March 10, 1942. M. W. SCHELDORF 2,275,868

CURRENT RESPONSIVE DEVICE

Filed March 30, 1940

Fig. 1.

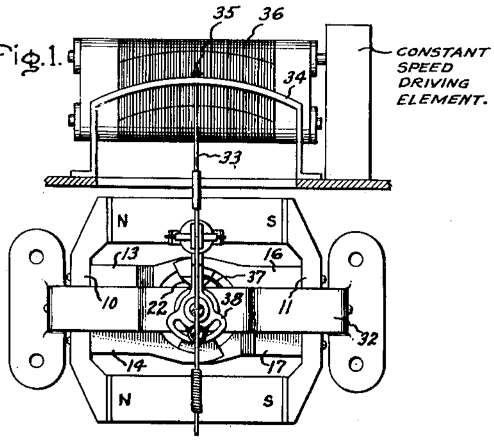


Fig. 2.

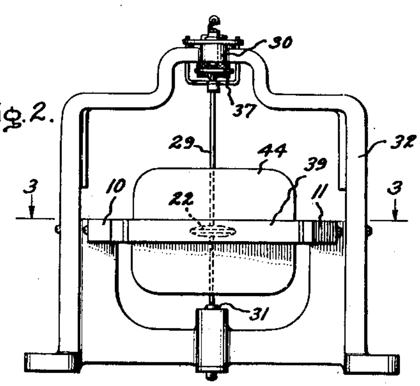


Fig. 3.

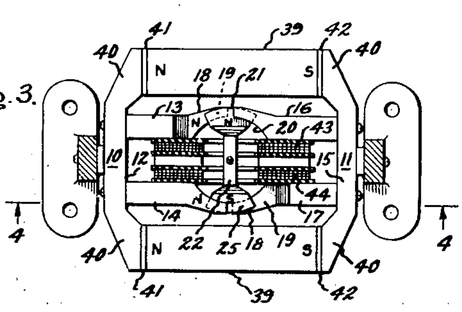


Fig. 4.

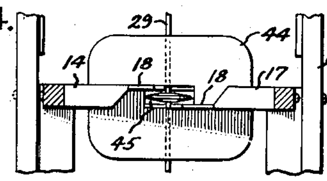


Fig. 5.

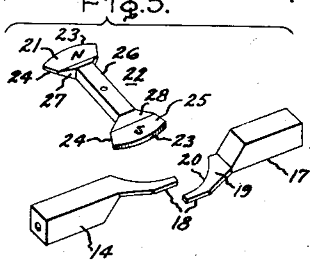
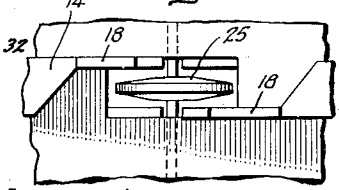


Fig. 6.



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UNITED STATES PATENT OFFICE

2,275,868

CURRENT RESPONSIVE DEVICE

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Application March 30, 1940, Serial No. 327,070

8 Claims. (Cl. 171—95)

The present invention relates to current responsive devices and more particularly to current responsive devices of the moving iron or balanced armature type.

It is an object of my invention to provide a new and improved torque producing element of the balanced armature or moving iron type.

It is another object of my invention to provide a new and improved galvanometer of the balanced armature type in which the angular range of movement of the armature is greatly increased over that obtainable with conventional devices of this general character.

It is another object of my invention to provide an improved torque producing element of the movable iron type in which the stability and sensitivity characteristics of the movable armature in response to current variations are greatly improved and which gives a quick directional response to succeeding impulses of different polarities.

Other objects and advantages of my invention will become apparent as the description proceeds.

The foregoing advantages are achieved by the employment of pole pieces and a movable armature of special construction. The stability and sensitivity characteristics of the device are improved still further by providing non-magnetic spacer elements between the flux producing element, such as the permanent magnet and the pole pieces which cooperate with the movable armature.

