Feb. 21, 1967 L. R. HULLS 3,305,770

SATURABLE CORE TRANSDUCERS

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Fig. 1

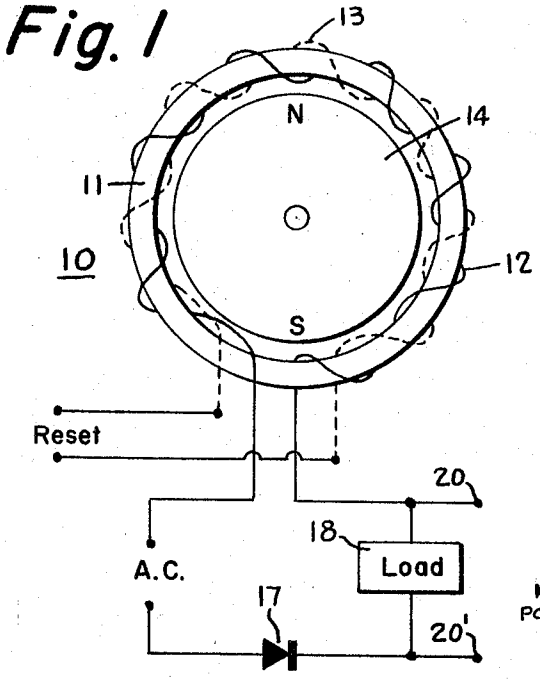
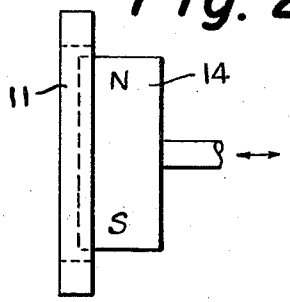


Fig. 2



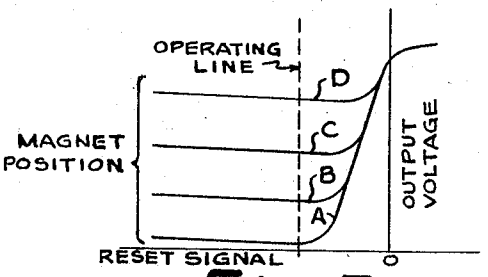
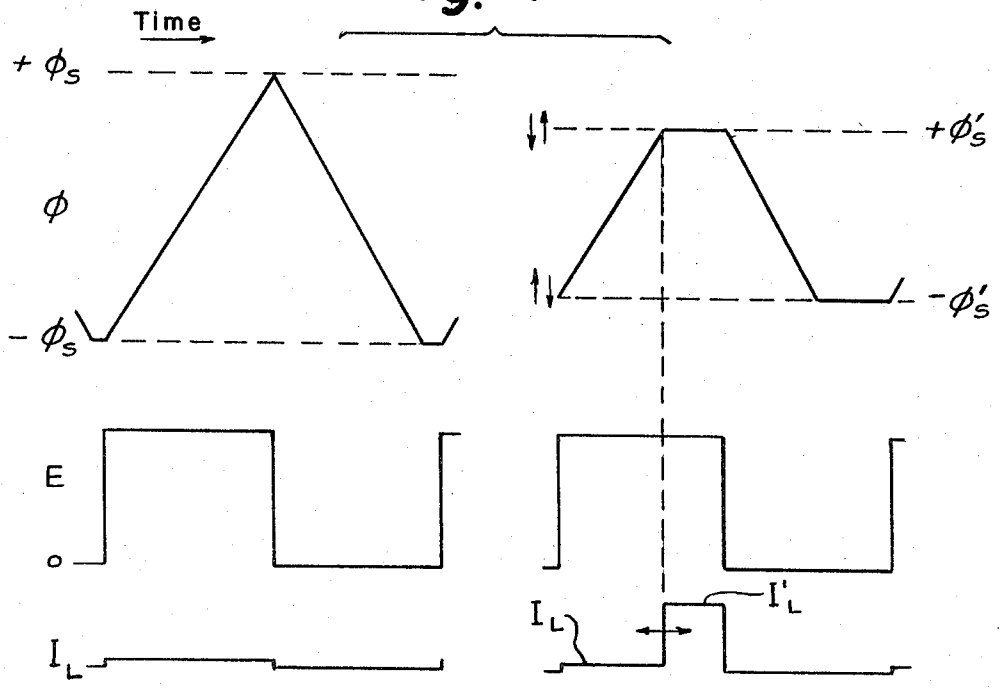


