

Jan. 31, 1967

H. PACKARD

3,302,099

ELECTROMAGNETIC TRANSDUCER

Filed Dec. 6, 1963

FIG. 1

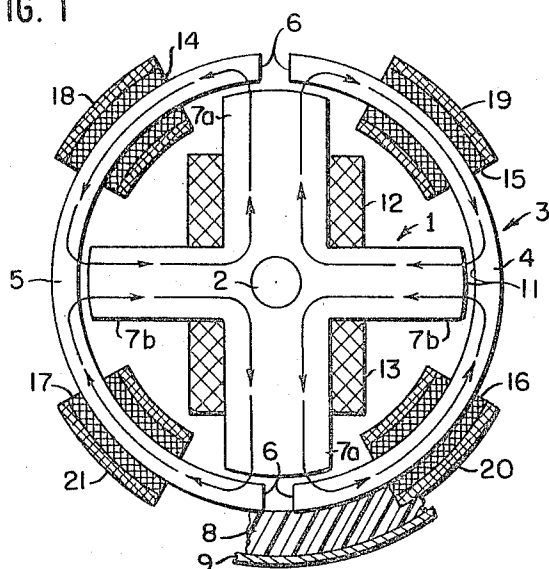
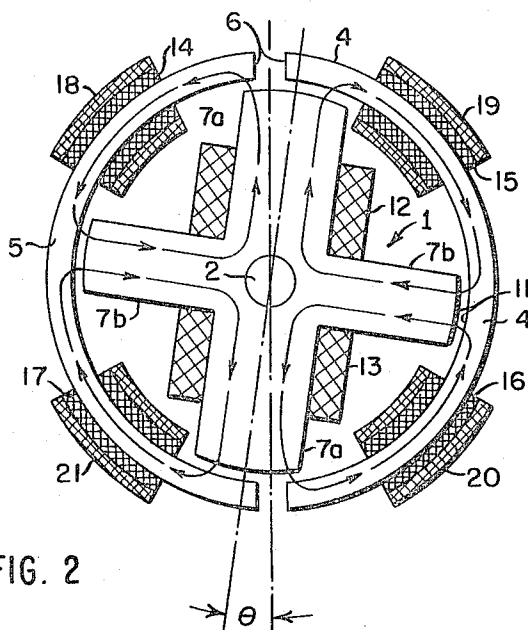


FIG. 2

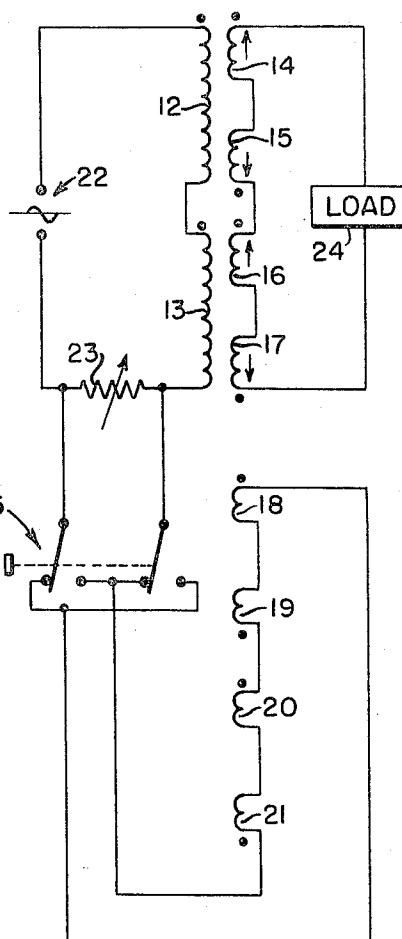


FIG. 3

INVENTOR

HENRY PACKARD

BY

Kenway, Jenney & Hildreth

ATTORNEYS

1

3,302,099

ELECTROMAGNETIC TRANSDUCER

Henry Packard, Norwood, Mass., assignor to Northrop Corporation, a corporation of California
Filed Dec. 6, 1963, Ser. No. 328,617
11 Claims. (Cl. 323—52)

My invention relates to electromagnetic transducers, and particularly to an improved electromagnetic transducer having a high signal sensitivity and low reaction torque.

