Oct. 3, 1939. R. A. WARNER 2,175,046

ELECTRICAL MEASURING INSTRUMENT

Filed Sept. 15, 1938

Fig.1.

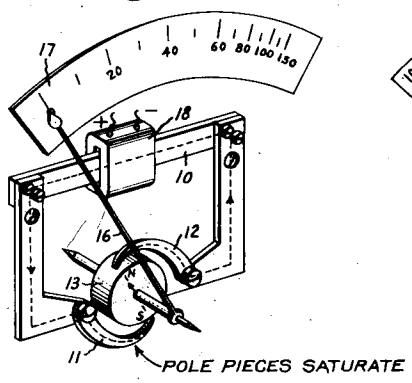


Fig.3.

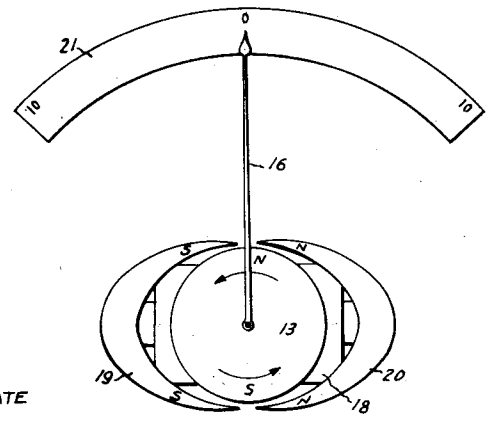


Fig.2.

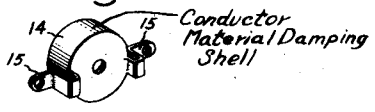


Fig.4.

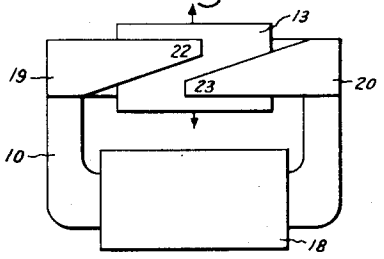


Fig.5.

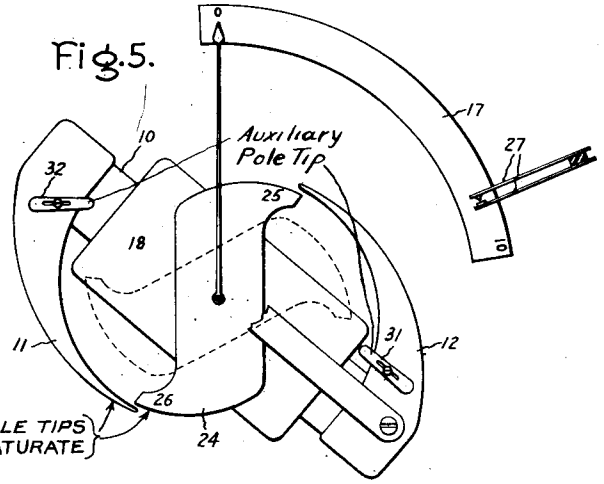
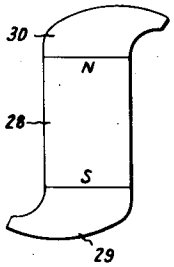


Fig.6.



Inventor:
Russell A. Warner,
by Harry E. Dunham
His Attorney.

Patented Oct. 3, 1939 2,175,046

UNITED STATES PATENT OFFICE

2,175,046

ELECTRICAL MEASURING INSTRUMENT

Russell A. Warner, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application September 15, 1938, Serial No. 230,050

7 Claims. (Cl. 171—95)

My invention relates primarily to direct current instruments such as those for measuring and relay purposes.

An object of my invention is to provide a direct current measuring instrument that supplies its own zero restoring torque and requires no zero return spring or other additional expedient for this purpose. In accordance with my invention, such an instrument may be provided without using a moving armature coil.

In carrying my invention into effect, I make use of a magnetic circuit for the instrument which includes an eccentric air gap determined by tapered pole pieces designed to become saturated so as to rotate the axis of flux distribution between the stationary field and moving armature of the instrument with different values of flux. The armature is made of magnetic material and is polar either by reason of its shape or because polarized.