Fig. 3

Fig. 4



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Fig. 5

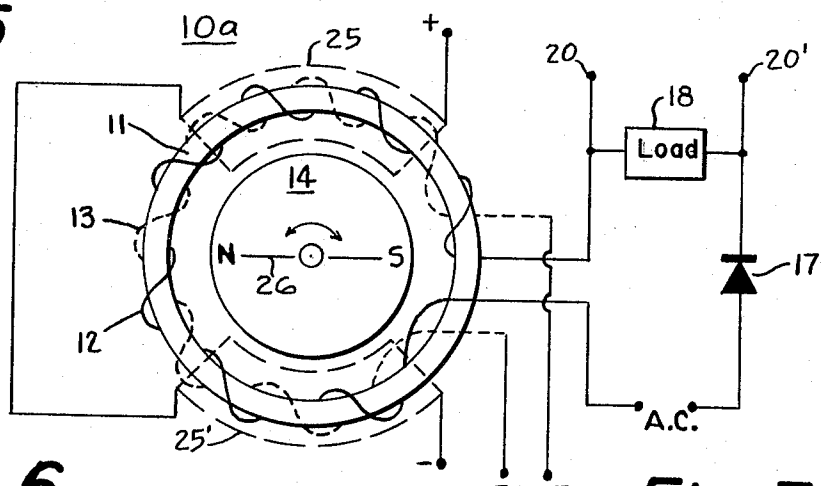


Fig. 6

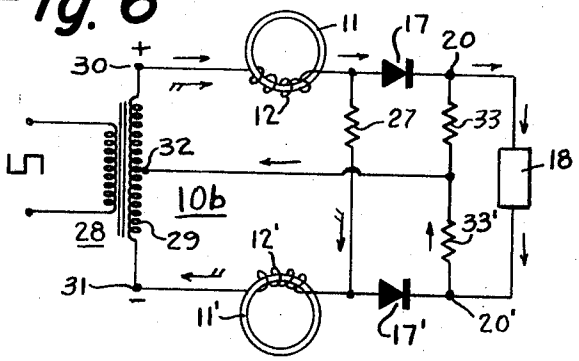


Fig. 7

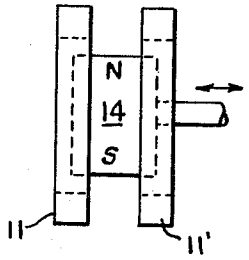
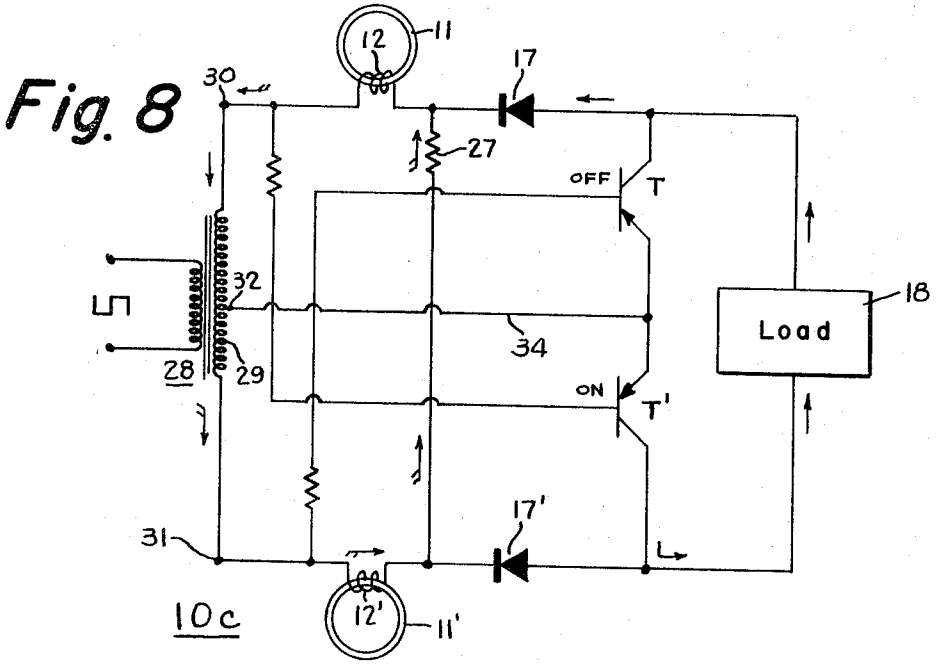


