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DOUBLE-LOOP DIRECTIONAL-ELEMENT

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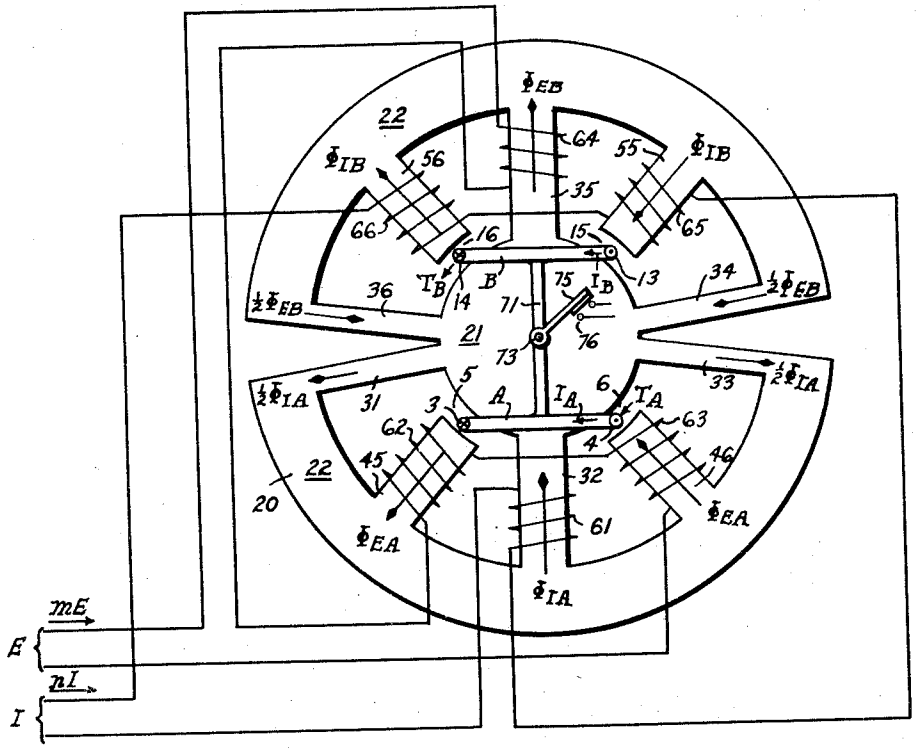


Fig. 1.

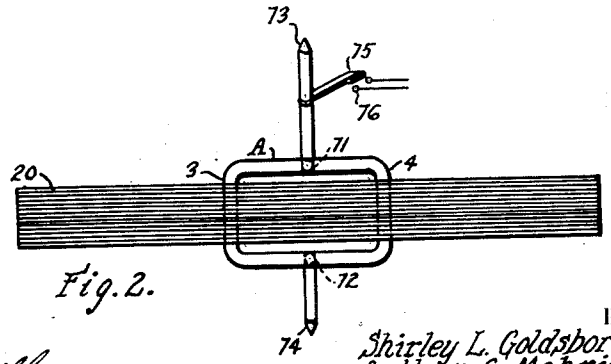


Fig. 2.

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DOUBLE-LOOP DIRECTIONAL ELEMENT

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Our invention relates to the elimination of the double-frequency pulsating torque-component of the high-speed loop-type wattmetric or directional relay. This pulsating torque has heretofore caused considerable difficulty in the operation of directional elements, especially at phase-angles which are close to the angle of zero-torque, or balance-point, of the element.

It has been known, heretofore, that this double-frequency torque can be eliminated by combining two directional elements, one of which has both its current and its voltage shifted 90° with respect to the current and voltage, respectively, of the other. Such a double-element device is shown in Fig. 4 of Patent No. 2,300,886, issued to the present applicant Goldsborough, and Bert V. Hoard, on November 3, 1942. It has three major disadvantages, first, in requiring two elements, second, in requiring a 90° external phase-shifter in the current-circuit, and, third, a 90° external phase-shifter in the voltage-circuit. A 90° phase-shifter is both difficult and expensive to achieve, without reducing the effective energy-producing torque on the element to a small and ineffective quantity.

It is the principal object of our invention to produce a practical type of non-vibrating single-phase directional-element, requiring only one element, and no external phase-shifters, to obtain the two torques having their pulsating components displaced 90° in time (on a normal-frequency basis), so as to produce a non-vibrating or constant-torque directional response.

Generally speaking, it is an object of our invention to utilize two loops, responding to the product of two alternating fluxes, times a function of the phase-angle displacement between them, in such manner that one loop is traversed, or excited, by one of the fluxes, and has its coil-sides or a coil-side thereof reacting with the second flux, while the other loop is traversed or excited by the second flux and has its coil-side or sides reacting with the first flux.

