

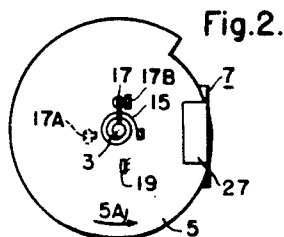
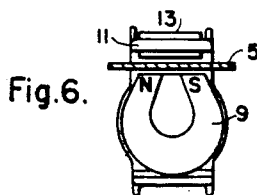
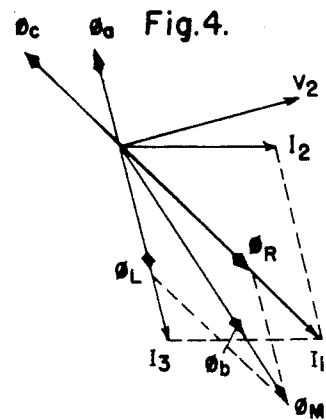
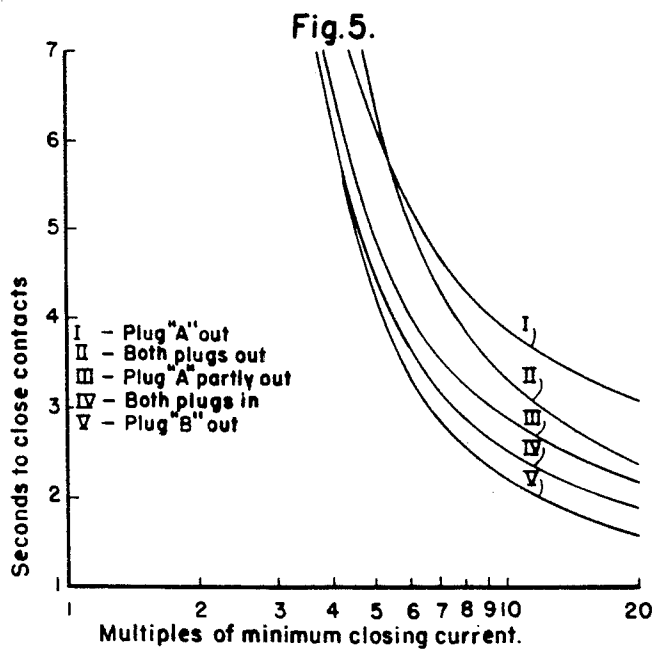
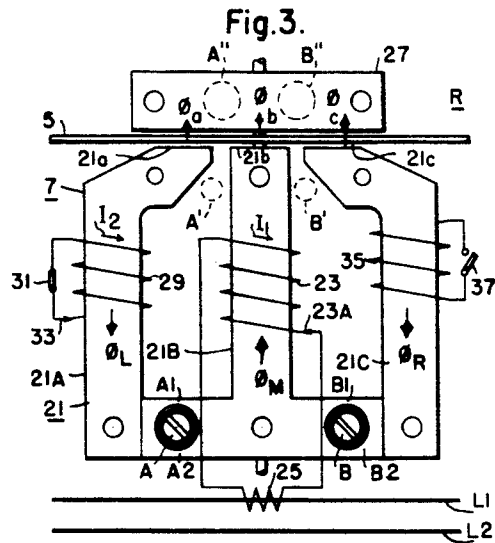
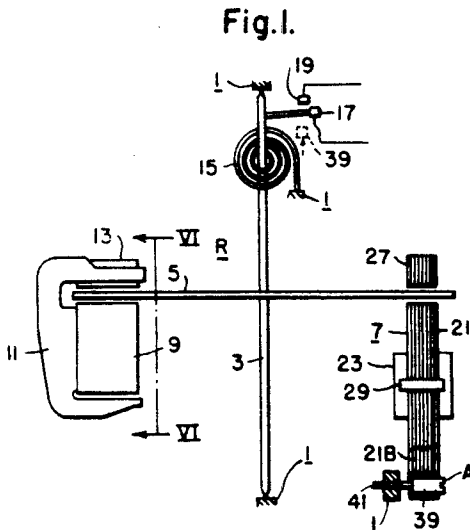
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INDUCTION TYPE ALTERNATING-CURRENT RELAY

Filed Oct. 13, 1951



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INDUCTION TYPE ALTERNATING-CURRENT RELAY

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This invention relates to devices responsive to an alternating quantity, and it has particular relation to induction-type alternating-current relays which operate with substantial time delay.