The features of my invention which are believed to be novel and patentable will be pointed out in the claims appended hereto. For a better understanding of my invention, reference is made in the following description to the accompanying drawing, in which Fig. 1 is a perspective view of a direct current instrument involving my invention and having a polarized magnetic armature. Fig. 2 represents a damper shell which is preferably provided between the armature and stator. Fig. 3 is a plan view of a zero center instrument involving the invention. Fig. 4 is a side view of a zero center instrument showing how the tapered stationary pole pieces may overlap. Fig. 5 is a plan view of an instrument in which the pole pieces of both stator and armature are tapered, and Fig. 6 shows a polarized armature having tapered saturable pole tips.

Referring first to Fig. 1, I have represented a stationary magnetic field member having a U-shaped yoke 10 and with tapered pole pieces 11 and 12 energized by a direct current winding 18.

The pole pieces 11 and 12 extend around the armature 90 degrees or more and not only taper toward their tips but also approach more closely to the armature at their tips. Between the pole pieces is an armature 13 mounted for rotation on suitable pivots, not shown, and carrying a pointer 16 cooperating with a stationary scale plate 17.

The armature is in this instance cylindrical in shape and may be made from a light weight magnetic sintered oxide and is polarized across a diameter thereof as indicated by the designations N and S indicating north and south magnetic poles. The armature may be made of the armature material described in United States Letters Patent No. 2,101,665, December 7, 1938, to Faus, assigned to the same assignee as the present invention.

It will be noted that the air gap between the armature 13 and the pole pieces 11 and 12 is smallest at the small ends of the horn-shaped pole pieces and gradually increases toward the large parts of the pole pieces where they are joined to the yoke 10. In the position of armature 13 represented in Fig. 1 that flux which is due to the permanent magnet armature 13 crosses the air gaps at the small pole tips and finds a return path through the pole pieces and yoke 10 as indicated by the dotted arrow line in Fig. 1. If this flux is not great enough to cause saturation of the small ends of the pole tips, the armature will be biased to the zero position shown in Fig. 1, where the permanent magnet armature aligns its magnetic poles across that diameter which has the minimum air gaps and which under this condition is the position of minimum reluctance for the permanent magnet flux. The armature need not be permanently magnetized up to its maximum capacity as a permanent magnet but sufficiently to force a small permanent magnet flux across the air gap and through the return flux path to hold the armature in the zero position shown when coil 18 is not energized. Also this zero position permanent magnet flux should be enough in comparison to the flux carrying capacity of the cross-sectional area of the small end of the pole pieces as to nearly but not quite saturate these portions of the pole pieces. The fact that there are two airs gaps in this permanent magnet flux path helps to reduce the permanent magnet flux to a low value sufficient to nearly but not quite saturate the pole tips. If now coil 18 be energized by direct current in a direction to force additional flux around the magnetic circuit in which the permanent magnet flux is flowing, the total flux in this circuit and across the air gap and through the armature will increase and the smallest parts of the pole pieces will start to saturate. Hence, they can carry no more flux and the extra flux then crosses the air gaps at points on the pole pieces which are of larger cross-section but as near the small pole tips as the degree of saturation will allow because the air gaps gradually increase as we recede from the tapered pole tips. The center of flux density crossing the air gaps thus shifts in a clockwise direction as viewed in Fig. 1, and the polarized

armature rotates by a corresponding amount to keep its polarized axis in line therewith. As the direct current excitation increases, the pole pieces become saturated further and further back from the small tips thereof and the center of flux density and armature rotate further in a clockwise direction. The extent of this rotation thus becomes a measure of direct current supplied to coil 18 and the scale is calibrated accordingly.

If the increase in cross-section of the pole pieces is uniform, from the pole tip to the pole base where it is joined to the yoke, and if the increase in air gap is uniform over the area of the pole face, the angular up scale deflection of the instrument plotted against current in coil 18 will not be a straight line. The upper graduations of the scale will be more crowded than the graduations at the lower end. This may be remedied to some extent by increasing the rate of changes of taper of the air gap and pole pieces at the small end of the pole pieces as compared to the large end of the pole pieces, and making the pole piece arc somewhat longer than the deflection range that will be used, and by an expedient described in connection with Fig. 5. When the current in coil 18 is reduced to zero and the flux decreased to the original value produced by the permanent magnet armature, the armature returns to the zero position where the minimum reluctance position for that value of flux exists due to the minimum air gap at such position. Hence the armature supplies its own zero restoring torque and no zero return spring or other extra equivalent expedient is required.