With the foregoing and other objects in view, our invention consists in the circuits, apparatus, systems, parts, constructions, and methods, hereinafter described and claimed, and illustrated in the accompanying drawing, wherein:

Figure 1 is a diagrammatic plan-view of circuits and apparatus showing our invention in an illustrative form of embodiment; and

Fig. 2 is a simplified or diagrammatic elevational view showing the structure without the coils on the various poles of the field-frame.

Essentially, our invention consists of means for providing two cooperating pairs of two alternating-current field-fluxes, which we can distinguish by calling one of the fluxes ϕ_I and the other ϕ_E. Two loops are also provided, which are mechanically fastened together and mounted for movement. The loops and fields are provided so that one of the loops, which may be designated A, is traversed by the first flux, which may be designated ϕ_{IA}, in one of the pairs of cooperating fluxes, while the coil-sides 3 and 4 of said loop A lie in airgaps 5 and 6, which are traversed by a second flux of that pair, said second flux of the loop-A pair being designated ϕ_{EA}. The other loop B is inversely related to the other pair of fluxes, which are designated ϕ_{IB} and ϕ_{EB}, respectively. The loop B is traversed by the second flux ϕ_{EB}, and its coil-sides 13 and 14 lie in airgaps 15 and 16 which are traversed by the first flux ϕ_{IB} of the second pair of fluxes.

As shown in the drawing, the fluxes are carried by a stack of magnetizable punchings 20, which constitute a field-magnet frame, which may be described as having a central magnetizable disk 21, and a peripheral yoke-member 22, with various radial magnetic legs 31, 32, 33, 34, 35, and 36 joining the two. On the two sides of the radial leg 32, the yoke 22 is provided with inwardly projecting pole-pieces 45 and 46, defining the airgaps 5 and 6 which are between the ends of these pole-pieces and the central disk 21. On the two sides of the radial leg 35 are two other pole-pieces 55 and 56, which extend inwardly from the outer yoke 22, to provide the airgaps 15 and 16.

The radial leg 32 is excited by a coil 61, which produces the flux ϕ_{IA}, the return-path for said flux being through the two radial legs 31 and 33, as indicated in Fig. 1. The pole-pieces 45 and 46 are excited with serially connected coils 62 and 63 which produce, respectively, north and south poles (at any instant), traversed by the flux ϕ_{EA}. These fluxes cooperate with the loop A, as shown and described.

On the loop-B side of the apparatus, the radial leg 35 is excited by a coil 64 so as to be traversed by the flux ϕ_{EB}, the return-paths for which are through the radial legs 34 and 36, as shown. The two pole-pieces 55 and 56 are excited by coils 65 and 66, so as to provide, at any instant, alternately north and south poles traversed by the flux ϕ_{IB}.

The various coils are excited, in either series or parallel circuit-relation, as may be desired, to provide the required exciting-currents. In the particular form illustrated, the coils 64, 62, and 63

are serially excited from a suitable alternating-current source, marked E, which may be a voltage-source, so that they are all traversed by an exciting-current mE. The other three coils, 66, 65, and 61, are shown as being connected together in series, in another circuit which is energized from a second alternating-current source, marked I, which may be a current-source, which supplies the exciting-current nI to the said coils.

The two loops A and B are mechanically connected together, as by cross-pieces 71 and 72, which may be insulating, if desired, the central portions of the cross-pieces being carried by vertically extending pivots 73 and 74, respectively. A contact-arm 75 is also provided, for cooperating with contact-points 76 of any suitable relay-circuit which is to be controlled by our relay.

The operation may be derived as follows.

The instantaneous values of the two relay exciting-currents mE and nI may be written $\sqrt{2}m\overline{E}\sin wt$ and $\sqrt{2}n\overline{I}\sin(wt-\theta)$, where θ is the angle by which I lags E, and $\overline{E}$ and $\overline{I}$ are the *rms* magnitudes of E and I.

The fluxes ϕ_{IA} and ϕ_{EB} lag behind their respective inducing-currents by a certain angle a, but by reason of the symmetry of the construction, that angle is the same for both of these fluxes.

The fluxes ϕ_{IB} and ϕ_{EA} lag behind their respective inducing-currents by a different angle b, but by reason of the symmetry of the construction, that angle also is the same for both of these fluxes.

The loop-currents I_A and I_B lag behind their respective inducing-fluxes ϕ_{IA} and ϕ_{EB} by a certain angle c, which, because the loops are identical, is the same for both loops.