In the prior art it has been customary to provide devices such as electrical relays which operate with substantial time delay. Since time curves which have different shapes often are desired, it has been the practice to construct relays having different electromagnets for the different desired time-curve shapes. This has necessitated the construction and stocking of different styles of relays. Examples of prior art time curves will be found on page 117 of a book entitled "Silent Sentinels" published by the Westinghouse Electric Corporation, Newark, New Jersey in 1949.

In accordance with the invention, a time delay device such as a relay is constructed with one or more adjustments permitting a single relay to be adjusted to provide various shapes of time curves. Consequently, by suitable adjustment of the relay, the time curve of the relay may be adjusted to conform to various standard and non-standard shapes as desired.

In a preferred embodiment of the relay, an E-shaped electromagnet is provided which has three pole pieces located in a common plane. An energizing winding surrounds the center pole piece whereas a lagging winding surrounds one of the outer pole pieces. An electroconductive armature is positioned adjacent the pole faces of the three pole pieces. These pole faces provide three time-displaced magnetic-flux components to establish a shifting magnetic field for the electroconductive armature. Independent adjustments are provided for the magnetic paths followed by two of the magnetic flux components. By manipulation of these adjustments, the shape of the time curve of the relay may be varied. Preferably, adjustable damping is provided for the electroconductive armature of the relay.

It is, therefore, an object of the invention to provide an improved electroresponsive time-delay device having an adjustable time curve.

It is a further object of the invention to provide an improved relay having an electroconductive armature and having a magnetic structure energized by a winding to provide three time-displaced magnetic flux components for the electroconductive armature.

It is also an object of the invention to provide a relay as defined in the preceding paragraph wherein the magnetic paths followed by two of the magnetic flux components are independently adjustable.

It is a still further object of the invention to provide a relay as defined in the preceding paragraph wherein adjustable damping is provided for the electroconductive armature.

Other objects of the invention will be apparent from the following description taken in conjunction with the accompanying drawing, in which:

Fig. 1 is a view in side elevation with parts broken away and parts schematically shown of an electrical relay embodying the invention.

Fig. 2 is a view in top plan of the relay illustrated in Fig. 1.

Fig. 3 is a view in side elevation with parts schematically shown of an electromagnet suitable for the relay of Fig. 1.

Fig. 4 is a vector diagram showing the relationships of certain electrical quantities which may be present in the relay of Fig. 1.

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Fig. 5 is a graphical representation of time curves which may be obtained from the relay of Fig. 1, and

Fig. 6 is a view taken along the line VI-VI of Fig. 1.

Referring to the drawing, Fig. 1 shows a relay K designed for energization in accordance with a variable alternating quantity. This relay includes a stator 1, in which a shaft 3 carrying an electroconductive armature 5 is mounted for rotation. Conveniently, the electroconductive armature 5 may be in the form of a disc constructed of aluminum or copper. An electromagnet 7 is provided for the purpose of establishing a shifting magnetic field within which a portion of the electroconductive armature 5 is located. As well understood in the art, a shifting magnetic field operates on the electroconductive armature to produce a torque urging the disc in a predetermined direction about its axis.

Preferably, adjustable damping is provided for the electroconductive armature 5. Conveniently, such damping may be provided by a horseshoe-shaped permanent magnet 9 constructed of a high-coercive permanent-magnet material. The permanent magnet 9 has its two pole faces (identified by the reference characters N for North pole and S for South pole) positioned adjacent one face of the armature 5. A plug 13 of soft magnetic material is positioned on the opposite side of the armature to define with the pole faces two gaps within which the armature 5 rotates. The magnet 9 and the plug 13 may be secured to a suitable holder 11 of non-magnetic material such as die cast aluminum alloy. Preferably, the plug is adjustable relative to the magnet to change the lengths of the air gaps and the strengths of the magnetic field therein. Conveniently, the plug may have screw threads in threaded engagement with threads provided in the holder 11. By rotation of the plug 13, the plug may be moved towards or away from the associated permanent magnet 9 to modify the strength of the magnetic field within which the electroconductive armature 5 rotates. As well understood in the art, such rotation of the electroconductive armature provides a damping force acting between the stator to which the body or holder 11 is secured and the electroconductive armature.

A spiral control spring 15 has its inner end secured to the shaft 3 and its outer end secured to a portion of the stator 1. This spring normally is in a plane substantially transverse to the shaft 3, but is shown rotated from its normal position in Fig. 1 to illustrate the convolutions thereof. The spring occupies its normal position in Fig. 2.

