My invention relates generally to relays and more particularly to alternating-current relays. 

An object of my invention is the provision of an alternating-current relay that shall be simple and reliable in operation and economically manufactured and installed. 

Another object of my invention is to provide a substantially definite time delay action in the operation of an alternating-current relay. 

A further object of my invention is to provide for establishing a unidirectional flux in the magnetic circuit of an alternating-current relay in order to prevent the armature of the relay from vibrating or chattering as the alternating current passes through zero. 

It is also an object of my invention to provide for establishing a limited amount of unidirectional flux in the magnetic circuit of an alternating-current relay so that the impedance of the alternating current winding of the relay remains substantially unchanged. 

Another object of my invention is to provide for operating a plurality of alternating-current relays in timed sequence, the interval between each successive operation being effected by the time delay action inherent in each relay. 

A still further object is the provision of an alternating-current relay that will operate on a relatively low frequency and at the same time prevent chattering and vibrating of its armature. 

Other objects of the invention will hereinafter become apparent. For a fuller understanding of the nature and the objects of my invention, reference should be had to the following detailed description, taken in connection with the accompanying drawings, in which: 

Figure 1 is a partially diagrammatic and a partially side elevational view of a relay embodying the features of my invention; 

Figure 2 is a partially diagrammatic and a partially side elevational view of a modified form of a relay embodying the features of my invention; 

Figure 3 is a top plan view of the relay shown in Fig. 2; 

Figure 4 is a diagrammatic view of a control system utilizing relays that are constructed substantially in accordance with the relay shown in Fig. 1; and 

Figures 5 and 6, respectively, show diagrammatic views of a control system utilizing relays that are constructed substantially in accordance with the relay shown in Figs. 2 and 3, except that in Fig. 5 each relay is associated with a pilot relay and a mechanical interlock. 

First, I will describe the construction and the operation of the relay shown in Fig. 1 followed by the accompanying control circuit in Fig. 4, which utilizes a plurality of such relays and, second, I will describe the construction and the operation of the relay shown in Figs. 2 and 3 followed by the accompanying control circuits shown in Figs. 5 and 6 which utilize a plurality of such relays. 

Referring to Fig. 1, I have shown the constructional features of the relay partially diagrammatically, since my invention may be utilized in relays of any general construction. 

Generally, the relay comprises a suitably mounted core 9 having a central-leg 11 and two end-legs 13 and 14, an armature 12 disposed in vertical alignment with said legs, a main alternating-current winding 15 mounted upon the central-leg 11, a demagnetizing winding 17, and a winding 16, having an asymmetric unit 19 in series therewith, mounted upon the leg 14. 

The core 9 may be mounted upon any suitable upright 10 in any well known manner such as by the illustrated bolts. In order to prevent saturation of the central leg 11, its cross sectional area is approximately twice the cross sectional area of each of the legs 13 and 14. 

For the purpose of convenience, the flux path through the central-leg 11 and the upper end-leg 13 will hereinafter be referred to as the upper magnetic circuit and, similarly, the flux path through the central-leg 11 and the lower-leg 14 will be referred to as the lower magnetic circuit. 

As illustrated, the upper-leg 13 is somewhat shorter in length than the central-leg 11 and the lower-leg 14, in order to provide an air gap 16 in the upper magnetic circuit. 

The armature 12 may be pivotally mounted in vertical alignment with the ends of the legs 11, 13 and 14 in any suitable manner. As shown, a support 25, suitably mounted on the upright 10 by means of the illustrated bolt, extends horizontally outward to provide a means for pivotally mounting the armature 12. A plate 48, having a tongue 24 that is integrally formed therewith and disposed upwardly at an angle of about 45°, is mounted on the end of the support 25 and its straight bifurcated portion extends somewhat beyond the end of the support 25 in order to provide a notch in which the upper inside edge 30 of the armature 12 may be pivotally disposed. 

Attached at the upper end of the armature 12 and disposed substantially in parallel alignment with the tongue 24 is an ear 23. 

As illustrated, the upper end of the tongue 24 and the ear 23 are provided with an opening for the bolt 22. A coil-spring 20 encompasses the bolt 22 and is disposed between the ear 23 and
the adjustable nut 2 in order to bias the armature in a counter-clockwise direction to oppose the magnetic attraction of the flux produced in the main winding 5. As shown, the ear 23 is disposed between the extended bifurcated ends of the plate 5, and as a result the armature 12 is prevented from moving sideways.

For a more detailed description of a relay having such an armature mounting and a demagnetizing winding, reference may be had to Patent No. 1,753,963, issued to Willard G. Cook, April 8, 1930, and assigned to the assignee of this invention.

The armature is shown provided with two pairs of contacts but it is apparent that the armature relay admits any desired number of contacts. In order that the relay may be utilized in the control circuit shown in Fig. 4, I illustrate a set of contacts 32 and 33, bridged by the bridging member 36, and a contact 38 carried by the lower bar 5 of the armature and disposed to engage a contact 43 mounted on the end of the bolt 35. The contacts 32 and 33 are respectively carried by L-shaped arms 41 and 42 that are mounted on the upright 10 by means of bolts 34 and 35. The bridging member 36 is pivotedally mounted on the armature 12 and insulated therefrom by means of the pivotingally mounted member 48, so that the circuits connected therethrough may be insulated from the contact member 38.

The main alternating current winding 15 of the relay is disposed to be connected across any suitable alternating-current source. In the operation of the relay, the flux produced by the main winding 15, in the absence of the winding 18 and the asymmetric unit 19, would divide and circulate through the upper and the lower magnetic circuits in the inverse proportion to the reluctance of the paths. Since the upper magnetic circuit is provided with an air gap 16, the greater portion of the flux produced by the winding 15, in the absence of the winding 18 and the asymmetric unit 19, would circulate through the lower magnetic circuit.

