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(12) **United States Patent**
Flynn

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(45) **Date of Patent:** **Jan. 29, 2002**

(54) **METHODS FOR CONTROLLING THE PATH OF MAGNETIC FLUX FROM A PERMANENT MAGNET AND DEVICES INCORPORATING THE SAME**

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(73) Assignee: **Magnetic Revolutions Limited, L.L.C., St. Louis, MO (US)**
(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **09/364,701**

(22) Filed: **Jul. 30, 1999**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/127,056, filed on Jul. 31, 1998.

(51) **Int. Cl.**⁷ **H02K 1/00; H02K 1/14**

(52) **U.S. Cl.** **310/181; 310/254**

(58) **Field of Search** 310/181, 254, 310/265, 152, 179, 180, 184, 185; 335/126, 131, 272, 279; 318/696, 701, 254

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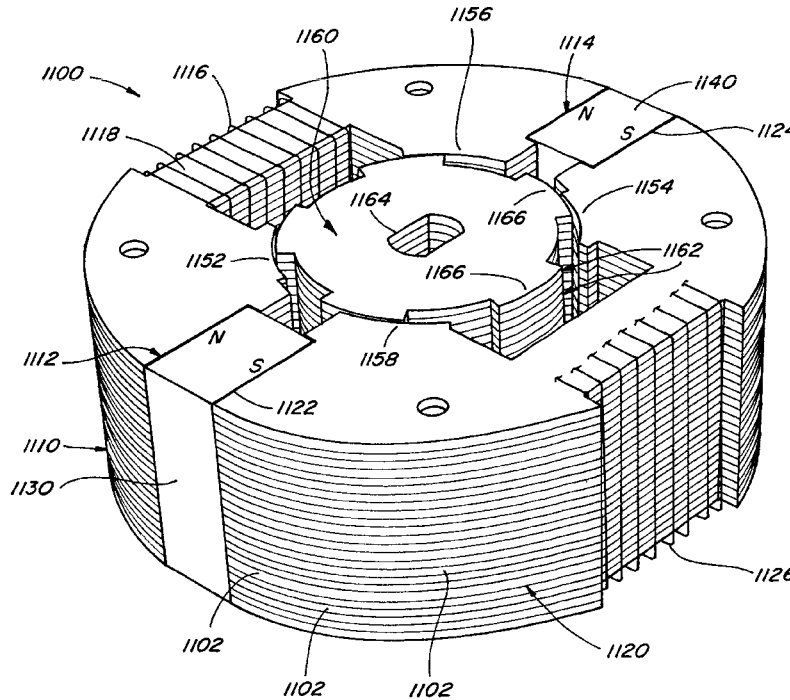
Primary Examiner—Tran Nguyen

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(57) **ABSTRACT**

A permanent magnet device includes a permanent magnet having north and south pole faces with a first pole piece positioned adjacent one pole face thereof and a second pole piece positioned adjacent the other pole face thereof so as to create at least two potential magnetic flux paths. A first control coil is positioned along one flux path and a second control coil is positioned along the other flux path, each coil being connected to a control circuit for controlling the energization thereof. The control coils may be energized in a variety of ways to achieved desirable motive and static devices, including linear reciprocating devices, linear motion devices, rotary motion devices and power conversion.

2 Claims, 34 Drawing Sheets



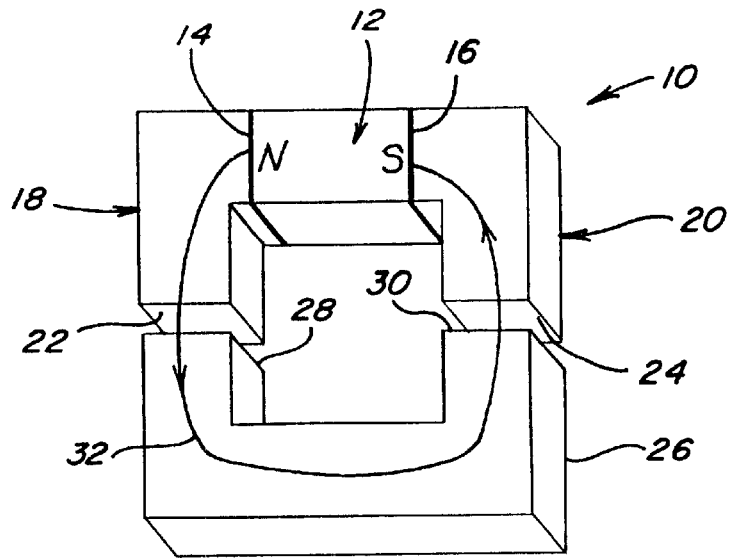


Fig. 1

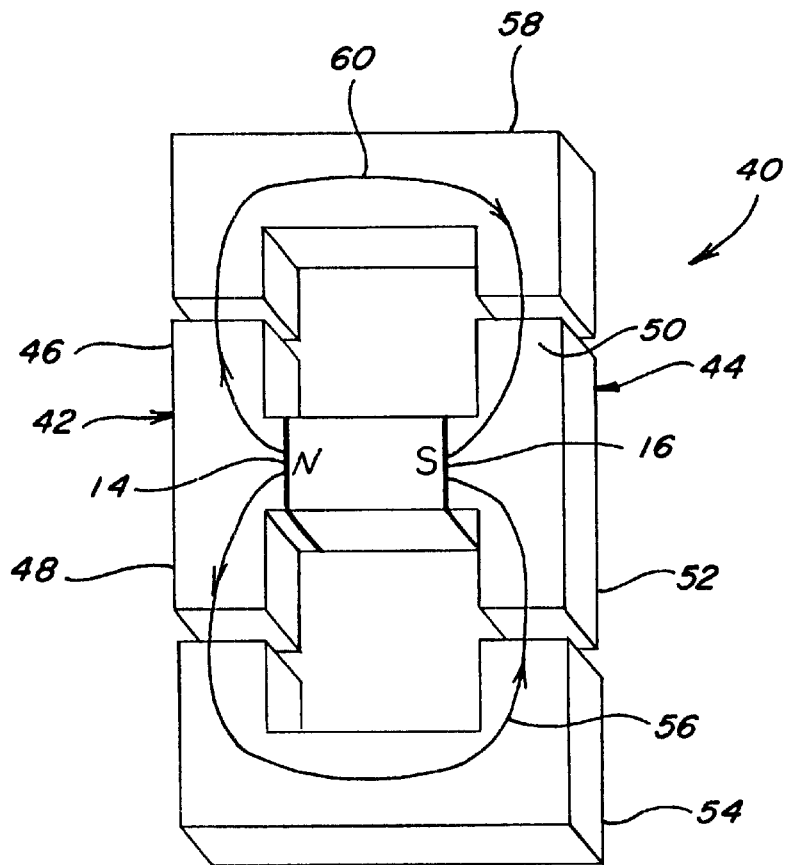


Fig. 2

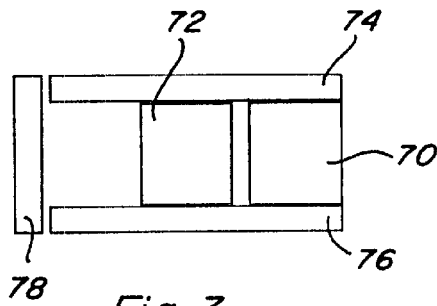


Fig. 3

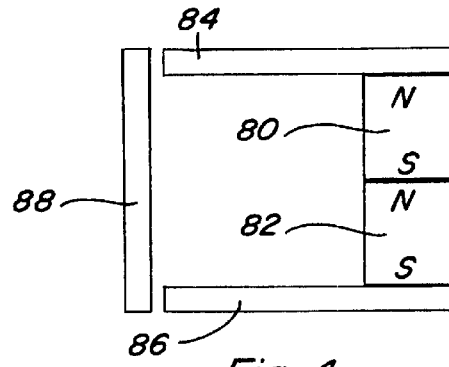


Fig. 4

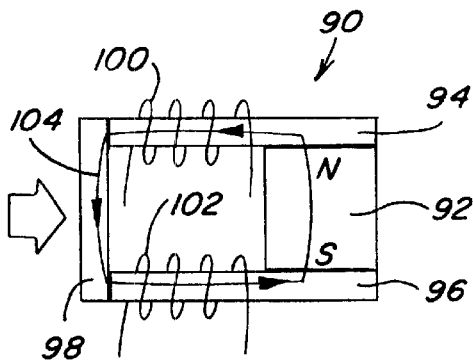


Fig. 5

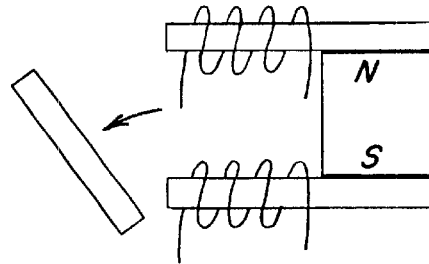


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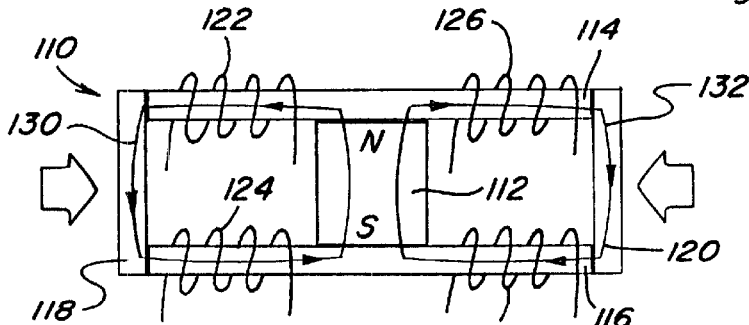


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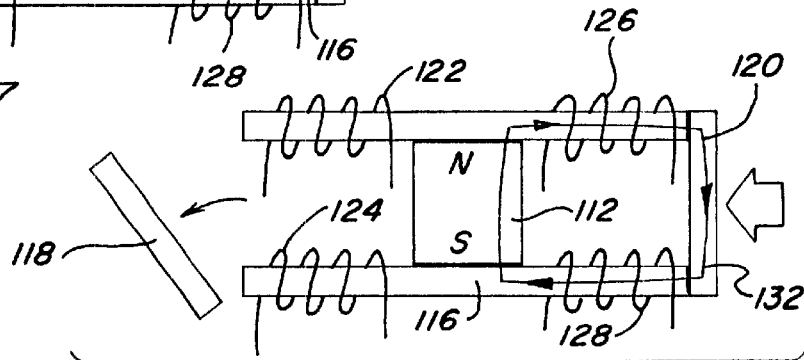


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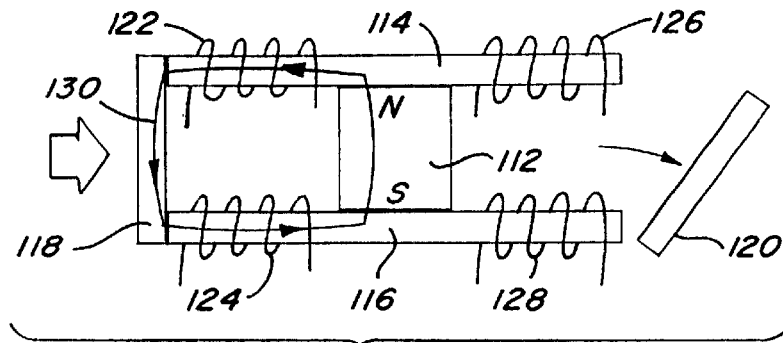


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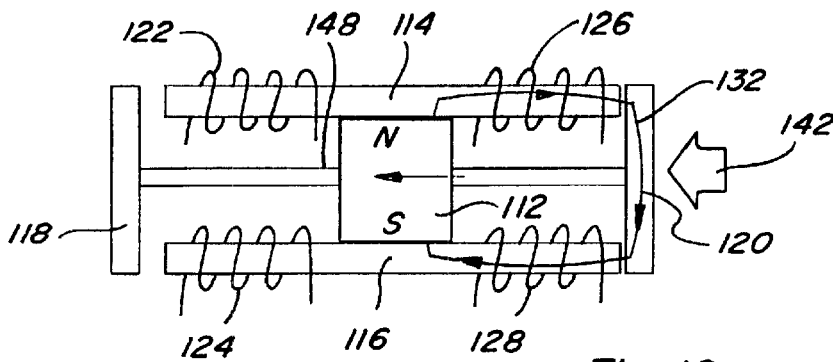


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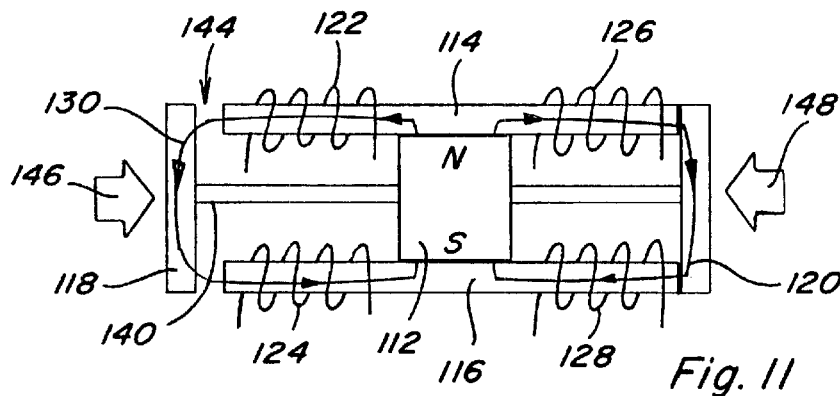


Fig. 11

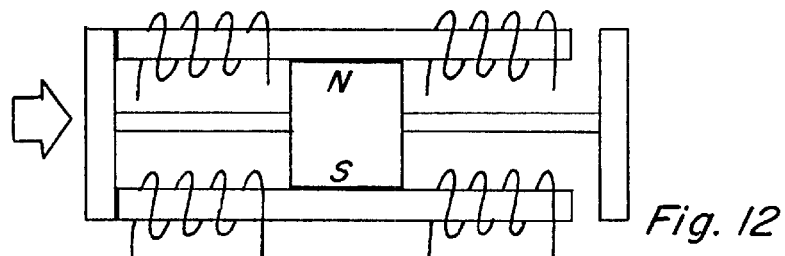


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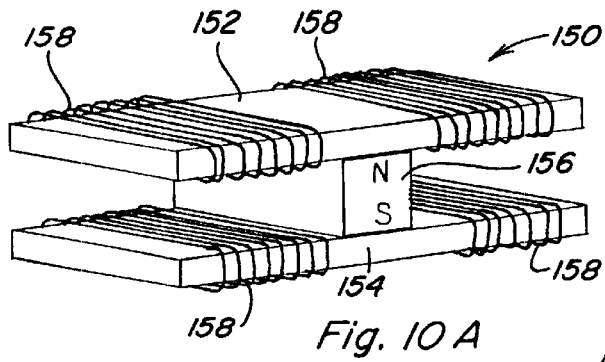


Fig. 10 A

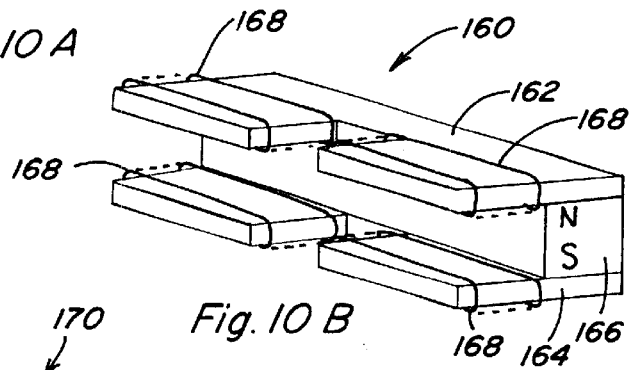


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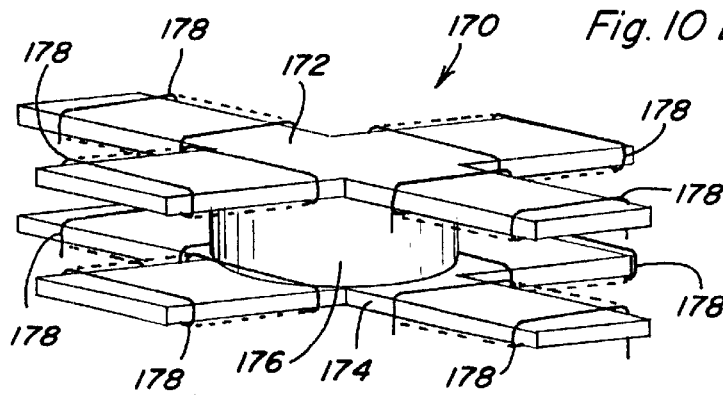


Fig. 10 C

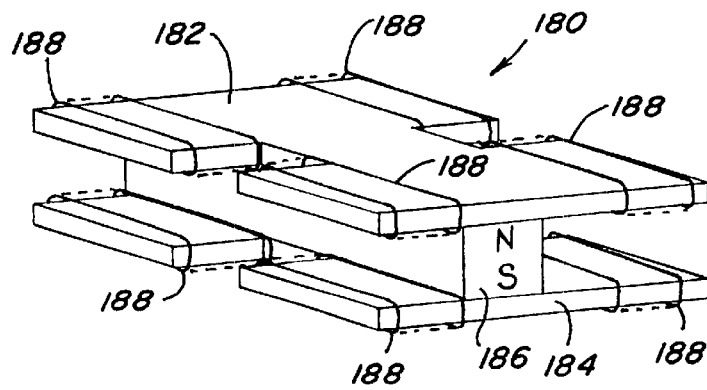


Fig. 10 D

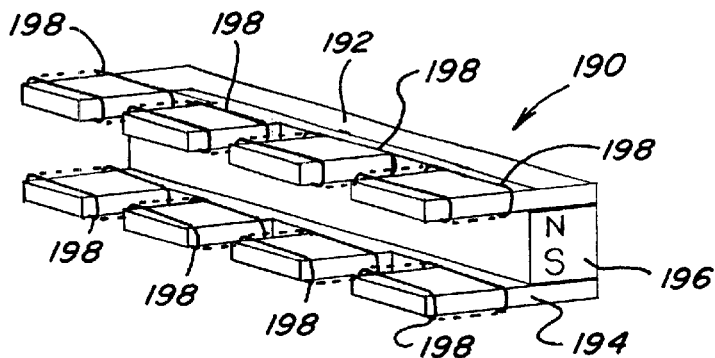


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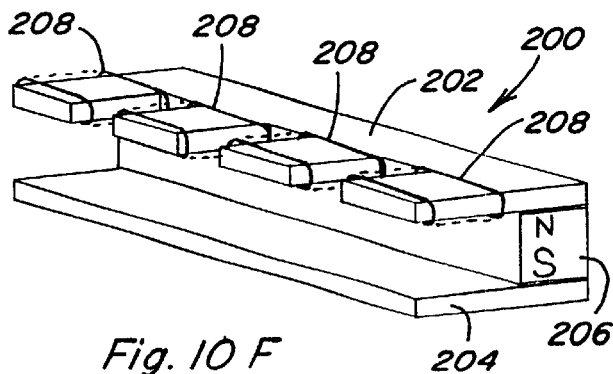


