May 5, 1942. F. KRAUTWIG 2,282,065

ELECTROMAGNETIC DEVICE

Filed June 2, 1939

Fig. 1.

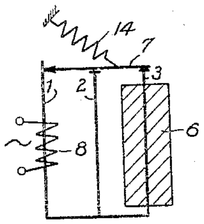


Fig. 2.

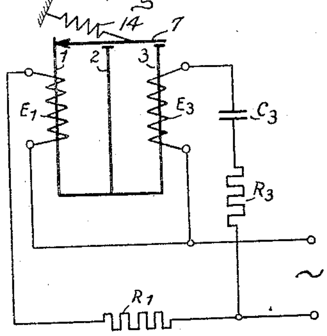


Fig. 3.

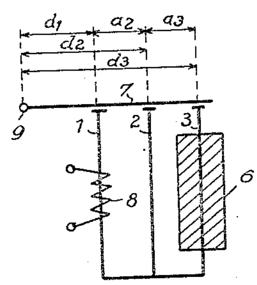


Fig. 4.

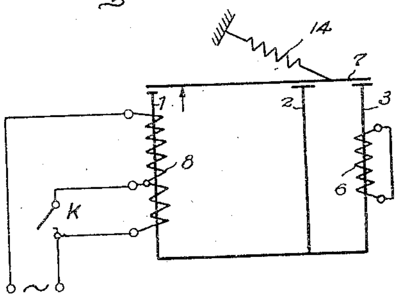


Fig. 6.

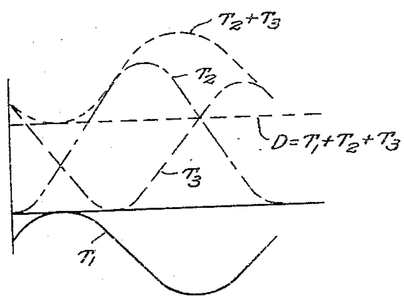
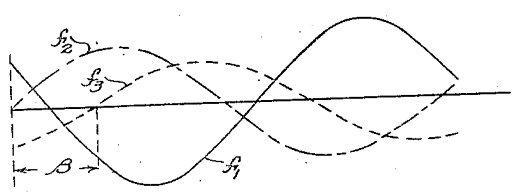


Fig. 5.



Inventor:
Franz Krautwig,
by Harry E. Dunham
His Attorney.

Patented May 5, 1942

UNITED STATES PATENT OFFICE

2,282,065

ELECTROMAGNETIC DEVICE

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Application June 2, 1939, Serial No. 277,117
In Germany June 3, 1938

8 Claims. (Cl. 175—338)

My invention relates to improvements in electromagnetic devices for use in alternating current circuits and more particularly electromagnetic devices, such as relays, having a movable armature whose movement is dependent on a single-phase alternating current quantity and which must be maintained in a definite position independently of the variation with respect to time of the instantaneous value of the quantity.

Some magnetic relays, such for example as voltage responsive relays, are energized by a single alternating voltage normally to maintain the movable armature of the relay in a predetermined contact controlling position from which it is to be moved to a different contact controlling position on the occurrence of a predetermined decrease in voltage. If the change in position is desired with a small decrease in voltage, then because of lack of uniformity in pull in consequence of the cyclic variation of the voltage, a false response of the relay may occur.

Thus it is well known to control many groups of lamps, water-heaters, etc. by reduction of the potential in alternating current systems. This may be accomplished by a plurality of operations of a circuit breaker, each operation consisting of an opening and a closing of the circuit to be controlled. Each operation has a very short duration and appears in the system as a momentary lowering of the voltage. The apparatus to be controlled comprises a relay responsive to the lowering of the voltage and it is well understood that each relay should release its armature in response to the same voltage decrease. For this purpose it is requisite that the resultant magnetic effect exerted on the armature be substantially independent of the variation with respect to time of the instantaneous value of the alternating current quantity energizing the relay. This can be attained, for example, by energizing the armature in dependence on two alternating fluxes which are suitably displaced in phase.

In some distance relays, particularly those of the impedance type in which a restraining effect, such as a force or torque dependent on voltage, is opposed to an operating effect, such as a force or torque dependent on current, the mere cyclic variation of the voltage with respect to time may result in such a decrease in the restraining effect as to cause a false operation of the relay particularly if a high degree of sensitivity is desired. In other words, because of the phase angle variation between the current and the voltage, the relay tends to respond to the instantaneous ratio of the voltage and the current and not the ratio of the root mean square values of these two quantities as is desired. Also, as is well known in alternating current and voltage relays, the lack of uniformity in attractive effort on the armature due to the cyclic variation in the current or voltage results in noise or hum and undesirable wear of the parts.