The winding 18 and its associated asymmetric unit 19 provides for establishing a unidirectional flux, the greater portion flowing through the lower magnetic circuit and indicated by the broken line 44, which must be dissipated or de-coupled or a predetermined value having an attractive force less than the biasing force of the spring 26, before the armature 12 opens. In other words, the time delay action of the relay depends upon the time required to dissipate the unidirectional flux to a predetermined value.

The asymmetric unit 19 may be of any well-known type so long as it affords a relatively high resistance to the flow of the current induced in the winding 18 in one direction and affords substantially no resistance to the flow of said current in the opposite direction.

As shown in the drawings, the flux produced by the main winding 15 during the first quarter-cycle traverses the central-leg 11 from left to right and, as explained hereinbefore, that the greater portion of the flux traverses the lower magnetic circuit. As the flux cuts the winding 18, a current would be induced in the windings were it not for the fact that the direction of its flow is such that the unit 19 prevents it from passing. In other words, the armature 12 of the first quarter-cycle, the winding 18 is in effect open-circuited by the unit 19. Consequently, the flux that is produced by the main winding 15 is permitted to traverse freely the lower magnetic circuit without being opposed by a flux set-up by the winding 18.

In the second quarter-cycle, the main flux that is established during the first quarter-cycle, hereinafter referred to as the first quarter-cycle main flux tends to decay in the usual manner, but in doing so, it induces a current in the winding 18 of such direction that the unit 19 permits the induced current to flow through it. Accordingly, the induced current establishes a flux of such direction as to oppose the first quarter-cycle main flux in the lower magnetic circuit. In this connection, it will be observed that since the winding 18 and the asymmetric unit 19 offer a slight resistance to the induced current, the decay of the said first quarter-cycle main flux will be totally opposed by the flux established by the induced current, but will decay very gradually.

In the third quarter-cycle, the direction of the main flux, established by the winding 15, traverses the central-leg from right to left and it will be noted that this third quarter-cycle main flux which flows in the lower magnetic circuit induces a current in the winding 18 in addition to the induced current already established by the decaying action of the said first quarter-cycle main flux. The flux produced by the induced current present in the winding 18 during the third quarter-cycle, opposes the passage of the said third quarter-cycle main flux in the lower magnetic circuit, with the result that the greater part of the said third quarter-cycle main flux traverses the upper magnetic circuit, notwithstanding the air gap 16. It will be noted that during the third quarter-cycle the rate of decay of the said first quarter-cycle main flux established in the lower magnetic circuit, is slightly faster than it was during the second quarter-cycle, since the said third quarter-cycle main flux is not totally opposed by the flux produced by the induced current of the winding 18. In other words, that part of the said third quarter-cycle main flux which is not opposed during the third quarter-cycle, since it is opposite in direction, slightly reduces the said first quarter-cycle main flux, in addition to the flux decay action of the said first quarter-cycle main flux which is present during the third quarter-cycle, the same as it was during the second quarter-cycle.

In the fourth quarter-cycle, that small part of the said third quarter-cycle main flux that was produced in the lower magnetic circuit, is the decay action of the said first quarter-cycle main flux. This rate of decay is substantially the same as it was during the second quarter-cycle.

From the foregoing, it will be noted that at the end of the fourth quarter-cycle, the said first quarter-cycle main flux is of a certain quantity, that is, the action of the winding 18 and the asymmetric unit 19 prevents the said first quarter-cycle main flux in the lower magnetic circuit from decreasing to zero, but sustaining it at a certain value. The flux action in the remaining cycles of the main alternating-current flux is the same as that for the first cycle, except that the first quarter-cycle main flux of each successive cycle is cumulative or additive and, in consequence, the stored or unidirectional flux gradually increases until it substantially saturates the lower magnetic circuit.
However, as the unidirectional flux gradually builds-up to almost saturation point of the lower magnetic circuit, the main flux produced by the winding 15 tends to flow through the upper magnetic circuit, notwithstanding the air gap 16, because the stator 18 is substantially unchanged. The lower magnetic circuit increases the reluctance thereof. In this manner, after the lower magnetic circuit becomes substantially saturated, the greater portion of the main flux traverses the upper magnetic circuit, with the result that the impedance of the main winding 15 is substantially unchanged, so that the relay will operate in shunt or across a suitable supply of alternating current. In other words, the upper magnetic circuit constitutes a flux by-pass when the lower magnetic circuit becomes substantially saturated with unidirectional flux, so that the impedance of the main winding is substantially unchanged.

In this connection, it will be noted that the unidirectional flux provides for continuously attracting the armature to the core, with the result that it eliminates any vibrating or chattering of the armature.

When the main winding 15 is deenergized, the main alternating-current flux produced thereby immediately decays but the unidirectional flux continues to exist, decaying at a slow and gradual rate. When the unidirectional flux decays to a value having an attractive force less than the biasing force of the spring 20, the armature 12 of the relay opens. The time required in dissipating the unidirectional flux to such drop-away value affords a time-delay action in the operation of the relay.

In order to insure that the unidirectional flux will decay to a value having an attractive force less than the biasing force of the spring 20, the demagnetizing winding 17 is energized with a unidirectional current which establishes a flux that opposes or dissipates the residual magnetism of the unidirectional flux. In this manner, the unidirectional flux is positively dissipated and, in consequence, the operation of the relay is positive. The size of the conductor and the number of turns provided in the winding 17 depends upon the amount of residual magnetism stored in the lower magnetic circuit and the time in which it is desired to dissipate the residual magnetism of the unidirectional flux. Usually the amount of current required for the winding 17 is very small and preferably, in most installations, since direct current is not generally available, the winding 17 may be energized by unidirectional current provided by an asymmetric unit. Such an arrangement is shown in the accompanying control circuit in Fig. 4.