The features of the invention which are believed to be novel and patentable are set forth with particularity in the appended claims. My invention, itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 is a plan view of a torque producing element in the form of a galvanometer constructed in accordance with my invention; Fig. 2 is a side elevation view of the arrangement shown in Fig. 1; Fig. 3 is a partial sectional view taken along the line 3—3 of Fig. 2 and showing the construction of the movable armature and the cooperating pole pieces of the instrument; Fig. 4 is a view, partly in section, taken along the line 4—4 of Fig. 3 showing further details of the movable armature and the pole pieces which are arranged in accordance with my invention; Fig. 5 is an exploded perspective view of the armature and a pair of pole pieces embodying my invention; and Fig. 6 is an enlarged view of the armature and pole tip portion of Fig. 4.

In order to illustrate the principles of my invention I have shown a current responsive device or a torque producing element of the balanced armature type employed as a galvanometer. Referring to the drawing, the galvanometer includes a pair of substantially U-shaped magnetic pole piece parts 10 and 11 with the leg portions extending toward each other to form a pair of spaced air gaps. The part 10 comprises a web portion 12 and legs 13 and 14. Similarly, the part 11 comprises a web portion 15 and legs 16 and 17. A portion of each of the legs or pole pieces 13 and 14 and 16, 17 is cut away to provide a flat thin portion 18 having a face 19 lying in a horizontal plane and having an arcuate inner edge 20. The polar surface 19 tapers in width toward the tip portion which is adjacent the air gap or toward the pole piece of opposite polarity with which it cooperates to form an air gap. The arcuate edges 20 of the pole pieces which face the axis of the movable element each lie on arcs described from a common radius or which lie on the same circle.

Positioned in overlapping relation between the surface 19 of the leg 13 and the corresponding parallel surface 19 of the leg 16 is the end portion 21 of a magnetic vane-type armature 22. This end portion which is relatively thin with a comparatively large surface area on opposite sides is substantially in the form of a sector in that it is bounded by an arc or arcuate portion 23 and radial side portions 24. Similarly, between the corresponding parallel surfaces 19 of the legs 14 and 17 is positioned the opposite and similarly shaped end portion 25 of the armature 22. The armature 22 also includes an intermediate bar-shaped portion 26 which joins the thin end portions 21 and 25 through tapered sections 27 and 28, respectively. So far as the cross-sectional area of the various sections of the armature is concerned, it is largely a matter of maintaining the proper flux density. It will be appreciated that there will be leakage flux passing through the intermediate portion 26 which does not pass through the tip portions. It will be appreciated also that an increase in the cross-sectional area in the end portions 21 and 25 increases the inertia and thus lowers the mechanical efficiency. In view of these considerations and to the end of securing better mechanical operation it may be expedient to effect a compromise by constructing the extreme tip portions of the armature so that they may even operate at a slightly higher flux density than the intermediate sections.

The armature 22 is fixed on a vertical shaft or spindle 29 which extends through the geometric center of the armature and at right angles to the plane of rotary movement thereof. The shaft 29 is pivotally mounted for rotation by means of upper and lower bearings 30 and 31, respectively, mounted in any suitable manner such as to a frame 32. To the shaft 29 is secured a pointer 33 which moves in front of a suitable scale 34 for visual indication. There is also provided a pen 35 which cooperates with a moving chart 36 driven by a suitable constant speed or clockwork mechanism for providing a continuous record of the deflections of the movable element. It will be appreciated that if desired and within my invention the indicating and recording device comprising the pen and pointer may be dispensed with for certain applications in which case I may provide a mirror on the shaft 29 and employ a light-ray system, as shown in my prior United States Patent 2,127,427, August 16, 1937, for providing an indication or for adapting the torque producing element for use as a control device. A spirally arranged biasing spring 37, one end of which is secured to the shaft 29 and the other end of which is fixed to a member 38 adjustable with respect to the frame 32, provides means for fixing the zero or neutral position of the movable element.