Fig. 10 F

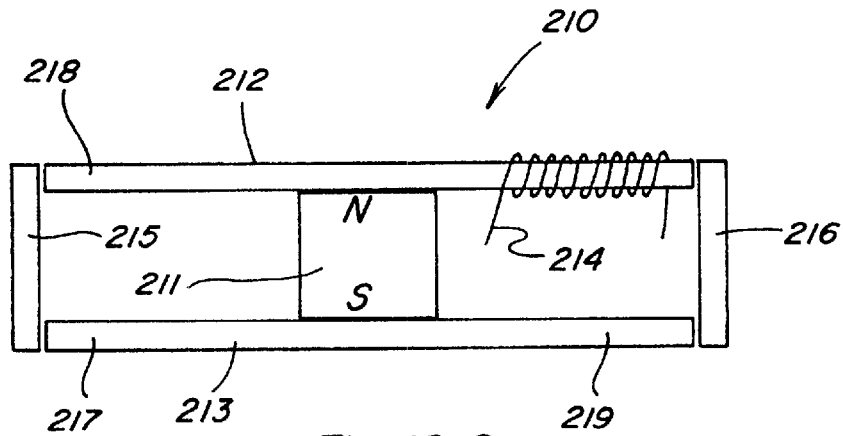


Fig. 10 G

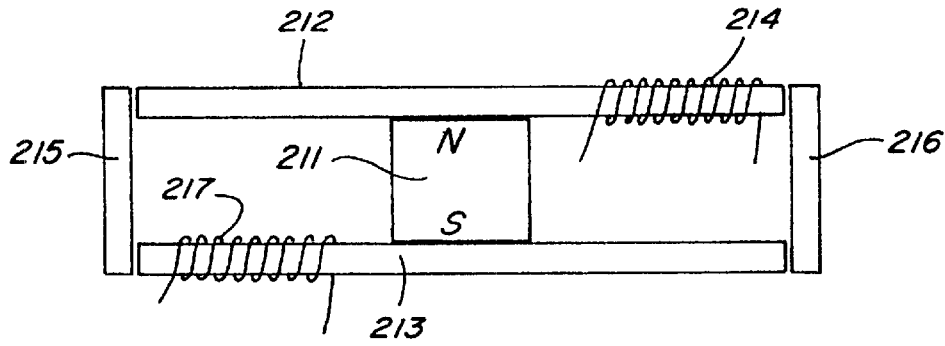


Fig. 10 H

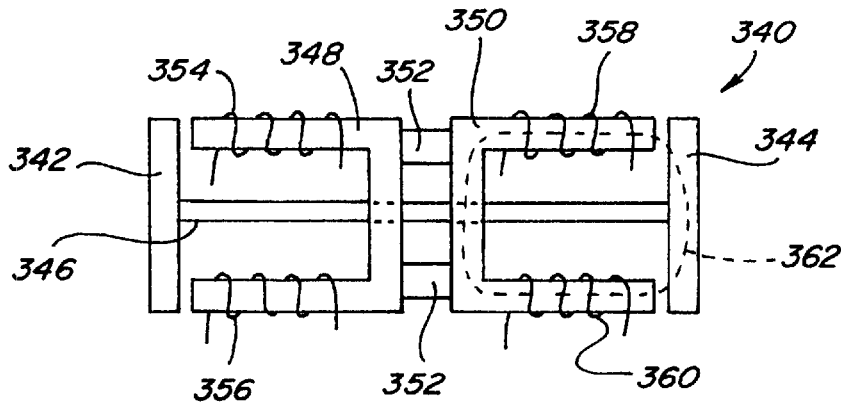


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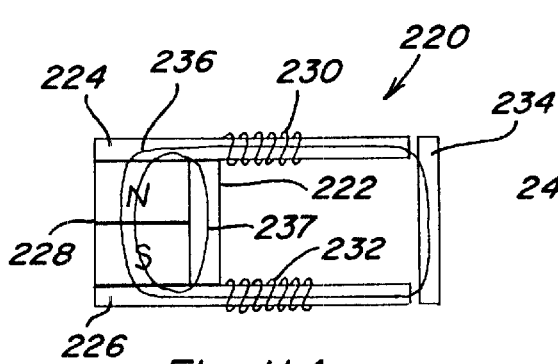


Fig. 11A

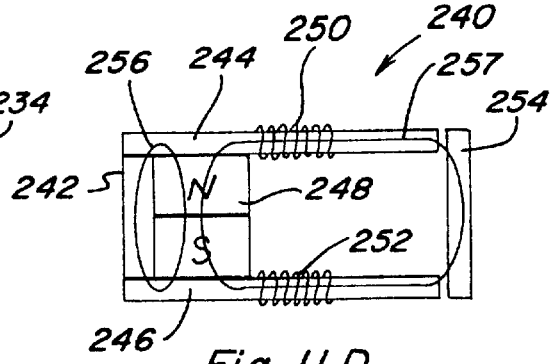


Fig. 11D

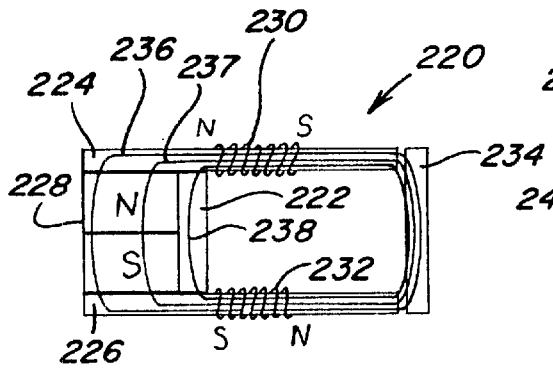


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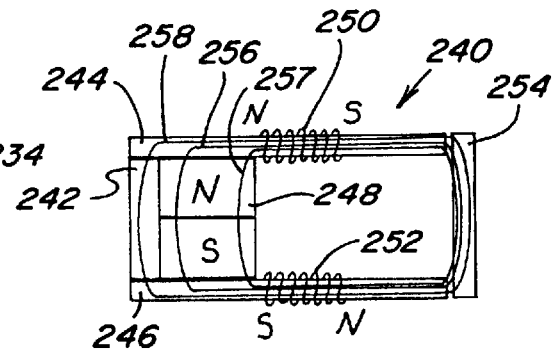


Fig. 11E

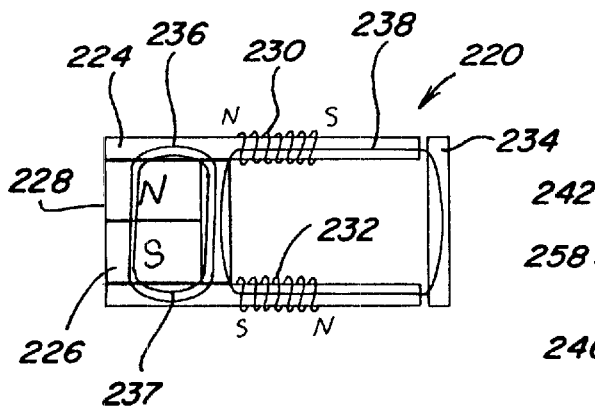


Fig. 11C

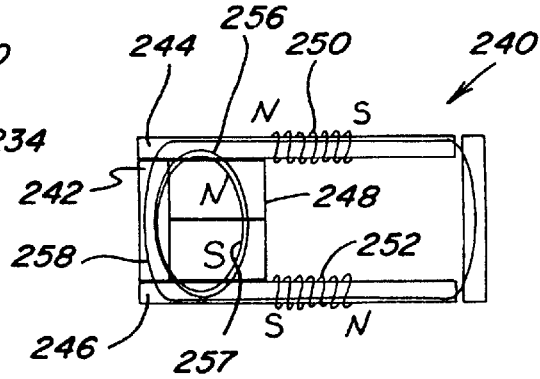


Fig. 11F

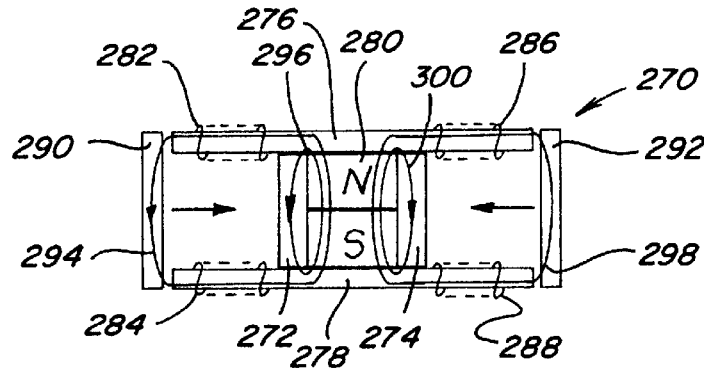


Fig. 12 A

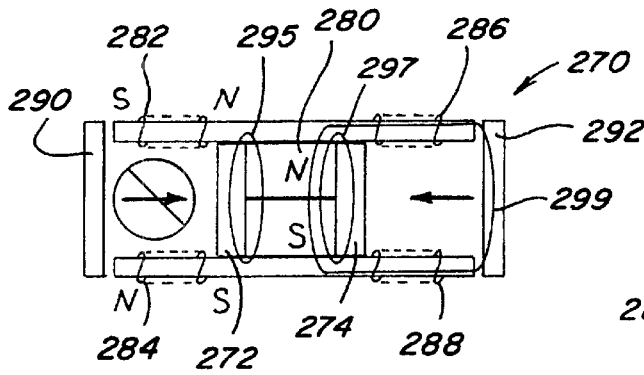


Fig. 12 B

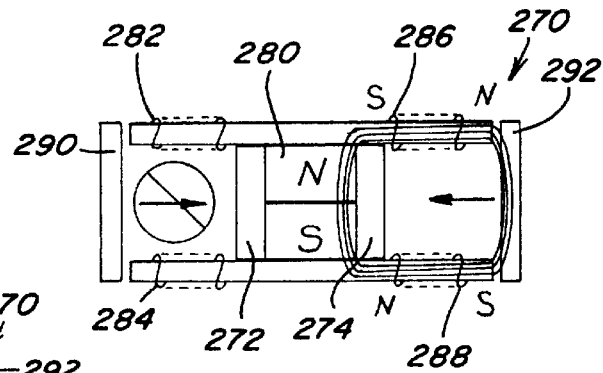


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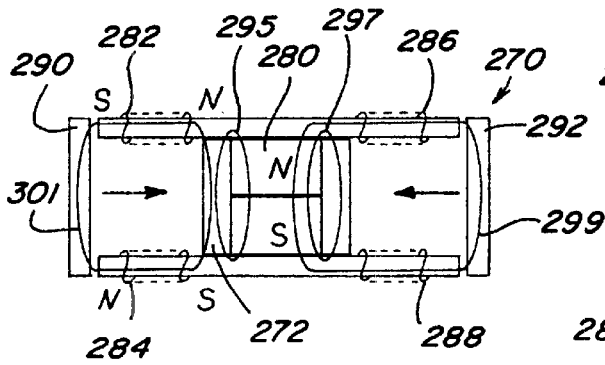


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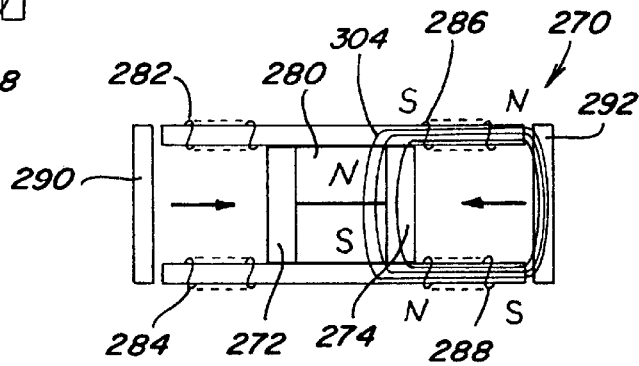


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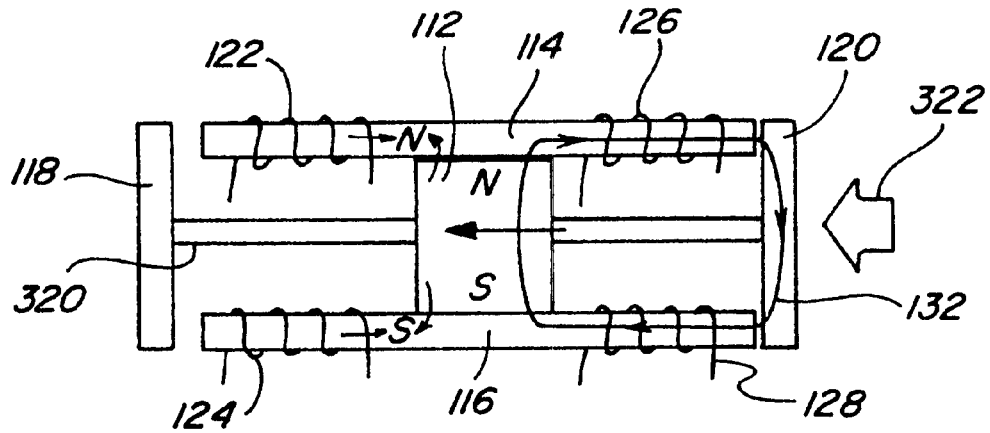


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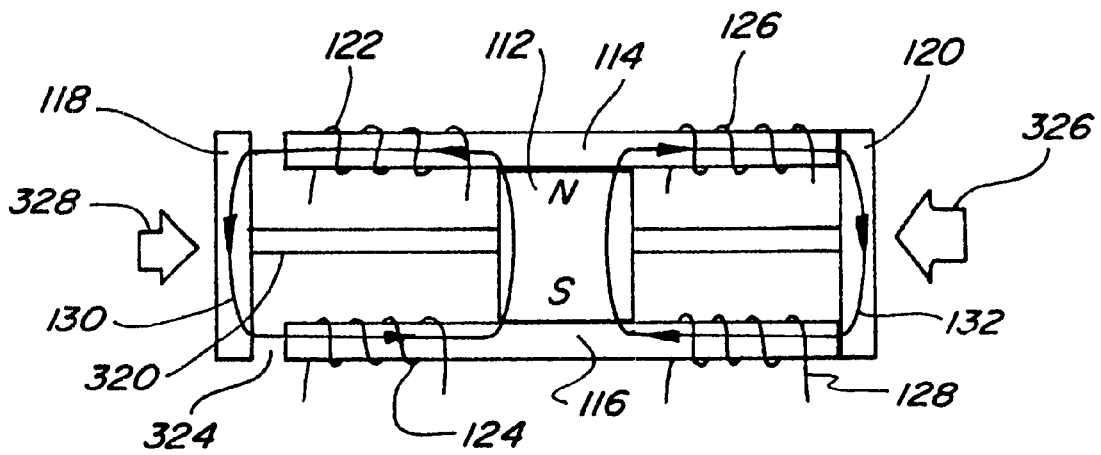


Fig. 13 B

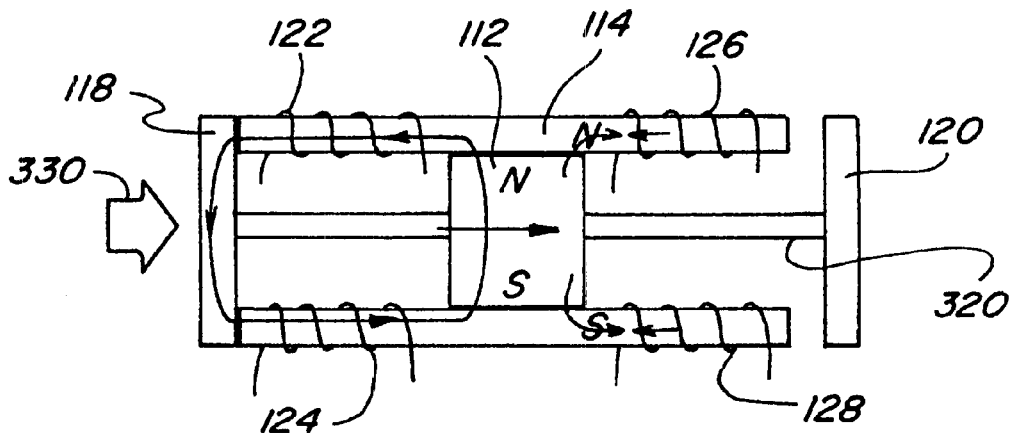


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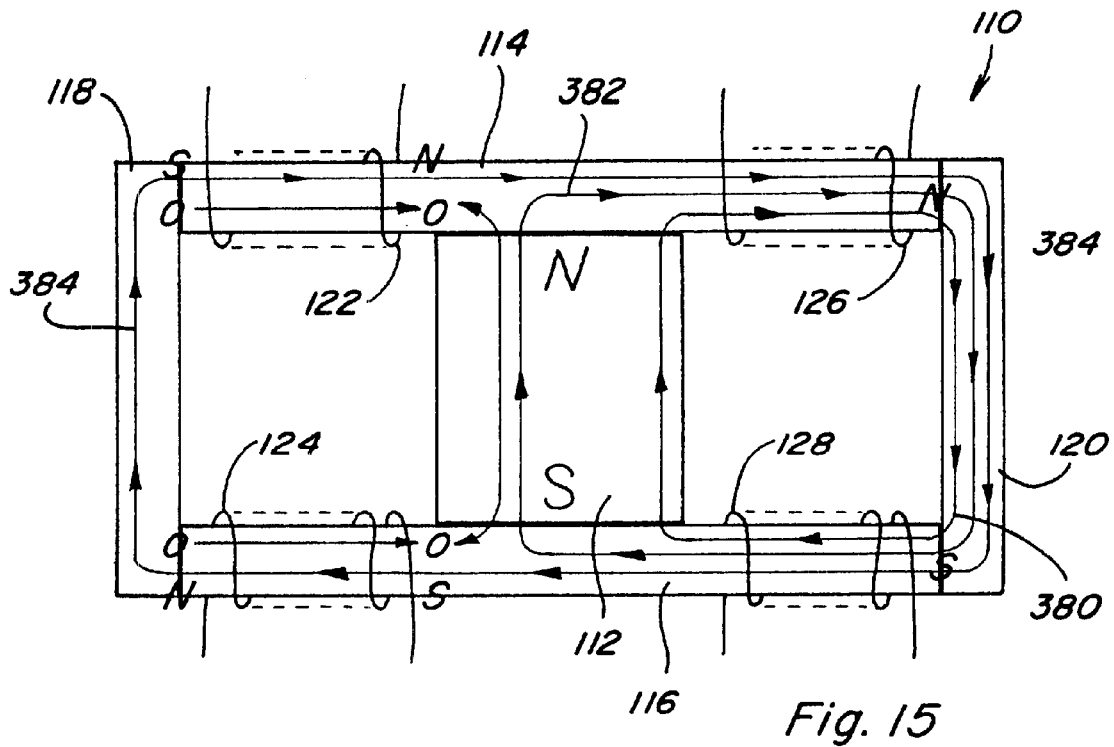