In this connection, it is to be understood that I do not intend to limit the application of the relay shown in Fig. 1, to such a control circuit as shown in Fig. 4, but that I have simply illustrated one of its uses for the purpose of showing its general utility.

The control system in Fig. 4 comprises, generally, a motor 73 having a primary winding 74 and a secondary winding 75, a plurality of sets of accelerating resistors 76, 77 and 78, a main line switch 92 actuated by a relay 90, a plurality of relays 98, 99 and 100 constructed substantially in accordance with the relay shown in Fig. 1 and a drum controller 87 having a plurality of contacts 101 to 107, inclusive, disposed to control the operations of the motor 73.

The motor 73 may be of any well-known type suitable for operation from a supply of three-phase alternating current connected in parallel with the line conductors 70, 71 and 72. The secondary circuit 75 of the motor 73 is connected with a plurality of sets of accelerating resistors 76, 77 and 78 which are disposed to be excluded in sequence by the operation of the relays 98, 99 and 90, respectively.

The relay 90 is substantially the same as the relay shown in Fig. 1, except that its armature is connected to operate the main line switch 92, and that no demagnetizing winding is provided to dissipate the residual magnetism of the unidirectional flux. However, in this relay, I provide for reducing the residual magnetism to a value, to have an attractive force less than the biasing force of the illustrated spring, by means of a shim or non-magnetic member 99. As shown, the shim 93 is disposed on the end of the lower leg of the core of the relay 90 so that when the armature is closed an air gap is, in effect, provided. In consequence, the magnetic reluctance of the lower magnetic circuit is increased so that, when the relay is deenergized, the residual magnetism is decreased in substantially the same proportion as the reluctance of the lower magnetic circuit.

In this connection, it will be readily understood that if a demagnetizing winding, such as the winding 17 in Fig. 1, were utilized to dissipate the residual magnetism of the relay 90, it would be of no utility upon a power failure, because there would be no current present to energize the demagnetizing winding.

However, in connection with the demagnetizing windings of the relays 98, 99 and 100, I find that it is advantageous not to dissipate the residual magnetism, upon a power failure. Consequently, such of the relays as are closed, when the power failure occurs, remain closed since the attractive force of the residual magnetism is greater than the biasing force of the illustrated springs. When the power returns, provided the main switch 92 has not opened, the motor will continue to operate at the same speed as it did before the power failure.

The winding 88 that surrounds the lower leg of the core of the relay 90 and its associated asymmetric unit 89 are connected in circuit with the drum controller 79, so that when the controller is actuated to the "off" position, "a", the circuit is open. By this arrangement, the instantaneous opening of the relay 90 may be effected on regular operations of the control system, that is by the operation of the drum controller 79. Otherwise, the operation of the relay 90 is substantially the same as that explained for the relay in Fig. 1.

Since the relay 90 affords a predetermined time delay before its armature opens after the main alternating current winding is deenergized it holds the main line switch 92 closed for a period of 1/4 to 2 seconds upon a power failure of the main supply line. If the power returns before the relay 90 deenergizes, or opens the motor 73 continues to run, which avoids the necessity of re-starting the motor with the drum controller 79, as would be the case if no time delay action were provided. For the purpose of insuring that the power, when it returns, will cause no injury to the motor 73, the time delay action of the relays 90, 98, 99 and 100 are so regulated by means of the illustrated coil springs and the adjustable nuts that the relay 90 opens the main line switch 92 before the relays 98, 99 and 100 open. Suppose, for example that the motor 73 is being op-
erated below maximum speed, that is, with one or more sets of the accelerating resistors in the secondary winding of the motor 73 and, if the time delay action of the relays 98, 99 and 100, which control the relay 90, they will open to exclude all of accelerating resistors before the main line switch 92 opens, and upon the return of the power the full voltage will be suddenly impressed upon the motor, which is running at a speed with no resistance in the secondary winding of the motor 73. This condition may cause injury to the motor and at the same time causes the motor to run at maximum speed while the drum controller is set to give one or another of the slower speeds.

As illustrated, the neutralizing windings 122, 123 and 124 of the relays 98, 99 and 100 are energized by unidirectional-current supplied by the system of asymmetric units 80 energized by alternating current. The circuit for energizing the asymmetric units 80 extends from the line conductor 70 through conductor 125, the control switch 126, conductors 127 and 128, the asymmetric units 80, the relay 144 and conductor 135 to the line conductor 71. The demagnetizing winding for each relay is directly connected across the two unidirectional-current supply conductors 147 and 148. The demagnetizing winding 122 of the relay 96 is connected across the supply conductors 147 and 148 through conductors 162 and 163. Similarly, the demagnetizing winding 123 for the relay 99 is energized through conductors 164 and 166, and the demagnetizing winding 124 for the relay 100, through conductors 169 and 170. Consequently, the demagnetizing winding of each relay is continuously energized as long as the control switch 126 is closed.

The closing of the control switch 126, in addition to energizing the demagnetizing windings, energizes the drum controller 78 and, in turn, the main windings of the relays 98, 99 and 100. The circuit for energizing the main winding of relay 98 extends from the energized drum controller 78 through the contact finger 105, conductors 131 and 132, the main winding of the relay 98, and conductors 133, 134 and 135 to the line conductor 71. Similarly, the circuit for energizing the main winding of the relay 99 extends from the energized drum controller 78 through a contact finger 105, conductors 136 and 137, the main winding of the relay 99, conductors 138, 134 and 135 to the line conductor 71. When the relay 99 closes an additional parallel circuit is established through the contacts 205 for energizing the main winding of the relay 98. This circuit may be traced from the energized conductor 127 through conductor 205, the contacts 205, conductors 207 and 132, the main winding of the relay 98, and conductors 133, 134 and 135 to the line 71.