In order to provide a unidirectional magnetomotive force between the respective pole pieces comprising the parts 10 and 11, I preferably employ a pair of similar permanent magnets 39 positioned on opposite sides of the instrument. Each of the permanent magnets 39 is arranged between projecting portions 40 of the webs 12 and 15. In order to improve still further the stability characteristic of the instrument over that obtainable by the use of an armature and pole pieces of the foregoing construction, I prefer to employ non-magnetic spacer elements 41 and 42 between each of the permanent magnets 39 and its respective cooperating pole piece parts 40. With an arrangement of this character, which is described and claimed in my prior patent previously referred to, there is a negligible change in the flux density across the armature air gap when the armature moves from the neutral to an extreme position, the relation between sensitivity and stability is improved, and the deflection of the armature is made more nearly proportional to the excitation current in the windings 43 and 44, presently to be described. The magnetic structure including the parts 10 and 11, and the two permanent magnets 39 are illustrated as supported from the framework 32.

I wish to point out that my invention is not limited to an arrangement in which two permanent magnets are arranged on opposite sides of the instrument for producing a unidirectial flux in the pole piece parts 10 and 11. Where desired, a single magnet may be employed. It may furthermore be one of substantially horse-shoe shape and joined to the web portions 12 and 15 with or without the employment of non-magnetic spacer elements 41 and 42. It will also be appreciated that this unidirectional flux may be produced by forming the elements 39 of relatively high permeability magnetic material with a current conducting coil wound thereabout to provide the magnetomotive force. However, for the sake of convenience, simplicity, and compactness I prefer to employ permanent magnets. While I do not limit my invention to the use of a particular material, the magnets 39 are preferably composed of some high grade permanent magnet material having a relatively high coercive force as compared to chrome steel for the sake of compactness and in order that a high degree of magnetization may be maintained for an almost indefinite period of time. Examples of materials which may be used with highly satisfactory results are cobalt steel or an alloy comprising aluminum, nickel, and iron as the basic or essential ingredients such as described in the Ruder Patents 1,947,274 and 1,968,569. The pole piece parts 10 and 11 are preferably composed of a relatively high permeability, low coercive force, magnetic material such as soft iron or a nickel-iron alloy of the character described in the Elmen Patent 1,586,884. The framework 32 is preferably composed of some suitable non-magnetic material such as brass.

An exciting winding comprising two coils 43 and 44 is positioned over the bar-shaped portion 26 of the armature 22 with the coils arranged on opposite sides of the vertical shaft 29. These coils may be connected in series or parallel circuit relation and they will be excited by the current to which the device is to respond. The excitation current in the windings 43 and 44 tends to polarize the magnetic armature 22 in the direction of its major length. As will be observed, the armature passes through an opening 45 which is formed in each of the coils 43 and 44. These openings are made of sufficient size to permit freedom of angular movement of the armature.

To obtain a better understanding of the operation of my invention let it be assumed that the permanent magnets are magnetized as indicated by the designations "N" and "S". As a result, the polar surfaces 19 of the legs 13 and 14 will be of north polarity and the corresponding polar surfaces of the legs 16 and 17 will be of south polarity. It will be appreciated that as the armature 22 rotates from its neutral position, as shown in Fig. 3, in a given direction, for example to left, it reduces the reluctance with respect to poles 13 and 17, and increases the reluctance with respect to poles 14 and 16. Referring to Fig. 3, if now it be assumed that the current flowing in the coils or windings 43 and 44 is such, for example, as to polarize the armature 22 to produce a north pole at the end adjacent the poles 13 and 16 and a south pole at the other end, as indicated in the drawing, the armature 22 will tend to rotate clockwise because of the attractive force exerted between the armature and the poles 14 and 16 and the force of repulsion exerted between the armature and the poles 13 and 17. A reversal of the current in the windings 43 and 44 will polarize the armature in the opposite direction and thus cause it to rotate in the counterclockwise direction.