Fig. 8



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Fig. 9

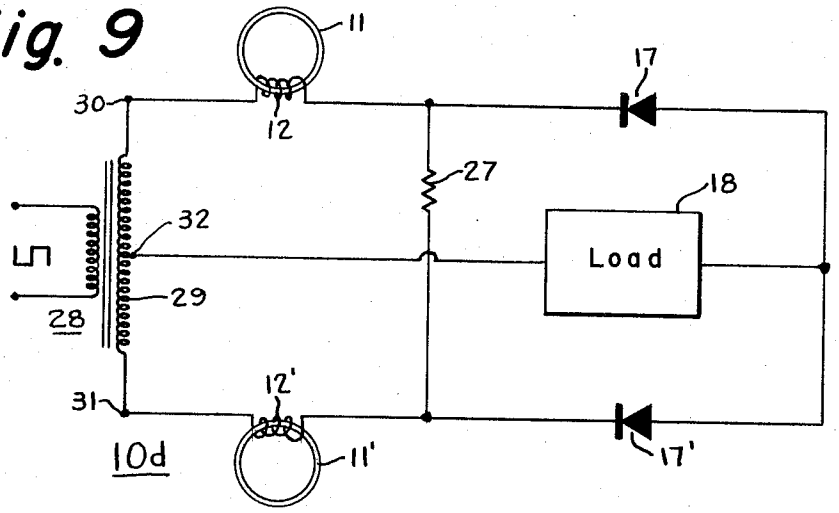


Fig. 11

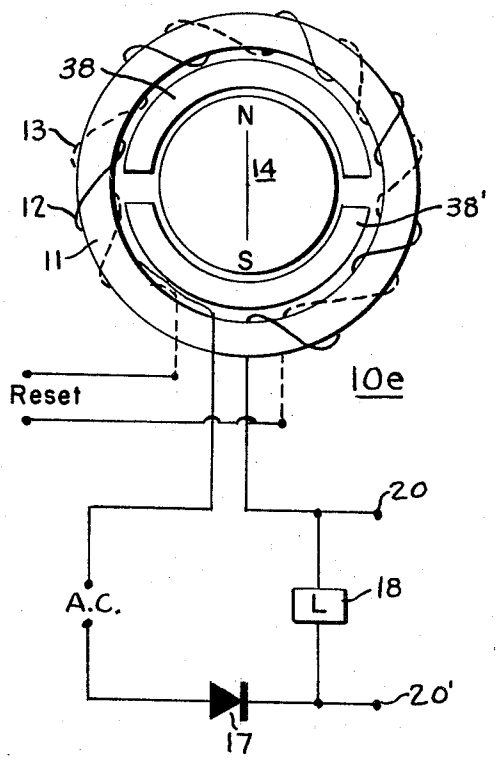
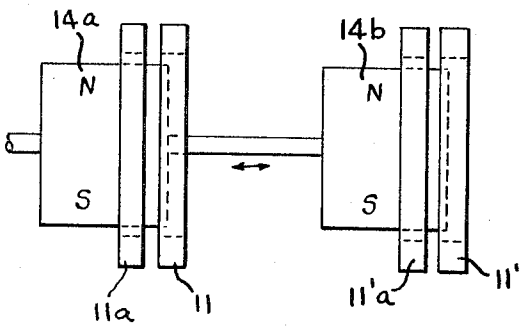


Fig. 10



United States Patent Office 3,305,770
Patented Feb. 21, 1967

3,305,770

SATURABLE CORE TRANSDUCERS

Leonard Robin Hulls, Gwynedd Valley, Pa., assignor to Leeds and Northrup Company, Philadelphia, Pa., a corporation of Pennsylvania

Filed Mar. 29, 1963, Ser. No. 268,879
17 Claims. (Cl. 323—89)

This invention relates to a transducer for converting a physical quantity such as a change in position into an electrical signal and has for an object the provision of a transducer which is operated on the principle of flux path distortion.

Transducers of the null-flux type for converting physical motion to an electrical signal are disclosed in U.S. Patent 3,076,137—Moore, and in co-pending application Serial No. 101,736 filed April 10, 1961, Patent No. 3,226,-639, issued December 28, 1965, by Will McAdam and assigned to applicant's assignee. Such transducers are highly sensitive and operate on the principle of a null-flux condition provided by balance of the M.M.F. from an input magnet probe and a feedback M.M.F. Such sensors due to the construction tend to be sensitive to rotary motion of the permanent magnet. The transducer of the present invention in one form is not sensitive to rotary motion of the probe magnet and operates upon the principle of variation in the volt second content of the core relative to a distributed winding on the core. The present transducer comprises a closed loop saturable core including a winding thereon, the core having a volt second content with respect to the winding, magnetic field means for reducing the volt second content of the core, means responsive to the variation of the volt second content to produce an output signal varying therewith. For a step change of voltage applied to a winding, the volt second content with respect to that winding may be defined as the product of the voltage applied to the winding times the period of time it requires to change the flux level from saturation of the core in one sense to saturation in the opposite sense.

The transducer of the present invention has numerous advantages, one of which is the fact that its output varies substantially linearly with change in position of the magnet. From a construction standpoint, it may be made relatively small in size and of low cost. It also has the advantage of being of simple construction, containing only about one-sixth the number of parts utilized in the transducers of the null-flux type mentioned above.

More specifically, in accordance with the present invention, there is provided a transducer for converting a physical motion into a corresponding change in an electrical signal comprising at least one saturable core in the form of a closed loop. A first winding is disposed on the core, the core having an effective volt second content with respect to the winding. The transducer further includes means for periodically exciting the winding to produce a saturation of the core material in one sense and means for resetting the core by saturating the core material in the opposite sense. The transducer further includes field producing means including a member movable in accordance with the physical motion to be converted for producing a change in the effective volt second content of the core with respect to the winding and means connected in the circuit between the winding and the exciting means for producing an electrical signal varying with change in position of the movable member. The field producing means may comprise various forms. For example, in the preferred form, it comprises a permanent magnet. In another form it may comprise a second winding and a magnetic member associated therewith and the latter may also comprise a permanent magnet. In another form, the field producing means may comprise

a permanent magnet and a magnetic structure comprising one or more pole pieces.