A movable contact 17 is secured to the shaft 3 for movement towards and from a fixed contact 19 which may be secured to the stator. When the relay is deenergized, the spring 15 biases the movable contact 17 away from the fixed contact 19. When the electromagnet 7 is sufficiently energized, the movable contact 17 is moved against the bias of the spring 15 into engagement with the fixed contact 19 to complete an electrical circuit. Such circuit completion may be employed for any desired purpose.

The time required for movement of the movable contact 17 into engagement with the fixed contact 19 depends on the torque developed by the electromagnet 7 acting on the electroconductive armature 5, and on the magnitude of the damping applied to the electroconductive armature 5 by the damping magnet assembly. The time also may be varied by adjusting the position of the movable contact 17 about the shaft 3. Thus, in Fig. 2, the movable contact 17 is illustrated as displaced by an angle of 180° about the shaft 3 from the fixed contact 19. If the movable contact 17 is adjusted about the axis of the shaft 3 to the position illustrated in dotted lines 17A, the time required for movement of the movable contact into engagement with the fixed contact 19 is materially decreased. Such adjustment of the movable contact about the axis of the shaft 3 is well understood in the art. If desired the movable contact, the shaft and the disc may be adjustable as a unit by a stop about the axis of the shaft to place the movable contact in any desired starting position. Such a stop 17B is illustrated in Fig. 2 and is well known in the art. Operation of the stop changes the tension in the spring 15 when the parts are in their deenergized positions. As the movable contact 17 moves towards the fixed contact 19, the biasing torque exerted on the shaft 3 by the spring 15 increases. To compensate

for such increase, the disc may have a spiral periphery which is shown in Fig. 2. It will be noted that as the movable contact 17 rotates towards the fixed contact 19, the radius of the disc 5 at the electromagnet 7 increases. Such increase in radius increases the torque exerted on the shaft 3 by the electromagnet 7 and may be proportioned to compensate for the increase in bias exerted by the spring 15. This means that if the electromagnet 7 is energized at the minimum required amount to initiate movement of the associated electroconductive armature in the direction of the arrow 5A, the armature will continue in substantially uniform motion as long as the energization of the electromagnet 7 remains constant until the contact 17 engages the fixed contact 19.

Referring to Fig. 3, it will be noted that the electromagnet 7 includes an E-shaped magnetic structure 21 having three pole pieces 21A, 21B and 21C disposed substantially in a common plane. The magnetic structure 21 may be constructed of a plurality of laminations of soft magnetic material, such as soft iron, each having a shape illustrated in Fig. 3. Alternatively, each of the laminations may be constructed of two or more parts, and the parts may be associated by means of butt or interleaved joints which are well known in the art.

The pole pieces 21A, 21B and 21C have pole faces 21a, 21b and 21c which are disposed in a common plane, and this plane is transverse to the plane of the pole pieces 21A, 21B and 21C.

Energization for the electromagnet 7 is provided by means of a winding 23 which surrounds the intermediate pole piece 21B. Conveniently, this winding may have an adjustable number of turns as represented by adjustable tap 23A.

The winding 23 may be connected for energization in accordance with any desired alternating quantity. For example, the winding 23 may be energized in accordance with alternating voltage. However, it will be assumed that the winding 23 is energized through a current transformer 25 in accordance with alternating current flowing in a circuit represented by the conductors L1 and L2. Although the circuit may be a polyphase circuit, it will be assumed that the conductors L1 and L2 represent a single-phase alternating-current circuit operating at a power frequency of 60 cycles per second.

When the winding 23 is energized, magnetomotive forces are established between the pole faces to produce a magnetic field in the area occupied by a portion of the electroconductive armature 5. In order to decrease the magnetic reluctance offered to the flow of magnetic flux, a magnetic member 27 is spaced from the pole faces 21a, 21b and 21c to provide air-gaps between the member 27 and the pole faces. The electroconductive armature 5 passes through these air-gaps.

The magnetic member 27, like the magnetic structure 21, may be constructed of soft magnetic laminations, each having a shape similar to that illustrated in Fig. 3.

When energized, the winding 23 produces a magnetomotive force which directs magnetic flux components through parallel paths. One of the paths includes the pole piece 21B, the pole piece 21A, a portion of the magnetic member 27, and the air-gaps between the magnetic member 27 and the pole faces 21a and 21b. The second path includes the pole piece 21B, the pole piece 21C, a portion of the magnetic member 27 and the air-gaps between the magnetic member and the pole faces 21b and 21c. Magnetic flux components flowing in the pole pieces 21A, 21B and 21C are represented in Fig. 4 by vectors ϕ_L , ϕ_M and ϕ_R .