Various expedients have been proposed to eliminate troubles attendant on the lack of uniformity in magnetic attractive effort due to the cyclic variation of the alternating current quantity whereby to maintain the stability of the armature position throughout such variation. Among other things, these expedients have included the use of a plurality of windings each energized by the alternating current quantity in question and one or more phase displacing means connected in circuit with the windings and so proportioned as to provide a reasonably uniform effect throughout the cyclic variation of the alternating current quantity. Such extra phase displacing items as condensers, resistors, etc., not only increase cost but also consume switchboard space. Also, in general, the more items of equipment, the more opportunities for breakdown and failure to operate properly at the critical time.

In accordance with my invention, I provide an electromagnetic device which has a movable armature and which can be energized by a single alternating current quantity whose cyclic variation does not materially affect the stability of the armature position. Moreover, in accordance with my invention, I provide an improved electromagnetic device in which this stability of position throughout the cyclic variation of the alternating current quantity is simply and economically achieved within the device itself and not by extraneous elements, such as condensers, resistors, and the like. These and other objects of my invention will hereinafter appear in more detail.

My invention will be better understood from the following description when considered in connection with the accompanying sheet of drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawing Figs. 1 and 2 illustrate diagrammatically for the purpose of leading up to a better understanding of my invention electromagnetic devices which have been proposed for maintaining the armature positioning effect constant during the cyclic variation of an alternating current quantity; Fig. 3 illustrates diagrammatically an electromagnetic device on which the analysis of the theory of action of my invention is based; Fig. 4 illustrates diagrammatically an electromagnetic device embodying my invention with the parts proportioned in accordance with specific assumptions; Fig. 5 is a diagram of curves illustrating flux relations in apparatus embodying my invention; and Fig. 6 is a diagram of curves illustrating torque relations in apparatus embodying my invention. In all the figures the magnetic members of the electromagnetic devices, that is the core and the armature thereof, are drawn in thick black lines in order to simplify the illustrations, and the fulcrums or pivotal supports are indicated by arrow heads and small circles.

Referring now to Fig. 1, the flux entering the armature 7 at the pivotal support on the core leg 1, in consequence of the energization of the winding 8 by an alternating current quantity, is divided into two fluxes which enter and leave the armature by way of the core legs 2 and 3. These two fluxes are dephased relatively to each other. The phase displacement is obtained in this case by providing the core leg 3 with a short-circuited winding 6. This structure presents the advantage of being cheap but is, on the other hand, disadvantageous in that it requires a phase displacement of 90° in order to maintain the resultant magnetic turning moment or torque acting on the armature constant. Such a large phase displacement cannot be obtained with a short-circuited winding. The result obtained on the whole is that the arrangement shown in Fig. 1 is not suited for the manufacture of a potential relay which can fulfill the requirements of a control of the type herein set forth.

These requirements are, however, satisfied by the arrangement shown in Fig. 2 by which it is possible to obtain a phase displacement of 90° between the two fluxes in the core legs 2 and 3 but only in connection with suitable auxiliary phase displacing means such as resistances R_1, R_3 and a condenser C_3 in circuit with energizing windings E_1 and E_3, if the resultant magnetic turning moment acting on the armature is to be maintained constant.

In arrangements such as those illustrated in Figs. 1 and 2 wherein the magnetic flux traverses the magnet armature at the pivotal support thereof, it is likely that the magnetic resistance of the support and also the response of the relay will vary in the course of time by reason of the wear and tear. In order to obviate this, it has been suggested to arrange the pivot 9 for the armature outside of the magnetic core, as shown in Fig. 3.

In accordance with my invention, I so proportion the distances d_1, d_2, d_3 of the magnetic centers of gravity of the three alternating fluxes entering and leaving the armature by way of the core legs 1, 2 and 3, respectively, as to obtain a substantially constant resultant magnetic turning moment acting upon the armature, with a phase displacement between the two fluxes in the core legs 2 and 3, respectively, which is less than 90°. A phase displacement less than 90° can readily be obtained with the aid of a short-circuited winding 6, for example, on the leg 3. This arrangement presents over the arrangement shown in Fig. 2 the advantage of a considerably smaller expenditure because it does not require another coil, the condenser C_3 and the resistance R_3.