In accordance with a further aspect of the invention, there is provided in a system including a magnetic amplifier having a closed loop saturable core, a winding on the core, an output device, means for periodically energizing the winding through the output device to produce saturation of the loop core in one sense and reset means for producing flux in the core in the opposite sense for providing a transfer characteristic between the signal applied to the reset means and the signal obtained at the output device of the magnetic amplifier which varies from minimum value to maximum value, the method of converting a motion into a corresponding change in electrical signal comprising the steps of energizing the reset means with an applied signal sufficient for operation of the amplifier at the minimum of its transfer characteristic, and moving a permanent magnet relative to the saturable core to vary the minimum value of the transfer characteristic to produce a change in electrical signal of the output device.

For a detailed disclosure of the invention and for further objects and advantages thereof, reference is to be had to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic diagram of a transducer embodying the present invention;

FIG. 2 is a side view of the toroid and magnet shown in FIG. 1 with the magnet adapted for translational movement;

FIG. 3 is a graph showing a family of curves useful in explaining the present invention;

FIG. 4 is a graph illustrating the operation of the transducer with a square wave A.C. excitation, the left-hand portion of the graph illustrating the operation with the permanent magnet completely removed from the toroid and the right-hand portion of the graph illustrating the magnet partially inserted into the toroid;

FIG. 5 is a modification of the invention illustrating a transducer sensitive to rotary motion of the magnet;

FIG. 6 is a schematic diagram of a modification of the invention utilizing a pair of toroids connected in circuit for push-pull operation;

FIG. 7 is a side view illustrating the physical position of the pair of toroids of FIG. 6 and the associated magnet position for translational motion;

FIG. 8 is a schematic diagram of another modification of the invention similar to that shown in FIG. 6;

FIG. 9 is a schematic diagram of a further modification of the invention utilizing two toroids but operating full wave rather than push-pull;

FIG. 10 is a side view showing the physical arrangement of the toroids and associated magnets utilized in the modification shown in FIG. 9; and

FIG. 11 is a diagrammatical view of a further modification of the invention utilizing pole pieces and where the permanent magnet is supported for rotary movement similar to the modificataion illustrated in FIG. 5.

Referring to FIG. 1, there is illustrated a transducer **10** including a single toroid or core **11** having distributed around the circumference thereof a pair of windings **12** and **13**. A permanent magnet **14** is supported for translational movement along the center axis of the toroid **11**. The magnet **14** is magnetized on a diameter of the toroid as indicated in FIG. 1. The magnet **14** may be of any suitable type. However, it is preferably of circular cross-section as illustrated and may include pole pieces similar to the permanent magnet probe illustrated in the aforesaid Moore Patent 3,076,137. The magnet **14** is adapted for translational movement as indicated by the double-ended arrow in FIG. 2 and such translational movement

may be derived from any suitable source such as, for example, pressure bellows or from the motor in a measuring or control instrument as illustrated in said Moore patent. It is to be understood that other suitable means may be utilized for providing the translational movement of the magnet **14**.

The toroid **11** is a saturable core and comprises a spirally wound strip of thin strip stock preferably of square hysteresis loop material. An example of such highly permeable material is a nickel-molybdenum-iron alloy manufactured by Carpenter Steel Company and sold under the trade mark Hy-Mu–80. In a typical application of the invention, the strip stock had a thickness of about 0.001 inch and a width of about 0.10 inch. The core included about 100 turns of the strip material and the layers of the material are so positioned that the flux due to the magnet **14** in at least a portion of the core follows its spiral layers and in the same direction as the main flux.

As shown in FIG. 1, an alternating current supply is applied to the circuit including the output winding **12** illustrated in full line. This circuit includes a diode or rectifier **17** thus causing a pulsating direct current to flow through the output winding **12**. The A.C. supply preferably is a square wave supply. The other winding **13** which is shown in dotted lines and is also distributed around the circumference of the toroid **11** is the control winding to which is applied a direct current signal which is normally referred to as a reset or biasing signal which produces a flux in the core **11** in direction opposite to that established by the pulsating direct current in winding **12**. As pointed out above, the toroidal core **11** has a rectangular hysteresis characteristic. If the magnet **14** were not present, there would exist a relationship between the D.C. signal applied as reset or bias voltage and the output voltage appearing across the load device illustrated as rectangle **18**. This relationship is graphically illustrated in FIG. 3 by the bottom transfer characteristic curve identified by reference character A which is plotted with the output voltage as ordinate and the control or bias winding current as abscissa. Essentially this is the operation of a conventional magnetic amplifier and such amplifier normally operates on that portion of the curve which has the steepest slope to provide maximum gain.

