

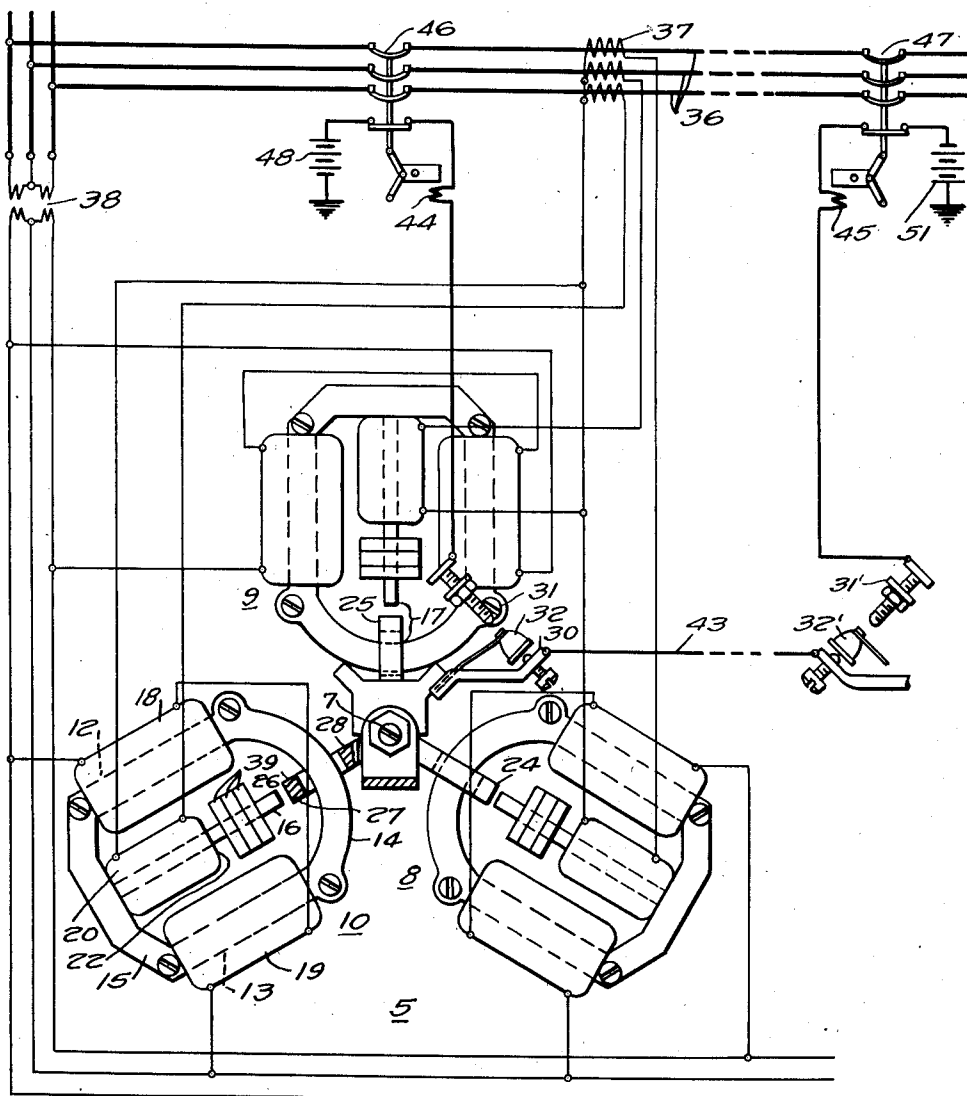
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B. V. HOARD

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PHASE-ANGLE SHIFTING-MEANS IN DIRECTIONAL RELAYS

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WITNESSES:

E. A. McLaughlin
Wm. L. Groome

INVENTOR

Bert V. Hoard

BY *O. D. Buchanan*
ATTORNEY

UNITED STATES PATENT OFFICE

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PHASE-ANGLE SHIFTING MEANS IN
DIRECTIONAL RELAYS

Bert V. Hoard, Millburn, N. J., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

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My invention relates to improved lag-ring means for securing a phase-angle shift in the current-responsive flux of a relay-mechanism having a salient-pole magnetizable leg-member, carrying a current-responsive coil and my novel lag-ring means for shifting the phase of the flux. While my invention, in some of its broader aspects, is of general application, it was particularly designed, and is particularly adapted, for incorporation in a directional relay of the inductor-loop type, and particularly in a three-phase inductor-loop directional relay.