The current I_A, flowing in the loop-sides 3 and 4, react with the flux ϕ_{EA} in the airgaps 5 and 6, to produce a torque T_A in a clockwise direction, which we may call negative.

The current I_B, flowing in the loop-sides 13 and 14, react with the flux ϕ_{IB} in the airgaps 15 and 16, to produce a torque T_B in a counterclockwise direction, which we may call positive.

Each of the instantaneous torques t_A and t_B is the product of the instantaneous value of its loop-current, times the instantaneous value of its airgap flux, so that the total instantaneous torque is

$$\begin{aligned}t_B-t_A=&[\sqrt{2}m\overline{E}\sin(wt-a-c)]\cdot[\sqrt{2}n\overline{I}\sin\\&(wt-\theta-b)]+-[\sqrt{2}n\overline{I}\sin(wt-\theta-a-c)]\cdot\\&[\sqrt{2}m\overline{E}\sin(wt-b)]\\=&mn\overline{IE}[\cos(\theta-a+b-c)-\\&\cos(2wt-\theta-a-b-c)]+\\-&mn\overline{IE}[\cos(\theta+a-b+c)-\\&\cos(2wt-\theta-a-b-c)].\end{aligned}$$

It will be noted that the double-frequency terms, involving the cosine of $2wt$ minus a certain angle, cancel each other, being exactly equal and opposite.

The total torque T_B-T_A is therefore a steady torque, without any pulsations, regardless of the angle θ between the alternating-current quantities whose relative directions are being responded to. The total torque is

$$\begin{aligned}T_B-T_A&=mn\overline{IE}[\cos(\theta-a+b-c)-\\&\qquad\cos(\theta+a-b+c)]\\&=2mn\overline{IE}\sin(a-b+c)\sin\theta\end{aligned}$$

It is to be noted that θ, in a general sense, is simply the angle between the two relay-currents mE and nI, or the time-phase angle between the two relay-fluxes ϕ_{EB} and ϕ_{IA}. It need not be the line-power-factor angle, which we may designate θ_1, but it may be any angle such as $\theta=(\theta_1\pm x)$. So, also the two relay-fluxes ϕ_{IA} and ϕ_{EB}, or their exciting-currents nI and mE, need not be derived from a line-current and a line-voltage, respectively, but they may be any two single-phase quantities, of the same frequency, whose phases or directions are to be compared, in a relay which will have a zero response at a predetermined phase-angle between the two quantities.

While we have illustrated our invention in but a single form of embodiment, we thus believe that the principles of the applications of physical laws are quite generic, and we desire that our appended claims shall be given the broadest interpretation consistent with their language.

We claim as our invention:

1. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux or fluxes in response to a first electrical quantity and a second alternating flux or fluxes in response to a second electrical quantity, said flux-producing means comprising magnetic circuits for said fluxes, at least some of said magnetic circuits having an airgap or airgaps; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second closed paths for circulating currents, a first circulating-current path being so disposed that it is interlinked by a first flux while its circulating current flows in an airgap or airgaps of a second flux, and a second circulating-current path being so disposed that it is interlinked by a second flux while its circulating current flows in an airgap or airgaps of a first flux.

2. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux or fluxes in response to a first electrical quantity and a second alternating flux or fluxes in response to a second electrical quantity, said flux-producing means comprising magnetic circuits for said fluxes, at least some of said magnetic circuits having an airgap or airgaps; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second loop-systems for circulating currents, a first loop-system being so disposed that it is interlinked by a first flux while its circulating current flows in an airgap or airgaps of a second flux, and a second loop-system being so disposed that it is interlinked by a second flux while its circulating current flows in an airgap or airgaps of a first flux.

3. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux or fluxes in response to a first electrical quantity and a second alternating flux or fluxes in response to a second electrical quantity, said flux-producing means comprising a first magnetic circuit and a fourth magnetic circuit both traversed by substantially said first flux, and a second magnetic circuit and a third magnetic circuit both traversed by substantially said second flux, at least said second and fourth magnetic circuits each having an airgap or airgaps; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second closed paths for circulating currents, a first circulating-current path being so disposed that it

is interlinked by the flux of the first magnetic circuit while its circulating current flows in an airgap or airgaps of the second magnetic circuit, and a second circulating-current path being so disposed that it is interlinked by the flux of the third magnetic circuit while its circulating current flows in an airgap or airgaps of the fourth magnetic circuit.

4. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux or fluxes in response to a first electrical quantity and a second alternating flux or fluxes in response to a second electrical quantity, said flux-producing means comprising a first magnetic circuit and a fourth magnetic circuit both traversed by substantially said first flux, and a second magnetic circuit and a third magnetic circuit both traversed by substantially said second flux, the second and fourth magnetic circuits each having two airgaps therein; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second loop-systems for circulating currents, the first loop-system being so disposed that it is interlinked by the first magnetic circuit and so that portions of said first loop-system lie in the airgaps of the second magnetic circuit, and the second loop-system being so disposed that it is interlinked by the third magnetic circuit and so that portions of said second loop-system lie in the airgaps of the fourth magnetic circuit.

5. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux and a fourth alternating flux in response to a first electrical quantity and a second alternating flux and a third alternating flux in response to a second electrical quantity, said flux-producing means comprising magnetic circuits for said fluxes, the magnetic circuits for at least the second and fourth fluxes each having an airgap or airgaps; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second closed paths for circulating currents, a first circulating-current path being so disposed that it is interlinked by the magnetic circuit for the first flux while its circulating current flows in an airgap or airgaps of the magnetic circuit for the second flux, and a second circulating-current path being so disposed that it is interlinked by the magnetic circuit for the third flux while its circulating current flows in an airgap or airgaps of the magnetic circuit for the fourth flux.

6. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux and a fourth alternating flux in response to a first electrical quantity and a second alternating flux and a third alternating flux in response to a second electrical quantity, said flux-producing means comprising magnetic circuits for said fluxes, the magnetic circuits for at least the second and fourth fluxes each having an airgap or airgaps; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second loop-systems for circulating currents, a first loop-system being so disposed that it is interlinked by the magnetic circuit for the first flux while its circulating current flows in an airgap or airgaps of the magnetic circuit for the second flux, and a second loop-system being so disposed that it is interlinked by the magnetic circuit for the third flux while its circulating current flows in an airgap or airgaps of the magnetic circuit for the fourth flux.

7. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising a relatively stationary flux-producing means for producing a first alternating flux and a fourth alternating flux in response to a first electrical quantity and a second alternating flux and a third alternating flux in response to a second electrical quantity, said flux-producing means comprising magnetic circuits for said fluxes, the magnetic circuits for the second and fourth fluxes each having two airgaps therein; and a relatively movable member comprising means, in said airgap or airgaps, for providing first and second loop-systems for circulating currents, the first loop-system being so disposed that it is interlinked by the magnetic circuit for the first flux and so that portions of said first loop-system lie in the airgaps of the magnetic circuit for the second flux, and the second loop-system being so disposed that it is interlinked by the magnetic circuit for the third flux and so that portions of said second loop-system lie in the airgaps of the magnetic circuit for the fourth flux.

8. The invention as defined in claim 5, characterized by the product of the first and second fluxes being at all times substantially identical, in magnitude, with the product of the third and fourth fluxes, and the phase-angle between the first and second fluxes being at all times substantially the same as the phase-angle between the third and fourth fluxes.

9. The invention as defined in claim 6, characterized by the product of the first and second fluxes being at all times substantially identical, in magnitude, with the product of the third and fourth fluxes, and the phase-angle between the first and second fluxes being at all times substantially the same as the phase-angle between the third and fourth fluxes.

10. The invention as defined in claim 7, characterized by the product of the first and second fluxes being at all times substantially identical, in magnitude, with the product of the third and fourth fluxes, and the phase-angle between the first and second fluxes being at all times substantially the same as the phase-angle between the third and fourth fluxes.

11. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising control-circuit means for supplying two out-of-phase single-phase exciting-currents, torque-producing means comprising two opposing torque-producing elements each producing a torque responsive to the product of a torque-producing alternating current times a torque-producing alternating flux times a predetermined function of the phase-angle between them, means for producing the torque-producing current of the first element and the torque-producing flux of the second element in response to the first exciting-current, with a predetermined phase-angle relationship other than 90° between current and flux in response to said first exciting-current, and means for producing the torque-producing current of the second element and the torque-producing flux of the first element in response to the second exciting-current, with said predetermined phase-angle relationship between current and flux in response to said second exciting-current.

12. A substantially non-vibrating single-phase torque-producing electro-responsive device comprising control-circuit means for supplying two out-of-phase single-phase exciting-currents, torque-producing means comprising two opposing wattmetrically responsive elements, and means for energizing said two wattmetrically responsive elements from said two exciting-currents in such manner that one of said elements is responsive to the product of said exciting-currents times a predetermined function of the sum of a constant angle other than 90° and the phase-angle between said exciting-currents, and in such manner that the other of said elements is responsive to the product of said exciting-currents times said predetermined function of the difference between said constant angle and said phase-angle.

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