If the resultant magnetic turning moment relatively to the armature fulcrum or pivot 9 is D, the instantaneous values of the fluxes in the legs 1, 2 and 3 are f_1, f_2, f_3, and the amplitudes of the flux waves are F_1, F_2, F_3, then

$$D=a_1f_1^2+a_2f_2^2+a_3f_3^2,$$

a_1, a_2, a_3 being constants involving factors of design.

Also $f_1+f_2+f_3=0$, since the algebraic sum of the fluxes entering and leaving the armature at any instant must be zero in accordance with Kirchoff's laws as adapted to flux flow. Accordingly,

$$f_1=-(f_2+f_3)$$

as shown graphically in Fig. 5.

$$D=(a_1+a_2)f_2^2+(a_1+a_3)f_3^2+2a_1f_2f_3 \qquad (1)$$

Also

$$f_2=F_2\sin pt,\ f_3=F_3\sin(pt+\beta) \qquad (2)$$

p is the angular velocity of the flux vectors in radians per second and β is the angle by which the flux f_3 is displaced from the flux f_2 in consequence of the effect of the short-circuited winding 6.

By inserting the values of f_2 and f_3 from Equation 2 in Equation 1, there results, after certain transformations, the following:

$$\begin{aligned}D=&\tfrac{1}{2}(a_1+a_2)F_2^2+\tfrac{1}{2}(a_1+a_3)F_3^2+a_1F_2F_3\cos\beta\\&+\sin 2pt\{\tfrac{1}{2}(a_1+a_3)F_3^2\sin 2\beta+a_1F_2F_3\sin\beta\}\\&+\cos 2pt\{-a_1F_2F_3\cos\beta-\tfrac{1}{2}(a_1+a_2)F_2^2-\tfrac{1}{2}(a_1+a_3)F_3^2\cos 2\beta\}\end{aligned} \qquad (3)$$

If the resultant torque D on the armature 7 is to be substantially independent of the cyclic variation of the alternating current quantity which energizes the winding 8, then the coefficients of both the sin $2pt$ and the cos $2pt$ terms in Equation 3 must equal 0 as expressed below:

$\tfrac{1}{2}(a_1+a_3)F_3^2\sin 2\beta+a_1F_2F_3\sin\beta=0$ which by transformation to functions of the single angle β may be expressed as

$$\sin\beta\{(a_1+a_3)F_3^2\cos\beta+a_1F_3F_2\}=0 \qquad (4)$$

and

$$-a_1F_2F_3\cos\beta-\tfrac{1}{2}(a_1+a_3)F_3^2\cos 2\beta-\tfrac{1}{2}(a_1+a_2)F_2^2=0 \qquad (5)$$

Solving these two Equations 4 and 5 simultaneously for cos β and

$$\frac{F_2}{F_3}$$

gives:

$$\frac{F_2}{F_3}=\sqrt{\frac{a_1+a_3}{a_1+a_2}} \qquad (6)$$

$$\cos\beta=\frac{-1}{\sqrt{1+\frac{a_1a_2+a_2a_3+a_3a_1}{a_1^2}}} \qquad (7)$$

The Equations 6 and 7 give the phase displacement and the flux ratio in dependence on the distances of the three magnetic centers of gravity as involved in the constants a_1, a_2, a_3 which can be expressed in terms of the distances d_1, d_2, d_3, since the torques D_1, D_2, D_3 due to the respective pole fluxes f_1, f_2, f_3 may be written as follows:

$$D_1=kd_1f_1^2=a_1f_1^2,\qquad a_1=kd_1$$
$$D_2=kd_2f_2^2=a_2f_2^2,\qquad a_2=kd_2$$
$$D_3=kd_3f_3^2=a_3f_3^2,\qquad a_3=kd_3$$