An object of my invention is to provide a salient-pole relay-electromagnet construction having both a current-winding and closed-circuit lag-coil-means disposed upon a salient pole-piece thereof.

A more specific object of my invention is to provide such a construction in which the current-energized coil or winding is disposed on the back part of the salient pole-piece, in spaced relation back from the face of the pole-piece, and in which the lag-coil-means is in the form of a plurality of lag-rings distributed at different points along the front portion of the salient pole-piece.

A still further object of my invention involves an application of the previously mentioned lag-ring means to an inductor-loop directional element of a type which is described and claimed in an application of S. L. Goldsborough and myself, Serial No. 374,110, filed January 11, 1941, in which the directional element comprises a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, and having a reentrant leg or salient pole-piece extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of the reentrant leg, said directional element further having a rotatably mounted inductor-loop having one side in the air-gap of said electromagnet-core, the reentrant leg being energized by a current-coil which is preferably disposed on the rear portion of said reentrant leg, while the two side-legs and the two yokes are energized, loop-fashion, by means of a voltage-responsive coil or coils, so that the relay develops a pulsating single-phase wattmeter-type torque, the lag-ring means being disposed on the front portion of the reentrant leg.

A still further object of my invention relates to a particularly advantageous application thereof to a three-phase inductor-loop directional relay, utilizing the well-known 90° connection, but

without any externally connected phase-shifting impedance in the voltage-coil circuits. In the 90° connection, the current-coil of each of the single-phase wattmeter elements is energized with a star-phase relaying-current, while the voltage-coil is energized with a delta-phase relaying-voltage which is displaced 90° in phase with respect to said current under unity-power-factor conditions. Heretofore, it has been necessary to insert capacitors in the voltage-coil circuits of such relays in order to obtain the necessary optimum phase-angle of response. By applying my lag-rings to the current-energized salient pole-piece, at a substantially negligible cost, I not only save the cost of the capacitors, and the cost of the labor involved in mounting and wiring said capacitors, but I also provide a more compact and a simpler-looking relay, and a relay which has shown better performance on tests.

A specific feature of my invention relates to the utilization of a distributed lag-ring effect which is obtained by placing a plurality of lag-rings distributed at different points along the front end of a salient pole-piece, along a portion of said pole-piece in which the pole-piece flux is leaking off to the sides. By this means, I can obtain a large phase-angle shift of the order of 45° or 60° with a relatively small reduction in the flux, which can be easily compensated for by slightly increasing the number of turns on the current-coil. By increasing the number of lag-rings, I have been able to obtain very extremely large phase-angle shifts without an excessive decrease in the air-gap flux. For example, I have obtained a 100° phase-angle shift, with a decrease in the magnitude of the air-gap flux to 25% of its original value, by utilizing my distributed lag-rings. Without the distributed effect which is obtained by placing a plurality of lag-rings at different points along the front portion of a salient-pole member from which flux is distributively leaking laterally, all along, the theoretical maximum phase-angle shift which is obtainable with a single lag-loop would be a limiting value of a 90° shift, with zero air-gap flux, as the absolute limit beyond which undistributed lag-ring phase-shifting could not be carried.

With the foregoing and other objects in view, my invention consists in the structures, combinations, methods and systems hereinafter described and claimed, and illustrated in the accompanying drawing, the single figure of which is a diagrammatic view of circuits and apparatus illustrating my invention in a preferred three-phase form of embodiment of a directional relay-mech-

anism which is somewhat schematically represented in top plan view, with the supporting-frame or bracket broken away, for clarity of illustration.

In the illustrated form of my invention, I have shown a three-phase wattmeter-type relay-element 5. The relay has a common shaft 7, and three loop-type, laminated, magnetizable, electromagnet-cores 8, 9, and 10, stationarily supported in a common plane and in spaced relation about the shaft 7. Each of the electromagnet-cores, such as the core 10, has two side-legs 12 and 13, two yokes 14 and 15, and a reentrant center-leg 16 which extends from the midpoint of the rear yoke 15 to an air-gap 17 between the midpoint of the front yoke 14 and the front end of said reentrant leg 16, the front yoke 14 being the one which is closest to the shaft 7. The two side-legs 12 and 13 are energized by means of two voltage-coils 18 and 19 which are connected so as to send a flux, loop-fashion, around the magnetic circuit composed of the two side-legs 12 and 13 and the two yokes 14 and 15.

