Phi$ is proportional to the first power of the slug current. Since Φ is large relative to $\Delta\Phi$ the pull per unit of slug current is substantially larger than in the Erickson design where it is proportional to $\Delta\Phi^2$.

From the foregoing analysis it is seen that for any selected minimum net holding magnet force it will be feasible and practical to attain that force with a lower slug current, or achieve a longer time element due to operating at a point further along on the decay curve of the slug current, with the structure disclosed herein.

It is necessary that the reluctance of the hinge gap be kept constant relative to the reluctance of the hold gap in order that the term Φ^2 can be controlled and kept in balance with the pull at the main gap. The present invention provides this control by introducing non-magnetic washers at the hinge pins.

There is an optimum range of thicknesses for the aforementioned washers. If they are too thin the final value of the hold gap flux Φ is small making the product $\Delta\Phi \cdot \Phi$ too small to effect a long time element. If the washers are too thick the total reluctance of the hold gap magnetic circuit is increased to the point where the time constant of the current in the copper slug is diminished so as to impair the large time element of the relay. With the particular size and proportions of structure disclosed herein, a washer of approximately .002 inch thickness has been found to be optimum. The drawings are representative of substantial full scale as regards the particular embodiment disclosed herein.

The adjustment of screw 46 determines the time constant of the holding magnet circuit. If the screw is backed away to produce a small air-gap the reluctance of the magnetic circuit is a minimum and the time constant a maximum. If the screw 46 is adjusted to produce a larger air-gap at the holding magnet surface the time

constant will be shorter. It has been found desirable to provide at all times a minimum height of this stop pin to assure a stable controllable time constant and to permit reasonable manufacturing variations in flatness of the mating surfaces of armature and core at area 52. In the particular structure disclosed a stop pin height of .0002 inch effected a time element of .35 second, while a stop pin height of .002 inch produced a time element of .12 second.

The adjustment of the stop pin screw 46 also affects the main gap. This effect is slight as the main gap is large relative to the change produced therein by the stop pin adjustment.

The adjustment of disc 20 on the end of the core at the main air-gap is a fine adjustment of the time element of the structure. The position of this disc, two examples of which are shown by Figs. 2 and 7, determines in part the amount of flux which is allowed to leak back to the hold gap by air paths. The adjustment shown in Fig. 2 represents the condition wherein an appreciable portion of the flux in the core will enter the disc 20 and thus by means of air paths leak back to the hold gap. This situation affords the main air-gap appreciably less than total available flux. The adjustment of disc 20 shown in Fig. 7, on the other hand, is one wherein the path for the flux from core to disc is of considerably greater reluctance than previously and thus represents less leakage flux. In the latter case the main gap has the benefit of more flux than in the former. This condition is manifested in a larger main air-gap moment about the hinge, higher ratio of main gap-hold gap moments and consequently a faster operating time. The condition wherein the disc 20 is removed entirely presents the least possible leakage condition and the fastest possible time element adjustment by this means.

The hold gap stop pin height is preferred as a factory adjustment since it is an over-all coarse adjustment which will compensate for manufacturing variations in dimensions of parts. The main gap adjustment by disc 20 may be used in maintenance work to compensate for wear which may appear over an extended period of operation. A life test on a model similar to that shown in Fig. 7 produced data to the effect that the time element remained within 2½ per cent of its initial value during 12 million consecutive operations during which the disc 20 was not adjusted from its initial setting.

Under steady flux conditions of an operated status of this relay the flux path will be via the hinge gap since this is the path of least reluctance when compared to the air path at the hold gap as shown in Fig. 2.

Upon deenergization of the winding the flux in the core tends to collapse. The slugs 14 will again produce a counter-magnetomotive force to oppose the change of the flux condition. This time, however, the counter-magnetomotive force will assist the steady-state condition and tend to sustain the steady flux to thereby delay the release of the relay armature. Since the hold gap magnetic circuit is open when the main gap is closed the hold gap has negligible effect upon the releasing time. The spring load on the armature will quickly overcome the main gap force to return the armature to its unoperated condition. The time element of release is dependent, among other factors, upon the main air-gap stop pin height. Generally, speaking, the release characteristics of this structure provided a

fairly fast release time relative to some well-known types of slow-operating relays. It has been determined experimentally that for stop pin heights of about .004 or greater in the main air-gap (screw head 60 as shown in Figs. 3 and 7) the release time of this relay is about 10 milliseconds. This release time increases, of course, as the height of the stop pin 60 is decreased and reaches the neighborhood of about 70 milliseconds with no stop pin height at all, representing non-existence of screw head 60. It is, of course, advisable to employ some stop pin height in order to prevent undesired sticking of the mutually attracted surfaces of the main gap.