I wish to direct particular attention to the shape of the armature end portions and the pole pieces with which they cooperate. By off-setting in different parallel planes the polar surfaces 19 of the poles 13 and 16 at one end of the armature and the polar surfaces 19 of the poles 14 and 17 at the opposite end of the armature, and by constructing the armature end portions 21 and 25 as described so that each moves in an air gap defined by two of these polar surfaces and in a plane which lies intermediate and substantially parallel to the planes of the surfaces 19, a wide range of angular movement of the armature is made possible. The armature being located in the air gap where the main flux must cross, it tends to lower the reluctance of this flux path and is most effectively positioned for producing torque. By tapering the width of the polar surfaces 19, which results in a corresponding reduction in the cross-sectional area of the pole piece portions 18, the portions of the poles positioned intermediate the thick sections and the tips adjacent the air gap, and which must carry all of the flux crossing the air gap, do not become saturated. The importance of this feature will be further appreciated when it is realized that this flux increases as the reluctance in its path decreases due to the movement of the armature toward it.

Referring to Fig. 3 assume that a plane perpendicular to the plane of the paper and including the axis of the shaft 29 is passed through the armature 22 along its longitudinal dimension. It is preferred to have the tips of the thin portions 18 of the pole pieces just meet this plane or be spaced back from it slightly rather than to have them pass through the plane to such an extent that they will overlap each other. In order words, I prefer that these tips be positioned on approximately the same diametrical line. They are illustrated as displaced slightly from such a position in order to clarify the drawing. With such an arrangement there occurs an appreciable change in reluctance between each pole and the armature as the latter moves toward or from a given pole.

Due to the foregoing construction as described, including the manner in which each of the armature end portions overlaps the pole pieces with which it cooperates, as the armature is rotated from the balanced condition or the neutral position there is a smooth reduction of reluctance with respect to each of the poles that is being approached and a smooth increase or reluctance with respect to each of the other poles as the armature recedes from them. Consequently, the movement takes place smoothly and with stability.

With the foregoing arrangement it may be seen that there is no change of flux necessary in the permanent magnet elements 39 as the armature moves from its neutral position since all flux variations take place in the soft iron or other relatively high permeability material which is accompanied by low losses. By employing a magnetic material having a relatively high permeability in the construction of the pole piece parts 10 and 11, the efficiency of the instrument is thus improved. A high flux density is obtained at the working air gaps through which the armature moves and, at the same time, the permanent magnet is operated at its most efficient flux density; in other words, the flux may be concentrated in the working air gaps without affecting the flux density in the magnet. For example, if the armature is polarized, as shown, the flux is increased in the legs 16 and 14 and decreased in the legs 13 and 17 but the total flux emanating from the permanent magnets remains substantially constant.

By virtue of the arrangement of the armature and the pole pieces, the armature is adapted for a considerably greater range of angular movement which hertofore has been a serious limitation to the use of such instruments. While it might be possible to secure an increase in the angular range of movement of the armature in conventional devices by providing a wider separation of the pole pieces, such a procedure would seriously reduce the air gap flux density and, in consequence thereof, would greatly impair the efficiency of the instrument. With the special shapes of the pole pieces and the armature provided by the present invention, large angles of rotation may be secured and at the same time satisfactory air gap flux densities are obtained with reasonable magnet structures. The arrangement of the substantially sector-shaped end portions of the armature each of which cooperates on one side with a pole face of one polarity and on the opposite side with a pole face of the opposite polarity provides a good path for the flux passing from the armature to either of the poles.

In torque producing elements wherein the coils of wire move in a magnetic field, the torque for a given power input to the coil may be shown to be proportional to the square root of the mass of the coil. Likewise, with some assumptions regarding constancy of the flux it may be shown that the torque of an armature type device also varies as the square root of the coil mass. These torque equations may be compared for equal flux densities in the effective air gap ratio. Thus, for the same air gap flux density, considerably higher torque may be secured with the balanced armature magnetic type torque producing element because of the ability to use considerably more conductor mass.