The circuit for energizing the main winding of the relay 100 extends from the energized drum controller 78 through a contact finger 105, conductor 139, the main winding of the relay 100, and conductors 141, 134 and 135 to the line conductor 71. When the relay 100 closes, an additional parallel circuit is established through the contacts 202 for energizing the main winding of the relay 99. This circuit extends from the energized conductor 127 through conductor 203, the contacts 202, conductors 204 and 137, the main winding of the relay 99, and conductors 138, 134 and 135 to the line main conductor 71. It will be noted that, as the relays 100, 99 and 98 close they, respectively, remove the shunts around the plurality of sets of resistors 78, 77 and 76 and thereby connect the said resistors in the secondary winding of the motor 73. This means that the motor 73 is in condition for starting by closing the main line switch 92.

In the starting of the motor 73, the usual practice is to immediately actuate the drum controller to "full on" position, namely, position "a" and thereby let the acceleration be taken care of by the delayed action inherent in the relays 100, 99 and 98. This circuit, when the controller is actuated to position "b", on its way to the "full on" position, a circuit is established for energizing the main winding of the relay 90 which causes the said relay to close the main line switch 92.

The circuit for energizing the relay 90 extends from the energized drum controller 78 through a contact finger 102, conductors 89 and 88, the main winding of the relay 90, and conductors 134 and 135 to the main line conductor 71. As soon as the relay 90 closes the main line switch 92, alternating current is supplied to the primary of the motor 73. Also, concurrently with the closing of the switch 92, a holding circuit is established by means of the contacts 94, for continuously energizing the relay 90 when the drum controller is advanced to positions "c", "d", "e" and "f". The holding circuit may be traced from the energized drum controller 78 through contact finger 104, conductor 171, the contacts 94, conductor 98, the main winding of the relay 90, and conductors 134 and 135 to the main line conductor 71.

Therefore, when the drum controller 78 is advanced beyond the position "b", the holding circuit, just described, is the only means for continuously energizing the relay 90. In this manner, a low-voltage protection is provided for the control system because the relay 90 will operate to open the main line switch 92 when the voltage of the supply line falls below a predetermined value. That is to say, when the relay 90 opens, as a result of the low voltage condition, it will not pick-up when the power returns on the line conductors, unless the drum controller is actuated back to position "b".

When the drum controller 78 is advanced to position "d", as it is being actuated to the "full on" position "f", the circuit that energizes the relay 100 is interrupted, then, after a predetermined length of time, depending on the time delay action afforded by the unidirectional flux, the relay 100 closes its contacts 185 to shunt out or exclude the set of resistors 78 from the secondary circuit of the motor 73. The shunting circuit comprises the conductors 182, 183 and 184 and the contacts 185 of the relay 100.

Simultaneously, with the operation of the relay 100, one branch of the parallel circuit that energizes the main windings of the relay 99 is interrupted through the opening of the contacts 202, while the other branch of said parallel circuit is interrupted at the contact finger 105, since it is assumed that the drum controller 79 is in position "f". Accordingly, a predetermined length of time after the deenergization of the relay 99, the said relay closes its contacts 181 to shunt out or exclude the set of resistors 77 from the secondary circuit of the motor 73. The shunting circuit comprises the conductors 178, 179 and 180 and the contacts 181 of the relay 99.

The operation of the relay 99, interrupts one branch of the parallel circuit that energizes the main winding of the relay 99 through the opening of the contacts 206 while the other branch of the said parallel circuit is interrupted at the 75.
contact finger 104. After a predetermined length of time from the interruption of the circuit for the main winding of the relay 88, the said relay closes its contact 178 to shut out or exclude the set of resistors 76 from the secondary of the motor 73. The shut circuit comprises the conductors 174, 175 and 178 and the contacts 177 of the relay 98.

From the foregoing description, it is noted that the relays 100, 99 and 101 operate in time sequence to successively exclude the resistors 78, 77 and 76 from the secondary winding of the motor circuit.

At this time I wish to point out that the time sequence operation of the relays may be effected by a push-button instead of the controller contact 133, but by providing the drum controller 79, it is possible to obtain speed control of the motor as well as to provide for starting the said motor.

Whenever it is desirable to run the motor at a minimum speed, this may be accomplished by advancing the drum controller 79 to position “b”, preferably position “c”, since it affords a low voltage protection for the control system.

In either one of these positions the relays 100, 99 and 88 are energized, with the result that all of the sets of accelerating resistors 78, 77 and 76 are included in the secondary circuit of the motor 73.

If, however, it becomes convenient to slightly increase the speed of the motor, this may be done by advancing the controller to position “d”. In this position the circuit for energizing the relay 100 is interrupted at contact finger 105 and the relay 106, after a predetermined length of time, operates to exclude the set of resistors 78 from the secondary winding of the motor 73.

In a similar manner, the speed may be further increased by advancing the controller to position “e”, which causes the relay 99 to exclude the sets of resistors 77 and 71 from the secondary winding of the motor 73. The maximum speed is finally attained when the controller is advanced to the “full-on” position “f”. In this position the relay 98 excludes all of the resistors from the secondary winding of the motor 73.

Therefore, the control circuit illustrated in Fig. 4, illustrates a very useful application of the relay shown in Fig. 1, but it is to be understood that I do not intend to limit the utility of my relay to such a control system, since my relay has universal application.

Referring now to Figs. 2 and 3 of the drawings, I will describe a modified form of my relay which finds useful application in the control circuit illustrated in Figs. 5 and 6. In Figs. 2 and 3, I have illustrated the modified form of my relay somewhat diagrammatically since my invention may be readily applied to any type of relay of any general construction.