The time constant of the hold magnet circuit of such a structure as described herein is determined for the most part by the resistivity of the copper slugs 14 and the reluctance of the magnetic circuits. The time element is proportional to the inverse product of these factors. The use of copper represents as high a conductivity as is practical. In order to attain a definitely controlled but low reluctance, to effect a large time element, the hinge gap is adapted with thin washers as described, pin-hinged and held closed by a biasing or armature return spring. The reluctance of the hold gap may be regulated by a stop pin or by finish thickness or by both in order to enable all relays of such construction to be adjustable within similar ranges of operating time. The disc 20 is the best presently known method of fine adjustment for each individual relay for a particular desired time element but it is to be understood that elimination of this means may be desirable for specific embodiments of this invention. Likewise, in specific cases the hinge pin washers may be omitted entirely and their function replaced by a non-magnetic finish thickness. As previously mentioned screw 46 with its stop pin and 53 represents the coarse factory adjustment of time element.

It is to be noted, particularly by reference to Figs. 3 and 7, that the ears 58 and 59 of the armature and extension 57 do not pick up the spring load represented by insulator studs 63 until a short amount of armature travel has taken place. This feature enables the operating time element of the structure to be independent of spring loading within capability limits of the relay.

The condition of operated armature represented by Fig. 2, shows that the release characteristic of this relay is determined by the tension of the contact springs and armature hinge spring 54 as well as by the main gap stop pin height and the effect of the copper slug pieces 14 as previously mentioned.

The fact that the operating time of this structure is dependent on the relative time rate of change of two opposing moments enables this relay to be substantially independent of ampere-turns energization. If the energization is lower than normal both hold gap and main gap forces are reduced by the same proportion and the ratio between the new hold gap moment and the new main gap moment is still substantially the same as previously and thus represents substantially the same operating time.

Fig. 8 represents the following conditions under which the data illustrated thereon was accumulated:

1. The energizing winding on the relay was composed of 7,750 turns of No. 35 wire having a direct-current resistance at room temperature of about 400 ohms.

2. The fine time delay control, the adjustable

disc 20 on the drawings, was set at its maximum time delay position such as approximated in Fig. 2. The adjustment shown in Fig. 2 is not fully maximum as there is shown a slightly closer possible adjustment of disc 20 to the end of core leg 10.

3. Three separate hold-gap adjustments, screw 46 at area 52 in the drawings, were used to record the effect of the adjustment.

It is noticed that as a general statement the operating time, ordinate, was substantially independent of the operating or energizing current, abscissa, when the latter was greater than certain values which depend upon the capabilities of the particular design tested. The current will also have an upper limit determined by the heating effect.

The three typical adjustments of the hold-gap length in Fig. 8 indicate the nature of delay time control available therefrom with various currents through the main winding.

Fig. 9 represents the same relay conditions as does Fig. 8 except:

1. The fine time delay control, adjustable disc 20 on the drawings, was set first at maximum time delay position, curve A, and then at minimum time delay or completely removed, curve B.

2. The operating current was constant at .1 ampere.

3. The hold-gap adjustment, screw 46 at area 52 on the drawings, was varied to indicate part of the range of time delay possible for that particular sample of the relay structure.

A typical method of using this relay structure might be as follows with reference to Fig. 9. Using curve A one might use this characteristic from point C, .5 second, down to point D, .25 second. From this point to shorter time delays one might then readjust the relay for the condition of curve B and use the relay from point E, .25 second, on down to shorter time delays. There may be numerous curves similar to A and B, between the limits designated by these curves, depending on previously described available adjustments.

It is not intended that any previous discussion of the optimum range of reluctance values for the hinge-gap or any other values set forth in connection with the exemplary disclosure shall limit the scope of this invention. Particular embodiments, like the one disclosed herein, may and probably will have critical ranges of values for adjustment and sizes of parts depending upon the results desired. The latter should not be understood to limit the present invention by such values set forth above as preferred values of an exemplary structure.