The apparatus of my invention may be found particularly useful in those instances where high torque is desired for operating recording elements. An example of such an application may be found by reference to the United States Letters Patent No. 1,897,850 to Cramer W. La Pierre, assigned to the assignee of the present invention. By means of my invention, the range of movement of the armature is greatly increased over that obtainable with prior arrangements, the device is highly sensitive, and stability of movement is also present.

In accordance with the provisions of the patent statutes, I have described the principle of operation of my invention together with the apparatus which I now consider to represent the best embodiment thereof but I desire to have it understood that the apparatus shown is only illustrative and that the invention may be carried out by other means.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In an electromagnetic current responsive device, a magnetic circuit comprising flux producing means and having polar extensions forming a pair of spaced north poles and a pair of spaced south poles, one of said north poles being arranged with its polar surface in opposed off-set parallel relation to the polar surface of one of said south poles to form an air gap and the other north pole being arranged with its polar surface in opposed off-set parallel relation to the polar surface of the other south pole to form a second air gap, a magnetic armature having one end positioned in one of said air gaps intermediate the polar surfaces of one pair of unlike poles and having the other end positioned in the other air gap intermediate the polar surfaces of the other pair of unlike poles, means for mounting said armature substantially at its geometrical center for rotation in a plane between and substantially parallel to said polar surfaces, and means for exciting said armature.

2. In a current responsive device of the balanced armature type, a magnetic circuit comprising a permanent magnet, a pair of spaced north poles composed of relatively high permeability magnetic material and joined to each other by means of an element of similar material and a pair of spaced and similarly arranged south poles composed of the same material, one of said north poles being arranged with its polar surface in opposed off-set parallel relation to the polar surface of one of said south poles to form an air gap and the other north pole being arranged with its polar surface in opposed off-set parallel relation to the polar surface of the other south pole to form a second air gap, a magnetic armature having one of its end portions positioned in one of said air gaps intermediate and in overlapping relation with the polar surfaces of one pair of unlike poles and having the other end portion positioned in the other of said air gaps intermediate and in overlapping relation with the polar surfaces of the other pair of unlike poles, means for pivotally mounting said armature substantially at its geometrical center for rotation in a plane between and substantially parallel to said polar surfaces, means for exciting said armature, and means operable in accordance with the rotary movement of said armature.

3. In a current responsive device of the balanced armature type, a magnetic circuit comprising a permanent magnet, a pair of spaced north poles composed of relatively high permeability magnetic material and joined to each other by means of a relatively high permeability magnetic material and a pair of spaced and similarly arranged south poles, one of said north poles being arranged with its polar surface in opposed off-set parallel relation to the polar surface of one of said south poles to form an air gap and the other north pole being arranged with its polar surface in opposed off-set parallel relation to the polar surface of the other south pole to form a second air gap, a magnetic armature comprising a substantially bar-shaped central portion and relatively thin substantially sector-shaped end portions, said armature being arranged with one of its end portions positioned in one of said air gaps intermediate and in overlapping relation with the polar surfaces of one pair of unlike poles and with the other end portion positioned in the other of said air gaps intermediate and in overlapping relation with the polar surfaces of the other pair of unlike poles, means for mounting said armature for rotation about an axis passing through the geometrical center of said bar-shaped portion whereby said armature is adapted to rotate in a plane between and substantially parallel to said polar surfaces, a stationary current conducting winding positioned about said armature for polarizing said armature along its longitudinal dimension in a direction and to a degree of magnetization determined by an electrical quantity to be measured, and means responsive to the movement of said armature for indicating the magnitude and direction of said electrical quantity.

4. A galvanometer comprising a magnetic circuit excited by a permanent magnet and having pole pieces positioned in off-set parallel planes defining an air gap, a magnetic vane armature, said armature being pivotally mounted for movement in a plane between and substantially parallel to the polar surfaces of said pole pieces, means for resiliently biasing said armature to a neutral position of maximum reluctance in the flux path across said air gap, an exciting winding which when energized polarizes said armature causing it to turn against its bias to a lower reluctance position with respect to one pole piece and a higher reluctance position with respect to the other pole piece, and means for indicating the movement of said armature as a function of the extent and direction of energization of said exciting winding.