In order to establish a phase displacement between certain of the magnetic fluxes, a closed lagging winding 29 surrounds the pole piece 21A. Although the lagging winding may be a continuous and fixed closed winding, it will be assumed that the winding is closed through a switch 31, and that the number of turns in the winding are adjustable by means of a tap 33.

The lagging winding 29 produces a substantial phase displacement between the magnetic flux components ϕ_L and ϕ_R . Since the magnetic flux component ϕ_M represents the vector sum of the flux components ϕ_L and ϕ_R , it will be understood that the three magnetic flux components may be phase displaced from each other as a result of the lagging winding 29.

A portion of the magnetic flux component ϕ_L crosses the air-gap between the magnetic member 27, and the pole face 21a, and is represented in Fig. 4 by a vector ϕ_A .

Another portion of the magnetic flux component ϕ_L flows directly between the pole pieces 21A and 21B without entering the electroconductive armature 5.

In an analogous manner a part of the magnetic flux component ϕ_R flows through the magnetic member 27 and is represented in Fig. 4 by a vector ϕ_C . Another portion of the magnetic flux component ϕ_R passes directly between the pole pieces 21B and 21C.

The vectors ϕ_A and ϕ_C are shown 180° out of phase with ϕ_L and ϕ_R , respectively, because the reference direction arrows are shown in opposite directions, respectively, in Fig. 3.

Magnetic flux which flows between the magnetic member 27 and the pole piece 21B is represented in Fig. 4 by a vector of ϕ_B .

When the lagging winding 29 is closed through the switch 31, the magnetic flux components traversing the electroconductive armature 5 reach their maximum values in the same relative directions through the gaps in the order ϕ_A , ϕ_B and ϕ_C . This produces a shifting magnetic field and applies a torque between the electromagnet and the electroconductive armature 5 which urges the armature from left to right as viewed in Fig. 3. If the switch 31 is opened, the two parallel paths for magnetic flux components become symmetric and no torque is applied between the electromagnet and the electroconductive armature.

The switch 31 may represent the contacts of a directional relay. If power flows in one direction in the associated electrical circuit, the switch 31 is closed to permit effective energization of the electromagnet 7. If the power flow is in the reverse direction, the switch 31 is opened to prevent operation of the relay R.

If the lagging winding 29 is omitted, or if the switch 31 is opened, and if a lagging winding is applied to the pole piece 21C, reverse operation of the relay R may be obtained. For example, let it be assumed that a lagging winding 35 surrounds the pole piece 21C and is closed through a switch 37. If the switch 37 is closed, and if the switch 31 is open, the shifting magnetic field produced by energization of the winding 23 urges the electroconductive armature 5 from right to left as viewed in Fig. 3. Consequently, by control of the switches 31 and 37, the direction of operation of the relay R may be controlled. For example, assume that in Fig. 1, the relay has an additional fixed contact 39, and that the spring 15 when the relay is deenergized urges the movable contact 17 to a position intermediate the two fixed contacts 19 and 39. If the switch 31 is closed, energization of the relay R urges the movable contact towards the fixed contact 19. If the switch 37 is closed, the movable contact is urged towards the fixed contact 39. It will be assumed for present purposes that the winding 35 is not employed, or that the switch 37 is open.

In order to control the shape of the time curve of the relay R, at least one of the two magnetic paths offered to magnetic flux produced by current flowing in the winding 23 is adjustable. Preferably both of the paths are independently adjustable. This may be effected by provision of one or more adjustable magnetic elements for each of the paths. Thus, in Fig. 3, magnetic elements may be located in the positions represented by the reference characters A, B, A', B', A'' and B''. The magnetic elements may take the form of plugs which are screw operated. For example, in Fig. 1 the plug A has a large magnetic head 39 with a stud 41 projecting from one end thereof. The stud 41 is in threaded engagement with a portion of the stator 1. The head 39 is constructed of soft magnetic material such as soft iron or steel. It is located within an opening provided in the magnetic structure 21 and is slidable through the opening in response to rotation of the plug. If desired, the head 39 may be spaced from the walls of the opening by a thin-walled non-magnetic sleeve. For example, a thin plating of non-magnetic material such as copper, may be applied to the head 39 for this purpose.

It will be noted that each of the plugs, for example the plug B, varies the series magnetic reluctance of the magnetic path with which it is associated. The portion of the magnetic structure adjacent the plug B carries the entire magnetic flux ϕ_R . The magnetic member 27 adjacent the position B'' carries only a portion of the magnetic flux represented by the vector ϕ_R . It will be recalled that a portion of this magnetic flux flows directly between the pole pieces 21B and 21C without entering the magnetic

member 27. Consequently, the magnetic plug in the position B' is effective only for the portion of the magnetic flux component represented by the vector ϕ_c .