As is well known, the flux required to permanently magnetize permanent magnets to a given stable value is considerably greater than the magnetism that will be retained by the material when the magnetizing force is removed even if the poles of the permanent magnet be connected by a keeper with no intervening air gap. Hence, the additional flux that is conveyed through the polarized armature due to energization of coil 18 will not increase the permanent magnet flux value when this magnetizing force is removed if proper precautions are taken. Part of the extra magnetizing force is used up in overcoming the reluctance of the air gap before the flux of the permanent magnet armature even increases to that stable flux value which would exist without an air gap. As the armature turns further up scale, the air gap reluctance increases and also flux leakage about the armature increases. Hence, with the proper design with the usual precautions for avoiding overloading of the instrument, the stable permanent magnet condition of the armature does not change. If the instrument coil 18 be reversely connected, the extra flux that appears at the pole tips is a repelling flux which turns the armature to an off scale position which is quickly noted, and the connection corrected as in common practice in using other types of direct current instruments.

In Fig. 2 I have shown a shell 14 of conducting material such as copper which may be used as a damper on the instrument. When used it closely surrounds the armature but without touching the same and is provided with bent tabs 15 for securing it in place at the extremities of the yoke 10. This damper is not shown except in Fig. 2 since clear views of the armature and pole piece arrangement are desired in other figures. It will be evident that the armature flux cuts such shell to produce damping of the armature where that is desired. The damper is not essential however.

In Fig. 3 I have shown my invention applied to a zero center scale instrument which will indicate direction and magnitude of direct current without the necessity of reversing the current connections.

This instrument differs from the instrument of Fig. 1 only with respect to the shape of the pole pieces and the calibration of the scale. In Fig. 3 the pole pieces are designated by reference characters 19 and 20, and the scale is designated by reference character 21, and other parts are designated as in Fig. 1.

In Fig. 3 there are both attraction and repulsion torques on the polarized armature by the fluxes produced in the double horn-shaped pole pieces when the coil 18 is energized by direct current.

If coil 18 be energized so as to make pole piece 20 a north pole and 19 a south pole, as indicated by the designations N and S in Fig. 3, the deflection will be to the left. The north pole of the armature is attracted by the adjacent south pole of pole piece 19 and is repelled by the adjacent north pole of pole piece 20. The south pole of the armature is simultaneously attracted by the adjacent north pole of pole piece 20 and repelled by the adjacent south pole of pole piece 19. If the current in coil 18 becomes reversed, pole piece 19 becomes a north pole and 20 a south pole, and the deflection is reversed. The zero position is determined by the fact that the double pole tips of both pole pieces approach nearest the armature on a diameter thereof. In this case the permanent magnet flux for zero deflection divides between the pair of adjacent pole tips. This instrument is particularly sensitive to small current flow in coil 18 and can be used as a null reading galvanometer in some bridge circuits. The initial deflections close to zero do not necessarily depend upon saturation of the pole tips but are due primarily to the attraction and repelling forces. The centers of these attraction and repelling forces move back from the pole tips and further apart as the pole tips become saturated to produce the up scale deflection.

If desired, the pole tips of this form of instrument may be made to overlap slightly as indicated by the adjacent pole tips 22 and 23 in Fig. 4.

Fig. 5 represents a further embodiment of the invention and comprises an instrument in which a non-polarized magnetic armature is used. This instrument will always deflect in the same direction irrespective of the reversal of current in the energizing winding. It also employs tapered pole tips in both the field and armature designed to become saturated. The field yoke structure and pole pieces are substantially similar to those of the instrument of Fig. 1, although the pole pieces do not need to extend over quite so long an arc for the same angle of deflection. The armature is a bar 24 of magnetic material having tapered pole pieces 25 and 26 extending angularly in opposite directions from the body of the armature. The armature has its maximum radius at the tip of these pole pieces and the inner periphery of stator pole faces have a minimum radius at their tips. Hence, when coil 18 is only slightly energized and the flux through the pole pieces is very small and not sufficient to cause complete saturation of the tip of pole pieces 11 and 12, the armature will turn to the minimum reluctance indicating position for this value of flux represented in Fig. 1 which may be considered for all practicable measurement purposes as the zero indicating position because the current measure-