In the apparatus shown in FIG. 1, the signal applied as Reset is of such magnitude as to produce operation at the value represented by the dotted line of FIG. 3 indicated as the operating line. Thus, it will be seen from FIG. 3 that the transducer of the present invention operates on a portion of the transfer characteristic between the applied input signal and the output signal in which the output signal is relatively insensitive to changes in the input signal rather than on the steep portion of the curve where the output signal is highly sensitive to change in the input signal as is the case in the conventional magnetic amplifier. It has been found that as a magnet **14** is inserted into the center of the core **11**, that the output voltage across the load **18** varies in amount substantially linearly related to the motion of the magnet **14**. The effect of this magnet on the transfer characteristic is illustrated in FIG. 3 where it will be seen that the minimum value of the transfer characteristic varies in accordance with the magnet position. It is to be remembered that the curve A in FIG. 3 illustrates the transfer characteristic before the magnet **14** has been inserted into the core **11**. Curves B, C and D in FIG. 3 illustrate the transfer characteristics with the magnet **14** inserted at increasing distance within the core **11**.

Referring to FIG. 4, there is graphically illustrated the operation of the transducer with a square wave A.C. excitation. The left-hand portion of the graph depicts the operation of the transducer with the magnet **14** completely removed from the toroid **11**. The portion of the graph on the right depicts the operation with the magnet **14** partially inserted into the toroid **11**. Looking now at the left-hand portion of FIG. 4, where the permanent magnet is completely removed from the core, it will be seen that as the square wave excitation voltage E is applied to the winding **12**, the flux in the core **11** varies along a straight line, the slope of which is dependent upon the magnitude of the voltage in accordance with the expression.

$$E = N\frac{d\phi}{dt}$$

where N is the number of turns, ϕ is instantaneous flux, and t is time. The transducer is designed so that during the time that the half-wave of excitation voltage E is applied the flux ϕ changes from its saturation level $-\phi_S$ to its saturation level $+\phi_S$ in the other direction. All of the curves illustrated in FIG. 4 are plotted against time as the abscissa and it will be seen that at the time the flux ϕ reaches $+\phi_S$ the excitation voltage E goes to zero. During the half-cycle that the voltage E is zero the reset signal which may be a D.C. voltage returns the flux to its negative saturation level $-\phi_S$. The above operation results in a very small amount of current I_L flowing through the load **18** during the half-cycle that the voltage E is applied to winding **12** and thus there is a very small output voltage. This current and voltage results from the inherent losses in the core.

Looking now at the right-hand portion of FIG. 4, there is graphically illustrated the flux, excitation voltage and load current characteristics with the magnet **14** inserted part way into the core **11**. It will be observed that the effective saturation levels for the flux have been moved closer together as indicated by the broken horizontal lines identified as $-\phi'_S$ and $+\phi'_S$. The reverse arrows associated with these broken horizontal lines indicate that the effective saturation levels for the flux may be adjusted closer together or further apart depending upon the position of the magnet **14** of FIG. 1. By moving the effective saturation levels for the flux closer together, as shown at the right-hand portion of FIG. 4, the flux cannot be changed by as great an amount when the excitation voltage is applied as it was when the magnet was not present within the core **11**. Because the excitation voltage is the same, the slope of the curve for the flux in the right-hand portion of FIG. 4 is the same as that in the left-hand portion and, therefore, the flux reaches its saturation level sooner because the effective saturation levels for the flux have been moved closer together. After the flux has changed from the $-\phi'_S$ level to the $+\phi'_S$ level in FIG. 4, the output winding **12** cannot then provide a large voltage drop but appears as practically a short circuit and the full excitation voltage E is applied across the load **18** to produce a load current I'_L. This load current I'_L is substantially larger than the very small amount of current I_L previously flowing through the load. The load current I'_L flows until the end of the excitation half-cycle at which time it is reduced to zero as shown in the lower right-hand curve in FIG. 4. It will thus be seen that as the position of the magnet **14** varies with respect to the core **11**, the magnet will vary the effective saturation level of the core which, in turn, will vary the time required for saturation of the core under the influence of the square wave excitation and result in variation in the average D.C. output voltage across the output terminals **20**, **20'** in FIG. 1.

Referring to FIG. 5, there is illustrated a transducer or toroidal core sensor **10***a* for sensing rotary motion of the magnet rather than translational motion. For convenience in explanation, the corresponding parts in FIG. 5 have been provided with corresponding reference characters to those shown in FIG. 1. A comparison of the transducer **10** of FIG. 1 with transducer **10***a* of FIG. 5 will show that there has been added in FIG. 5 an additional winding in the form of a pair of coils **25** and **25'** which are disposed on opposite sides of the toroid or core

11. The coils 25, 25' provide a magneto-motive force which is equal and opposite to that of the magnet 14 when the magnet is in its zero position as illustrated in FIG. 5. In the zero position, the magnetic axis is indicated by the solid line 26 extending through the center of the magnet 14. In this zero position, the two opposing coils 25 and 25' on the toroid 11 are adapted to buck out the effect of the magnet 14. The ability of the coils 25, 25' to oppose the effect of the magnet depends upon the angular relationship between the magnetic axis 26 of the magnet 14 and the axis of symmetry of the coils 25, 25'. The axis of symmetry of the coils 25, 25' coincides with the axis 26 of the magnet 14 when the latter is in the zero position as shown in FIG. 5. However, when the magnet 14 is rotated about the central axis as indicated by the double-ended arrow in FIG. 5, the consequent rotation of the magnetic axis 26 relative to the stationary axis of symmetry of the coils 25, 25' will decrease the ability of the coils to oppose the effect of the magnet. Thus, it will be seen that this construction permits the transducer 10*a* to be utilized as a rotational sensor where the input motion to the magnet 14 is rotational rather than translational as in FIG. 1.