Considerable effort has been devoted to the development of transducers of the variable transformer type, which may be used either to develop an electrical signal in response to an angular shaft rotation or to produce an output torque in response to an applied electrical signal. Such devices desirably have two characteristics; a high sensitivity to an applied signal, and low magnetic reaction torque and magnetic elastic restraints. In prior constructions, so far as I am aware, these characteristics have tended to be mutually exclusive. For example, one known form of transducer attains low reaction torque by the use of large working air gaps, which inherently reduce signal sensitivity. It is the object of my invention to improve both the signal sensitivity and the reaction torques and magnetic elastic restraints of electromagnetic transducers.

Briefly, an electromagnetic transducer in accordance with my invention is characterized by a relatively movable stator and rotor, each of which is provided with windings. On one of these members, at least two pole pieces are provided which are linked by an electromagnetic coil and confront the second member with a relatively small working air gap. The other member is provided with at least two ferromagnetic portions, separated by an air gap larger than the gap between the pole pieces of the first member and the second member. On each of the ferromagnetic portions of the second member, an electromagnetic coil is wound. The coils wound on the second member link the coil wound on the first pole piece of the first member through the working air gaps. One pole piece of the first member is arranged to confront the gap in the second member in a reference position, and the second pole piece is arranged to confront both of the ferromagnetic portions of the second member, being divided into two or more segments for this purpose if necessary. The arrangement is such that the reluctance of the path including the pole piece confronting the gap in the second member and the two ferromagnetic portions of the second member varies as the first member is rotated with respect to the second member, but the total reluctance of the circuit does not change. Since the total reluctance does not change with relative rotation of the parts, no magnetic reaction torque to rotation is produced and no magnetic elastic restraints are encountered. Also, since the working air gaps between the pole pieces and the second member may be made quite small, as compared with the large working air gaps required in certain prior art devices, the signal sensitivity may be quite high. An added advantage of the construction of the electromagnetic transducer of my invention is that it is amenable to the use of tertiary windings associated with the windings on the second member, which may be variably excited to adjust the electrical null of the device to coincide with the mechanical null.

The mode of construction of the electromagnetic transducer of my invention will best be understood by reference to the following detailed description, together with the accompanying drawings, of a preferred embodiment thereof.

2

In the drawings:

FIG. 1 comprises a schematic end view, with parts shown in cross section and parts broken away, of an electromagnetic transducer in accordance with my invention;

FIG. 2 is a view similar to FIG. 1, but showing the parts in a relatively rotated position; and

FIG. 3 comprises a schematic wiring diagram of the electromagnetic transducer of FIGS. 1 and 2.

Referring now to FIG. 1, I have shown an electromagnetic transducer comprising a ferromagnetic core member generally designated at 1 mounted on a shaft 2 for relative rotation with respect to a toroidal member generally designated as 3. The toroidal member 3 comprises a first ferromagnetic portion 4 and a second ferromagnetic portion 5 attached together by any suitable means, as by embedment in a conventional potting compound 8 in a suitable housing 9, the whole being mounted together for relative rotation about the axis of the shaft 2 by any suitable conventional means, not shown.

The ferromagnetic core member 1 is provided with projecting pole pieces 7a and 7b terminating in surfaces, confronting the member 3, which conform to portions of the surface of a cylinder described about the center of the shaft 2 and are separated from the member 3 by working gaps, as at 11, which are preferably relatively small. The gaps 6 between the elements 4 and 5 of the second member are preferably of the same size, and are such that the reluctance between these gaps is high compared to the reluctance of the gaps between the pole pieces 7a and 7b and the second member 3. This relationship is important because it enables the device to display a high level of signal sensitivity.

A pair of electromagnetic coils 12 and 13 are wound on non-adjacent pole pieces 7a, as shown. As will appear in connection with the description of FIG. 3, these coils are connected in series aiding relationship.

The core member 1 may be made by stacking a series of ferromagnetic laminations normal to the plane of FIG. 1, and the toroidal member comprising the ferromagnetic portions 4 and 5 may be made by stacking a series of ferromagnetic rings in the same plane. The windings to be described are placed on these rings, and the assembly is then potted in a suitable housing by means of a conventional potting composition. Thereafter, the slot 6 may be provided by making saw cuts through the ferromagnetic rings. Other suitable methods of construction will occur to those skilled in the art.

A series of secondary windings 14, 15, 16 and 17 are wound on the ferromagnetic portions 4 and 5 of the toroidal member 3. As shown in FIG. 1, each of these coils is located between a pair of adjacent pole pieces on the core member 1. If desired, a group of tertiary windings 18, 19, 20 and 21 may be wound on the portions 4 and 5 together with the secondary windings, for a purpose to be described.