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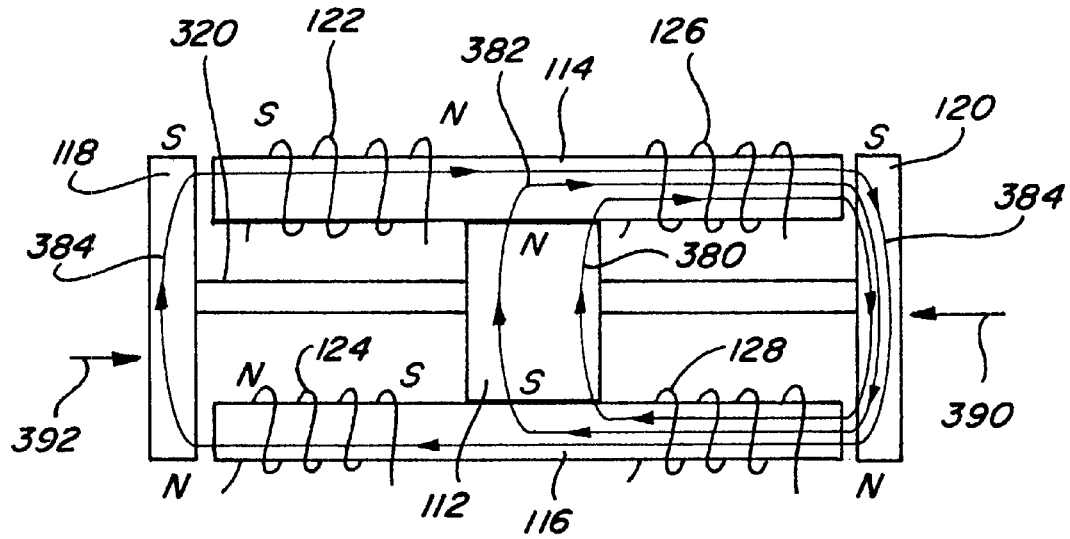


Fig. 16 A

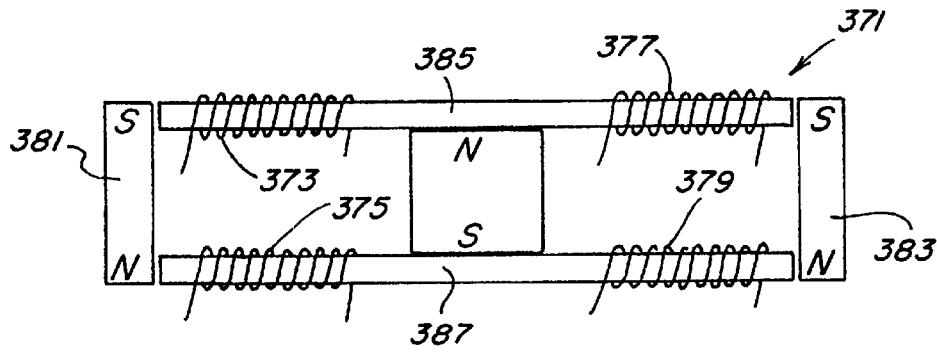


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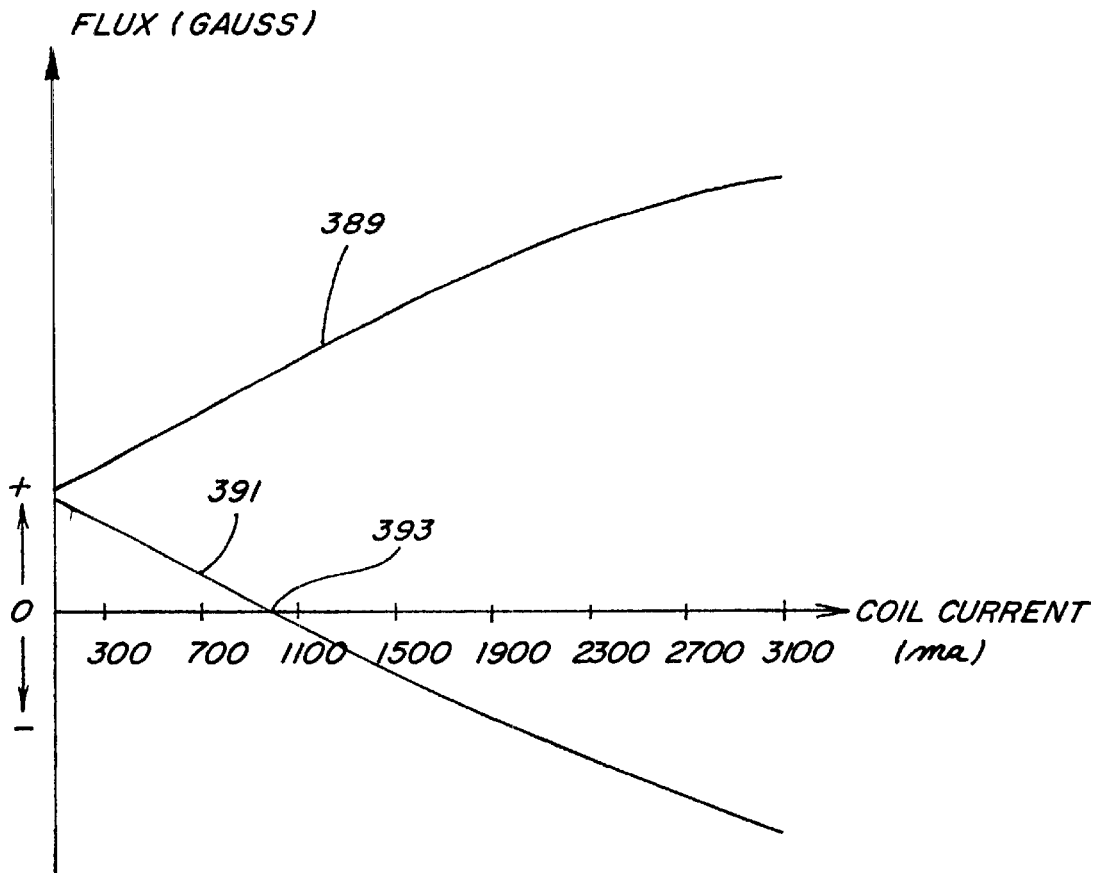


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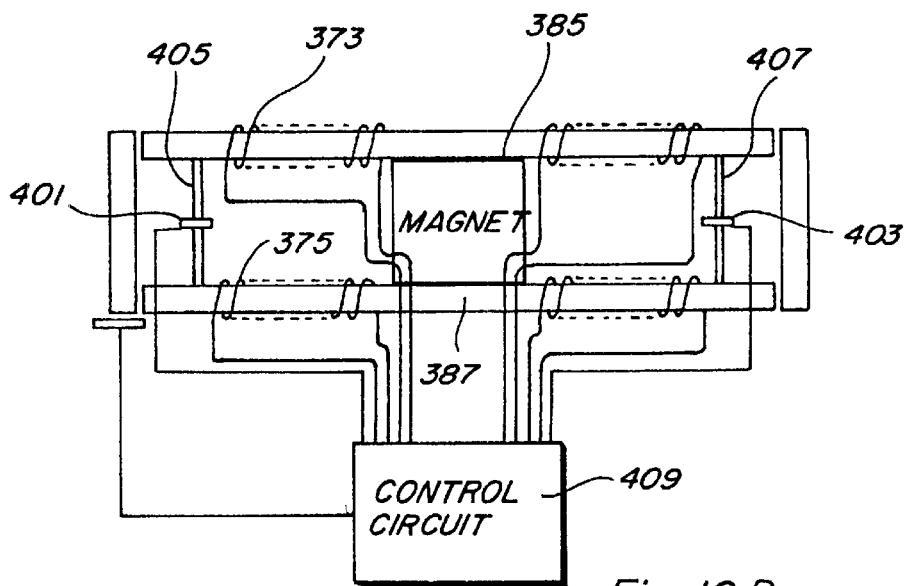


Fig. 16 D

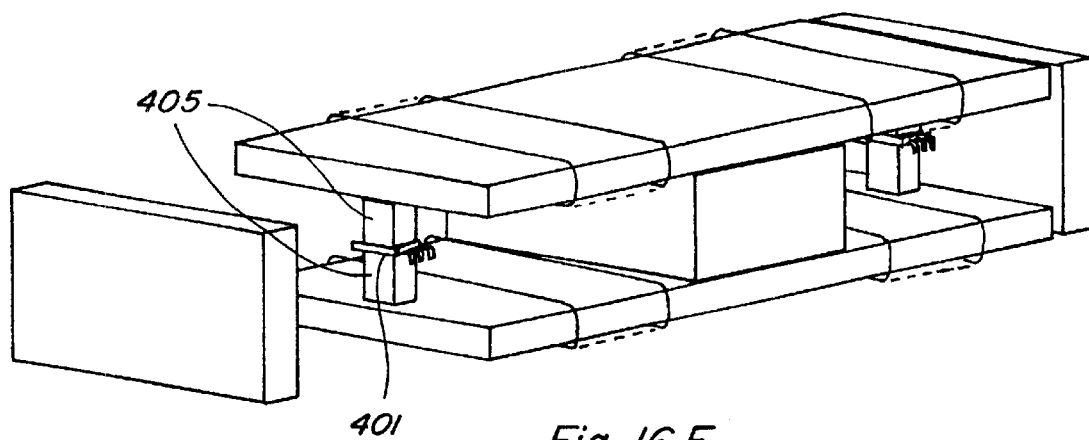


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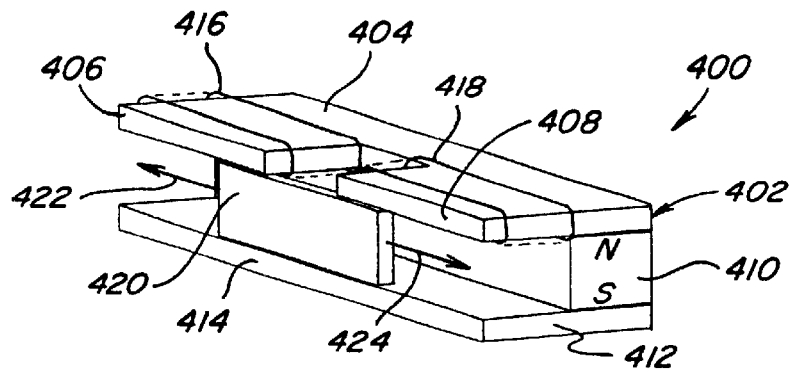