Accordingly, by substitution, the Equations 6 and 7 can be expressed in terms of d_1, d_2, d_3, as follows:

$$\frac{F_2}{F_3}=\sqrt{\frac{1+\frac{d_3}{d_1}}{1+\frac{d_2}{d_1}}}$$

$$\cos\beta=\frac{-d_1}{\sqrt{d_1^2+d_1(d_2+d_3)+d_2d_3}} \qquad (8)$$

which may be expressed as follows:

$$\frac{F_2}{F_3}=\frac{(d_1+d_3)^{1/2}}{(d_1+d_2)^{1/2}}$$

and

$$\cos\beta=\frac{-d_1}{(d_1+d_2)^{1/2}(d_1+d_3)^{1/2}} \qquad (9)$$

Consequently for $d_1=0$, that is to say, for arrangements according to Figs. 1 and 2, $\cos\beta$ would be equal to zero and β, accordingly, 90°, a condition impossible to obtain with a shading winding alone. But if d_1 is not zero, it is possible to accomplish the desired action with phase angles less than 90°, which can readily be obtained with short-circuiting rings. In this case it is immaterial which of the two fluxes F_2 and F_3 is leading or lagging. Since

$$\frac{F_2}{F_3}$$

and $\cos\beta$ depend solely on the relative values of d_1, d_2, d_3, linear increases of all dimensions do not produce a variation in the resultant magnetic effect. In order to obtain this effect, the two Equations 8 must be satisfied by suitable proportioning of the determining quantities. This can be attained, for example, by adjustment of d_1 (horizontal displacement of the armature fulcrum).

Referring now to Fig. 6, T_1, T_2 and T_3 are curves showing the values of the torques exerted on the armature in consequence of the attractions due to the fluxes f_1, f_2, and f_3, illustrated by wave forms in Fig. 5. D is the curve of the algebraic sum of the torques T_1, T_2 and T_3 or, in other words, the difference between T_1 and the sum of T_2 and T_3. Since D is to be substantially independent of the cyclic variation of the applied alternating current electric quantity when the armature is in a predetermined position, it appears as a straight line whose distance above the zero axis depends on the effective value of the quantity.

Fig. 4 illustrates my invention in a specific embodiment which is based on the foregoing analysis and in which, for example, $d_1=-0.5$ (the armature fulcrum lies between the legs 1 and 2), $d_2=2$, and $d_3=3$. Then according to the Equation 8: $\cos\beta=0.258$, $\beta=75°$ (attainable with a short-circuited winding),

$$\frac{F_2}{F_3}=1.29$$

The contact K serves for repositioning the dropped armature.

I claim:

1. An electromagnetic device comprising an armature, a cooperating magnetic member presenting at least three pole faces to said armature, winding means on said member adapted when energized from a single-phase source of alternating current to establish alternating fluxes in the pole faces of said member and in said armature, short-circuited winding means on said magnetic member for effecting a phase displacement between at least two of said fluxes, and means supporting said armature intermediate one of said pole faces and the other pole faces for angular movement so positioned relatively to said pole faces that the resultant torque effect on the armature due to the attractions between the respective pole faces and the armature when the armature is in a predetermined position and said winding means is energized from a single-phase source of alternating current is substantially constant as long as the effective value of said current is substantially constant.

2. An electromagnetic device comprising an armature, a cooperating magnetic member having three polar projections directed towards said armature, winding means on said member adapted when energized from a single-phase source of alternating current to establish alternating fluxes in said projections and said armature, short-circuited winding means on one of said projections for effecting a predetermined phase displacement between at least two of said fluxes, and a pivotal support for said armature so positioned intermediate the third of said polar projections and said two polar projections that the resultant torque effect on the armature due to the attractions between the respective polar projections and the armature when the armature is in a predetermined position and said winding means is energized from a single-phase source of alternating current is substantially independent of the cyclic variation of the current.

3. An electromagnetic device comprising an armature, a cooperating magnetic member having three legs presenting pole faces to said armature, winding means on one outside leg of said member adapted when energized from a single-phase source of alternating current to establish alternating fluxes in the legs of said member and in said armature, short-circuited winding means on the other outside leg of said member for effecting a predetermined phase displacement between the fluxes in said other outside leg and the leg intermediate the two outside legs, and a pivotal support for said armature between said intermediate leg and said one outside leg so positioned relatively to the pole faces of said legs that the resultant torque of the attractive effects on the armature is substantially independent of the cyclic variation of the alternating current quantity energizing said winding means when the armature is in a predetermined position.