Referring now to FIG. 3, I have there shown the manner of interconnection of the coils of the apparatus shown in FIGS. 1 and 2 to form a transducer for producing an electrical signal in accordance with the angular displacement of the core member 1 with respect to the toroidal member 3. The primary windings 12 and 13 are connected together in series aiding relationship and in series with a source of alternating voltage 22 and a variable resistor 23. The secondary windings 14, 15, 16 and 17 are connected in series, with the relative polarities shown, across the terminals of a suitable load 24, which may be a conventional indicator or control apparatus or the like. The tertiary windings 18, 19, 20 and 21 are connected together with the relative polarities shown, and are connected across the variable resistor 23 through a conventional reversing switch 25.

With the connections shown in FIG. 3, and the apparatus in the position shown in FIG. 1, no output voltage across the load 24 will be produced. In this position, the voltages induced in the secondary windings 14 and 15 are mutually equal and opposite, and the voltages induced in the windings 16 and 17 are also equal and opposite. Considering the secondary winding 14, it is influenced by flux flowing primarily through a path extending through one of the pole pieces 7a, the air gap between the pole piece 7a and the ferromagnetic portion 5 of the toroidal member 3, the air gap between the adjacent return pole piece 7b and the portion 5, and back to the first pole piece 7a. The oppositely wound secondary winding 15 is influenced by a path including the pole piece 7a confronting the gap 6, the portion of the ferromagnetic element 4 threading the coil 15, and the adjacent pole piece 7b, together with the air gaps between these parts. With the pole pieces 7a disposed symmetrically with respect to the air gaps 6, it will be apparent that the paths threading the coils 14 and 15 are of equal reluctance, and equal and opposite voltages will be induced in them. The same considerations apply to the secondary windings 16 and 17, which are influenced by the primary winding 13 and the pole pieces 7a and 7b linking the primary winding 13.

If the core member 1 is relatively displaced by an angle θ with respect to the toroidal member 3, as indicated in FIG. 2, the total flux flowing in the various magnetic circuits will not change, but individual circuits will be affected differently. Specifically, the portion of the flux path threading the secondary winding 14 which includes the air gap between the pole piece 7b and the ferromagnetic portion 5 will remain constant, but the reluctance of the path including the air gap between the pole piece 7a and the ferromagnetic portion 5 will be greatly increased, such that the voltage induced across the coil 14 will be reduced. At the same time, the reluctance of the path threading the secondary winding 15 which includes the air gap between the pole piece 7b and the ferromagnetic portion 4 will be unchanged, but the reluctance of the portion of this path which includes the air gap between the pole piece 7a and the ferromagnetic portion 4 will be reduced, such that an increased voltage will be induced across the coil 15. Similar considerations will show that the flux threading the secondary winding 17 will be increased, whereas the flux threading the secondary winding 16 will be reduced. Since the windings 15 and 17 across which the greater voltages are induced are in series aiding relationship, a net increase of voltage of a first phase will appear across the load 24, having a magnitude proportional to the angular deflection of the core member 1 with respect to the toroidal member 3. In response to an angular deflection of these parts oppositely from that shown in FIG. 2, a voltage of an opposite phase would be produced across the load 24. In this manner, an output voltage having a phase dependent on the direction of angular deflection and a magnitude proportional to the extent of angular deflection may be produced.

The tertiary windings 18, 19, 20 and 21 may be provided with a biasing voltage by adjustment of the resistor 23 and selection of the portion of the switch 25 in the manner and for the purpose disclosed in U.S. Patent No. 2,882,484, issued April 14, 1959, to Edward L. Swainson, for Null Shifting Device for Variable Dynamo Transformer. The apparatus of my invention is particularly adapted to be used in combination with these tertiary coils to adjust the electrical null of the apparatus to the mechanical null position in which the pole pieces 7a are symmetrically disposed with respect to the air gaps 6. As indicated in FIG. 3, these tertiary coils are wound in such a way as to reinforce all secondary coils. Thus, a small voltage applied to the coils 18, 19, 20 and 21 will bias the output applied to the load 24 in one sense or the other, and adjustment of the resistor 23 makes it

possible to bring the electrical null of the transducer into a desired relationship with the mechanical relative position of the members 1 and 3. The reversing switch 25 may be employed to select the direction in which the null biasing adjustment is made.