In general, the relay in Fig. 2 comprises a core 49 having two legs 53 and 54 upon which are respectively provided windings 61 and 62 that are connected in closed-circuit, through an asymmetric unit 55, an armature 51 having a central-core 52 extending upwardly, a main alternating current winding 56 being mounted on said central-core, and a contact 57 actuated by the armature 51.

As illustrated in Figs. 2 and 3, the core 49 comprises two inverted L-shaped members, having their adjoining ends secured together in spaced relation by the side members 59 and 59', for the purpose of providing an opening 50 through which the central core 52 of the armature extends. The air gap that is provided between the central core 52 and the adjoining ends of the core 49, together with the side members 59 and 59' and through which the alternating current flux set-up by the winding 56 must traverse, provides for limiting the maximum value of said flux. Moreover, by this construction, the chattering caused by a low-frequency alternating current is greatly alleviated, because the said air-gap remains the same regardless of the position of the armature 51 and, in addition, the varying flux attraction at the said air gap caused by a low-frequency flux is horizontal and does not have any chattering effect upon the downward pull of the armature.

Two non-magnetic screws 64 and 65 are provided in threaded openings in the ends of the armature 51 for the purpose of providing an adjustable air gap. Accordingly, the drop-away value of the armature may be selected by adjusting the width of the said air gap. Also the non-magnetic screws prevent the armature from sticking to the core as a result of the residual magnetism established by the unidirectional flux.

For the purpose of convenience the flux path through the central-core 52 and the right-leg 53 will be designated as the right-hand magnetic circuit and the flux path through the central-core 52 and the left-leg 54 will be designated as the left-hand magnetic circuit.

The operation of the relay shown in Figs. 2 and 3 is slightly different from that shown in Fig. 1, since both of the legs 53 and 54 of the core are respectively provided with a winding connected in closed-circuit through an asymmetric unit 55.

Assuming that the alternating current flux established by the winding 56 of the central core 52 is flowing upwardly and in the absence of the windings 61 and 62 and the asymmetric unit 55, the flux would divide equally and circulate through the right and left hand magnetic circuits.

However, the action of the alternating-current flux is altered by means of the said windings and the asymmetric unit 58 and as a result a unidirectional flux indicated generally by the broken line 56 is established.

Assuming again that the alternating-current flux is flowing upwardly in the central core, and now as a result of the action of the said windings 61 and 62 and the asymmetric unit 58 that part of the flux which attempts to traverse the left-hand magnetic circuit is opposed by a flux set-up by the current which is induced in the winding 62, said current also flowing through the winding 61 and the asymmetric unit 58.

On the other hand, the flux that traverses the right-hand magnetic circuit is unopposed since the current that would be induced in the winding 61 is prevented from flowing through the asymmetric unit 58. In fact, it will be noted that the current induced in the winding 62, since it flows through the winding 61 establishes a flux in the leg 53 which flows in the same direction as that part of the alternating-current flux circulating through the right-hand magnetic circuit.

When the alternating-current flux of the central core reverses and flows downwardly, that part of said flux which tends to circulate in the right-hand magnetic circuit is opposed by the flux set-up by the current induced in the winding 61. On the other hand, that part of the flux which traverses the left-hand magnetic circuit is unopposed. Moreover, the current induced in the winding 61, since it flows through the winding 62, establishes a flux in the left-leg 54 which flows in the same direction as that part
of the alternating-current flux circulating in the left-hand magnetic circuit. The resultant action
of the flux is such as to establish a unidirectional flux, indicated by the broken line 66, which cir-
culates through the main core 49 and the armature 51.

From the foregoing, it will be readily under-
stood that the presence of the unidirectional flux
provides for continuously attracting the arma-
ture 51 to the main core 49, while the flux pro-
duced by the winding 56 is passing through zero;
even though the frequency of the alternating-
current flux approaches a relatively low value,
such as it will in the control circuit illustrated
in Figs. 5 and 6.

In this embodiment of the relay, since there is
no by-pass for the alternating-current flux,
such as the air gap 16 provided in the relay in
Fig. 1, it is necessary to limit the current that
flows through the winding 56 by operating the relay in series with some other electrical appar-
atus. That is to say, if the winding 56 were operated to operate across a source of constant
potential, the impedance thereof would gradually
decrease to a very low value since the main core
49 would eventually become completely saturated
by the unidirectional flux. The alternating cur-
rent flowing through the winding 56 would, con-
sequently, increase to such a value as to reduce
the armature 51 downwardly, against the action of the spring 256, when the pilot relay
232 is energized.

In this manner, the armature of the relay 226 is prevented from dropping, by means of gravity,
unless the pilot relay 232 has been previously
energized.

The winding 215 of the relay 226 is connected in
series with one of the phases of the secondary windings of the motor 220 by the conductors 266
and 267. When the pilot relay 235 is energized, the winding 217 of the relay 228 is connected in
series with the other phase of the secondary wind-
ing of the motor 220, but at a point before the point of the sets of resistors 224 and 225. Also, as illustrated, the closing of relay 235 excludes the sets of re-
sistors 223 and the winding 218 of the relay 226
from the secondary circuit of the motor. Simi-
larly, when the pilot relay 234 is energized the winding 216 of the relay 227 is connected in
series with the same phase of a secondary wind-
ing of a motor 220, but at a point between the sets of resistors 223 and 224. Likewise, the clos-
ing of the pilot relay 234 excludes the sets of resistors 224 and 225, and the windings of the relays 226 and 228 from secondary winding of 55 the motor 220. Finally when the pilot relay 233 operates, all of the sets of resistors 223, 224 and
225 and the windings of all the relays 226, 228 and
230 are excluded from the secondary wind-
ing of the motor 220.