5. A galvanometer comprising pole pieces composed of relatively high permeability magnetic material and separated in off-set parallel relation to form an air gap, a permanent magnet for producing a unidirectional flux between said pole pieces across said gap, a magnetic vane armature having a relatively thin and substantially sector-shaped end portion, means for pivotally mounting said armature for movement of said sector-shaped end portion in said air gap and in a plane between and substantially parallel to the polar surfaces of said pole pieces, means for biasing said armature to a neutral position of maximum reluctance with respect to the permanent magnet flux crossing said air gap, said armature being movable in opposite directions from such position to lower reluctance positions, an exciting winding which when energized polarizes said armature causing it to turn from its neutral position to intercept some of the permanent magnet flux crossing said gap, and means for measuring the extent of movement of said armature in either direction.

6. In a current responsive device of the balanced armature type, two pairs of pole pieces, the pole pieces of each pair being of unlike polarity, one pole piece of each pair being spaced and off-set from a pole piece of opposite polarity of the other pair thereby forming a pair of spaced armature air gaps, a permanent magnet associated with said pole pieces in a magnetic circuit for producing a unidirectional flux across said air gaps, a magnetic vane armature having end portions adapted to operate in said gaps, means for pivotally mounting said armature at a position intermediate said gaps so that one of the end portions of said armature moves in one of said gaps and the other end portion moves in the other of said gaps, said movement taking place smoothly and in a plane between and substantially parallel to the polar surfaces of said pole pieces, resilient means for biasing said armature to a neutral maximum reluctance position with respect to the flux crossing said air gaps but permitting the armature to turn in either direction from such position to lower reluctance positions with respect to one north pole and one south pole and to higher reluctance positions with respect to the other north pole and the other south pole, a current conducting winding which when energized polarizes said armature to cause it to deflect from said neutral position, and means for indicating the extent of said deflection.

7. In a current responsive device, a magnetic circuit comprising flux producing means and having polar extensions forming a pair of spaced north poles and a pair of spaced south poles, one of said north poles being arranged with its polar surface in opposed off-set parallel relation to the polar surface of one of said south poles to form an air gap and the other north pole being arranged with its polar surface in opposed off-set parallel relation to the polar surface of the other south pole to form a second air gap, each of said polar extensions being tapered in

cross sectional area in the direction of the respective polar surface of opposite polarity with which it cooperates to form an air gap, an armature composed of magnetic material and having substantially sector-shaped end portions, means for mounting said armature for rotary movement in a plane between and substantially parallel to said polar surfaces and in such a manner that one of said end portions moves in one of said air gaps and the other of said end portions moves in the other of said air gaps, the surface of said polar extensions facing the rotary axis of said armature being arcuate in shape and spaced equidistantly from said axis, means for biasing said armature to a neutral position, means for polarizing said armature to a degree of magnetization and in a direction determined by variations in an electrical quantity to which the device is to respond, and means responsive to the movement of said armature.

8. In an electromagnetic current responsive device of the balanced armature type, a magnetic circuit comprising a permanent magnet and two pairs of pole pieces of unlike polarity, said pole pieces being composed of relatively high permeability magnetic material and the pole pieces of like polarity being joined to each other through a member of magnetic material, the pole pieces of one pair extending towards the pole pieces of the other pair in off-set relation to form a pair of air gaps spaced from each other, an armature having relatively thin arcuate end portions, means for mounting said armature with its end portions extending into the spaced air gaps for rotation in a plane between and substantially parallel to the polar surfaces of said pole pieces, means for creating variable magnetic lines of force at said poles to cause the armature to move between the same, said pole pieces being shaped to cooperate with the end portions of said armature in such a manner that as the armature moves in a given direction it reduces smoothly the reluctance with respect to one set of poles and increases smoothly the reluctance with respect to another set of poles.

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