Numerous modifications in the construction of the apparatus of FIGS. 1, 2 and 3 may be made without departing from the scope of my invention. Specifically, the toroidal member 3 may be the inner member, in which case the pole pieces of the ferromagnetic core member 1 would be inwardly directed from an outer annular ferromagnetic ring. Also, more or less pole pieces and associated gaps in the member 3 could be employed. The essential relationship involves the use of a pair of pole pieces on the core member 1 for each slot such as 6 in the toroidal member 3, one pole piece confronting the gap 6, and the other pole piece being arranged to have a constant reluctance connection with the ferromagnetic portions of the member 3. In case only one gap 6 was employed, the portions 4 and 5 would be joined together and the return pole such as 7b would be shared by both of the ferromagnetic portions 4 and 5 linking the coils such as 14 and 15. In general, the number of pole pieces on the core member 1 must be even, and the number of gaps such as 6 required will be one-half of the number of pole pieces on the core member 1. It will be apparent that one of each pair of pole pieces provided will act as a sensing pole in connection with the gap such as 6, and the other pole piece will act as a return pole.

While I have described my invention with respect to the details of a specific embodiment thereof, many changes and variations will be apparent to those skilled in the art upon reading my description, and such may obviously be made without departing from the scope of my invention.

Having thus described my invention, what I claim is:

1. In combination, a first member comprising first and second ferromagnetic portions separated by a gap having a first reluctance, a second ferromagnetic member mounted adjacent said first member for relative movement with respect to the first member over a range of relative positions disposed about said gap including a first position in which the reluctance of a first path including said second member and said first portion is equal to the reluctance of a second path including said second member and said second portion, said first and second members being separated by a second gap which is the same in all of said positions and has a second reluctance substantially less than said first reluctance, said range of positions including positions on either side of said first position in which the reluctances of said paths are unequal, a first electromagnetic coil wound on the first ferromagnetic portion of said first member, a second electromagnetic coil wound on the second ferromagnetic portion of said first member, and a third electromagnetic coil wound on said second ferromagnetic member, said third coil being inductively coupled with said first coil through said first path and with said second coil through said second path.

2. The apparatus of claim 1, in which the reluctance of said first path is progressively greater in relative positions of said members on one side of said first position progressively farther from said first position and is progressively smaller in relative positions of said members on the other side of said first position progressively farther from said first position and the reluctance of said second path increases as the reluctance of said first path decreases and conversely.

3. The apparatus of claim 2, in which the gap between said first and second members includes a variable gap and a constant return gap in said first path between said second member and the first ferromagnetic portion of said first member and a variable gap and a constant return gap in said second path between said second member and the second ferromagnetic portion of said first

5

member, the reluctance of said return gaps being equal.

4. The apparatus of claim 3, in which said first and second electromagnetic coils are wound in series opposition.

5. An electromagnetic transducer comprising a first ferromagnetic member and a second member, said first member comprising two poles, said members being mounted for relative movement over a range of positions in all of which said poles are each spaced from said second member by a predetermined gap having a first reluctance, said range of positions being bounded by a first position and a second position, said second member comprising third and fourth ferromagnetic members and means for securing said third and fourth members together in spaced relation and separated by a gap having a second reluctance substantially greater than said first reluctance, the reluctance of the path including said first member, a first of its poles, and the third member being equal to the reluctance of the path including said first member, said first pole, and the fourth member in all of said positions, said gap being located over the other of said poles in a position intermediate said first and second positions to produce equal reluctances in said intermediate position and unequal reluctances in other positions in the path including said first member, its second pole and the third member and the path including said first member, its second pole, and the fourth member, a first electromagnetic coil wound on said first member, a second electromagnetic coil wound on said third member, and a third electromagnetic coil wound on said fourth member, said third and fourth coils being connected in series in a sense to produce equal and opposite voltages in response to a voltage applied across said first coil.