In the starting and in the accelerating of the motor 220, the drum controller 236, as is usual prac-
tice, may be immediately actuated to the full-on position, namely, position "v".
However, in case speed control of the motor is desired, the controller 236 may be advanced to one of the positions to accommodate the operating con-
ditions. At this time, I wish to point out that if speed control of the motor is not neces-
sary, the drum controller 236 could be replaced by a starting push-button which would give the desired operations for starting and accelerating the motor 220.

When the drum controller 236 is immediately actuated to the full-on position, "v", for starting
the motor 220, the pilot relay 232 immediately
opens the main line switch 24, which energizes
the motor 220 from the three-phase supply con-
ductors represented by the reference characters
222, 230 and 231. The circuit for energizing
the pilot relay 232 extends from the line conductor 231, through conductor 263, contact fingers 237
and 238, bridged by the drum controller 236, con-
ductor 264, the winding of the pilot relay 232, and
conductor 265, to the line conductor 230.

As the armature of the pilot relay 232 moves
upwardly, the pivotally mounted arm 254 de-
presses the hook release rod 256 and, in conse-
quency frees the armature of the relay 226 from
the mechanical interlock. However, simultaneously with the depressing of the release rod 256, a
voltage is induced in the secondary winding of
the motor 220 which immediately energizes
the winding 215 of the relay 226 and, thereby,
prevents the armature from falling and closing
the contact 251.

During the initial portion of the starting pe-
riod of the motor 220, since the speed of the rotor is very low, the frequency of the current induced
in the secondary winding 222 is approximately
the same as the frequency of the primary circuit.
However, as the speed of the rotor increases the
frequency and current in the secondary winding
decreases to such an extent that the attractive
force of the flux produced by the winding 215 of

the relay 226 becomes less than the force of gravity. When this flux condition occurs, the armature drops and closes the contact 251.

The closing of the contact 251 establishes a circuit for energizing the current 234 which actuates the associated mechanical interlock to permit the relay 228 to be free to open. This circuit may be traced from the energized drum controller 226, through the contact finger 228, conductor 226, contact 251, conductor 226, the windings of the pilot relay 234, and conductors 271 to the line conductor 230.

Operation of the pilot relay 235, in addition to operating the mechanical interlock, connects the winding 217 of the relay 228 in series with the same phase of the secondary winding of the motor 220, as the winding of the relay 226 was connected, but at a point between the sets of resistors 224 and 225. The circuit for connecting the winding 217 of the relay 228 in series with one phase of the secondary winding of the motor extends through conductor 274, the lower contacts of the pilot relay 235, conductor 275, winding 217 of the relay 228, conductor 275 to the opposite side of the phase. Furthermore, the operation of the relay 235 excludes the relay 226 and the set of resistors 225 from the secondary winding of the motor 220 by means of the shunting conductors 273, 273, and 274. Since the relay 228 is energized simultaneously with the operation of the mechanical interlock, the armature is prevented from dropping and closing the contact 253.

Just as soon as the set of resistors 225 and the relay 226 are excluded from the secondary winding of the motor 220, the current induced therein suddenly increases from the previously low value to a higher value sufficient to operate the relay 228. However, as the motor gains speed the current and the frequency of the secondary winding gradually decreases to such an extent that the attractive force of the flux produced by the winding 217 of the relay 228 becomes less than the force of gravity, and the armature, accordingly, drops and closes the contact 253. The closing of the contact 253 establishes a circuit for energizing the pilot relay 234. This circuit may be traced from the energized drum controller 226 through the contact finger 240, conductor 260, contact 253, conductor 276, the winding of the pilot relay 234, and conductors 277 and 211 to the line conductor 230.

The pilot relay 234, when energized, actuates the mechanical interlock to free the armature of the relay 227, but at the same time it electrically connects the winding 216 of the relay 227 in series with the same phases of the secondary winding of the motor as the relays 226 and 228 were connected, but at a point between the sets of resistors 225 and 224. Since the relay 227 is simultaneously energized with the operation of the mechanical interlock, the armature is prevented from dropping and thereby closing the contact 252.

The circuit for connecting the main winding of the relay 227 in one phase of the secondary winding of the motor extends through conductor 280, the lower contacts of the pilot relay 234, conductor 281, the main winding of the relay 227, and conductor 275, to the other side of the phase. The closing of the pilot relay 234, also excludes the sets of resistors 224 and 225, and the windings of the relays 226 and 228 from the secondary circuit of the motor by means of the shunting conductors 278, 279, and 280.

Just as soon as the sets of resistors 224 and 225, and the windings of the relays 226 and 228 are excluded, the current in the secondary winding suddenly increases from its previously small value to a higher value sufficient to operate the relay 227. However, as the motor gains speed the current and the frequency of the secondary winding gradually reduces to such an extent that the attractive force of the flux produced by the winding 216 of the relay 227 becomes less than 10 the force of gravity, and the armature, accordingly, drops and closes the contact 252.

The closing of the contact 252 establishes a circuit for energizing the pilot relay 233, which, when operated, excludes all of the sets of resistors and the windings of the relays 226, 227 and 228 from the secondary circuit of the motor by means of shunting conductors 285, 286, and 287. Under this condition the motor runs at maximum speed. The circuit for energizing the pilot relay 233 extends from the energized drum controller 226 through the contact finger 241, conductor 260, contact 253, and the winding of the pilot relay 233 and conductors 284 and 271 to the line conductor 230.

In this connection, it will be noted that, as the speed of the rotor increases, the frequency of the current induced in the secondary winding of the motor approaches a very low value which offers an opportunity for the armature of the relays 226, 228 and 227, particularly relay 227 to chatter or even drop while the induced current passes through zero. However, the unidirectional flux produced by the illustrated windings and their respective asymmetric units, provide for continuously attracting the armature while the low frequency flux passes through zero.