ment range of the instrument is so much greater than the current necessary to produce a flux which will not saturate the smallest cross-section of the pole tips. Now with increasing excitation and flux the tips of the pole pieces 11 and 12 start to saturate and the center of flux distribution between armature and field poles moves around to the right, causing the armature to follow, since with respect to this additional flux, the saturated pole tips act as so much air. The armature pole tips are preferably shaped so that no appreciable saturation occurs until the armature has deflected towards the upper part of its range. However, over the upper part of the deflection range the armature pole tips also start to saturate back from the tip to an appreciable extent, and the armature thus turns by an additional amount, tending to expose a non-saturated portion to the extra flux now crossing the air gap. The armature flux tends to pass through the armature pole tips until they are saturated, notwithstanding the fact that the pole tips of the field are now radially opposite the end surfaces of the bar portion 24 because the radius of the armature decreases back from its pole tips at a greater rate than the radius of the stator pole faces increase away from their pole tips. The minimum air gap is always opposite the armature pole tip regardless of its deflecting position, as will be evident from an inspection of the dotted line position of pole piece 25 when approaching the upper part of its range of deflection. When the current again decreases, the armature will return toward zero position because the minimum reluctance position of the armature is that position of smallest air gap at which the center of flux is permitted, by reason of the conditions of saturation, to cross the air gap. Hence, although the armature may not be polarized or have a zero return spring, it will return to a zero position with a decrease of the energizing current to zero. When there is zero flux the armature will have no torque and can be moved to any indicating position. Hence, if this instrument is to be used on a moving vehicle such as an automobile where the armature is likely to be jarred out of a zero position when the instrument is not energized and it is important that it indicate zero under these condition, it may be advisable to add a weak zero positioning spring or to polarize the armature to hold the armature in a zero position. The scale distribution in any form of the invention described may be modified by providing the pole pieces with one or more small magnetic fingers such as shown at 31 and 32, Fig. 5, adjustable into and out of the air gap and adjustable about the air gap to modify the flux distribution.

If the armature is not polarized, it will always deflect up scale regardless of how the coil is connected to a direct current circuit, and it may also be calibrated to measure alternating current. The magnetic material used in the instrument and in the field structure of the other instruments described should have low hysteresis; otherwise the instrument will have a hysteresis error noticeable between increasing and decreasing excitation. In order to keep the energy input to the instrument low, it will also be desirable to make the saturable portions of the magnetic circuit of a material having a low saturation point. A suitable magnetic material which is low in hysteresis and which has a low saturation point is known to the trade as "mumetal" and may be obtained from the Alleghany Steel Company. Another material which I have found to be satisfactory is a nickel non-alloy of the character described in United States Letters Patents Nos. 1,586,883 and 1,586,884, Elmen, June 1, 1926. These instruments can be used as current limiting relays by providing contacts such as represented at 27 Fig. 5, to be actuated when a certain desired deflection is reached.

The principle of double saturation in armature and field poles used in the instrument of Fig. 5 may be used in a polarized armature instrument in the manner indicated in Fig. 6. Here the main body of the armature 28 is a permanent magnet having soft iron tapered pole pieces 29 and 30 secured to the ends thereof.

While I have described and illustrated an embodiment of my invention, modifications will occur to those skilled in the art. I desire it to be understood, therefore, that my invention is not to be limited to the particular arrangement disclosed, and I intend in the appended claims to cover all modifications which do not depart from the spirit and scope of my invention.

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

1. An electrical instrument comprising a stationary bipolar magnetic yoke portion provided with an energizing winding and with magnetic pole pieces and a polar magnetic armature pivoted for rotation between said pole pieces, the pole pieces of the yoke portion having a tapered cross-section with the part of largest cross-section at the yoke portion and the part of smallest cross-section approaching closest to the armature, said pole pieces extending partially around the armature so as to provide diametrically opposite symmetrical air gaps between pole pieces and armature, which gaps are smallest opposite the pole tips of minimum cross-section and which gradually increase at the larger portions of the pole pieces, said pole pieces being designed to become progressively magnetically saturated first at the pole tips and then progressively back from the pole tips in proportion to the energization of said winding over the energization range.

2. An electrical measuring instrument comprising a bipolar magnetic yoke having an energizing winding and magnetic pole pieces, a polarized magnetic armature mounted for rotation between the pole pieces, the pole pieces being of a curved horn shape with the large part joined to the yoke and the remaining part curved about the armature and approaching closest to the armature at their tips, said pole tips being designed to become magnetically saturated, first at the tips and then progressively back from the tips towards the yoke as the winding of the instrument is progressively energized, thereby causing the flux axis between the pole pieces to progressively rotate from a position of minimum air gap at the pole tips to positions of progressively greater air gaps back from the tips and towards the junction of the pole pieces with the yoke, said armature being free to rotate and to align its polarized axis with the axis of the flux between the pole pieces.