If the magnetic plug is in the position represented by the reference character B', it controls the amount of magnetic flux shunted away from the electroconductive armature 5. Some magnetic flux passes between the tips of the pole pieces 21B and 21C which are relatively close as shown in Fig. 3. The magnetic plug in the position B' adjustably bridges the air-gap between the tips to increase the amount of magnetic flux shunted away from the armature 5. Similar comments apply to the positions A, A' and A'' for plugs associated with the remaining magnetic paths.

In a preferred embodiment of the invention, the plugs A and B are employed only in the positions shown in full lines in Fig. 3. It will be understood that the openings provided in the magnetic structure 21 to receive the plugs leave bridges A1, A2, B1 and B2 which saturate for low values of magnetic flux therethrough. When the plugs A and B are introduced into their associated openings, they shunt magnetic flux around their associated bridges and thus alter the magnetic reluctances of the paths which contain the plugs.

Although unnecessary for an understanding of the invention, it may be helpful to consider my present understanding of the vector relationships existing in the relay of Fig. 2. The windings 23 and 29, together with associated parts of the magnetic structure, correspond somewhat to a transformer having a short-circuited secondary winding. Let it be assumed that a current represented by a vector I_2 (Fig. 4) flows in the winding 29. A voltage V_2 must be induced in the winding to produce the desired flow of current. In Fig. 4 the current I_2 is illustrated slightly lagging the voltage V_2 .

To induce the voltage V_2 , a flux ϕ_L is required, and this is shown lagging the voltage V_2 by 90° . The amount of current in the winding 23 required to produce a flux ϕ_L is represented in Fig. 4 by the current I_3 . Inasmuch as the magnetic core for the windings 23 and 29 has substantial air-gaps therein, it will be assumed that the current I_3 is substantially in phase with the magnetic flux ϕ_L .

The vector sum of the currents I_2 and I_3 represents the current I_1 which flows in the winding 23. The magnetomotive force produced by the current I_1 flowing through the winding 23 also produces a flux ϕ_R which flows through the pole piece 21C. The flux ϕ_R is shown in phase with the current I_1 in Fig. 4. The vector sum of the magnetic fluxes ϕ_R and ϕ_L represents the magnetic flux ϕ_M flowing in the pole piece 21B.

As previously pointed out, part of the magnetic flux ϕ_M does not pass through the magnetic member 27. Consequently, the portion ϕ_b which passes through the magnetic member 27 is illustrated in Fig. 4 with a somewhat smaller magnitude. For the assumed conditions, the vectors ϕ_a and ϕ_c are shown 180° displaced respectively from the fluxes ϕ_L and ϕ_R and somewhat smaller in magnitude. From a consideration of Fig. 4, it will be noted that the phase order of the air-gap magnetic fluxes is ϕ_a , ϕ_b and ϕ_c . This produces a shifting magnetic field and effects the desired rotation of the electroconductive armature 5.

The effect of the plugs A and B on the performance of the relay may be considered with particular reference to Fig. 5. In Fig. 5 ordinates represent the time in seconds required for the movable contact 17 to move into engagement with the fixed contact 19 after the application to the relay of an energizing element. Abscissa in Fig. 5 represent multiples of the minimum current required to effect engagement of the contacts 17 and 19.

If the plug A is completely out of the magnetic structure 21, and if the plug B is completely inserted in the magnetic structure, a time curve I is obtained. If both of the plugs A and B are completely out of the magnetic structure, a time curve II is obtained. If the plug A is partly out of the magnetic structure, whereas the plug B is completely in the magnetic structure, the time curve III is obtained. If both of the plugs A and B are completely in the magnetic structure, the relay has the time curve IV. If the plug A is completely in the magnetic structure and the plug B is completely out of the magnetic structure, the relay has a time curve V. Intermediate positions of the plugs have intermediate effects on the shape of the time curve.

It will be noted that the plugs A and B do not have

similar effects on the shape of the time curve. Thus, removal of the plug A results in the curve I which differs appreciably from the curve V obtained when the plug B is removed from the magnetic structure. Because of the difference in the effect of the two plugs on the time curve, the shape of the time curve may be completely controlled over a wide range of variation.