Referring again to FIG. 3, it will be recalled that with a system of the type shown in FIG. 1 where only the single toroid is used, there is produced a small output voltage even though the magnet 14 is not present. This is indicated by curve A in FIG. 3. In other words, the output voltage versus magnet position does not start at a zero output voltage. Also, the output voltage can be of only one polarity. There are certain applications where it is desirable that a zero output voltage be obtainable and that the output voltage be of reversible polarity. In order to overcome these disadvantages of a single core system, there may be provided a pair of cores such as disclosed in the system of FIG. 6. In that system, the transducer can be provided with a push-pull arrangement which permits a zero voltage output and a variation from this condition in either direction. The relative positions of the two cores 11 and 11' and the magnet 14 of the transducer 10*b* are shown in FIG. 7. The cores 11 and 11' are of similar construction to those previously described in connection with FIGS. 1 and 5.

As may be seen in FIG. 6, the cores 11 and 11' are provided respectively with output windings 12 and 12'. While for push-pull operation the cores may be provided as in the single core arrangement with separate reset or bias windings as described above, such separate windings are not necessary in the particular circuit arrangement illustrated in FIG. 6. This is for the reason that the resistor 27 shown connected directly between the output terminals of the windings 12 and 12' provides a reset for one core while the other core is being saturated by the A.C. excitation. The A.C. excitation may be derived from any suitable source of voltage such as, for example, a square wave pulse generator or oscillator which is adapted to energize a transformer 28. The secondary 29 of the transformer 28 is provided at its outer ends with terminals 30 and 31. The output winding 12 of core 11 is connected in series with the rectifier or diode 17 between the output terminal 20 and the terminal 30 of the secondary 29. The output winding 12' of the core 11' is connected in series with the diode 17' between the output terminal 20' and the terminal 31 of the transformer. The intermediate or center tap terminal 32 of the transformer secondary 29 is connected by mixing resistors 33, 33' to the output terminals 20, 20' to which the load device 18 is connected.

In explaining the operation of the transducer 10*b* of FIG. 6, it will first be assumed that the permanent magnet 14 is in the center position as shown in FIG. 7. In this position, the magnet will affect the two cores 11 and 11' equally and the average D.C. signal to the load will be zero. Assuming the above conditions, when the voltage at terminal 30 is positive with respect to the center tap 32, FIG. 6, the output winding 12 of the core 11 drives this core to saturation in one sense. The circuit components are so selected that this occurs during the first quarter of a cycle and only a small current flows through winding 12 at that time. During the second quarter cycle, the winding 12 appears as a short circuit and an output current (unfeathered arrows) flows from terminal 30 by way of winding 12 and diode 17 to one side of the load device 18. The current returns from the load device 18 by way of mixing resistor 33' to the center tap 32. The diode 17' is not conductive for this half-cycle of the voltage.

Similarly, during the negative half-cycle of the voltage, the path of the output current for core 11' will be from terminal 31 through output coil 12', diode 17', load 18 and mixing resistor 33 back to the intermediate terminal 32.

During the first half-cycle of the voltage, a resetting current (feathered arrows) for resetting the core 11' flows in a path which may be traced from terminal 30, through output winding 12, resistor 27, output winding 12' of core 11' and back to the terminal 31. The value of resistor 27 is so selected for the current/magnetic characteristic of a particular core that it permits a magnetizing current sufficiently large to reset the core to the saturation in its opposite sense as indicated by the flux curve in the right-hand portion of FIG. 4. For the second half-cycle, resetting current for resetting the core 11 will be from terminal 31 through output winding 12' through resistor 27, output winding 12 and back to terminal 30. Thus, it will be seen that the resistor 27 provides a reset for one of the cores 11, 11' while the other core is producing its output current.

It will now be assumed that the magnet 14 has been displaced to the right as viewed in FIG. 7 thus moving the magnet into the core 11' and out of the core 11. The flux saturation levels in core 11' will move closer together and the flux saturation levels in core 11 will move apart. This will increase the average current flow to the load 18 by way of winding 12' and reduce the average current flow through the load 18 by way of winding 12. The net effect is to produce a D.C. current through the load device 18 with the terminal 20' positive relative to the terminal 20. It will be evident that movement of the magnet 14 in the positive direction will produce a similar but reverse effect with the polarity at terminals 20, 20' reversed.