The centrally-disposed reentrant leg 16 is excited by a current-coil 20, and this current-coil is preferably disposed on the extreme rear end of the center leg 16, close up against the rear yoke 15, and the center leg 16 is made quite long, so that the front end 22 of the current-coil 20 is spaced a considerable distance back from the air-gap 17, the purpose of this construction being to increase the magnetic leakage, particularly under high-current conditions, at which time the center leg 16 is saturated. In the preferred form of my invention, I also make at least the front end of the center reentrant leg 16 very narrow, in a circumferential direction with respect to the shaft 7, so as to have a sufficiently small cross-section to become saturated during high-current conditions, thus increasing the leakage-flux.

The three stationary electromagnet-cores 8, 9 and 10 cooperate with three aluminum inductor-loops 24, 25 and 26, respectively, each loop being threaded by the front yoke 14 of its electromagnet-core. Each of the inductor-loops has a thin front-leg 27 which is disposed within the air-gap 17 of its corresponding electromagnet-core, and a thick rear-leg 28 which is mounted on, or integral with, the shaft 7.

The shaft 7 also carries a movable contact-member 30 which cooperates with a stationary contact-member 31. Preferably, the movable contact-member 30 terminates in a tungsten-powder-filled conducting capsule 32 which dampens bouncing, by reason of the movement of the sharp-edged tungsten-powder granules over each other, as shown and described in an application of W. V. Johnson, Serial No. 352,915, filed August 16, 1940, and assigned to the Westinghouse Electric & Manufacturing Company. The non-bouncing contact 32 is shown in the drawing, because that is the construction which I prefer. It should be understood, however, that, so far as my present invention is concerned, any form of movable contact-member could be utilized.

As particularly set forth in the aforesaid joint application of S. L. Goldsborough and myself, the front yokes 14 of each of the three electromagnet-cores 8, 9 and 10 are humped at their midpoints, where they project toward the shaft 7. This humped construction has two important advantages. In the first place, it enormously increases the distance between adjacent electromagnet-cores. In the second place, it produces a voltage-

responsive decentering-torque which is particularly advantageous.

In the drawing, I show an illustrative wiring diagram of connections whereby the polyphase wattmeter element 5 is energized to be responsive to polyphase power-direction of a three-phase line 36 which is to be protected.

The three current-coils 20 of the polyphase wattmeter element 5 are energized with relaying currents which are derived from, and responsive to, the respective line-currents in the three conductors of the protected line 36, the relaying currents being derived by means of three star-connected current-transformers 37. The three pairs of voltage-coils 18 and 19 of the three electromagnets of the polyphase wattmeter element 5 are energized from different delta relaying voltages which are derived from the line 36 through potential transformers 38. The two voltage-coils 18 and 19 of each electromagnet-core are preferably connected in series with each other, and each pair of voltage-coils is energized from the delta-phase opposite to the star-current with which the corresponding current-coil 20 is energized, thus utilizing what is known as the 90° connection.

The impedance of each of the voltage-coils 18 and 19 is mostly resistance, so that the fluxes which circulate, loop fashion, around each electromagnet-core, that is, through the two outer legs 12 and 13 and through the two yokes 14 and 15, are practically in phase with the voltage impressed upon the two voltage-coils 18 and 19. Each of the inductor-loops 24, 25 and 26 has a sufficiently low effective cross-section (with respect to currents circulated within said loop) so that the loop has a relatively low reactance as compared to its resistance, so that the loop-current lags behind the voltage applied to the voltage-coils 18 and 19 of its electromagnet-core by a small angle of the order of 15°. The flux in the air-gap 17 of each electromagnet-core, such as the core 10, is, of course, in phase with the current in the current-coil 20 of the said electromagnet-core. The response of each of the single-phase wattmeter elements is to the product of the loop-current times the air-gap flux, multiplied by the cosine of the phase-angle between these two quantities. Consequently, the maximum torque of each of the single-phase wattmeter elements, as thus far specifically described, is produced when the current which is supplied to the current-coil 20 lags the voltage which is impressed upon the voltage-coil 18 and 19 by about 15°.