In the preferred embodiment of the invention, the time curves all approach a common point. For example, in the embodiment illustrated in Fig. 5, all of the curves approach a point at which the relay, when energized with twice minimum closing current, requires 27 seconds for the contacts to close. The position of this common point is controlled by adjustment of the damping magnet assembly. This is for the reason that the bridges A1, A2, B1 and B2 of Fig. 3 do not saturate at the low energization represented by twice minimum closing current. For this reason the common point is substantially independent of the adjustment of the plugs A and B. For larger energizations of the relay, the bridges alone are unable to carry the entire magnetic flux without saturating. For this reason, the plugs A and B have substantial effects on the shape of the time curve.

Although the invention has been described with reference to certain specific embodiments thereof, numerous modifications falling within the spirit and scope of the invention are possible.

I claim as my invention:

1. In an electrical time-delay relay device responsive to an alternating quantity, a magnetic structure having first, second and third spaced pole pieces, a winding surrounding the first pole piece and effective when energized for directing magnetic flux in parallel through the second and third pole pieces, an electroconductive member mounted for movement relative to the magnetic structure, said pole pieces having pole faces adjacent the electroconductive member for directing thereto magnetic flux having components substantially transverse to the electroconductive member, closed-circuit electroconductive means associated with the second pole piece for continuously altering the time phase of magnetic flux passing therethrough by a predetermined amount when the winding alone is energized to produce a shifting magnetic field for the electroconductive member, said electroconductive member being mounted for rotation relative to the magnetic structure, in combination with adjustable damping means for opposing rotation of the electroconductive member by an adjustable force which varies as a function of the rate of rotation of the electroconductive member, and means for varying the magnetic path for magnetic flux traversing the second pole piece independently of the magnet path for magnetic flux traversing the third pole piece.

2. In an electrical induction relay device responsive to an alternating quantity, a magnetic structure comprising first, second and third pole pieces having pole faces disposed substantially in alignment in a common plane, a magnetic member spaced from said pole faces to define an air-gap between the member and each of the pole faces to reduce the magnetic reluctance offered to magnetic flux produced by magnetomotive forces across said pole faces, an electroconductive armature mounted for rotation relative to the magnetic structure about an axis, said electroconductive armature having a portion spaced from the axis and positioned for movement through the air-gap, a winding surrounding the first pole piece, the intermediate one of said pole faces being on the first pole piece, said magnetic structure being effective for directing magnetic flux produced by the winding when energized through the second and third pole pieces in parallel paths, a closed-circuit lagging coil linked with the magnetic flux traversing the second pole piece to produce a shifting magnetic field in the air-gap having components entering a surface of the armature in directions substantially transverse to the surface when the winding is energized by alternating current, said lagging coil being closed through a circuit independent of the position of the electroconductive armature, damping means for opposing rotation of the electroconductive member with a force which varies as a function of the rate of rotation of the armature; and adjusting means for varying the magnetic path for magnetic flux traversing one of said parallel paths independently of the other of said parallel paths.

3. A device as claimed in claim 2 wherein a first

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magnetic flux component produced by energization of the winding traverses a first magnetic path which includes in series the first pole piece, the second pole piece, a portion of the magnetic member and the air-gaps between the magnetic member and the first and second pole faces, and wherein a second magnetic flux component produced by energization of the winding traverses a second magnetic path which includes the first pole piece, the third pole piece, a portion of the magnetic member and the air-gaps between the magnetic member and the first and third pole faces, and wherein said adjusting means comprises a variable magnetic section located in one of said magnetic paths.

4. A device as claimed in claim 3 wherein the adjusting means comprises a separate magnetic element located in each of said magnetic paths, each of the magnetic elements being independently adjustable relative to the magnetic structure for varying the effective cross-section of the associated magnetic path.

5. In an induction time-delay relay, an electromagnet having an airgap and having means effective when energized for producing magnetic flux creating a shifting magnetic field in the airgap, an electroconductive armature mounted for rotation relative to the electromagnet and having a portion spaced from the axis of rotation positioned in the airgap, said portion being positioned substantially transversely relative to at least a part of the magnetic flux of said magnetic field biasing means for biasing the armature towards a predetermined position relative to the electromagnet with a torque which varies as the armature rotates relative to the electromagnet, said armature having a configuration presenting a varying effective portion to said airgap as the armature rotates to compensate substantially for the variation in the bias exerted by said biasing means, adjustable damping means for damping rotation of the armature relative to the electromagnet, and adjusting mechanism adjustable for varying the shape of the curve representing the ratio of energization applied to the electromagnet relative to the time required for the armature to rotate through a predetermined angular distance over a substantial range of the magnitude of the energization applied to the electromagnet said adjusting mechanism comprising a manually-adjustable device for adjusting the magnetic path offered to magnetic flux producing said shifting magnetic field.