From the foregoing description of the operation, it has been observed that by immediately actuating the drum controller 226 to the "full on" position, the motor is automatically accelerated by the operation of the relays 226, 228 and 227. However, if it is desirable to operate the motor less than maximum speed, this may be done by actuating the drum controller on one of the less advanced positions. Minimum speed may be attained by actuating the drum controller on position "n". In this position all of the sets of resistors 223, 224 and 225 are included in the secondary winding of the motor, since the circuits for energizing the said pilot relays are interrupted at the contact fingers of the drum controller 236, except that for the pilot relay 232. By advancing the drum controller 236 to position "r", the circuit is established for energizing the pilot relay 235 which, accordingly, excludes the set of resistors 225 from the secondary winding of the motor and thereby effects a slightly higher speed. A still higher speed may be attained by actuating the drum controller 236 to positions "u", and finally maximum speed is attained when the controller is actuated to position "p".

In this particular control system since the frequency of the secondary winding of the motor 220 decreases to a very low value as the motor approaches synchronous speed, relays of the type shown in Figs. 2 and 3 find very useful application, because the unidirectional flux provides for continuously attracting the armature while the low frequency alternating current flux is passing through zero.

The relay of the type shown in Figs. 2 and 3, also finds very useful application in the control circuit shown in Fig. 6.
Generally, the control circuit in Fig. 6 comprises a synchronous motor 300, a starting transformer having windings 342 and 343, dual operation starting relays 332 and 333 mechanically interlocked by a pivotally mounted member 341, a relay 304 of the type shown in Figs. 2 and 3, a time element relay 326 of the dash-pot type, and a line relay 339.

The synchronous motor 300 is of the conventional type having an alternating-current primary winding 302 and a direct-current winding 301. The starting transformer having windings 342 and 343 is energized from a polyphase alternating-current source represented by the line conductors 329, 330 and 331. The windings 342 and 343 of the transformer are so interconnected with the primary winding 302 of the synchronous motor 300 that substantially one-half of the line potential is impressed upon the said winding when the contacts of the relay 332 are closed and that the full line potential is impressed upon the said winding when the contacts of the relay 333 are closed. This arrangement is in accordance with the usual method of starting synchronous motors, in that, substantially one-half of the line potential is impressed upon the primary winding during the initial portion of the starting period, and then, after the motor attains a predetermined speed, the full line potential is impressed upon the said winding.

The time sequence operation of the dual starting relays 332 and 333 is accomplished by the time element relay 326 of the dash-pot type. When the lower contacts of the relay 332 are closed, the circuit is completed by energizing the starting relay 332, which when operated, closes its own contacts and which opens those of the relay 333 by means of the interlock 341. After a predetermined length of time depending upon the delayed action of the dash-pot, the relay 332 closes its upper contacts and establishes a circuit for energizing the starting relay 333 which, when operated, closes its own contacts and which opens those of the relay 332 by means of the interlock 341.

The relay 304 is of the type shown in Figs. 2 and 3, and when the line relay 309 is closed during the starting period, said relay is connected in series circuit relation with the direct current winding 301 of the motor 300 which is closed upon itself, through a circuit extending from one terminal of the motor field winding 301, conductors 312 and 313, the relay winding 305, conductor 314, lower contacts of the relay 309, conductors 365 and 310 to the opposite terminal of the motor field winding 301. As a result the relay 304 is energized by the current induced in the winding 301. In this connection, when the speed of the motor is low as it will be during the initial portion of the starting period, the frequency of the current induced in the winding 301 is substantially the same as the frequency of the alternating current supply source. However, as the speed of the motor approaches synchronous speed, the frequency thereof becomes less and less until finally the relay 304 drops to establish a circuit for energizing the line relay 309 which connects the direct current supply conductors 301 and 308 to the direct current winding 301, through conductors 310 and 311.

In explaining the operation of the control circuit, I will assume that the alternating current supply conductors 329, 330 and 331 are energized together with the direct current supply conductors 301 and 308, and that the manually operated switch 328 has just been closed. The closing of the switch 328 establishes a circuit for energizing the time delay relay 326 and the starting relay 332. The time delay relay 326 may be traced from the supply conductor 330 through conductor 351, the switch 328, conductors 352 and 353, the winding of the relay 326, and conductors 354 and 355 to the supply conductor 328. The parallel circuit for energizing the relay 326 may be traced from the energized conductor 332, through conductor 356, the lower contacts of the relay 326, conductor 357, and the winding of the relay 332 to the supply conductor 328.

Operation of the relay 326 connects one-half of the windings 342 and 343 to the primary winding 302 of the synchronous motor. The line conductor 329 is connected to the terminal 316 of the winding 302 through a conductor 350, the contacts 357, the upper half of the winding 342, the contacts 339 and the conductor 353, the supply conductor 330 is connected to the terminal 317 of the primary winding through a conductor 362, the contacts 339, and conductors 361 and 360, and the supply conductor 331 is connected to the terminal 318 of the primary winding through a conductor 355, the contacts 341, the lower half of the winding 343, the contacts 340 and the conductor 346.

Therefore, one-half of the line potential is impressed upon the primary winding of the synchronous motor when the contacts of the relay 332 are closed. As will be observed, this condition only exists for a short time, depending upon the time delay action of the relay 326 afforded by the dash-pot 321. In practice, the delayed action of the relay 326 is of such duration that the motor attains a speed of such value that the back induced voltage thereof is great enough to oppose the full line potential without causing injury to the motor windings.