Fig. 17A

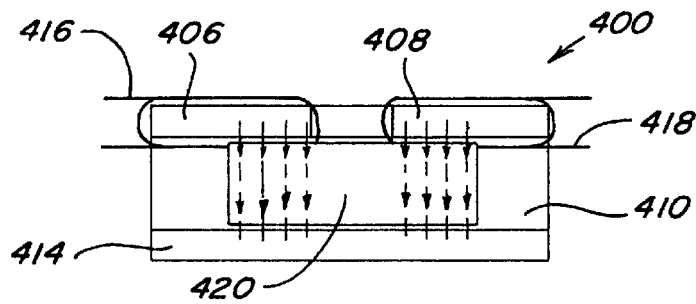


Fig. 17B

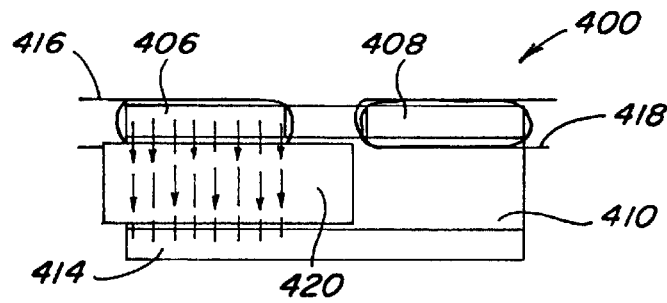


Fig. 17C

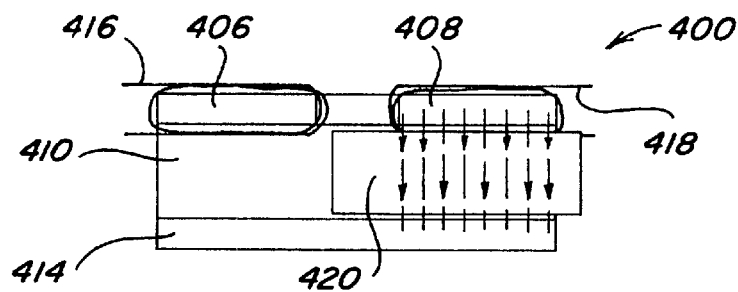


Fig. 17D

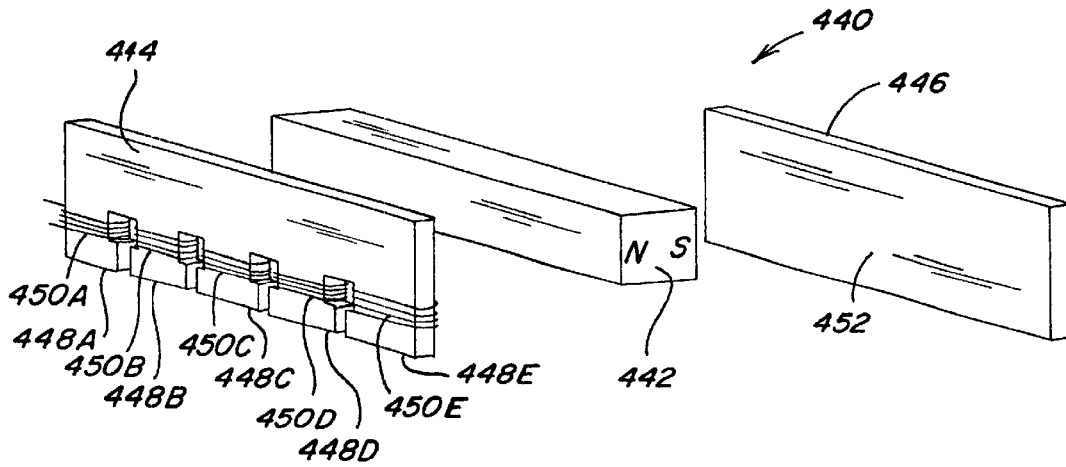


Fig. 18 A

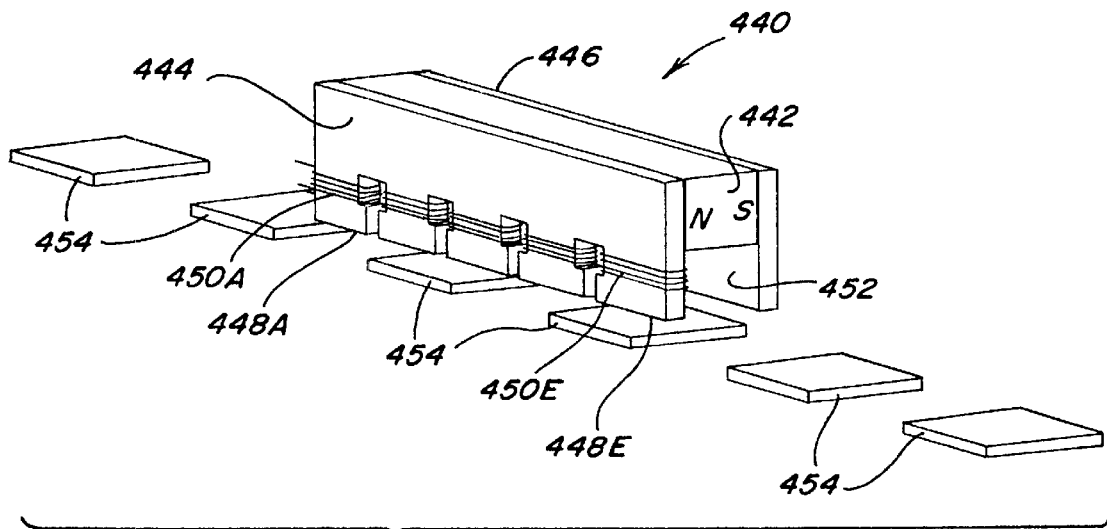


Fig. 18B

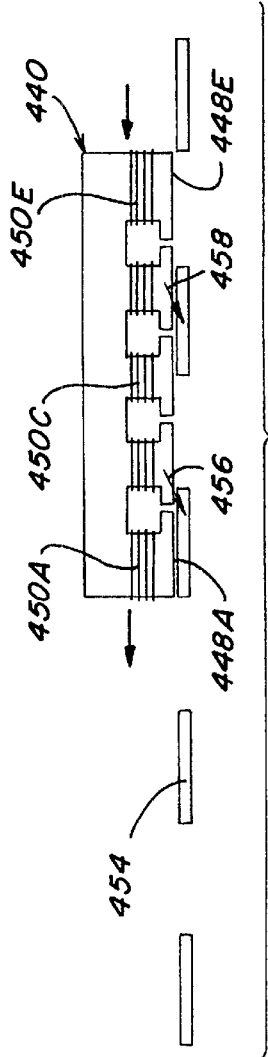


Fig. 18C

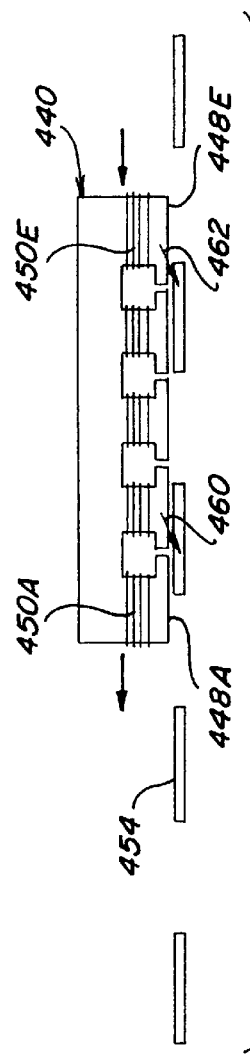


Fig. 18D

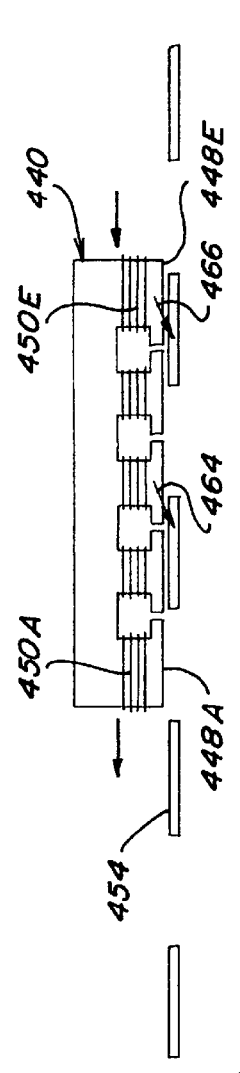


Fig. 18E

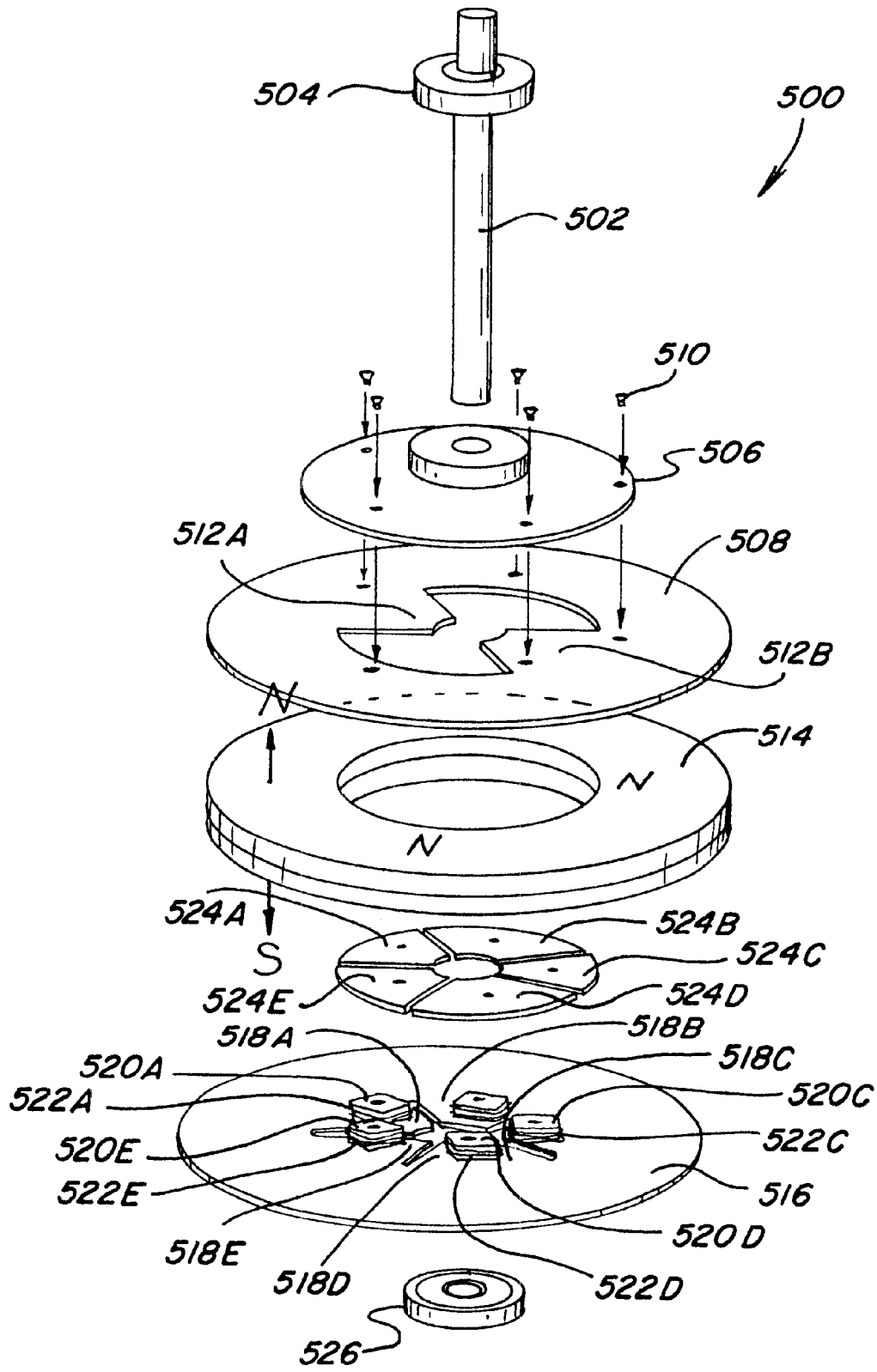


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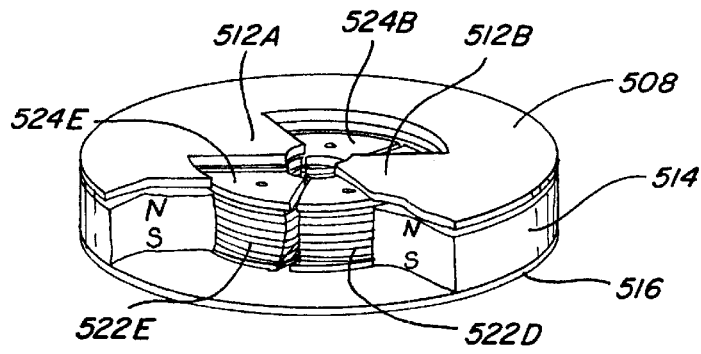


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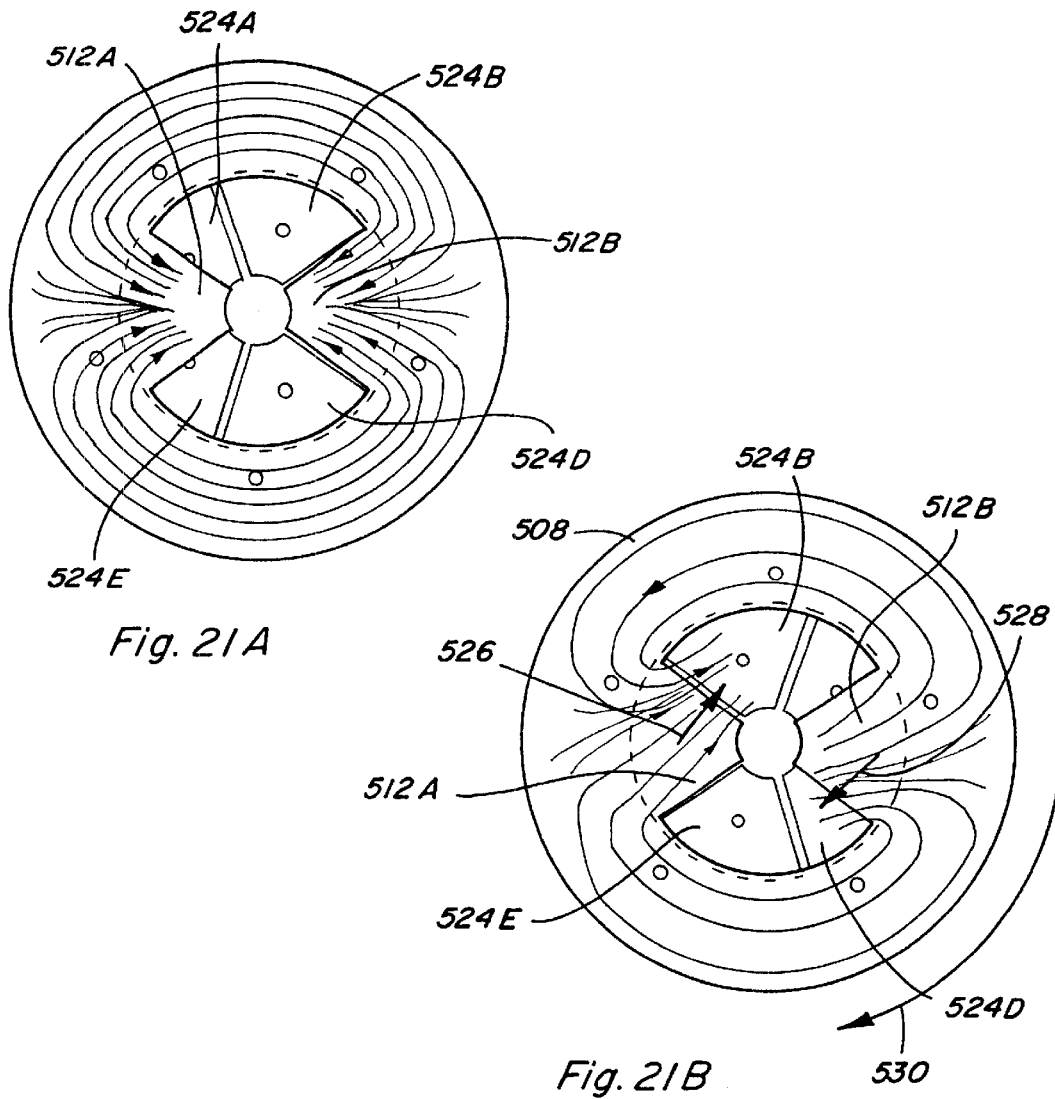


Fig. 21A

Fig. 21B

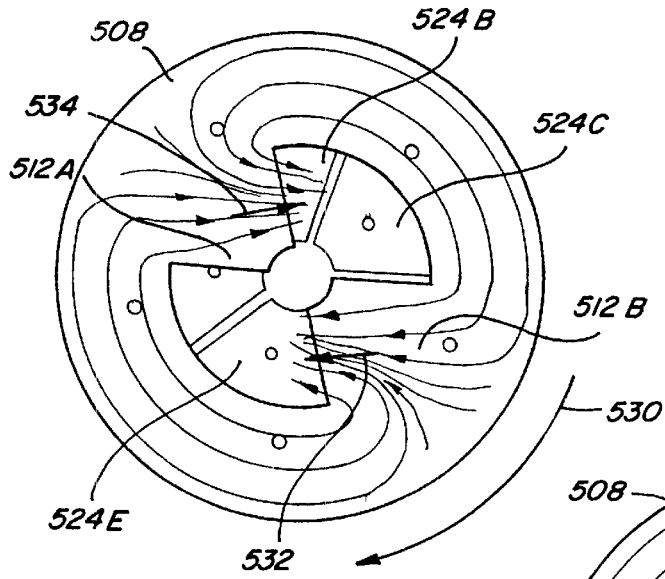


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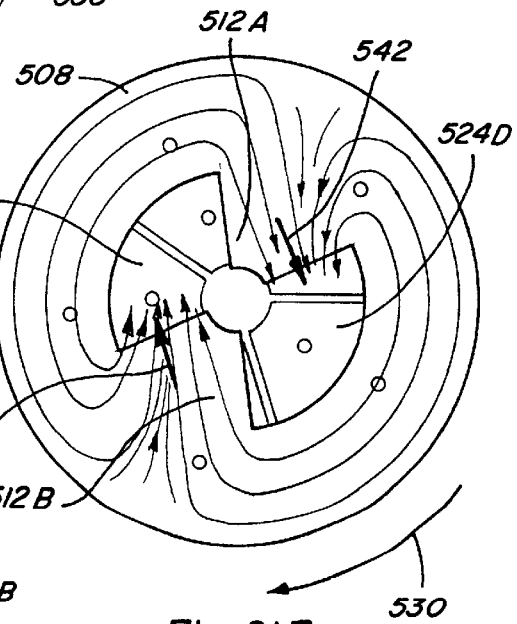


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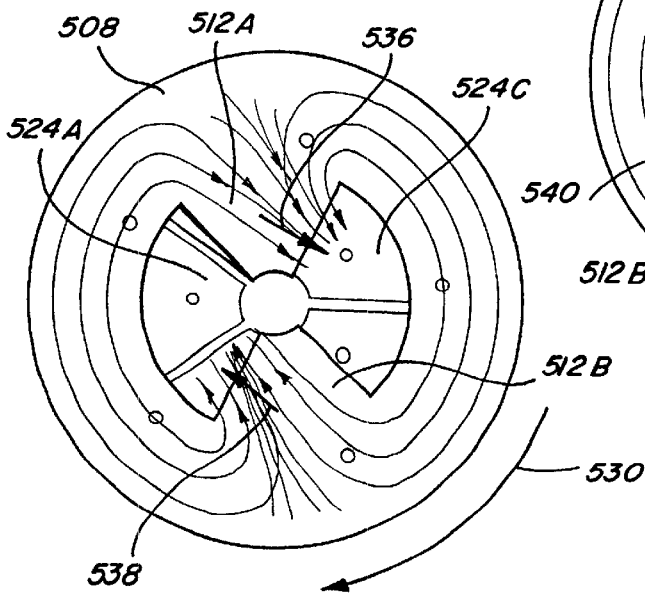


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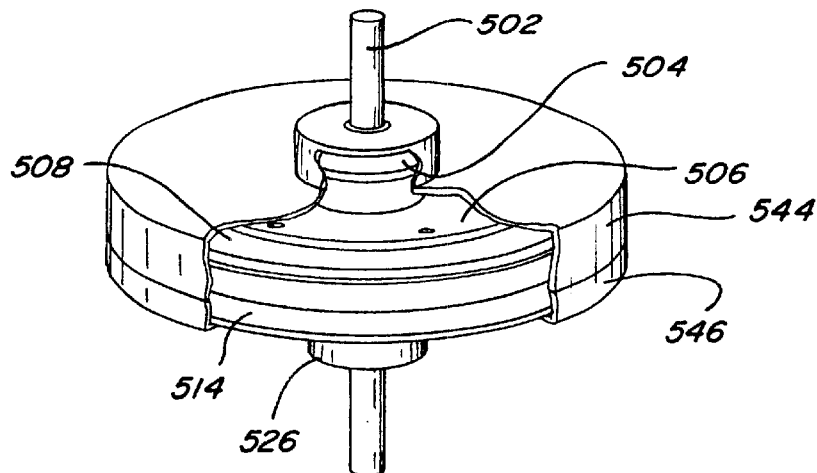


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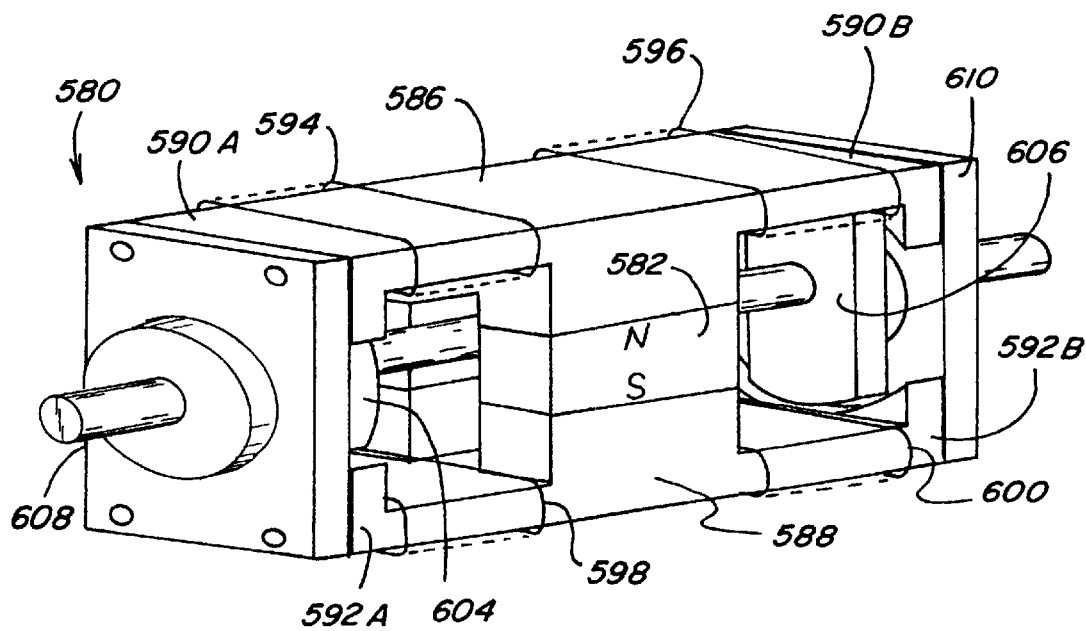