6. In an induction time-delay relay, an electromagnet having an airgap and having means effective when energized for producing magnetic flux creating a shifting magnetic field in the airgap, an electroconductive armature mounted for rotation relative to the electromagnet and having a portion spaced from the axis of rotation positioned in the airgap, said portion being positioned substantially transversely relative to at least a part of the magnetic flux of said magnetic field biasing means for biasing the armature towards a predetermined position relative to the electromagnet with a torque which varies as the armature rotates relative to the electromagnet, said armature having a configuration presenting a varying effective portion to said airgap as the armature rotates to compensate substantially for the variation in the bias exerted by said biasing means, damping means for damping rotation of the armature relative to the electromagnet with a force dependent on the rate of rotation of the armature, said electromagnet comprising a first winding, a first magnetic path for directing a first magnetic flux produced by the first winding when energized by alternating current into the airgap, a second magnetic path for directing a second magnetic flux produced by the first winding when energized into the airgap, a closed winding linked with the first magnetic path for lagging magnetic flux traversing the first path to alter the phase relationship between the first and second magnetic fluxes, one of said magnetic paths having a portion which saturates in the range of energization of the electromagnet to an extent dependent on the magnitude of such energization, and adjustable mechanism for adjustably decreasing the magnetic reluctance of said portion of the last-named magnetic path to vary the shape of the curve representing the ratio of energization applied to the electromagnet relative to the time required for the armature to rotate through a predetermined angular distance.

7. In an induction time-delay relay, an electromagnet having an airgap and having means effective when

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energized for producing magnetic flux creating a shifting magnetic field in the airgap, an electroconductive armature mounted for rotation relative to the electromagnet and having a portion spaced from the axis of rotation positioned in the airgap, said portion being positioned substantially transversely relative to at least a part of the magnetic flux of said magnetic field biasing means for biasing the armature towards a predetermined position relative to the electromagnet with a torque which varies as the armature rotates relative to the electromagnet, said armature having a configuration presenting a varying effective portion to said airgap as the armature rotates to compensate substantially for the variation in the bias exerted by said biasing means, permanent magnet damping means establishing a damping magnetic field for the armature, said electromagnet comprising a first winding, a first magnetic path for directing a first magnetic flux produced by the first winding when energized by alternating current into the airgap, a second magnetic path for directing a second magnetic flux produced by the first winding when energized into the airgap, a closed winding linked with the first magnetic path for lagging magnetic flux traversing the first path to alter the phase relationship between the first and second magnetic fluxes, each of said magnetic paths having a portion which saturates in the range of energization of the electromagnet to an extent dependent on the magnitude of such energization, adjusting mechanism for adjustably decreasing the magnetic reluctance of each of said portions of the last-named magnetic path, and adjustable damping means for damping rotation of the armature relative to the electromagnet, said adjusting mechanism being adjustable for varying the shape of the curve representing the ratio of energization applied to the electromagnet relative to the time required for the armature to rotate through a predetermined angular distance over a substantial range of the magnitude of the energization applied to the electromagnet.

8. In an induction time-delay relay, an electromagnet having an airgap and having means effective when energized for producing magnetic flux creating a shifting magnetic field in the airgap, an electroconductive armature mounted for rotation relative to the electromagnet and having a portion spaced from the axis of rotation positioned in the airgap, said portion being positioned substantially transversely relative to at least a part of the magnetic flux of said magnetic field biasing means for biasing the armature towards a predetermined position relative to the electromagnet with a torque which varies as the armature rotates relative to the electromagnet, said armature having a configuration presenting a varying effective portion to said airgap as the armature rotates to compensate substantially for the variation in the bias exerted by said biasing means, circuit-controlling means responsive to a predetermined rotation of the armature, said electromagnet comprising a first winding, a first magnetic path for directing a first magnetic flux produced by the first winding when energized by alternating current into the airgap, a second magnetic path for directing a second magnetic flux produced by the first winding when energized into the airgap, a first lagging winding linked with the first magnetic path, means for closing the lagging winding through a circuit independent of the position of the armature, a second lagging winding linked with the second magnetic path, means for closing the second lagging winding through a circuit independent of the position of the armature, and manually-operable means for adjusting the magnetic reluctance of at least one of said magnetic paths.