When the relay 326 operates and closes its upper contacts a circuit is established for energizing the starting relay 333, and at the same time, the circuit for energizing the relay 332 is interrupted. The circuit for energizing the relay 333 extends from the energized conductor 352 through the upper contacts of the relay 326, conductor 344, the winding of the relay 333, and conductors 345, 346 and 355 to the supply conductor 328. The operation of the contacts of the relay 333 impresses the full line potential upon the primary winding of the synchronous motor, bringing it up to full speed. As will be observed, the supply conductors 329, 330 and 331 are, respectively, connected to the terminals 316, 317 and 318 of the primary winding of the synchronous motor by means of the contacts 334, 335 and 336.

As is usual practice, in starting synchronous motors, the direct current winding is short-circuited and, accordingly, the synchronous motor is operated as a straight induction motor until it obtains substantially full speed, and then the direct-current winding is open-circuited and energized from a source of direct current. As shown, during the starting period, the direct-current winding 301 is short-circuited through the lower contacts of the relay 309, under this condition the winding 305 of the relay 304 is connected in series-circuit relation with the short-circuited winding 301.

During the initial portion of the starting period the frequency and the magnitude of the current
induced in the short-circuited winding is sufficient to operate the relay 304, thus opening the contacts 306. However, as the speed of the motor increases the frequency of and the current in 
56 a secondary circuit 301 gradually becomes less and less until the armature of the relay 304 drops and closes the contacts 306.

When the armature of the relay 304 closes the contacts 336 a circuit is established for energizing the line switch 339 for delivering direct current to the windings 302 of the synchronous motor. The circuit that energizes the relay 309 may be traced from the energized conductor 322 through the upper contacts of the relay 326, conductor 319, the winding of the relay 309, conductor 320, contacts 336, and conductors 321, 346 and 355 to the supply conductor 329.

As much as the frequency and the current of the secondary circuit 301 becomes less and less as the motor speeds up, I find that relays of the general type, even though having a shading coil, chatter and vibrate a great deal. This is particularly true of relays of the armature. On the other hand, the relay 304, since it establishes a uni-directional flux throughout the core and its armature, provides for reducing substantially all of the chattering generally incident in other types of relays. Herein resides the utility of my directional flux relay.

I find that it is of prime importance to prevent the relay 304 from chattering. The preventing of chattering materially increases the useful life of the relay.

Since certain changes in my invention may be made without departing from the spirit and scope thereof, it is intended that all matters contained in the foregoing description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. In combination, a magnetic circuit, means for establishing a reversing flux in said magnetic circuit, and means influenced by said reversing flux for establishing a unidirectional flux in said magnetic circuit.

2. In combination, a magnetic circuit, means for establishing a reversing flux in said magnetic circuit, and a winding influenced by said reversing flux, a rectifier in circuit with said winding, said winding and rectifier thus offering a relatively high resistance to the flow of the induced current caused by the said reversing flux in one direction and a relatively low resistance to the flow of said current in the opposite direction to produce a unidirectional flux in said magnetic circuit.

3. In combination, a structure having a plurality of magnetic circuits, a main winding for establishing a reversing flux in said magnetic circuits, a second winding influenced by said reversing flux, and an asymmetric unit in series with said second winding for permitting current to flow in one direction but not in the other direction to produce a unidirectional flux in one of said magnetic circuits.

4. In combination, a magnetic circuit, a main winding for establishing a reversing flux in said magnetic circuit, a second winding influenced by said reversing flux, an asymmetric unit in series with said second winding for permitting current to flow in one direction but not in the other direction to produce a unidirectional flux in the other of said magnetic circuits.

5. In combination, a core having a multiple of magnetic circuits, means for establishing a reversing flux in said circuits, and a winding including an asymmetric unit influenced by the reversing flux that is traversing one of the said magnetic circuits, said winding and asymmetric unit thus offering a higher resistance to the flow of current in one direction than in the other direction.

6. In combination, a magnetic circuit, a winding including an asymmetric unit offering a higher resistance to the flow of current in one direction than in the other direction associated with said magnetic circuit, a second magnetic circuit associated with said first-mentioned magnetic circuit, said second magnetic circuit having a higher reluctance than said first-mentioned magnetic circuit, and means for establishing a reversing flux in both of said magnetic circuits.

7. In combination, a magnetic circuit, means for establishing a reversing flux in said magnetic circuit, means influenced by said reversing flux for establishing a unidirectional flux in said magnetic circuit, and a second magnetic circuit associated with said first-mentioned magnetic circuit for limiting said unidirectional flux.

8. In a relay, in combination, a core having an armature disposed in alignment therewith, a main winding for establishing a reversing flux in said core, and a second winding influenced by said reversing flux for establishing a unidirectional flux in said core and armature, and means associated with said second winding for permitting current to flow in one direction but not in the other direction.

9. In a relay, in combination, a magnetic circuit, a winding for said magnetic circuit, means for energizing said winding with alternating current, means influenced by said alternating current for establishing a unidirectional flux in said magnetic circuit, and means for dissipating said unidirectional flux when said winding is deenergized.

10. In combination, a magnetic circuit having an air gap, means for establishing a reversing flux in said magnetic circuit, means influenced by said reversing flux for establishing a unidirectional flux in said magnetic circuit, and a second magnetic circuit associated with the first-mentioned magnetic circuit, said second magnetic circuit having a greater reluctance than the first-mentioned magnetic circuit.

11. In a control system, in combination, a relay having an armature energized by a source of alternating current of relatively low frequency, and means associated with the relay for producing a unidirectional flux for continuously holding the armature closed as the low-frequency current passes through zero.

12. In a control system, in combination, a relay having an armature, energized by a source of alternating current, and a core member, and means comprising only a coil and an asymmetric unit in closed circuit relation disposed on the core member and adapted to continuously hold the armature closed as the alternating current passes through zero.

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