Since the features disclosed above constitute a valuable progression in the art by virtue of the results attainable therefrom, appended are the following claims which alone define the scope of the invention exemplified by such disclosure.

What is claimed is:

1. An electromagnetic relay structure including a core, an armature hinged to said core in a magnetic path at a free end of each, said core and said armature having directly therebetween two cooperating air-gaps of variable size, the first of said gaps, normally large when said armature is unoperated, located at the unhinged ends of said core and said armature, the second of said gaps, normally small when said armature is unoperated, located between said first gap and said hinge, an energizing winding on said core between said air-gaps, short-circuited turns on said core between said second air-gap and said

hinge, whereby upon energization of said core the forces in said air-gaps produce opposing moments on said armature about said hinge to thereby delay the operation of said armature, single means for effecting a coarse control of the operating delay time of the armature and additional means for effecting a fine control of the operating delay time of the armature.

2. An electromagnetic relay structure including a core, an armature hinged thereto in a magnetic path, an energizing winding on said core for producing a given flux therein when energized, said core and said armature having directly therebetween two air-gap flux paths, one of said paths being normally small and the other normally large when said armature is unoperated, means for diverting flux from said hinge path to said small air-gap path during transient periods after energization of said core, said two air-gap paths so disposed that respective forces created therein by passage therethrough of flux effect opposing moments on said armature about said hinge to thereby impose a time delay on the operation of said armature, means for adjusting the ratio of moments effected by said forces and additional means for independently controlling the moment effected by the force created in said large air-gap path.

3. An electromagnetic relay structure including a core, an armature hinged thereto in a magnetic path, an energizing winding on said core for producing a given flux therein, said core and said armature having directly therebetween two air-gap flux paths, one of said paths being normally small and the other normally large when said armature is unoperated, means for diverting flux from said hinge path to said small air-gap path during transient periods after energization of said core, said two air-gap paths so disposed that respective forces created therein upon energization of said core effect opposing moments on said armature about said hinge to thereby impose a time delay on the operation of said armature, an adjustable armature stop pin at said small air-gap adapted to alter the relative normal sizes of said air-gaps to thereby adjust the ratio of magnetic forces effective therein and adjustable magnetic means at said large air-gap path adapted to divert controlled portions of the given flux therefrom to air leakage paths, whereby said adjustable stop pin acts as a coarse control of the operating time delay of said armature and said adjustable magnetic means acts as a fine control of said time delay.

4. An electromagnetic relay structure including a core, an armature hinged to said core in a magnetic path at a free end of each, said core and said armature having therebetween two cooperating air-gaps of variable size, the first of said gaps, normally large when said armature is unoperated, located at the free ends of said core and said armature, the second of said gaps, normally small when said armature is unoperated, located between said first gap and said hinge, an energizing winding on said core between said air-gaps, short-circuited turns on said core between said second air-gap and said hinge, whereby upon energization of said core said air-gaps are so disposed that the forces created therein upon energization of said energizing winding produce opposing moments on said armature about said hinge to thereby delay the operation of said armature, an adjustable armature stop pin located on the armature at the normally

small air-gap for adjusting the relative sizes of said air-gaps when said armature is unoperated, to thereby effect a coarse control of the operating delay time of the armature, and a disc of magnetic material attached by means of an adjustable reluctance connection to the free end of said core on the opposite side of said core end from the normally large air-gap, said disc adapted to control the amount of flux conducted by said first air-gap by controlling the amount of flux diverted therefrom to air leakage paths by way of said disc, to thereby effect a fine control of the operating delay time of the armature.

5. An electromagnetic relay of the slow operating type having unpolarized magnetic circuits and comprising a core, an energizing winding on said core, a short-circuited winding on said core, an armature, an armature-core hinge, said core and said armature having therebetween two air-gaps so disposed that respective forces created therein upon energization of said energizing winding have oppositional effect on said armature, and structural means in the unpolarized magnetic circuit of said relay for effecting in one of said air-gaps upon energization of said energizing winding a magnetic flux having both steady and transient components, said means including means for controlling the reluctances of said hinge and of said one air-gap.