Fig. 24

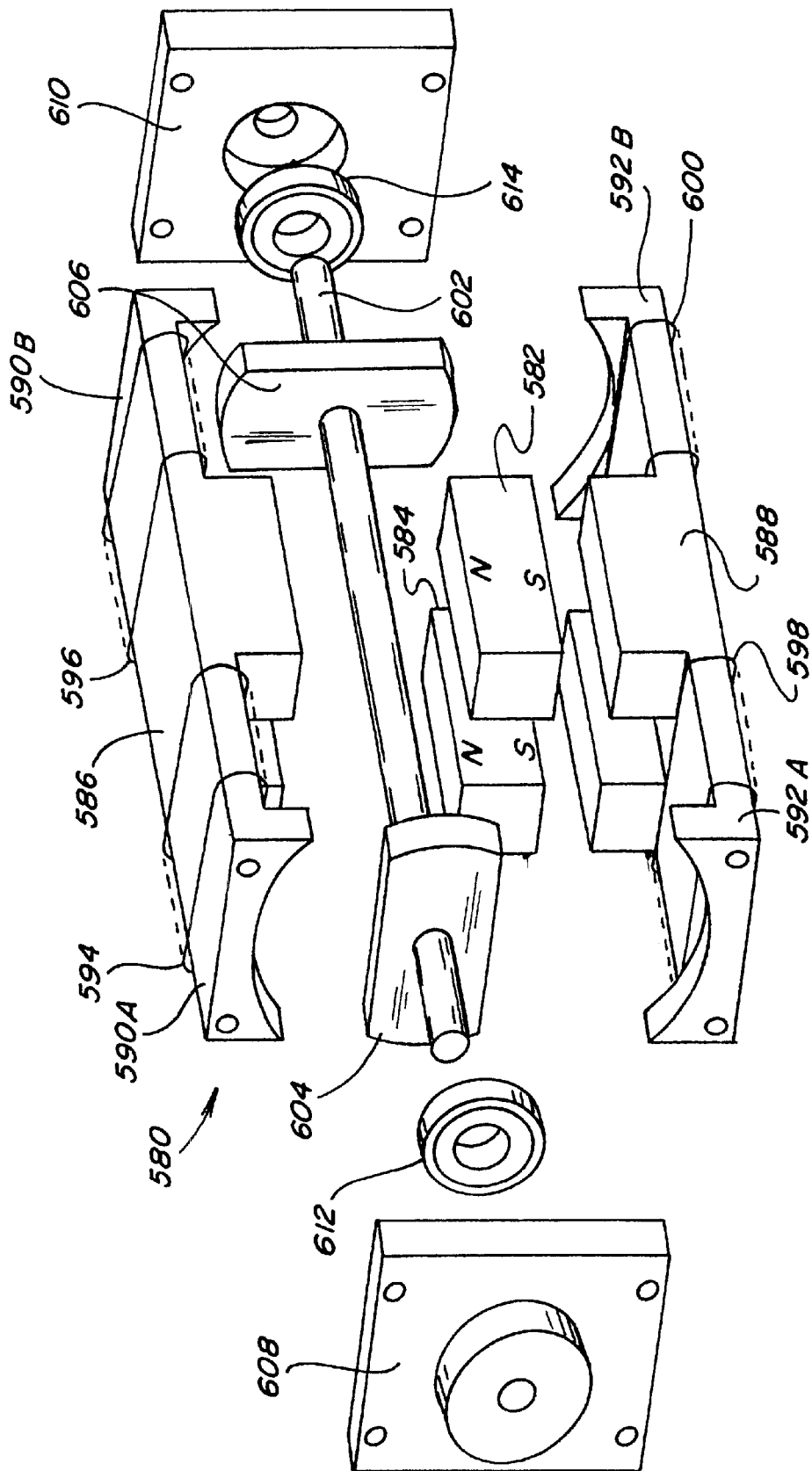
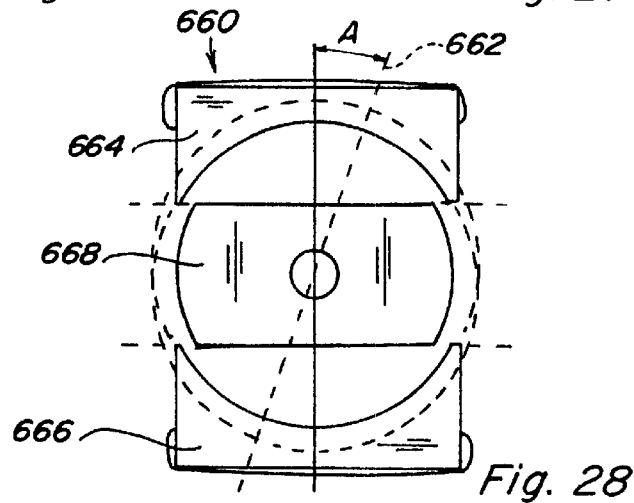
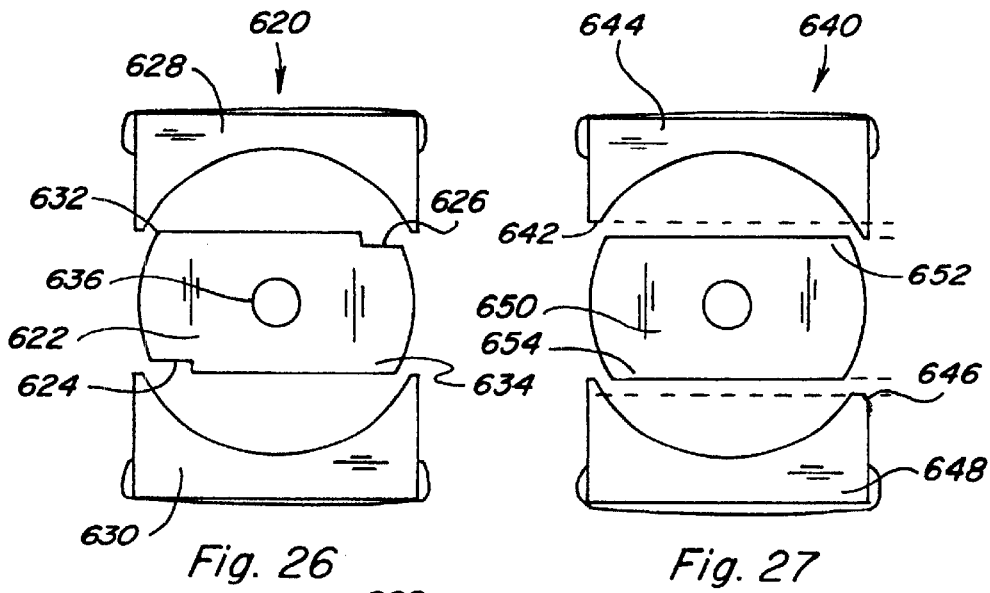
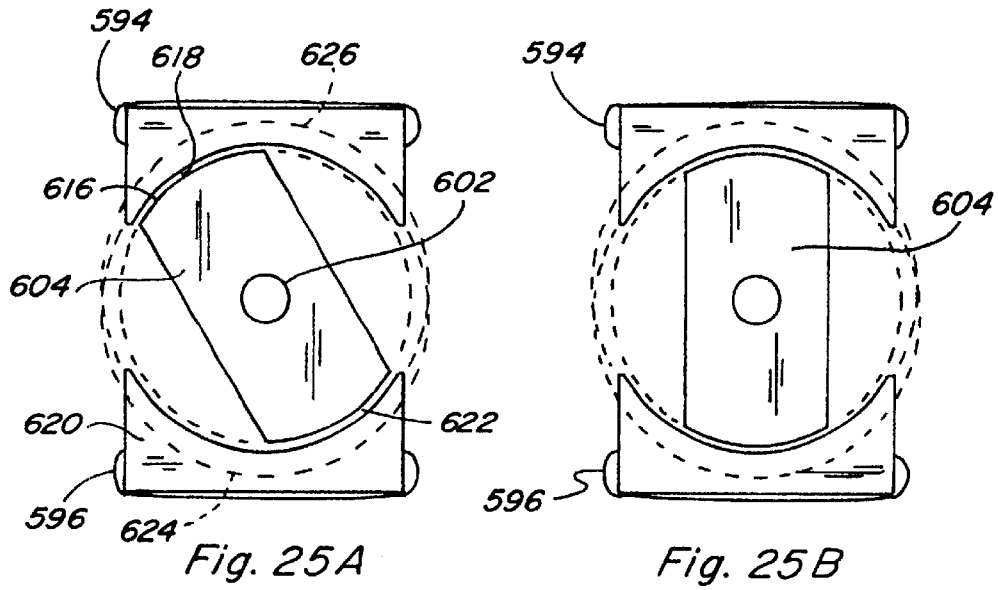


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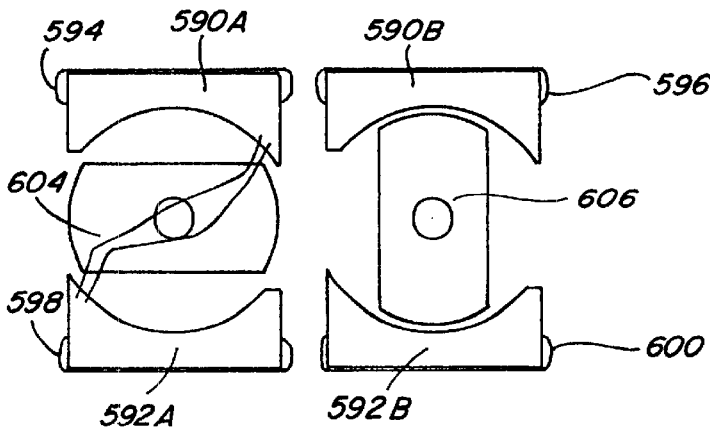


Fig. 29A

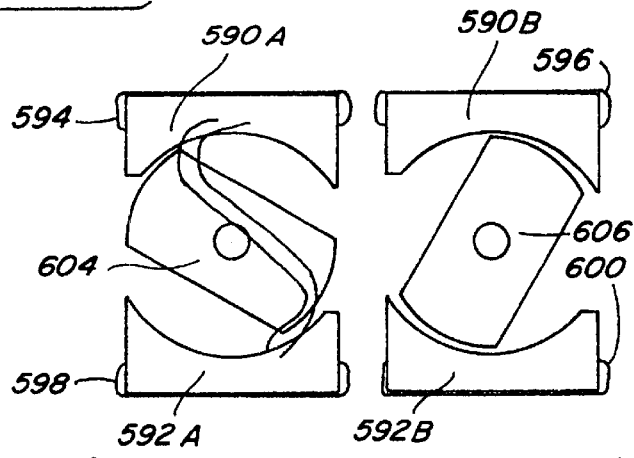


Fig. 29B

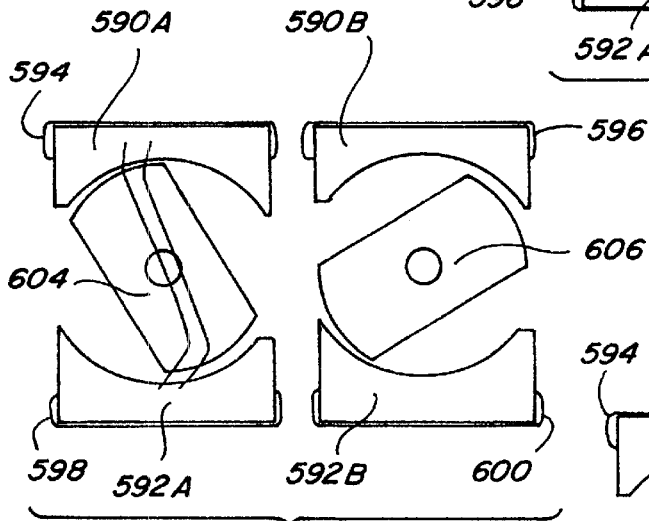


Fig. 29C

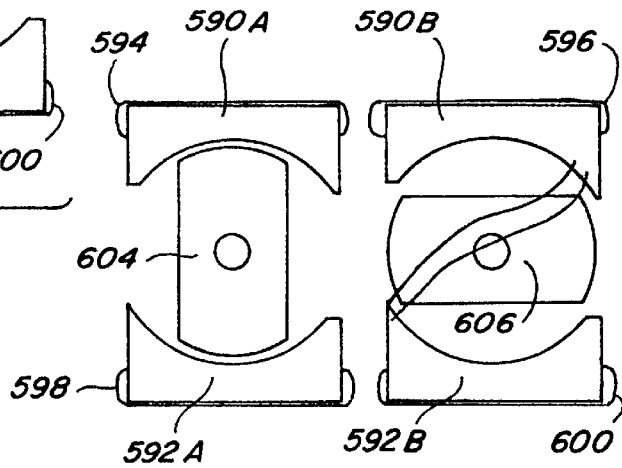
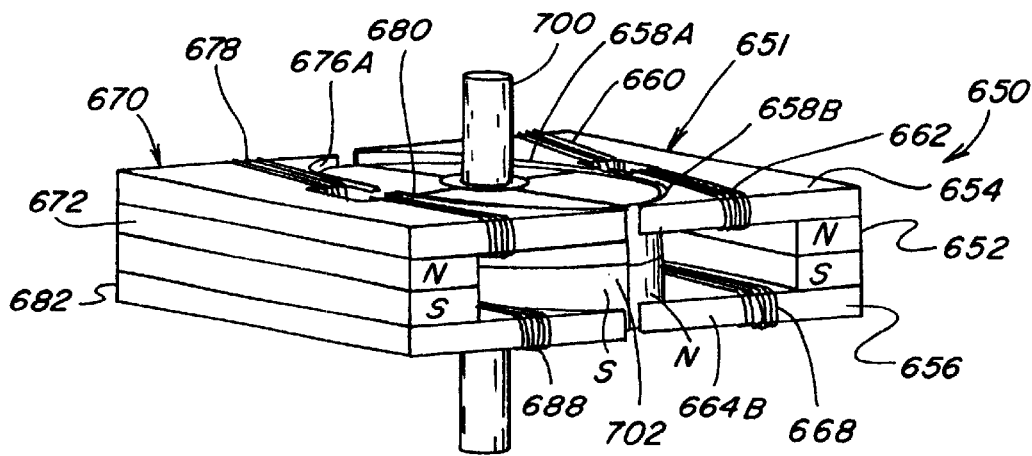
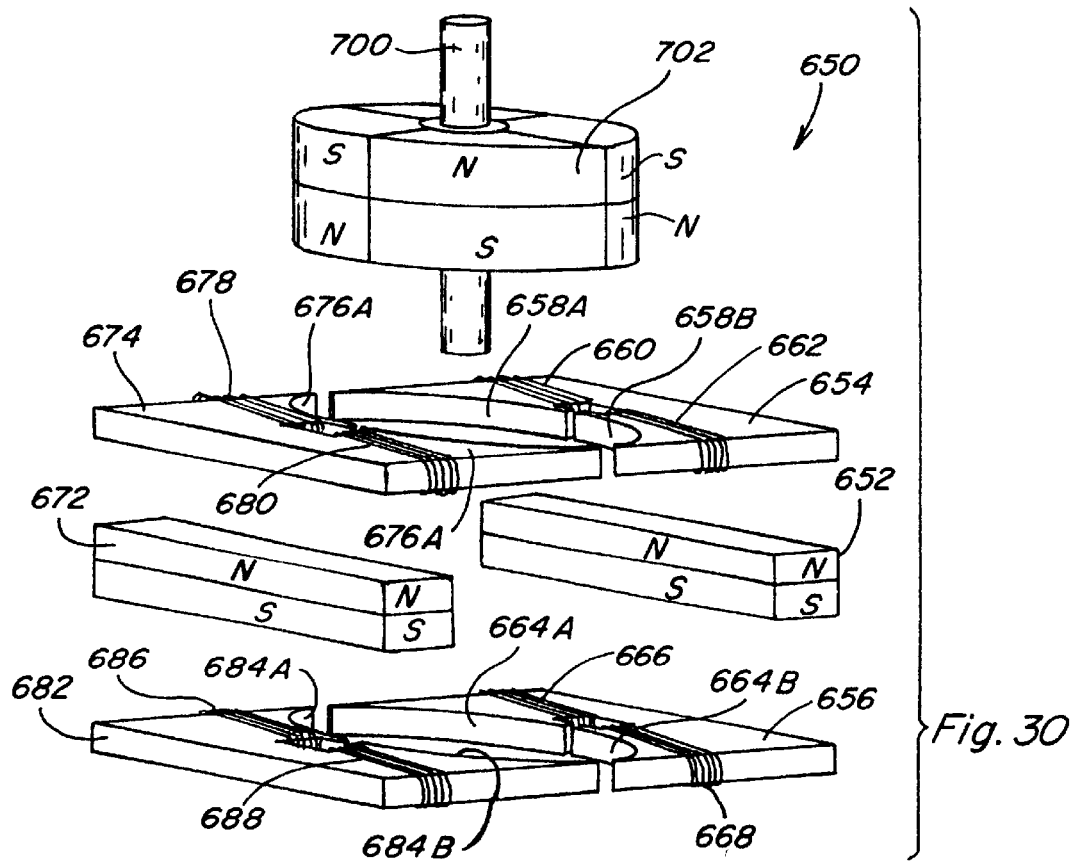


Fig. 29D



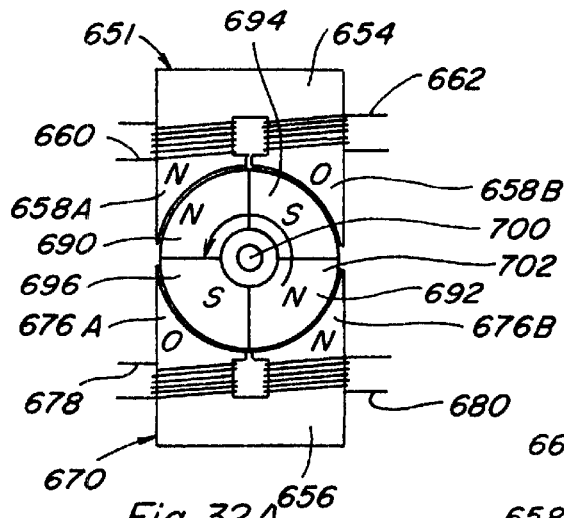


Fig. 32A

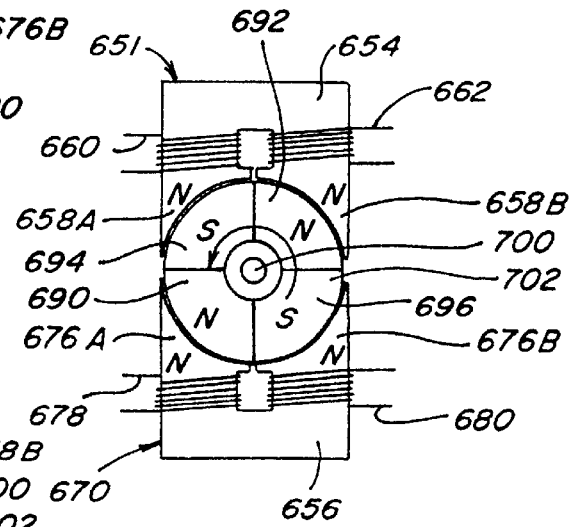


Fig. 32B

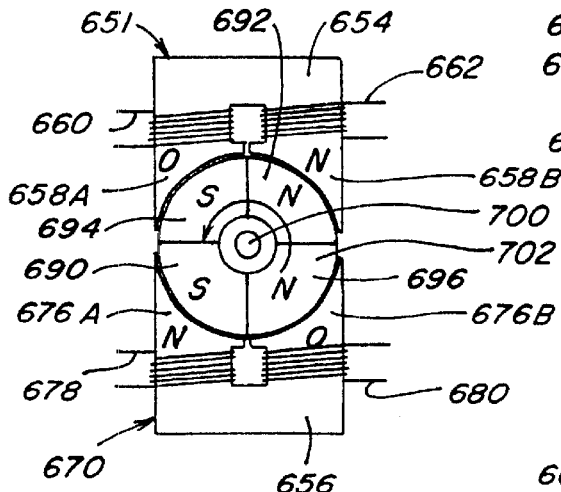


Fig. 32C

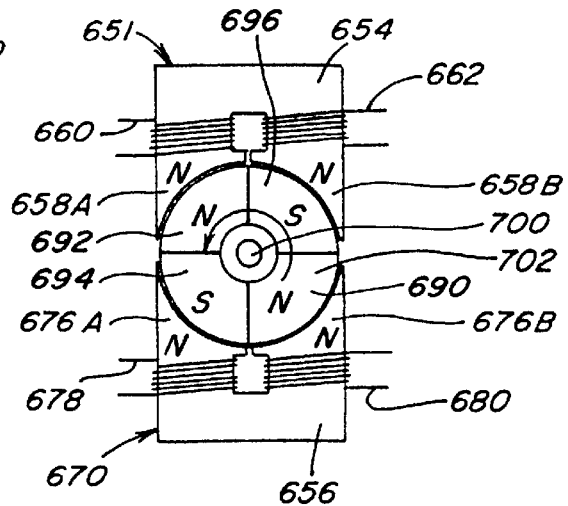


Fig. 32D

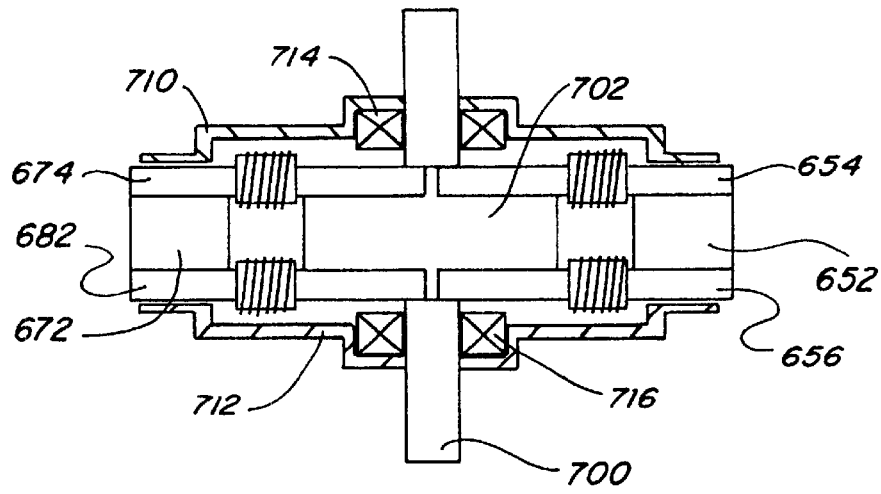


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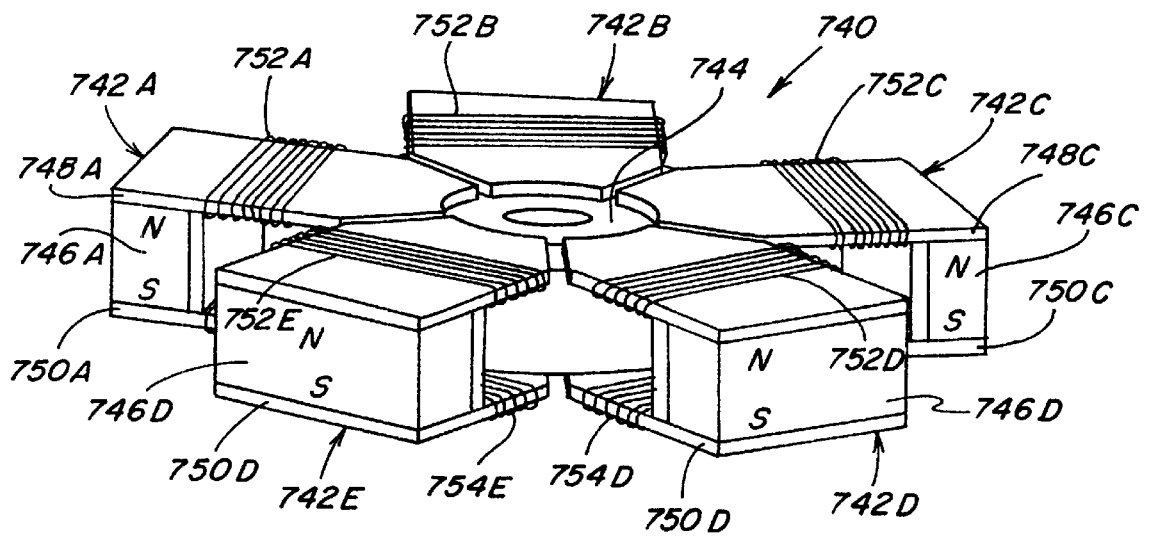