3. A direct current electrical measuring instrument comprising a bipolar magnetic yoke provided with an energizing winding and magnetic pole pieces, a polarized magnetic armature freely rotatively mounted between the pole pieces, said pole pieces having horn-shaped extensions symmetrically curved each way about the armature from the point where the pole piece is joined with the yoke, which extensions progressively decrease in cross-section and approach nearer the armature towards their outer tips, the tips

of extensions from different pole pieces approaching near each other on opposite sides of the armature, the arrangement being such that when the winding is not energized, the armature takes a position of minimum reluctance with its magnetic poles opposite said pole tips, and when the winding is energized the armature rotates from the aforesaid position in a direction depending upon the direction of current flow in the winding and in proportion to the magnitude of such current, said pole tips and a substantial portion of the pole pieces being designed to become magnetically saturated within the current measuring range of said instrument.

4. A direct current measuring instrument comprising a cylindrical armature of a magnetic sintered oxide polarized on a diameter thereof, means for mounting said armature for free rotation, a bipolar magnetic yoke having an energizing winding and having pole pieces between which said armature is symmetrically located, each pole piece being made of a magnetic material having a low saturation point and negligible hysteresis, and in the shape of a curved horn which progressively increases in cross-section from the tip end to the large portion thereof, said pole pieces being joined to the yoke at the large portion of the pole piece with the concave sides of the pole pieces facing the armature and each extending about the armature from the yoke junction a distance of about 90 degrees and with their small tip ends nearer the armature than their large portions, the small tip ends of said pole pieces being designed to carry the residual flux of the armature with no material saturation thereof but said pole pieces being designed to become progressively magnetically saturated beginning at their tips and progressing back toward their large portions when the winding of the instrument is progressively energized over the measurement range of the instrument.

5. A measuring instrument comprising a stationary bipolar magnetic yoke, an energizing winding thereon, magnetic pole pieces joined to the yoke and forming an armature gap between them, a bar-shaped magnetic armature symmetrically mounted for rotation between said pole pieces, said armature having pole pieces which curve away from the axis of the bar armature in the direction of the deflection of the armature when the instrument is energized, said pole pieces being tapered in cross-section toward their tips and the armature having its maximum radius at such pole tips, the pole pieces of the yoke extending about the armature away from the yoke in a direction opposite to the instrument deflection when energized and having a tapered cross-section and approaching nearest the armature at their tips, the pole pieces of the yoke and armature being designed to become magnetically saturated when the winding is energized over the normal measurement range of the instrument, saturation occurring first in the pole tips and progressing backward from the pole tips as the instrument is progressively energized.

6. An electrical measuring instrument having a bipolar magnetic stator part and a rotary armature magnetic part, said stator part having pole pieces between which the armature is symmetrically located and from which the armature is separated by air gaps, the stator pole pieces extending about the armature over an arc of at least 90 degrees from the points where they are joined to the yoke, said pole pieces being tapered in cross-section away from the yoke towards their tips and having pole faces facing the armature which are eccentric with respect to the axis of rotation of the armature and which approach nearest such axis at the pole tips, said armature being polarized and having a zero indicating position where its polarized axis aligns with the minimum air gap position between the stator pole tips and forces a permanent magnetic flux through the stator which is sufficient to nearly saturate the pole tips thereof, a direct current winding on the stator which when energized produces an additional flux therethrough and through the armature which causes the pole tips to become saturated.

7. An electrical measuring instrument comprising a bipolar magnetic field member having an exciting winding and having pole pieces separated by an armature air gap, a polarized magnetic armature rotatively mounted within said gap, the pole pieces of said field member having a varying cross-section in the path of the flux of said instrument so as to become progressively saturated as the excitation of said instrument is increased over its normal excitation range, said pole pieces extending a substantial distance in one direction about the armature and having their tip portions of smallest cross-section and nearest the armature so as to cause the center line of the flux between the pole pieces to rotate about the axis of rotation of the armature with changes in the magnitude of such flux, said pole tips serving to rotatively position the polarized armature in a zero position when the winding is not energized.

RUSSELL A. WARNER.