6. An electromagnetic relay of the slow operating type having unpolarized magnetic circuits and comprising a core, energizing means associated with said core, an armature, an armature-core hinge, said core and said armature having therebetween an operating air-gap and a holding air-gap, said air-gaps so disposed that respective forces created therein upon energization of said core have oppositional effect on said armature, and structural means in the unpolarized magnetic circuit of said relay including control of the reluctances of said hinge and said holding air-gap for effecting in said holding air-gap upon energization of said core a magnetic flux having both steady and transient components.

7. An electromagnetic relay of the slow operating type having unpolarized magnetic circuits and comprising a core, energizing means associated with said core, an armature, an armature-core hinge, said core and said armature having therebetween an operating air-gap and a holding air-gap, said air-gaps so disposed that respective forces created therein upon energization of said core have oppositional effect on said armature, and a combination of structural means in the unpolarized magnetic circuit of said relay for effecting in said holding air-gap upon energization of said core a magnetic flux having both steady and transient components, one of said means comprising a control of the reluctance of said holding air-gap and adapted to regulate the time constant of said transient component, another of said means comprising a control of the reluctance of said hinge and adapted to control the magnitude of said steady component.

8. An electromagnetic relay structure including a core, an energizing winding on said core, a short-circuited winding on said core and separated thereon from said energizing winding, an armature, an armature-core hinge, said core and said armature having therebetween two air-gaps so disposed that respective forces created therein upon energization of said energizing winding have oppositional effect on said armature, one of said air-gaps located at the core space between said windings, and structural means in the mag-

netic circuit of said relay including means for controlling the reluctances of said armature-core hinge and said one air-gap for effecting in the said one of said air-gaps upon energization of said energizing winding a magnetic flux having both steady and transient components.

9. An electromagnetic relay structure including a core having two exposed ends, an energizing winding on said core adjacent one exposed end thereof, a short-circuited winding on said core adjacent the other exposed end thereof and separated thereon from said energizing winding, an armature, an armature-core hinge at the said other exposed end thereof, said core and said armature having therebetween two air-gaps so disposed that respective forces created therein by energization of said energizing winding have oppositional effect on said armature, one of said air-gaps located at the core space between said windings, the other of said air-gaps located at the said one exposed end of said core, and structural means in the magnetic circuit of said relay including control of the reluctances of said hinge and said one air-gap for effecting in the said one of said air-gaps upon energization of said energizing winding a magnetic flux having both steady and transient components.

10. An electromagnetic relay structure including a core having two exposed ends, an energizing winding on said core adjacent one exposed end thereof, a short-circuited winding on said core adjacent the other exposed end thereof and separated thereon from said energizing winding, an armature, an armature-core hinge at the said other exposed end thereof, said core and said armature having therebetween two air-gaps so disposed that respective forces created therein upon energization of said energizing winding have oppositional effect on said armature, one of said air-gaps located at the core space between said windings, the other of said air-gaps located at the said one exposed end of said core, and structural means in the magnetic circuit of said relay for effecting in the said one of said air-gaps upon energization of said energizing winding a magnetic flux having both steady and transient components, one of said means comprising a control of the reluctance of said hinge for controlling the magnitude of said steady component and another of said means comprising a control of the unoperated air-gap size of said one air-gap for regulating the time constant of said transient component.

11. An electromagnetic relay structure including a core having two exposed ends, an energizing winding on said core adjacent one exposed end thereof, a short-circuited winding on said core adjacent the other exposed end thereof and separated thereon from said energizing winding, an armature, an armature-core hinge at the said other exposed end thereof, said core and said armature having therebetween two air-gaps so disposed that respective forces created therein upon energization of said energizing winding have oppositional effect on said armature, one of said air-gaps located at the core space between said windings, the other of said air-gaps located at the said one exposed end of said core, and structural means in the magnetic circuit of said relay including the size of the said one of said air-gaps and the reluctance of said hinge for effecting in the said one of said air-gaps a magnetic flux having both steady and transient components, said size of said one air-gap controllable for regulating the time constant of said transient

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component, said reluctance of said hinge control-
lable for controlling the magnitude of said steady
component.

EDMUND R. MORTON.
HUGH M. STOLLER.

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