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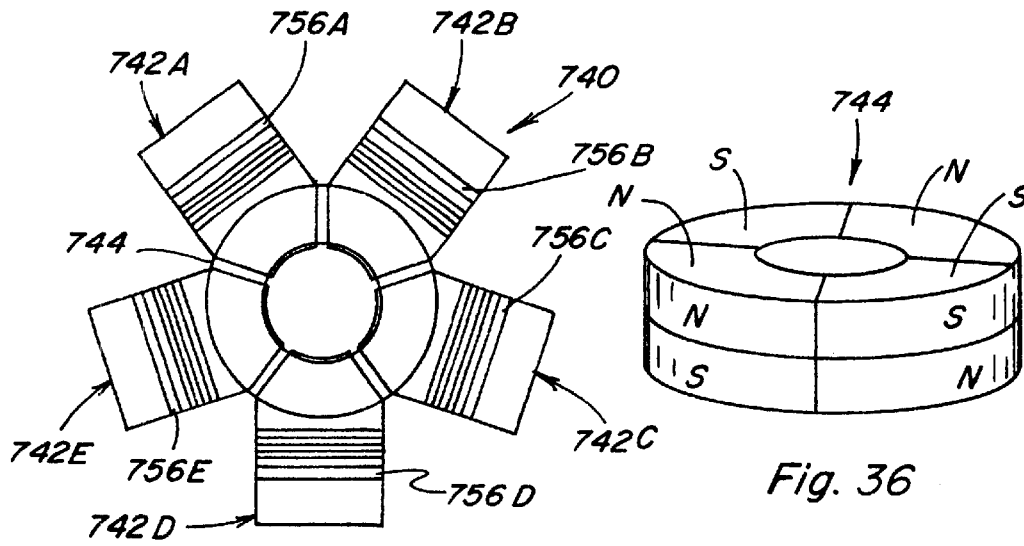


Fig. 35

Fig. 36

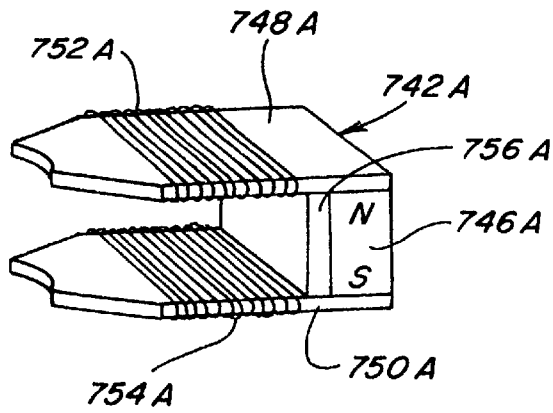


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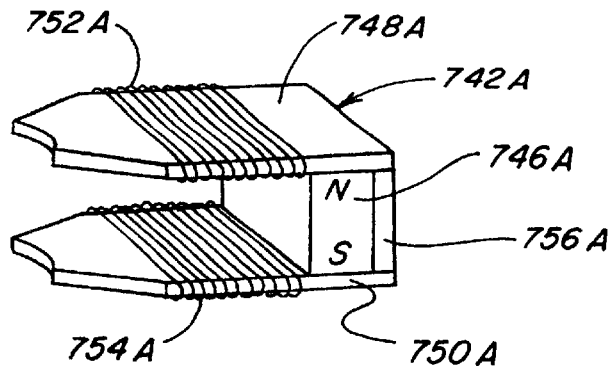
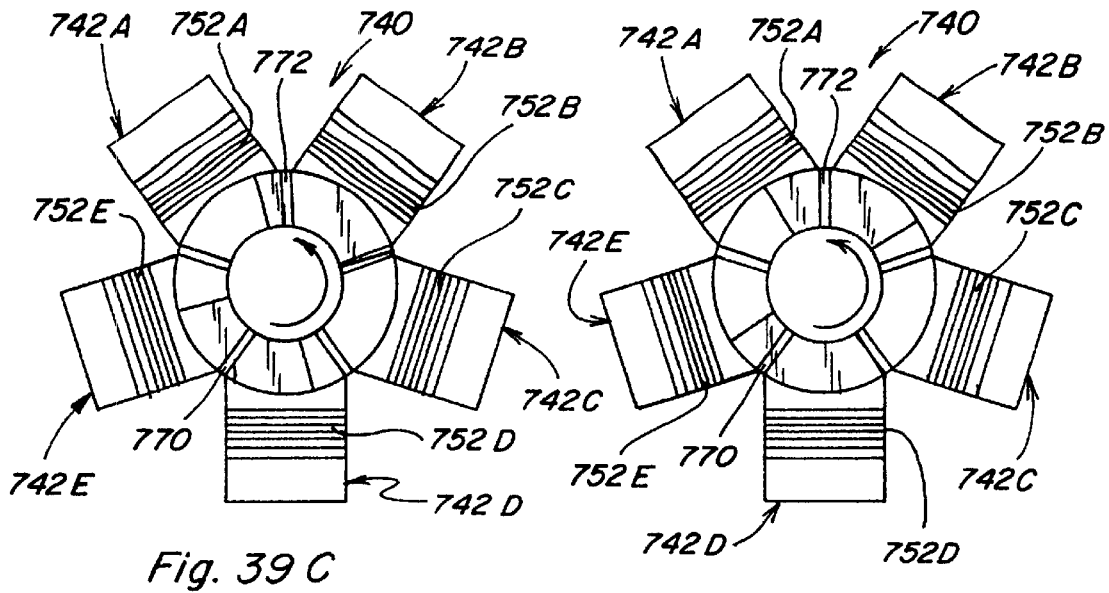
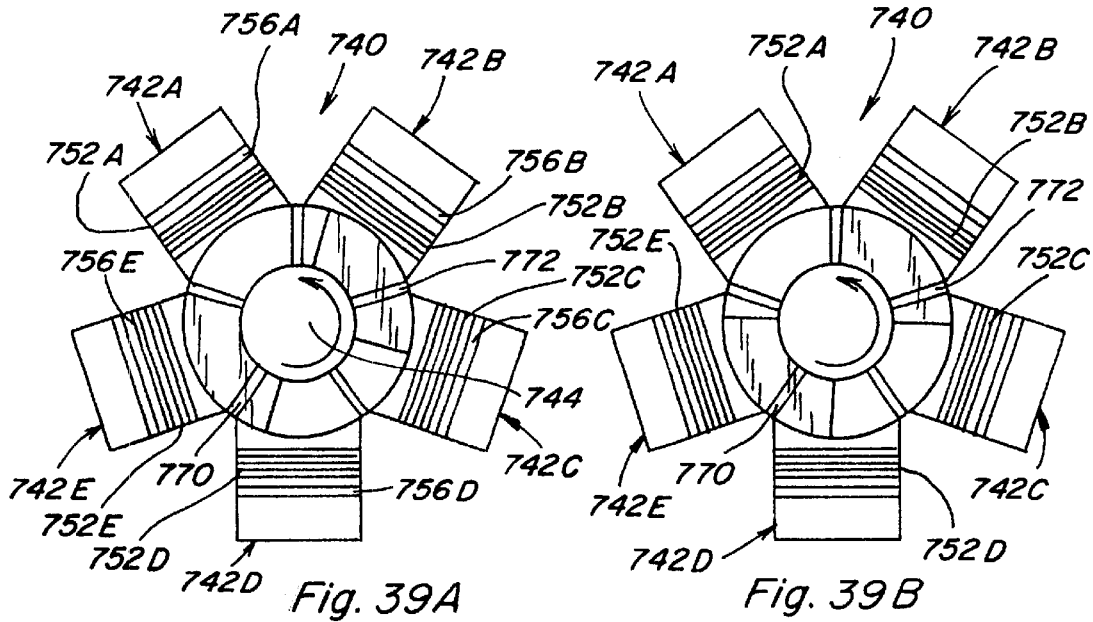