I preferably utilize the 90° connection, in which the current-coil is energized from a "phase" or "star" line-current, while the voltage-coil circuit is energized from the opposite delta voltage in such polarity that the voltage lags the current by 90° when the power-factor of the line or system is unity. I normally use this 90° connection, with polyphase directional relays, because such relays give faster and more sensitive operation during phase-to-phase faults, because the two single-phase elements in which the fault-currents are flowing are excited with unfaulted (and hence undiminished) delta-voltages.

Thus, for unity power-factor in the system or on the protected three-phase line or apparatus, when utilizing the 90° connection, the current through the relay-electromagnet is leading the applied voltage by 90°. For a fault-condition, however, which causes the line-current to lag by 45°, the relay-current leads the applied relay-

voltage by 45°. It is desirable to adjust the phase-angle characteristic of the relay so that the relay will have its maximum response at this phase-angle, that is, when the system fault-current is lagging by 45°, and the relay-current is leading the applied relay-voltage by 45°.

Heretofore, the necessary shifting of the optimum phase-angle response of 90°-connected polyphase relays has been obtained by connecting an external impedance, usually a capacitor, in series with the respective voltage-coils of the relay. In accordance with my present invention, such external voltage-circuit impedances have been altogether omitted, and I utilize lag-ring means, preferably in the form of a plurality of rectangular-shaped copper phase-loops 39 distributed at spaced points along the front portion of each of the salient pole-pieces or reentrant legs 15 of the several electromagnet-cores 8, 9 and 10. These loops are thus placed on that part of the magnetic circuit where there are distributed magnetic leakage-flux paths in parallel with the air-gap flux in the air-gap 17; and a plurality of phasing-loops are disposed at distributed points, so that their phase-retarding effect is also distributed. The total resultant phase-shift which is obtainable in this manner is greater than if the combined effects of distributed leakage and distributed lag-rings were not present. The distributed effect also decreases the amount by which the useful air-gap flux is reduced, so that phase-angle shifts of even more than 90° can be obtained, such as a 100° shift, while still obtaining a useful air-gap flux which is as much as 25% of the original value of the flux before the lag-loops were added.

In the particular embodiment of my invention, utilizing the 90° connection, with rotor-element inductor-loops 24, 25 and 26 introducing a 15° lag in the loop-current as compared to the applied relaying-voltage, I preferably employ such number and size of lag-rings 39 as to cause the air-gap flux, in the air-gap 17, to lag 60° behind the current in the current-coil 20, the number of turns in the current-coil 20 being slightly increased to compensate for the slight reduction in air-gap flux which is caused by the addition of the lag-loops 39. This 60° lag in the air-gap flux, coupled with the 15° lag in the loop-current, gives the relay a 45° characteristic which causes it to develop its maximum torque when the current supplied to the current-coil 20 leads the voltage impressed upon the voltage-coils 18 and 19 by 45°. The 90° connection provides a source of relaying current which leads the relaying voltage by 90° when the power factor of the line or system is unity. Hence, with a 45° relay-characteristic and a 90° connection, maximum torque is obtained when the system fault-current is lagging by 45°.

While my preferred form of closed-circuited lag-coil-means comprises a plurality of lag-rings 39 distributed at different points along the current-energized salient-pole member or reentrant leg 16, different constructions of the closed-circuited lag-coil-means may be utilized, particularly when the phase-angle shift is to be small, in which case the distributed effect is relatively unimportant as compared with cases in which a relatively large phase-angle shift is required.

The relaying equipment which has been illustrated and described in the drawing is useful in many different ways. By way of illustration, I have indicated one particular use of my apparatus, involving a direct-current pilot-wire 43 for

joining the two ends of a three-phase transmission-line section 36 which is to be protected, so as to control the energization of the trip-coils 44 and 45 of the line-circuit-breakers 46 and 47 at the respective ends of the protected line-section. The relay-contacts 31—32 are connected in series with the pilot-wire 43 at one end thereof, in series with the trip-coil 44 and a station-battery 48 at that end of the protected line-section 36. At the other end, a pair of similar relay-contacts 31'—32' are serially connected to the pilot-wire 43, in series with the trip-coil 45, and the station-battery 51 at that end of the protected line-section 36. One of the station-batteries has its negative terminal grounded, while the other has its positive terminal grounded, so that, when a fault occurs anywhere within the protected line-section 36, the two directional relay-contacts, (31—32 at one end, and 31'—32' at the other end), will close, each in response to a power-direction of current flowing into the faulted line-section from its respective end. The direct-current pilot-wire 43 is thus energized only when the power-direction is internal, or inflowing, at both ends of the protected line-section. For a fault outside of the protected line-section, only one of the directional relays responds, so that the pilot-wire circuit 43 is not energized.