The following test results were obtained from a transducer similar in construction to that illustrated in FIG. 6:

Description:	Numerical value
Linear output voltage range, volts	+2.5 to −2.5
Input motion, inches	+.050 to −.050
Linearity, percent	±.19
Temperature coefficient, percent per degree F.	.006
Output impedance, ohms	170
Output power in 1K load, milliwatts	25
Excitation, volts 5 kc.	30

In FIG. 8 there has been illustrated a transducer having an electrical circuit similar to that of transducer 10*b* shown in FIG. 6. The transducer 10*c* illustrated in FIG. 8 differs from that shown in FIG. 6 in that the resistors 33, 33' connected across the load 18 have been replaced by switching transistors T, T', respectively. For purposes of explanation, it will be assumed that during the first half-cycle of operation the terminal 31 is positive with respect to terminal 32 so that transistor T is reverse biased to be non-conducting or off while the transistor T' is forward biased or on. The current through the load 18 indicted by the unfeathered arrows passes through the diode 17 and through the coil or winding 12 on core 11, through the terminal 30 and the upper half of the secondary 29 of the transformer 28 to the center tap 32 and thence through the conductor 34 to the transistor T'

and to the opposite side of the load **18**. During this same half-cycle, the reset current indicated by the feathered arrows is flowing through coil **12** on core **11**, through the entire secondary winding **29** of transformer **28** and thence through coil **12'** on core **11'** and thence through resistor **27** which is connected across the output of coils **12** and **12'**. During the second half-cycle of the voltage with transistor T biased on and T' off, the current through the load **18** will be in the opposite direction. Under these conditions, it will also be seen that the reset current during the second half-cycle will be flowing around the same loop but in the opposite direction to that illustrated by the feathered arrows in FIG. 8. The use of the switching in transducer **10***c* results in improved efficiency over the use of mixing resistors as utilized in the transducer **10***b* of FIG. 6 because less power is dissipated in the transistors than the mixing resistors.

Referring to FIG. 9, there is illustrated a transducer **10***d* using two cores **11** and **11'** similar to the arrangement shown in FIGS. 6 and 8 but operating full wave single-ended rather than push-pull. Such an arrangement provides greater output for a given size although it does result in an output voltage at the zero position of the magnet and only a single polarity of signal. For the circuit arrangement illustrated in FIG. 9, the magnet is divided into two sections **14***a* and **14***b* so that changes in magnet position shown in FIG. 10 will affect both cores in the same sense. Each core then operates in the same manner but in opposite half-cycles so that a full wave current flows through the load **18**.

In order to make the relation between magnet position and output signal more nearly linear, it is desirable to reduce the effect of the fringing field associated with the end of the magnet **14**. To this end, each of the cores **11** and **11'** is provided with a magnetic shielding toroid **11***a* and **11'***a*, respectively, as shown in FIG. 10. These shielding toroids **11***a* and **11'***a* may be unwound toroids of the type used for cores **11** and **11'** and have been found to improve the linearity between input displacement and output voltage.

A similar arrangement of shielding could be used to improve the linearity of the system shown in FIG. 1. If the cores **11** and **11'** of FIGS. 6–8 are mounted sufficiently close together, the shields may be omitted as the cores **11** and **11'** serve as shields for each other.

When it is desired to provide a push-pull, full wave output, a four core arrangement similar to those used in the magnetic amplifier art may be employed. Each core would include an output winding such as on cores **11** and **11'** in FIG. 6 and each pair of cores would be associated with a separate magnet **14** in the manner illustrated in FIG. 7. The circuit connections would be similar to those shown in FIG. 6 except with the second pair of output windings and diodes cross-connected with respect to output terminals **20**, **20'**, such as the circuit arrangement shown in co-pending application Serial No. 258,267 filed February 13, 1963, by James L. Cockrell and Patent No. 3,271,690, issued September 6, 1966 assigned to applicant's assignee.

Referring to FIG. 11, there is illustrated another modification utilizing rotational movement of the magnet **14** rather than translational movement. The modification illustrated in FIG. 11 is similar to the modification previously illustrated and described in connection with FIG. 5. The principal difference, however, is that the transducer **10***e* in FIG. 11 utilizes a pair of magnetic pole pieces **38**, **38'** in place of the opposing coils **25**, **25'** shown in FIG. 5. The remaining components of the transducer **10***e* illustrated in FIG. 11 are the same as those illustrated in FIG. 5. When the magnetic axis of the magnet **14** is in the position shown in FIG. 11, the pole pieces **38**, **38'** do not interfere with the effect of the magnet **14** on the core **11**. However, when the magnet **14** is rotated 90° from the position illustrated in FIG. 11, the magnetic axis of the magnet **14** will be in a horizontal position parallel to the respective ends of the pole pieces **38** and **38'**. In this latter position, the field from the magnet **14** instead of passing into the core **11** will be shortcircuited through the shorter respective paths provided by the pole pieces **38**, **38'**. Thus it will be seen that the effect of the magnet **14** on the core **11** will vary from a maximum in the position as illustrated in FIG. 11 to a minimum in the position when the magnet **14** is rotated through 90° from the position illustrated in FIG. 11. With this arrangement it is to be understood that a similar effect could be accomplished if the magnet **14** were to remain stationary and the pole pieces **38**, **38'** be rotated.