9. In an induction time-delay relay, an electromagnet having an airgap and having means effective when energized for producing magnetic flux creating a shifting magnetic field in the airgap, a current transformer having a secondary winding connected for energizing said means, an electroconductive armature mounted for rotation relative to the electromagnet and having a portion spaced from the axis of rotation positioned in the airgap, biasing means for biasing the armature towards a predetermined position relative to the electromagnet with a torque which varies as the armature rotates relative to the electromagnet, said armature having a configuration presenting a varying effective portion to said airgap as the armature rotates to compensate substantially for the variation in the bias exerted by said bias-

ing means, circuit-controlling means responsive to a predetermined rotation of the armature, damping magnet means for damping rotation of the armature relative to the electromagnet with a force dependent on the rate of rotation of the armature, said electromagnet comprising a first winding, a first magnetic path for directing a first magnetic flux produced by the first winding when energized by alternating current into the airgap, a second magnetic path for directing a second magnetic flux produced by the first winding when energized into the airgap, a closed winding linked with the first magnetic path for lagging magnetic flux traversing the first path to alter the phase relationship between first and second magnetic fluxes, means for adjusting the lagging effect of said lagging winding, and adjusting mechanism for adjusting the magnetic reluctance offered by one of the magnetic paths to the associated magnetic flux to vary the shape of the curve representing the ratio of energization applied to the electromagnet relative to the time required for the armature to rotate through a predetermined angular distance.

10. An alternating-current, electro-responsive, adjustable-time-delay relay wherein contacts are operated to control an electrical circuit, the combination with said contacts of contact operating relay means comprising a three-pole electromagnet field-element having a yoke piece and three projecting pole pieces disposed substantially in a common plane, an electroconductive contact-operating armature disc, means mounting the armature disc for rotation about its axis relative to the electromagnet field-element, biasing means for biasing the armature disc relative to the field-element about the axis in a predetermined direction, said pole pieces having pole faces disposed substantially in a common plane substantially parallel to and spaced by an air gap from a portion of a first face of the armature disc spaced from the axis, alternating-current exciting winding means disposed on the central one of said pole pieces for producing magnetic flux in the central pole piece, the outer pole pieces and the two halves of the yoke piece constituting first and second parallel return-flux paths for the center pole piece magnetic flux, closed winding means on one of said outer pole pieces for lagging magnetic flux passing therethrough to establish when the exciting means is excited a torque urging the armature disc against said biasing, a permanent magnet assembly establishing a magnetic field for a portion of the armature disc for damping rotation of the armature disc, and a pair of independently operable adjusting mechanisms each operable for adjusting the effective magnetic cross-section of a portion of each of the return-flux paths, whereby each of the adjusting mechanisms may be operated to vary the relationship between the time required for the armature disc to make a predetermined rotation against said biasing and the magnitude of the excitation of said exciting winding means.

11. An alternating-current, electro-responsive, ad-

justable-time-delay relay wherein contacts are operated to control an electrical circuit, the combination with said contacts of contact-operating relay means comprising a three-pole electromagnet field-element having a yoke piece and three projecting pole pieces disposed substantially in a common plane, an electroconductive contact-operating armature disc, means mounting the armature disc for rotation about its axis relative to the electromagnet field-element, biasing means for biasing the armature disc relative to the field-element about the axis in a predetermined direction, said pole pieces having pole faces disposed substantially in a common plane substantially parallel to and spaced by an air gap from a portion of a first face of the armature disc spaced from the axis, alternating-current exciting winding means disposed on the central one of said pole pieces for producing magnetic flux in the central pole piece, a magnetic structure spaced by an air gap from a second face of the armature disc providing two halves for respectively guiding magnetic flux traversing said armature disc between the central pole piece and each of the outer pole pieces, the outer pole pieces, the two halves of the magnetic structure, and the two halves of the yoke piece constituting first and second parallel return-flux paths for the center pole piece magnetic flux, closed winding means on one of said outer pole pieces for lagging magnetic flux passing therethrough to establish when the exciting means is excited a torque urging the armature disc against said biasing, an adjustable permanent magnet assembly establishing an adjustable magnetic field for a portion of the armature disc for damping rotation of the armature disc, and a pair of independently operable adjusting mechanisms each operable for adjusting the effective magnetic cross-section of a portion of each of the return-flux paths, whereby each of the adjusting mechanisms may be operated to vary the relationship between the time required for the armature disc to make a predetermined rotation against said biasing and the magnitude of the excitation of said exciting winding means, said adjusting mechanisms being operated to provide different cross sections for said return-flux paths.

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