4. An electromagnetic device comprising an armature, a cooperating magnetic member presenting three pole faces to said armature, winding means on said member adapted when energized from a single-phase source of alternating current to establish fluxes f_1, f_2 and f_3 having amplitudes F_1, F_2 and F_3 in the poles of said member and the armature, the algebraic sum of the fluxes f_1, f_2 and f_3 entering and leaving the armature at any instant being substantially zero, short-circuited winding means on said member for effecting a phase displacement β between the fluxes f_2 and f_3, and a pivotal support for said armature so positioned at distances d_1, d_2 and d_3, respectively, from the centers of magnetic attraction of said pole faces and relatively to said phase displacement β and said flux amplitudes F_2 and F_3 that

$$\cos\beta=\frac{-d_1}{(d_1+d_2)^{1/2}(d_1+d_3)^{1/2}}$$

and

$$\frac{F_2}{F_3}=\frac{(d_1+d_3)^{1/2}}{(d_1+d_2)^{1/2}}$$

5. An electromagnetic device comprising an armature, a cooperating magnetic member having three polar projections directed towards said armature, winding means on said member adapted when energized from a single-phase source of alternating current to establish in said three polar projections fluxes f_1, f_2 and f_3, respectively, which have amplitudes F_1, F_2 and F_3, the algebraic sum of the fluxes f_1, f_2 and f_3 entering and leaving the armature at any instant being substantially zero, short-circuited winding means associated with one of said polar projections for effecting a predetermined phase displacement β between the fluxes f_2 and f_3, and a pivotal support for said armature intermediate the polar projections in which the fluxes f_1 and f_3 occur so positioned at distances d_1, d_2 and d_3, respectively, from the centers of magnetic attraction of said polar projections and relatively to said phase displacement β and said flux amplitudes F_2 and F_3 that

$$\cos \beta = \frac{-d_1}{(d_1+d_2)^{1/2}(d_1+d_3)^{1/2}}$$

and

$$\frac{F_2}{F_3} = \frac{(d_1+d_3)^{1/2}}{(d_1+d_2)^{1/2}}$$

6. An electromagnetic device comprising an armature, a cooperating magnetic member having three polar projections directed towards said armature, winding means on said member adapted when energized from a single-phase source of alternating current to establish in said three polar projections fluxes f_1, f_2 and f_3, respectively, which have amplitudes F_1, F_2 and F_3 the subnumbers 1, 2 and 3, respectively, indicating the order of said polar projections in series, the algebraic sum of the fluxes f_1, f_2 and f_3 entering and leaving the armature at any instant being substantially zero, short-circuited winding means associated with the polar projection energized by the flux f_3 for effecting a predetermined phase displacement β between the fluxes f_2 and f_3, and a pivotal support for said armature intermediate the polar projections in which the fluxes f_1 and f_2 occur so positioned at distances d_1, d_2 and d_3, respectively, from the centers of magnetic attraction of said polar projections and relatively to said phase displacement β and said flux amplitudes F_2 and F_3 that

$$\cos \beta = \frac{-d_1}{(d_1+d_2)^{1/2}(d_1+d_3)^{1/2}}$$

and

$$\frac{F_2}{F_3} = \frac{(d_1+d_3)^{1/2}}{(d_1+d_2)^{1/2}}$$

7. An electromagnetic device comprising an armature, a cooperating magnetic member presenting at least three pole faces to said armature, winding means on said member adapted when energized by a single-phase alternating current to establish alternating fluxes in the pole faces of said member and in said armature, means comprising a short-circuited winding for effecting a phase displacement between at least two of said fluxes, and means intermediate one of said pole faces and the other two of said pole faces supporting said armature for angular movement so positioned relatively to said pole faces that the resultant torque effect of the attractions between the respective pole faces and the armature when the armature is in a predetermined position and said winding means is energized by a single-phase alternating current is substantially independent of the cyclic variation of the current.

8. An alternating current electromagnetic device comprising an armature, a cooperating magnetic member having at least three pole faces arranged adjacent said armature so that the flux passing between one of said pole faces and the armature is the sum of the fluxes passing between the other faces and the armature, a winding on said member arranged when energized by a single-phase alternating current to magnetize the member, means for effecting a predetermined phase displacement between the fluxes in said other pole faces, and means intermediate said one pole face and the other pole faces supporting said armature for angular movement characterized by the fact that said pole faces are so arranged relatively to each other and to said supporting means that the resultant torque effect produced by the flux on said armature is substantially constant in a predetermined direction when the armature is in a predetermined position and said winding is energized by a single-phase alternating current having a constant effective value.

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