As will be seen from FIG. 4, the output signal across terminals **20**, **20'**, FIG. 1 is a series of width modulating pulses, the width of the pulses depending upon the position of the magnet **14** relative to the core **11**. This pulse width modulated signal may be used in any of the applications normally employing such signals such as pulse-height, pulse-width amplifiers, analog-to-digital converters and the like.

It is further to be understood that while the transducers disclosed in this application have used change in relative position as the variable physical quantity, the principles used are applicable to a transducer in which the variation in field may be produced by changes in temperature, pressure and other physical quantities that may change magnetic properties of the materials of the transducer.

What is claimed is:

1. A transducer for converting a displacement into a corresponding change in an electrical signal comprising at least one saturable core in the form of a closed loop, a distributed winding on said core, said core having an effective volt second content with respect to said winding, means for periodically exciting said winding to produce a saturation flux around said loop in one sense, means for resetting said core to a saturation flux around said loop in the opposite sense, field producing means including a transversely magnetized member movable in accordance with the motion for producing a change in the effective volt second content of said core with respect to said winding, and circuit means connected between said winding and said exciting means for producing an electrical signal varying with change in position of said movable member.

2. A transducer according to claim **1** wherein said field producing means comprises a second winding.

3. A transducer according to claim **1** wherein said field producing means comprises at least one magnetic pole piece.

4. A transducer for converting a motion into a corresponding change in an electrical signal comprising a saturable core in the form of a closed loop, an output winding on said core, said output winding having a load device, diode means and alternating signal means in circuit therewith for periodically exciting said output winding to produce a saturation flux around said core in one sense, a reset winding on said core for resetting said core to a saturation flux around said core in the opposite sense, and permanent magnet means disposed centrally of said core for movement relative to said core in accordance with the motion for producing an electrical signal varying with position of said permanent magnet means.

5. A transducer according to claim **4** wherein said permanent magnet means is supported for translational movement axially of said core.

6. A transducer according to claim **4** including a shielding core positioned adjacent said first-named core.

7. A transducer according to claim **4** wherein said alternating signal means produces a square wave signal.

8. A transducer according to claim **4** including a pair of field coils disposed on opposite sides of said core and wherein said permanent magnet means is adapted for rotational movement.

9. A transducer according to claim 4 including a pair of magnetic pole pieces disposed within said core and on opposite sides of the central axis thereof and wherein said permanent magnet means and said pole pieces are adapted for relative rotational movement.

10. A transducer for converting a displacement into a corresponding change in an electrical signal comprising at least one pair of saturable cores, each core being in the form of a closed loop, an output winding on each of said cores, electrical circuit means connecting said output windings for push-pull operation, means connected in said electrical circuit for periodically exciting first one of said windings and then the other of said windings to produce saturation flux around said cores in one sense, means connected in said electrical circuit for resetting one of said cores and then the other of a saturation flux around said cores in the opposite sense, a load device connected in said electrical circuit between said output windings, and field producing means including a transversely magnetized member movable between said cores and axially thereof.

11. A transducer according to claim 10 including magnetic shielding means associated with said cores.

12. A transducer according to claim 10 wherein said electrical circuit includes mixing means in circuit with said load device.

13. A transducer according to claim 10 wherein said electrical circuit includes switching means in circuit with said load device.

14. A transducer for converting a motion into a corresponding change in electrical signal comprising a first pair of saturable cores in the form of closed loops, an output winding on each of said first pair of cores, an electrical circuit connecting said output windings for full wave operation, a load device connected across the output of said electrical circuit, means for periodically exciting one of said windings and then the other to produce a saturation flux around the respective loops in one sense, means for resetting first one and then the other of the respective cores to a saturation flux around said loops in the opposite sense, and a pair of permanent magnets associated respectively with said pair of saturable cores and movable relative thereto in accordance with the motion for producing a change in the effective volt second content of said cores with respect to either of the windings.

15. A transducer according to claim 14 including a pair of shielding cores, one shielding core being associated with each of said cores in said first pair and with each of said permanent magnets of said pair of permanent magnets.

16. A transducer for converting a motion into a corresponding change in electrical signal comprising:

a magnetic amplifier including a core having only one magnetic path with two saturation levels,

a first winding on said core for producing an output,

a second winding on said core,

first means associated with said first winding to excite said core to saturation level in one sense,

second means asociated with said second winding to return said core to saturation level in another sense whereby said one magnetic path of said core has two saturation levels, and

a transversely magnetized magnet movable relative to said core in accordance with said motion to be converted for varying the saturation level in said core to produce a change in output of said magnetic amplifier during the excitation of said first winding.

17. A transducer according to claim 16 wherein said transversely magnetized magnet is axially movable relative to said core.

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JOHN F. COUCH, *Primary Examiner.*

L. McCOLLUM, *Examiner.*

W. E. RAY, *Assistant Examiner.*