Fig. 38



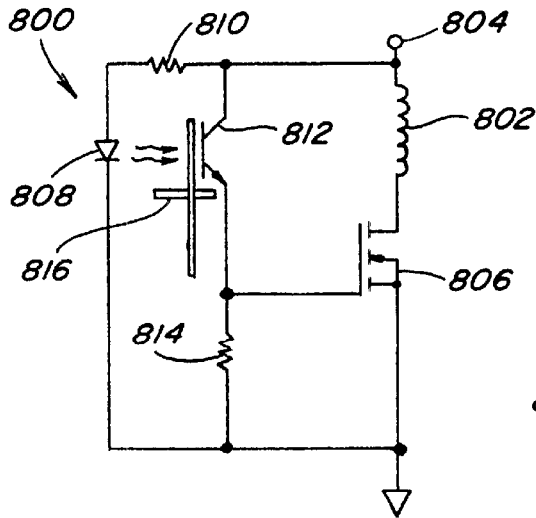


Fig. 40

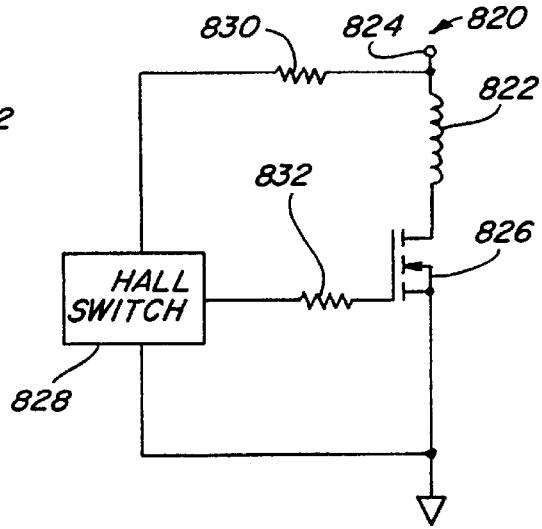


Fig. 41

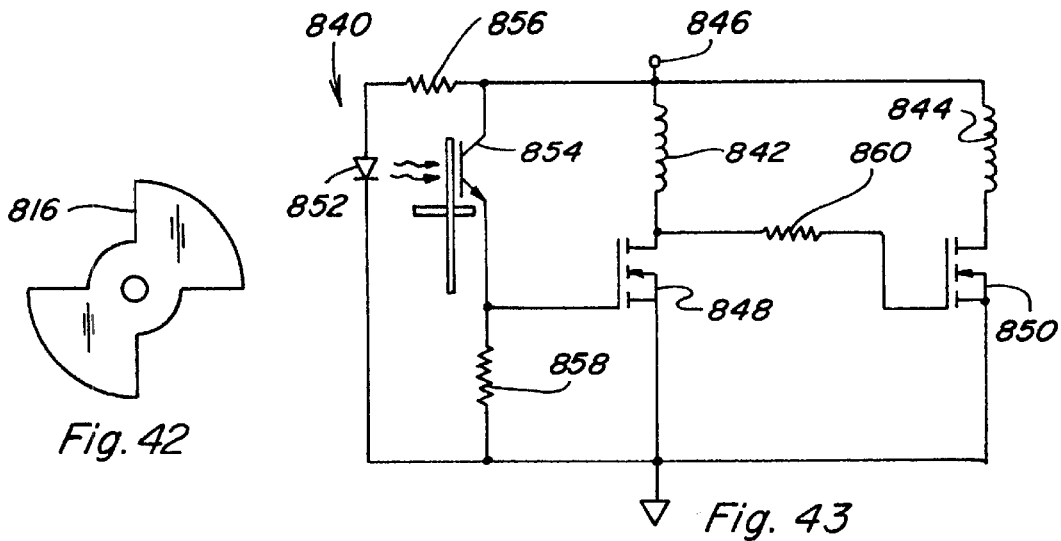


Fig. 42

Fig. 43

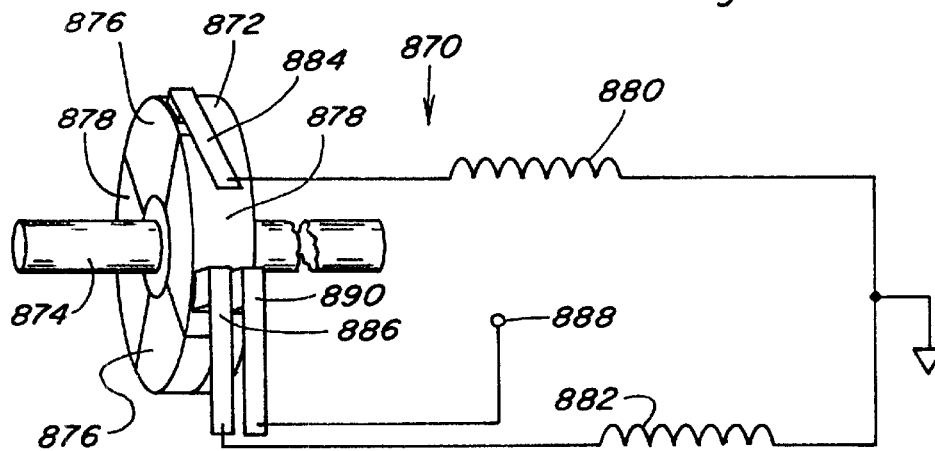


Fig. 44

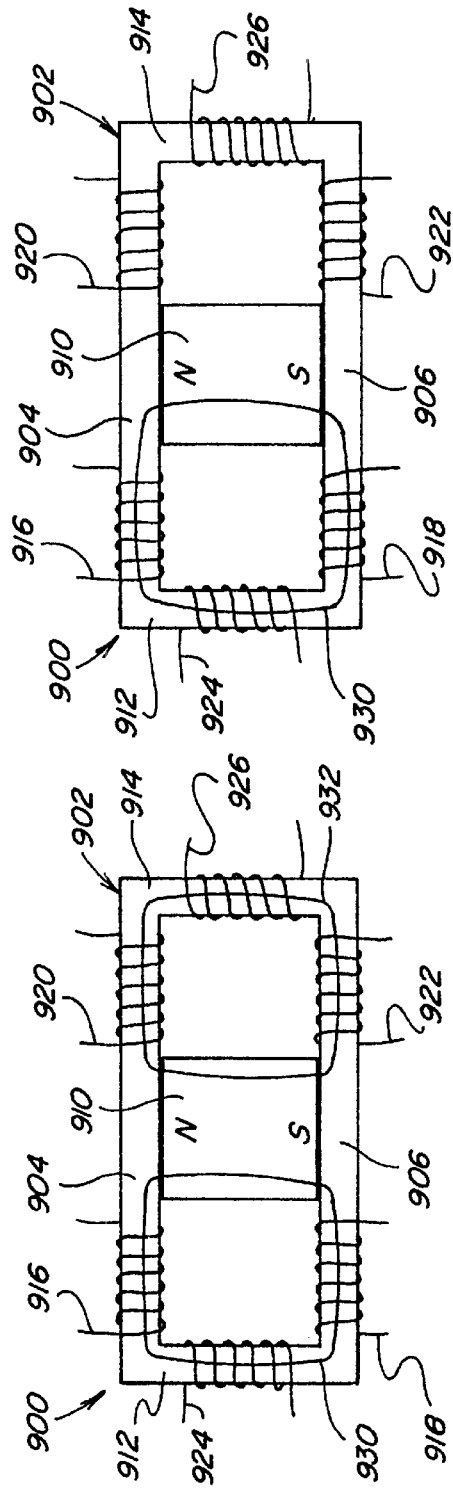


Fig. 45A

Fig. 45B

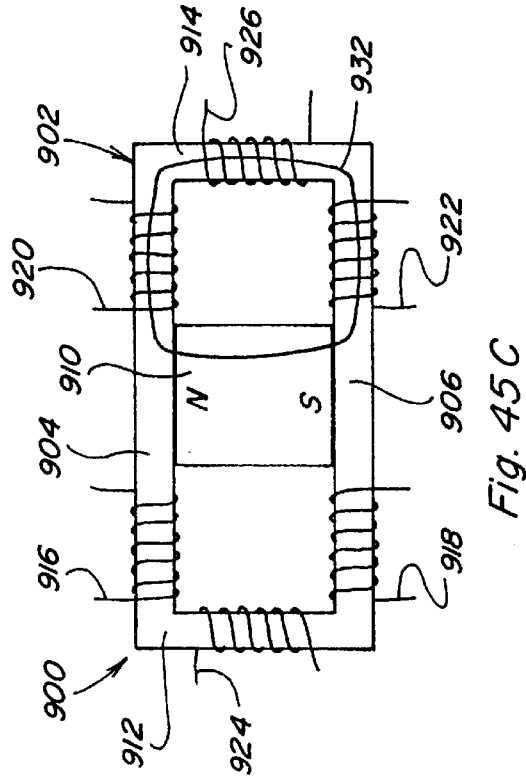


Fig. 45C

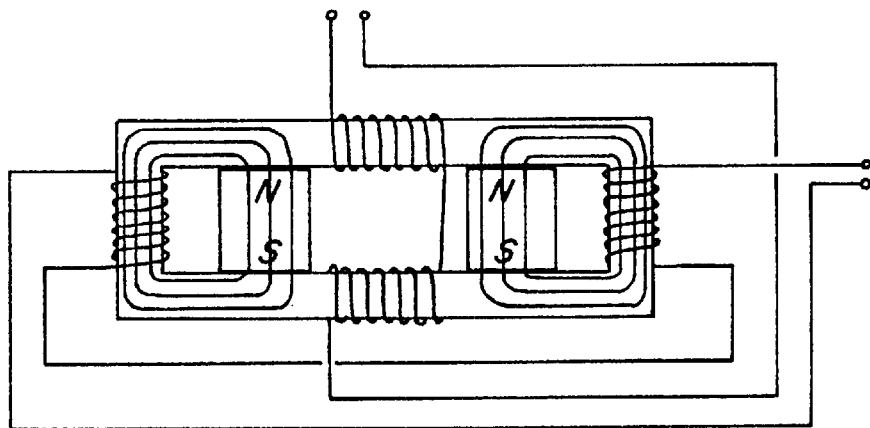


Fig. 45 X

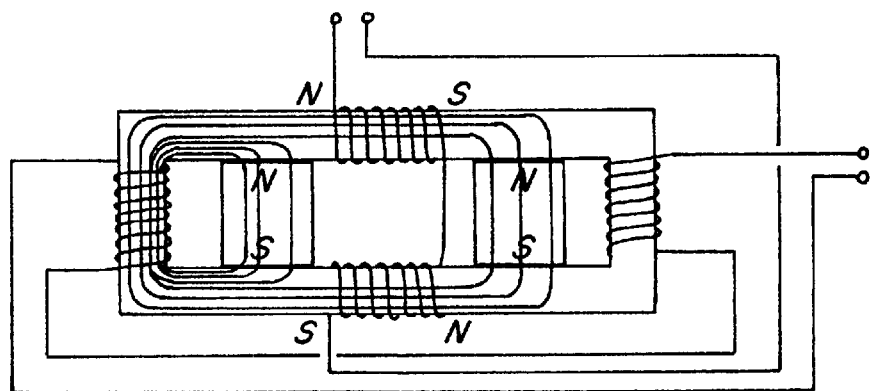


Fig. 45 Y

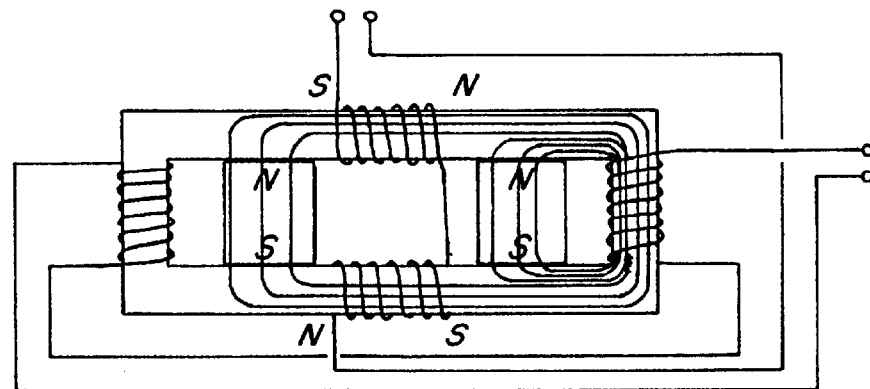


Fig. 45 Z

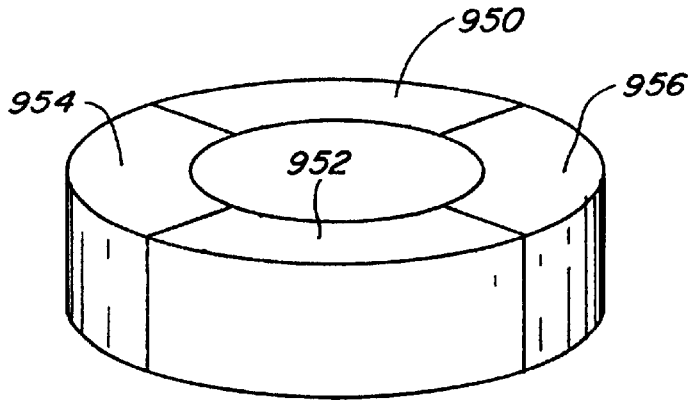


Fig. 46

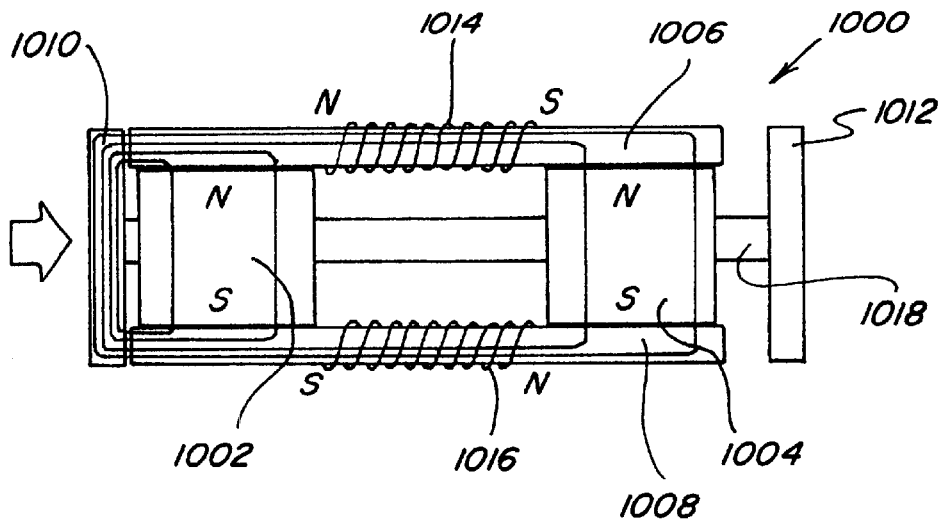


Fig. 47

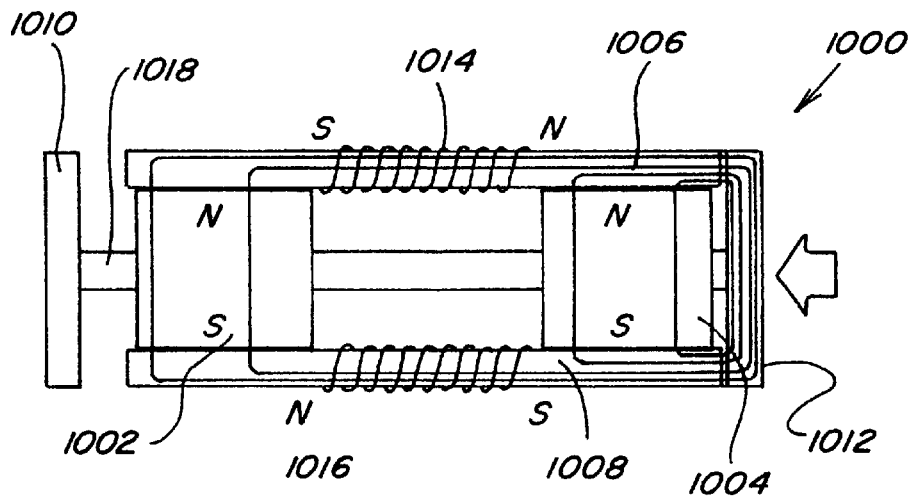


Fig. 48

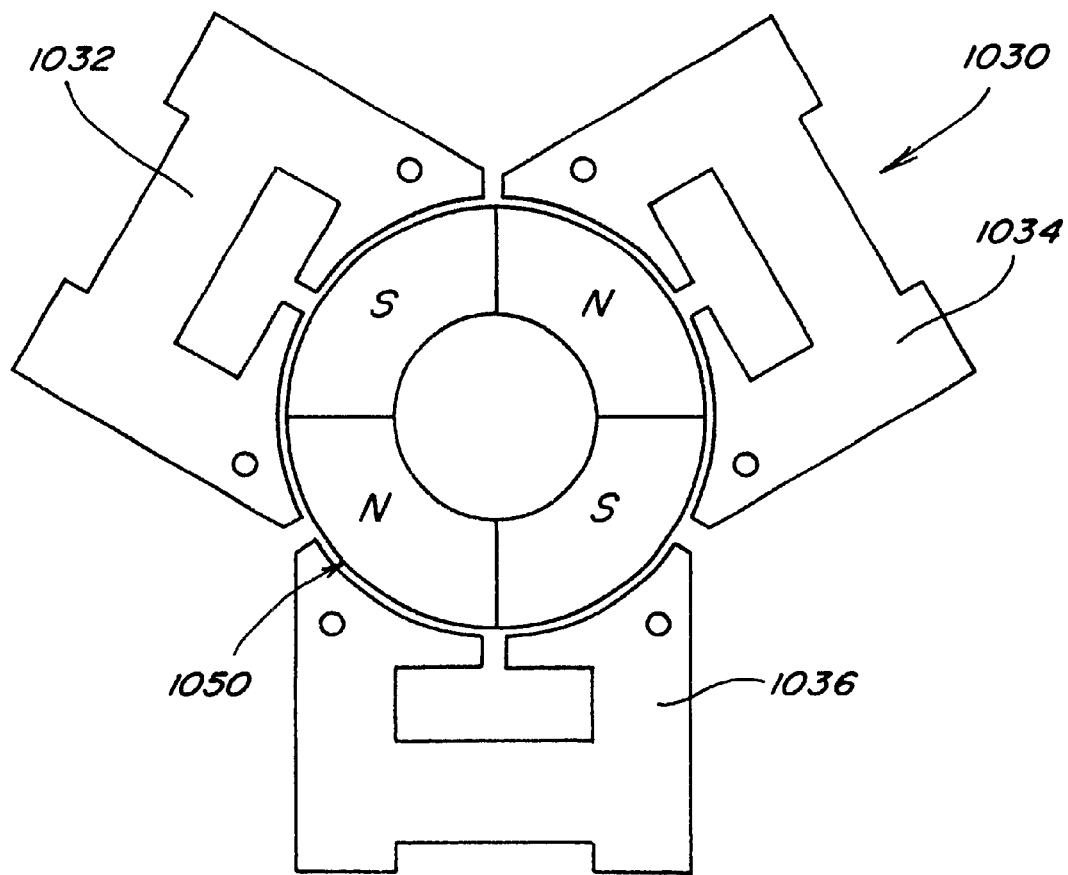


Fig. 49

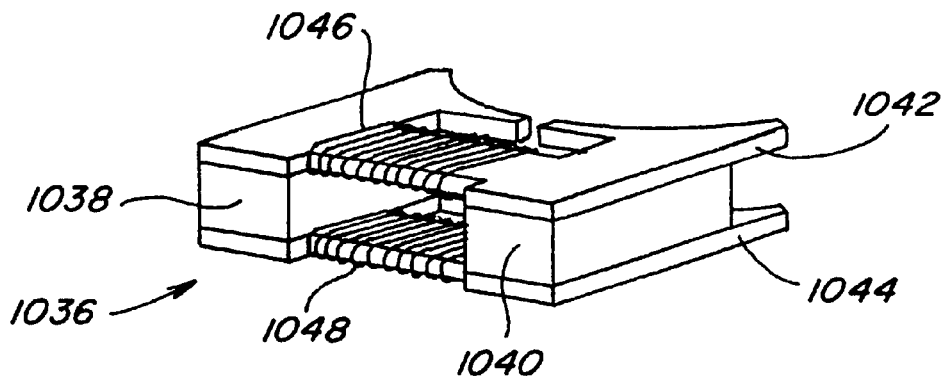


Fig. 50

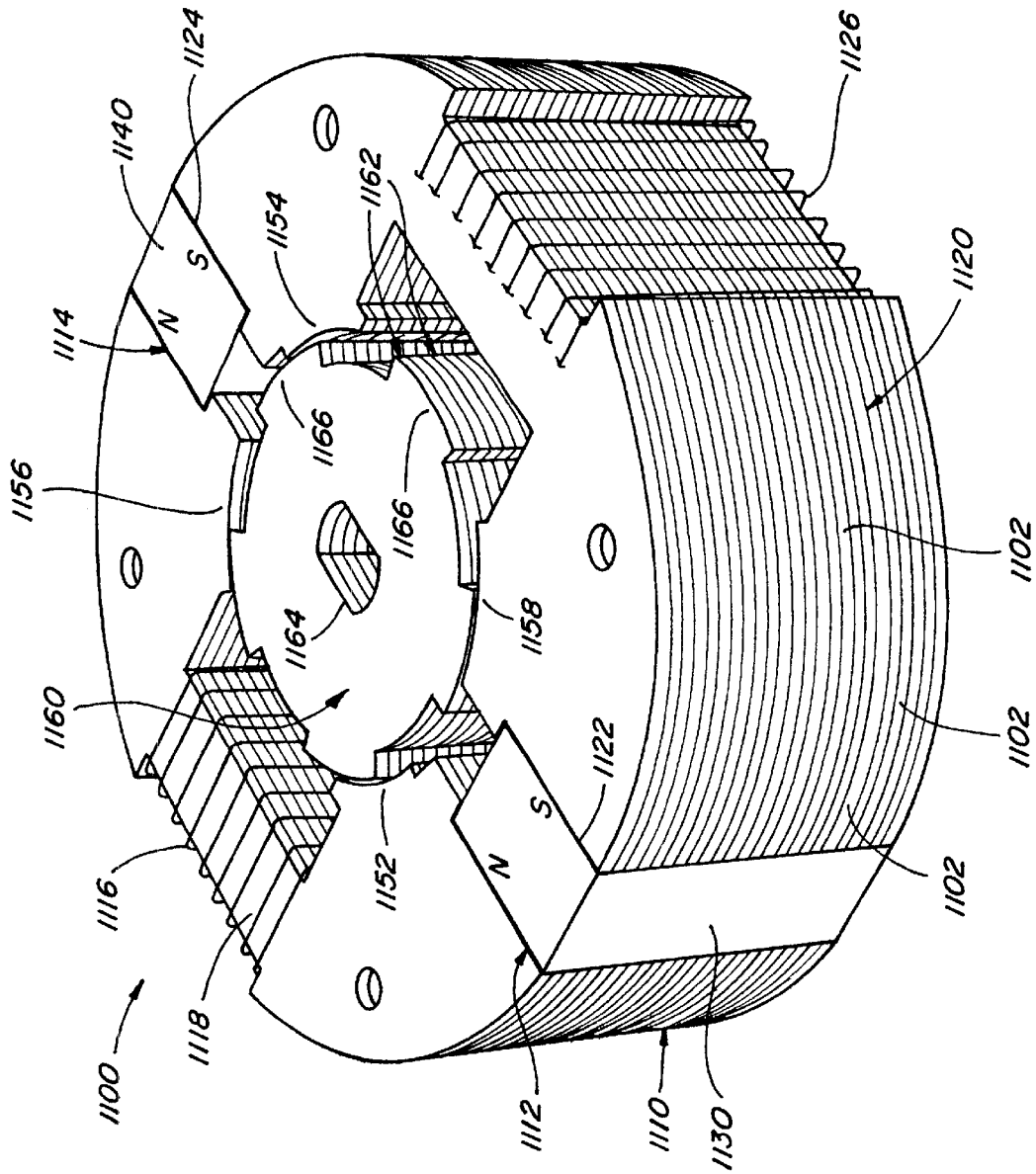


Fig. 51

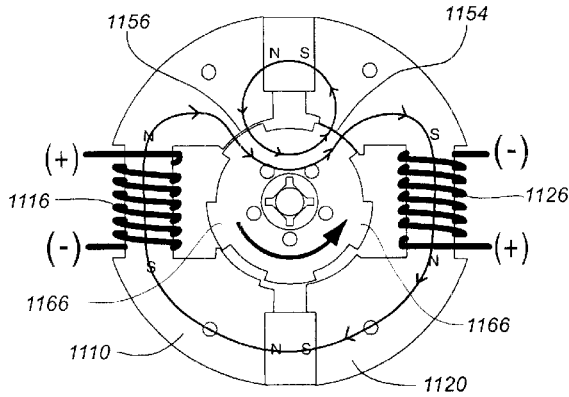


Fig. 52A

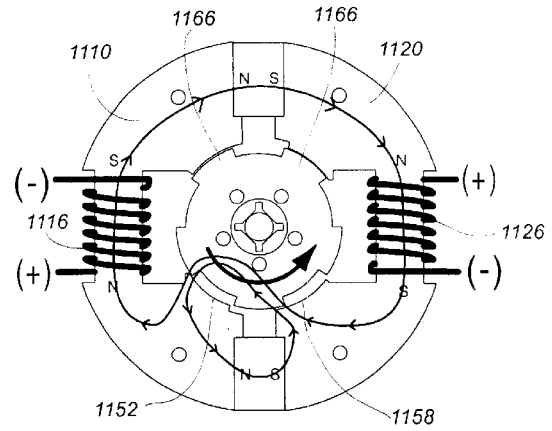


Fig. 52B

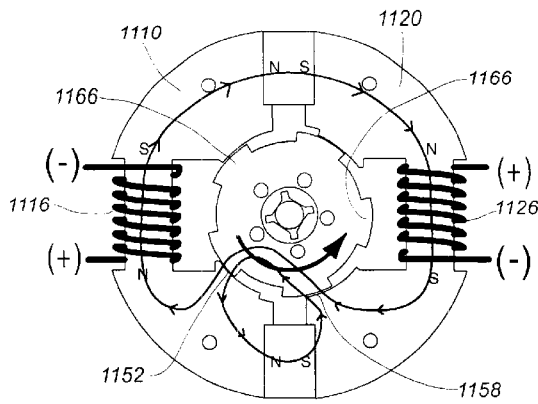


Fig. 52C

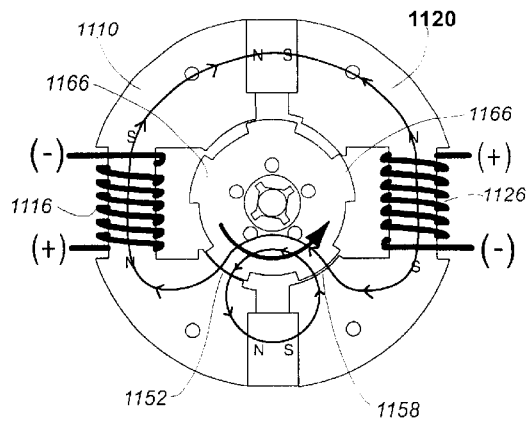


Fig. 52D

**METHODS FOR CONTROLLING THE PATH
OF MAGNETIC FLUX FROM A
PERMANENT MAGNET AND DEVICES
INCORPORATING THE SAME**

This is a continuation-in-part application of U.S. Ser. No. 09/127,056, filed Jul. 31, 1998.

BACKGROUND OF THE INVENTION

This invention relates to devices such as electric motors (rotary, linear, or reciprocating) which use permanent magnets and electromagnetic coils.

More particularly, this invention relates to devices such as motors having flux-controlling assemblies which, during operation, cause the magnetic flux from a permanent magnet to be alternated between two or more flux paths. This is accomplished by using timed delivery of electric current through one or more electromagnetic coils which are positioned, in novel arrangements as disclosed herein, around or adjacent to at least one of the flux paths. Such flux-control assemblies may take on a variety of configurations, such as in electric motors for generating reciprocating, linear, or rotary motion, and in devices useful for voltage or power conversion.

Such devices are especially useful for rotary motors that do not require any wires, coils, or circuitry in the rotor component, and which instead use rotors containing permanent magnets, or magnetizable alloys such as steel. The motors disclosed herein do not require brushes or commutators to control current which flows through rotor coils, since there are no rotor coils.