6. An electromagnetic transducer, comprising a toroidal member, said toroidal member comprising a plurality of ferromagnetic core pieces separated by equal gaps of a first reluctance extending axially of the toroidal member and means for securing said core pieces together in toroidal form, a ferromagnetic core member mounted for rotation adjacent said toroidal member; said core member being provided with a pair of pole pieces for each gap in said toroidal member, each pole piece being separated from the toroidal member in all relative rotated positions of the core member by a fixed gap of reluctance substantially less than said first reluctance, one of each pair of pole pieces being symmetrically disposed with respect to core pieces adjacent its associated gap in a reference relative position of said members, the second of each pair of pole pieces being adjacent one of the core pieces adjacent the gap in said reference position, an electromagnetic coil for each pair of pole pieces wound on said ferromagnetic member and linking the associated pair of poles, and an electromagnetic coil wound on each of said core pieces and inductively coupled with the pair of pole pieces associated with the adjacent gaps in said toroidal member.

7. An electromagnetic transducer comprising a toroidal member bounded by a cylinder of revolution about an axis and a ferromagnetic core member mounted for rotation relative to said toroidal member about said axis and having an even number of pole pieces confronting said toroidal member and separated therefrom by predetermined gaps of a first reluctance, said toroidal member comprising a plurality of toroidal sectors of ferromagnetic material separated by gaps of a second reluctance substantially greater than twice said first reluctance and means for holding said toroidal sectors together in spaced relation, the number of gaps between said sectors being equal to one-half the number of pole pieces, said pole pieces comprising pairs of pole pieces, one pole piece of each pair being disposed adjacent a gap and confronting two sectors and the other pole piece of each pair being disposed adjacent and confronting a single sector in a reference relative position of said members, an electro-

6

magnetic coil wound on one pole piece of each pair, and an electromagnetic coil wound on each sector and linking the confronting pole pieces.

8. The apparatus of claim 7, in which the coils wound on said pole pieces are connected in series and the coils wound on said sectors are connected in series.

9. An electromagnetic transducer, comprising a ferromagnetic member symmetrical about a first axis and having four radially projecting pole pieces terminating in surfaces conforming to sectors of a circular cylinder described about said first axis, first and second coils wound about non-adjacent ones of said pole pieces and connected in series aiding relationship, a toroidal member symmetrically disposed about said first axis, means mounting said toroidal member and said ferromagnetic member for relative rotation about said axis, said toroidal member having a cylindrical surface confronting the surface of said pole pieces and separated therefrom by a predetermined gap of a first reluctance, said toroidal member comprising two ferromagnetic portions separated by first and second gaps each of a second reluctance substantially greater than twice said first reluctance, said first gap confronting the center of one pole piece and said second gap confronting the center of another non-adjacent pole piece in a reference relative position of said members, and a coil wound on each ferromagnetic portion of said toroidal member, the coils wound on said ferromagnetic portions being connected in series opposition.

10. The combination of claim 9, further comprising means for applying an alternating voltage to the coils wound on said ferromagnetic member, a tertiary coil wound on each ferromagnetic portion of said toroidal member, said tertiary coils being connected in series, and adjustable means for applying a biasing voltage to said tertiary coils to make the electrical null of the other series-connected coils wound on said ferromagnetic portions occur at a reference relative portion of said members.

11. An electromagnetic transducer, comprising a rotor member and a stator member, means mounting said members for relative rotation over a predetermined range of angular positions including a reference position, one of said members comprising a ferromagnetic member having an even number of pole pieces confronting the other member and separated therefrom by an air gap of a first reluctance, said poles comprising a set of pairs of adjacent poles, a coil wound on one pole of each pair, said coils being connected in series aiding relationship, the other member comprising a toroid of toroidal sectors of ferromagnetic material separated by air gaps of a second reluctance greater than twice said first reluctance, the number of gaps being equal to one-half the number of poles and each gap confronting one pole of a different pair, the other pole of each pair confronting one of said sectors, and a coil wound on each sector and inductively coupled with the coils wound on confronting pairs of said poles, the coils wound on said sectors being connected in series and alternately oppositely wound, means for applying a reference alternating voltage across the coils wound on said poles, whereby a voltage is produced across the coils wound on said sector having a phase in accordance with the sense, and a magnitude in accordance with the extent, of the relative angular displacement of said members from the reference position.

References Cited by the Examiner

UNITED STATES PATENTS

755,829	3/1904	Zani	323—90 X
2,427,213	9/1947	Jewell	323—90
2,839,733	6/1958	Bassett	336—30
3,214,717	10/1965	Brodersen	336—135
3,217,308	11/1965	Maxwell	340—196

JOHN F. COUCH, *Primary Examiner.*

W. E. RAY, *Assistant Examiner.*