It will be understood by those who are familiar with relaying systems that I have very much simplified my diagram of connections, which omit the usual contactor-switches which I actually utilize to by-pass the sensitive relay-contacts so as to relieve said relay-contacts of the burden of interrupting the tripping-circuit.

While I have illustrated my invention in a single preferred or illustrative form of embodiment, I desire it to be understood that my invention is not limited to the particular illustrated form, as various changes, by way of additions, omissions and substitutions, may be made by those skilled in the art without departing from the essential spirit of my invention. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language.

I claim as my invention:

1. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, the front yoke of said core being adjacent to the axis of said rotatably supported member, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said rotatably supported member comprising an inductor-loop having one side in the air-gap of said electromagnet-core, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, alternating-current terminal-means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means with two different alternating-current quantities so that said inductor-loop develops a pulsating single-phase wattmeter-type torque, and closed-circuited lag-coil-means disposed on the reentrant leg of the electromagnet-core.

2. A wattmeter-type relay comprising a rotat-

ably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, the front yoke of said core being adjacent to the axis of said rotatably supported member, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said rotatably supported member comprising an inductor-loop having one side in the air-gap of said electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of the electromagnet-core, closed-circuited lag-coil-means disposed on the front portion of said reentrant leg, electromagnet-coil-means for energizing the side-legs of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, and alternating-current terminal-means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means with two different alternating-current quantities so that said inductor-loop develops a pulsating single-phase wattmeter-type torque.

3. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, the front yoke of said core being adjacent to the axis of said rotatably supported member, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said rotatably supported member comprising an inductor-loop having one side in the air-gap of said electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of the electromagnet-core, a plurality of lag-rings distributed at different points along the front portion of said reentrant leg, electromagnet-coil-means for energizing the side-legs of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, and alternating-current terminal-means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means with two different alternating-current quantities so that said inductor-loop develops a pulsating single-phase wattmeter-type torque.

4. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said front yoke being adjacent to the axis of said rotatably supported member, said rotatably supported member comprising an inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear

portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, closed-circuited lag-coil-means disposed on the front portion of said reentrant leg, and alternating-current terminal-means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means with two different alternating-current quantities so that said inductor-loop develops a pulsating single-phase wattmeter-type torque.

5. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said front yoke being adjacent to the axis of said rotatably supported member, said rotatably supported member comprising an inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, a plurality of lag-rings distributed at different points along the front portion of said reentrant leg, and alternating-current terminal-means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means with two different alternating-current quantities so that said inductor-loop develops a pulsating single-phase wattmeter-type torque.

6. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in the air-gap of its electromagnet-core, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of each electromagnet-core, the side-leg-energizing mag-

net-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, closed-circuited lag-coil means disposed on the reentrant leg of each electromagnet-core, and circuit-connection means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means of each electromagnet core from a three-phase set of star-phase relaying currents and a three-phase set of delta-phase relaying voltages, with a pair of single-phase relaying quantities consisting of a star current and a delta voltage which are 90° related to each other under unity-power-factor conditions, different pairs of currents and voltages being utilized for the three different electromagnet-cores.

7. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in the air-gap of its electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of each electromagnet-core, closed-circuited lag-coil-means disposed on the front portion of each reentrant leg, electromagnet-coil-means for energizing the side-legs of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, and circuit-connection means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means of each electromagnet core from a three-phase set of star-phase relaying currents and a three-phase set of delta-phase relaying voltages, with a pair of single-phase relaying quantities consisting of a star current and a delta voltage which are 90° related to each other under unity power-factor conditions, different pairs of currents and voltages being utilized for the three different electromagnet-cores.

8. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in the air-gap of its electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of each electromagnet-core, a plurality of lag-rings distributed at different points along the front portion of each reentrant leg, electromagnet-coil-means for energizing the side-legs of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, and circuit-connection means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means of each electromagnet core from a three-phase set of star-phase relaying currents and a three-phase set of delta-phase relaying voltages, with a pair of single-phase relaying quantities con-

sisting of a star current and a delta voltage which are 90° related to each other under unity power-factor conditions, different pairs of currents and voltages being utilized for the three different electromagnet-cores.

9. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, closed-circuited lag-coil-means disposed on the front portion of each reentrant leg, and circuit-connection means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means of each electromagnet core from a three-phase set of star-phase relaying currents and a three-phase set of delta-phase relaying voltages, with a pair of single-phase relaying quantities consisting of a star current and a delta voltage which are 90° related to each other under unity power-factor conditions, different pairs of currents and voltages being utilized for the three different electromagnet-cores.

10. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width

and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, a plurality of lag-rings distributed at different points along the front portion of each reentrant leg, and circuit-connection means adapted to be energized for energizing the respective side-leg-energizing and reentrant-leg-energizing magnet-coil-means of each electromagnet core from a three-phase set of star-phase relaying currents and a three-phase set of delta-phase relaying voltages, with a pair of single-phase relaying quantities consisting of a star current and a delta voltage which are 90° related to each other under unity power-factor conditions, different pairs of currents and voltages being utilized for the three different electromagnet-cores.

11. The invention as defined in claim 1, characterized by the means for energizing said reentrant-leg electromagnet-coil energizing-means being a current-responsive means.

12. The invention as defined in claim 2, characterized by the means for energizing said reentrant-leg electromagnet-coil energizing-means being a current-responsive means.

13. The invention as defined in claim 3, characterized by the means for energizing said reentrant-leg electromagnet-coil energizing-means being a current-responsive means.

14. The invention as defined in claim 6, characterized by the means for energizing said reentrant-leg electromagnet-coil energizing-means being a current-responsive means.

15. The invention as defined in claim 7, characterized by the means for energizing said reentrant-leg electromagnet-coil energizing-means being a current-responsive means.

16. The invention as defined in claim 8, characterized by the means for energizing said reentrant-leg electromagnet-coil energizing-means being a current-responsive means.

17. Relaying means comprising a stationarily supported electromagnet core comprising a salient-pole magnetizable leg-member, a movable relay-member operatively disposed with respect to the magnetic flux at the face of said salient-pole magnetizable leg-member, an energizing coil on said salient-pole magnetizable leg-member, single-phase terminal-means adapted to be energized for supplying a relaying current to said energizing coil, and closed-circuited lag-coil-means disposed on said salient-pole magnetizable leg-member.

18. Relaying means comprising a stationarily supported electromagnet core comprising a salient-pole magnetizable leg-member, a movable relay-member operatively disposed with respect to the magnetic flux at the face of said salient-pole magnetizable leg-member, an energizing coil on the rear portion of said salient-pole magnetizable leg-member in spaced relation back from said face, single-phase terminal-means adapted to be energized for supplying a relaying current to said energizing coil, and closed-circuited lag-coil-means disposed on the front portion of said salient-pole magnetizable leg-member.

19. Relaying means comprising a stationarily supported electromagnet core comprising a salient-pole magnetizable leg-member, a movable relay-member operatively disposed with respect to the magnetic flux at the face of said salient-pole magnetizable leg-member, an energizing coil on the rear portion of said salient-pole magnetizable leg-member in spaced relation back from

said face, single-phase terminal-means adapted to be energized for supplying an energizing current to said energizing coil, and a plurality of lag-rings distributed at different points along the front portion of said salient-pole magnetizable leg-member.

20. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, the front yoke of said core being adjacent to the axis of said rotatably supported member, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said rotatably supported member comprising an inductor-loop having one side in the air-gap of said electromagnet-core, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, and closed-circuited lag-coil-means disposed on the reentrant leg of the electromagnet-core.

21. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, the front yoke of said core being adjacent to the axis of said rotatably supported member, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said rotatably supported member comprising an inductor-loop having one side in the air-gap of said electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of the electromagnet-core, closed-circuited lag-coil-means disposed on the front portion of said reentrant leg, and electromagnet-coil-means for energizing the side-legs of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core.

22. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, the front yoke of said core being adjacent to the axis of said rotatably supported member, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said rotatably supported member comprising an inductor-loop having one side in the air-gap of said electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of the electromagnet-core, a plurality of lag-rings distributed at different points along the front portion of said reentrant leg, and electromagnet-coil-means for energizing the side-legs of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core.

23. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends

of the side-legs, said electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said front yoke being adjacent to the axis of said rotatably supported member, said rotatably supported member comprising an inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, and closed-circuited lag-coil-means disposed on the front portion of said reentrant leg.

24. A wattmeter-type relay comprising a rotatably supported contact-controlling member, a loop-type electromagnet-core having two side-legs and two yokes joining the respective ends of the side-legs, said electromagnet core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, said front yoke being adjacent to the axis of said rotatably supported member, said rotatably supported member comprising an inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of the electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, and a plurality of lag-rings distributed at different points along the front portion of said reentrant leg.

25. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in the air-gap of its electromagnet-core, electro-

magnet-coil-means for respectively energizing the side-legs and the reentrant leg of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, and closed-circuited lag-coil means disposed on the reentrant leg of each electromagnet-core.

26. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in the air-gap of its electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of each electromagnet-core, closed-circuited lag-coil-means disposed on the front portion of each reentrant leg, and electromagnet-coil-means for energizing the side-legs of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core.

27. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in the air-gap of its electromagnet-core, electromagnet-coil-means disposed on the rear portion of the reentrant leg of each electromagnet-core, a plurality of lag-rings distributed at different points along the front portion of each reentrant leg, and electromagnet-coil-means for energizing the side-legs of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core.

28. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said

reentrant-leg magnet-coil-means, whereby to increase said leakage flux, and closed-circuited lag-coil-means disposed on the front portion of each reentrant leg.

29. Wattmeter-type relay-mechanism comprising three electromagnet-cores, each having two side-legs and two yokes joining the respective ends of the side-legs, each electromagnet-core further having a reentrant leg extending from the midpoint of the rear yoke to an air-gap between the midpoint of the front yoke and the front end of said reentrant leg, each electromagnet-core further having associated therewith a rotatably supported inductor-loop having one side in said air-gap, electromagnet-coil-means for respectively energizing the side-legs and the reentrant leg of each electromagnet-core, the side-leg-energizing magnet-coil-means of the electromagnet being adapted to circulate a flux in loop-fashion around the core, the reentrant-leg-energizing magnet-coil-means being disposed on the rear portion of said reentrant leg so that the front end of said magnet-coil-means is spaced back from the front end of said reentrant leg whereby to provide a leakage-flux path, in front of said reentrant-leg magnet-coil-means, from the front portion of said reentrant leg to the respective side-legs of the electromagnet-core, at least the front end of said reentrant leg, adjacent to the air-gap, being of a narrow width and of a sufficiently small cross-section to become saturated during high-current exciting-conditions of said reentrant-leg magnet-coil-means, whereby to increase said leakage flux, and a plurality

of lag-rings distributed at different points along the front portion of each reentrant leg.

30. Relaying means comprising a stationarily supported electromagnet core comprising a salient-pole magnetizable leg-member, a movable relay-member operatively disposed with respect to the magnetic flux at the face of said salient-pole magnetizable leg-member, an energizing coil on said salient-pole magnetizable leg-member, and closed-circuited lag-coil-means disposed on said salient-pole magnetizable leg-member.

31. Relaying means comprising a stationarily supported electromagnet core comprising a salient-pole magnetizable leg-member, a movable relay-member operatively disposed with respect to the magnetic flux at the face of said salient-pole magnetizable leg-member, an energizing coil on the rear portion of said salient-pole magnetizable leg-member in spaced relation back from said face, and closed-circuited lag-coil-means disposed on the front portion of said salient-pole magnetizable leg-member.

32. Relaying means comprising a stationarily supported electromagnet core comprising a salient-pole magnetizable leg-member, a movable relay-member operatively disposed with respect to the magnetic flux at the face of said salient-pole magnetizable leg-member, an energizing coil on the rear portion of said salient-pole magnetizable leg-member in spaced relation back from said face, and a plurality of lag-rings distributed at different points along the front portion of said salient-pole magnetizable leg-member.

BERT V. HOARD.