The closest known prior art to the present invention is disclosed in U.S. Pat. Nos. 5,254,925, 5,463,263 and 5,455,474 (all issued to Flynn, or to Flynn et al). Briefly, these patents disclose various rotor and stator arrangements wherein a permanent magnet in the rotor is pulled in the desired direction of rotation, because it is magnetically attracted to a fixed and permanent stator magnet. As the rotor magnet reaches a point of closest proximity to the stator magnet, the magnetic field of the stator magnet is suddenly counteracted, or overridden, so that it effectively disappears. This is accomplished by means of a timed pulse of electrical current, which flows through an electromagnetic coil wrapped around or near the stator magnet. The current which momentarily passes through the coil generates a magnetic field that counter-balances and offsets the magnetic field of the permanent stator magnet, effectively causing it to suddenly disappear just as the rotor magnet reaches its closest proximity to it. When the attractive force generated by the permanent stator magnet suddenly disappears, the momentum of the rotor causes the rotor magnet to travel on, past the stator magnet, without being pulled back. Once the rotor magnet has traveled a certain distance, it is then attracted toward the next stator magnet lying adjacent to its ongoing path.

Although motor designs of that nature continue to hold promise, they have not yet been commercialized and made publically available, and research by Flynn et al has continued on methods and designs for increasing the torque and efficiency of motors within that general class.

As a result of that ongoing research, several methods and designs have been created which build upon a highly useful realization and discovery, to substantially improve motor performance compared to prior patented designs. Without limiting the invention by means of the following overview and summary, it has been realized and discovered that a

novel and highly useful type of control method involves controlling and directing a magnetic flux generated by a permanent magnet through two alternate pathways, in an alternating manner.

In one type of motor which uses this design, one of the flux pathways is a torque-generating pathway, while the other pathway is simply a "bypass", which carries the flux from the permanent magnet in the stator to a secondary position, where the flux will not interfere with rotation of the rotor when the rotor is at its point of closest proximity to the permanent magnet. It has been discovered that providing a piece of flux-carrying metal to provide this type of "bypass" pathway can greatly reduce the amount of electrical current and voltage that was required to counterbalance and offset the flux in the prior designs disclosed in prior U.S. Pat. Nos. 5,254,925, 5,463,263 and 5,455,474. Accordingly, the new designs and methods disclosed herein significantly improve the efficiency of the motors disclosed herein, and allow these new designs to use significantly smaller and less expensive coils, and lower voltages.

In a second type of motor disclosed herein, the use of two alternating flux pathways, under the control of one or more coils and an electronic control system, cause the magnetic flux from a permanent magnet to alternate between two different pathways, both of which can generate useful torque or linear attractive force, depending on the position of the rotor or other moving device at any particular instant. Since the flux from each permanent magnet in this class of device is constantly performing useful work, in two alternating locations, this design is even more efficient and productive than the prior systems disclosed in U.S. Pat. Nos. 5,254,925, 5,463,263 and 5,455,474, which expended electrical energy to counter-balance or offset a permanent magnet flux in a way that did not perform useful work during the intermittent stoppages of the flux.

As a result, the methods, designs, and constructions disclosed herein are substantially improved when compared to the prior art. These improved designs offer high efficiency in converting electrical energy to mechanical power and work, and also offer desirable torque and performance characteristics.

Accordingly, one object of the present invention is to provide an electromagnetic flux control assembly, which allows the path of magnetic flux from a permanent magnet to be controlled and directed in an alternating manner between two or more pathways, by means of a relatively small current at a relatively low voltage, flowing through one or more electromagnetic coils which are part of the flux control assembly.

Another object of the present invention is to provide a permanent magnet flux control assembly in which substantially all of the flux from a permanent magnet can be switched between at least two different flux paths, both of which are positioned within a device such as a motor, to enable useful work in the form of linear, reciprocating, and rotary motion.

Another object of the present invention is to provide permanent magnet flux control components and motor constructions in which flux path control is provided by energizing an electromagnet in a manner which supplements and increases the magnetic flux of one or more permanent magnets.

Yet another object of the present invention is to provide permanent magnet motor constructions having improved design, construction, operating, and electrical characteristics.

These and other objects and advantages of the present invention will become apparent after considering the following detailed specification describing several preferred embodiments in conjunction with the accompanying drawings.

SUMMARY OF THE INVENTION

A device such as a rotary or linear motor is disclosed, comprising at least one permanent magnet having north and south pole faces. A first pole piece made of a flux-carrying metal is placed adjacent the north pole face of the permanent magnet, preferably pressed directly against the magnet. The first pole piece extends beyond the perimeter of the north pole face of the magnet, to define a first flux path and a second flux path, either path capable of carrying magnetic flux emanating from the north pole face of the permanent magnet. Similarly, a second pole piece made of a flux-carrying metal is placed adjacent the south pole face of the permanent magnet, preferably pressed directly against the magnet. The second pole piece also extends beyond the perimeter of the south pole face of the magnet, to define first and second flux paths emanating from the south pole face of the permanent magnet.

At least one first control coil is positioned around the first path portion of the first pole piece, and is provided with electronic circuit control means for intermittently passing current through the coil in a time-controlled manner. If desired, a second control coil (also provided with electronic circuit control means) can also be positioned around the second path portion of the first pole piece. Alternately or additionally, one or more other control coils can also be placed around the first and/or second path portions of the second pole piece as well. The various control coils are alternately energized in a timed sequential manner, thereby causing the magnetic flux from the permanent magnet to be alternately shuttled back and forth between two different flux pathways. These two flux pathways are established by (i) the two first flux paths, established by the first and second pole pieces, acting together when appropriate, and (ii) the two second flux paths, established by the first and second pole pieces, acting together when appropriate.

By proper arrangement and assembly of the permanent magnet(s) in conjunction with the pole pieces, coil(s), and electronic circuit control means, in a manner which allows them to form a stator assembly which interacts with a rotor or other movable component that does not require any windings, brushes, or commutators, this design provides for rotary, linear, or reciprocating motors or similar devices which generate high efficiency and high torque with relatively low weight and electrical requirements, combined with various manufacturing, operating, and other advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention reference may be made to the accompanying drawings in which:

FIG. 1 is a perspective view of a magnetic device in which the magnetic flux from a magnetic member traverse a single path to produce a coupling force;

FIG. 2 is a perspective view of a magnetic device in which the magnetic flux from a magnetic member splits between two paths;

FIG. 3 is a side view of two magnetic members arranged in parallel between pole pieces;

FIG. 4 is a side view of two magnetic members arranged in series between pole pieces;

FIGS. 5-6 are side views of a permanent magnet device including a permanent magnet having pole pieces positioned against the pole faces thereof and including a movable armature;

FIGS. 7-9 are side views of a permanent magnet device including a permanent magnet having pole pieces positioned against the pole faces thereof to provide two magnetic flux paths and including a movable armature positionable along each magnetic flux path;

FIGS. 10-12 demonstrate how the principles shown in FIGS. 7-9 can be used to create a reciprocating motor;

FIGS. 10A-10H are perspective views of various embodiments of permanent magnet control components which include two or more magnetic flux paths, generated from a single permanent magnet;

FIGS. 11A-11F are side views of a permanent magnet device including a permanent magnet having pole pieces positioned against the pole faces thereof and including a movable armature and a permanent bypass extending between the pole pieces;

FIGS. 12A-12E are side views of a two path permanent magnet device including two bypasses;

FIGS. 13A-13C are side views of a permanent magnet linear reciprocating device;

FIG. 14 is a side view of an electromagnetic linear reciprocating device;

FIG. 15 is a side view of a two path permanent magnet device showing control coils energized in an exceeding manner;

FIGS. 16A-16E depict a linear reciprocating device with control coils energized in an exceeding manner;

FIGS. 17A-17D depict another embodiment of a linear reciprocating device;

FIGS. 18A-18E show a linear motion device;

FIG. 19 is an exploded perspective view of a rotary motion device;

FIG. 20 is a partial assembled and cut away view of the rotary motion device of FIG. 19;

FIGS. 21A-21E are top views of the partial assembly of FIG. 20, which views depict rotational motion thereof;

FIG. 22 is an assembled, cut-away view of the rotary motion device of FIG. 19 including a housing;

FIG. 23 is an exploded perspective view of another embodiment of a rotary motion device;

FIG. 24 is a perspective view of the rotary motion device of FIG. 23 as assembled;

FIGS. 25A-25B are end views of the rotary motion device of FIG. 24 with the end cap removed to expose the rotor member;

FIGS. 26-28 show end views of various configurations for skewing the direction of rotation in the rotary motion device of FIG. 24;

FIGS. 29A-29D are end views of the rotary motion device of FIG. 24 illustrating a sequence of rotational movements;

FIG. 30 is an exploded partial perspective view of another embodiment of a rotary motion device;

FIG. 31 is a perspective view of the rotary motion device of FIG. 30 as assembled;

FIGS. 32A-32D are top views of the rotary motion device of FIG. 31 illustrating rotational movement thereof;

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FIG. 33 is a side view of the rotary motion device of FIG. 31 as assembled and including a housing;

FIG. 34 is a perspective view of another embodiment of a rotary motion device;

FIG. 35 is a top view of the rotary motion device of FIG. 34;

FIG. 36 is a perspective view of the permanent magnet rotor member of the rotary motion device of FIG. 34;

FIGS. 37 and 38 show alternative configurations for the control component incorporated into the rotary motion device of FIG. 34;

FIGS. 39A–39D are top views of the rotary motion device of FIG. 34 and depict rotational movement thereof;

FIGS. 40–44 are alternative variations of circuit means for controlling the timed energization of control coils in the various devices of the present invention;

FIGS. 45A–45C and 45X–45Z are side views of two path power conversion devices;

FIG. 46 is a schematic view of the permanent magnet portion of a rotor for use in some embodiments of the present device;

FIGS. 47 and 48 show other embodiments of a linear motion device;

FIG. 49 is a top view of another embodiment of a rotating motor like construction; and

FIG. 50 is a schematic view of one of the three stator portions of the device shown in FIG. 49.

FIG. 51 depicts a rotary motor wherein the north and south magnet faces are substantially aligned on opposite sides of the shaft.

FIGS. 52A–52D showing various flux paths, under the control of north coil and south coil at different positions of the rotor.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, FIGS. 1–4 are provided to facilitate an understanding of various aspects or features of the technology utilized in the present invention. FIG. 1 depicts a device 10 having a magnetic flux producing member 12 which may be a permanent magnet or electro-magnet with magnetic poles 14 and 16 as shown. Pole pieces 18 and 20 are positioned adjacent respective poles 14 and 16 to provide a path for the magnetic flux of member 12. Each pole piece 18 and 20 includes a respective pole piece end face 22 and 24. As used throughout this specification it is understood that a pole piece, regardless of its shape or size, is preferably formed of soft iron, steel or some other magnetic material, with the preferred material being one which provides low reluctance, exhibits low hysteresis, and has a high magnetic flux density capability. Accordingly, the various pole pieces disclosed and described herein could likewise be of laminate type construction. Referring again to FIG. 1 an armature 26, also formed of magnetic material, is shown with end faces 28 and 30 which are positioned and sized for being placed adjacent pole piece end faces 22 and 24, such that when so positioned a substantially continuous low reluctance path 32 is provided for magnetic flux from north pole 14, through pole piece 18, through armature 26, through pole piece 20, and to south pole 16. The magnetic flux traveling along such path 32 results in a force which tends to hold armature 26 in position adjacent pole piece end faces 22 and 24. The resulting magnetic coupling or holding force F provided between adjacent pole piece end face 22

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and armature end face 28, and between adjacent pole piece end face 24 and armature end face 30, can be approximated by the following equation:

$$F=B^2A/2\mu_0$$

where B is the magnetic flux density passing through the adjacent end faces and where A is the surface area of the adjacent end faces. Assuming B uniform throughout flux path 32 and the area A of all end faces 22, 24, 28, and 30 to be the same, the total holding force FT26 of armature 26 against pole pieces 18 and 20 will be:

$$F_{T26}=B^2A/\mu_0$$

In FIG. 2 a device 40 having the same magnetic flux producing member 12 with magnetic poles 14 and 16 is shown. Pole pieces 42 and 44 are positioned adjacent respective pole faces 14 and 16 to provide two paths, as opposed to one above, for the magnetic flux of member 12. In particular, pole piece 42 includes a first path portion 46 extending beyond a perimeter of north pole face 14 in one direction and a second path portion 48 extending beyond the perimeter of north pole face 14 in another direction. Similarly, pole piece 44 includes a first path portion 50 extending beyond the perimeter of south pole face 16 in one direction and a second path portion 52 extending beyond the perimeter of south pole face 16 in another direction. Each pole piece path portion 46, 48, 50, 52 includes a respective end face. A first armature 54 is positionable adjacent the end faces of pole piece path portions 48 and 52 to provide a first magnetic flux path 56 and a second armature 58 is positionable adjacent the end faces of pole piece path portions 46 and 50 to provide a second magnetic flux path 60. If the flux carrying area along flux paths 56 and 60 is the same as the flux carrying area along flux path 32 of FIG. 1, the magnetic flux density along each flux path 56 and 60 will be one-half the magnetic flux density along flux path 32 of FIG. 1 because the same amount of flux is split between two like paths. The effect of dividing a given amount of magnetic flux along two like flux paths instead of along one flux path can be seen by examining the holding force on armature 54 as compared to the holding force on armature 26 of FIG. 1. As already noted the magnetic flux density along path 56 will be one-half that along flux path 32 and thus the total holding force FT54 can be determined as:

$$FT54=(B/2)^2A/\mu_0=B^2A/4\mu_0=FT26/4.$$

It is therefore seen that dividing the same amount of magnetic flux along two flux paths rather than along one flux path reduces the magnetic holding or coupling force on an armature by one-fourth rather than one-half as might have been expected. This unexpected magnetic holding or coupling force differential, resulting from multiple flux paths, can provide advantageous properties in linear, reciprocating, and rotary motion devices.

Referring now to FIGS. 3–4, the behavior of multiple magnetic flux sources arranged in parallel and series is described as compared to a single flux source. When identical flux sources or magnetic flux producing members 70 and 72 are positioned in parallel as shown in FIG. 3 with pole pieces 74 and 76 positioned adjacent the poles thereof to provide a flux path through armature 78, the flux density 3 through armature 78 is double what the flux density would be if only one magnetic flux producing member were present. However, the field intensity H resulting from the two members 70 and 72 remains unchanged. This result holds true regardless of whether members 70 and 72 are both

permanent magnets, are both electromagnets, or are a combination of one permanent magnet and one electromagnet. On the other hand, the properties resulting from magnetic flux producing members **80** and **82** arranged pole-to-pole in series between pole pieces **84** and **86**, with armature **88**, as shown in FIG. 4, will vary depending on the nature of the members **80** and **82**.

In a first case, if both members **80** and **82** are permanent magnets, the magnetic field intensity H resulting from the two permanent magnets will be double that of one permanent magnet and the flux density B through armature **88** will be the same as what the flux density would be if only one permanent magnet type member were present.

In a second case, if both members **80** and **82** are electromagnets, the field intensity H again doubles and the flux density B increases according to the B/H curve or relationship of the pole piece **84**, **86** and armature **88** materials.

In a third case, if member **80** is a permanent magnet and member **82** is an electromagnet, the field intensity H again doubles, but, since the permanent magnet is near flux density saturation Br the flux density can only be increased from Br to Bmax of the permanent magnet. At the point where electromagnet-type member **82** contacts permanent magnet-type member **80** the flux from the electromagnet-type member **82** couples with the flux of the permanent magnet-type member **80** until the flux density through permanent magnet-type member **80** reaches Bmax. At that point additional flux from electromagnet-type member **82** does not contribute to the flux density along the flux path unless a bypass path around the permanent magnet-type member is provided. Use of such bypass paths will be described hereinbelow.

Controlling the flow of flux along both one and multiple flux paths is best described with reference to FIGS. 5-9. In FIGS. 5 and 6 a permanent magnet device **90** including a permanent magnet **92** having pole pieces **94** and **96** positioned adjacent the pole faces thereof and an armature **98** completing a low reluctance path **104** from pole to pole is shown. Control coils **100**, **102** are positioned along path **104**. When control coils **100**, **102** are not energized, the magnetic flux of permanent magnet **92** follows path **104** as shown and armature **98** is held in place against pole pieces **94**, **96** due to the resulting magnetic coupling forces. However, if coils **100**, **102** are energized to provide an equal but opposing magnetic flux to that of permanent magnet **92**, the result is that the magnetic flux of permanent magnet **92** is blocked and no magnetic flux traverses the path which includes armature **98** and therefore no magnetic coupling forces act on armature **98** allowing it to fall away as shown in FIG. 6. The permanent magnet device **90** is useful, although as will become apparent below, it is more advantageous to provide multiple flux paths rather than one.

In this regard, in FIG. 7 a permanent magnet device **110** includes a permanent magnet **112** having pole pieces **114**, **116** positioned adjacent the pole faces thereof with armatures **118**, **120** completing two low reluctance paths **130**, **132** from pole to pole thereof. Control coils **122**, **124** are positioned along path **130** and control coils **126**, **128** are positioned along path **132**. The two paths provided are assumed to be of equal reluctance. With no coils energized, the magnetic flux of permanent magnet **112** divides equally along flux path **130** and along flux path **132** such that both armatures **118**, **120** are subjected to a magnetic coupling force which holds them in place against pole pieces **114**, **116**.

If coils **122**, **124** are energized to provide a magnetic flux equal to but opposing the magnetic flux which travels along flux path **130** from permanent magnet **112** when no coils are

energized, the result is that the magnetic flux of permanent magnet **112** is blocked and no magnetic flux traverses the path which includes armature **118** and therefore no magnetic coupling forces act on armature **118** allowing it to fall away as shown in FIG. 8. Further, the magnetic flux traversing path **132** will be double that of when no coils are energized and therefore the magnetic coupling force on armature **120** will be about four (4) times that of when no coils are energized. By energizing coils **126**, **128** in an opposing manner a similar result would be achieved such that armature **120** would fall away and such that the magnetic coupling force on armature **118** would be increased.

If coils **122**, **124** are energized to provide a magnetic flux equal to and aiding the magnetic flux which travels along flux path **130** when no coils are energized, the result is that the control coils couple completely with the magnetic flux of permanent magnet **112** and no magnetic flux traverses the path which includes armature **120** and therefore no magnetic coupling forces act on armature **120** allowing it to fall away as shown in FIG. 9. Further, the magnetic flux traversing path **130** will be double that of when no coils are energized and therefore the magnetic coupling force on armature **118** will be about four (4) times that when no coils are energized. By energizing coils **126**, **128** in an aiding manner a similar result would be achieved such that armature **118** would fall away and the magnetic coupling force on armature **120** would be increased.

Based on the foregoing it is seen that the full magnetic coupling force available from the permanent magnet **112** can be switched from one path to another path by the application of one half the power it would require for a coil alone to produce the same magnetic flux along one path. The ability to easily switch the full magnetic coupling force from one path to another allows for efficient reciprocating, linear, and rotary motion and power conversion to be achieved.

The basic device utilized to achieve permanent magnet flux division and to control such permanent magnet flux division is defined herein as a "permanent magnet control component," various configurations of which are shown by way of example only, and not by way of limitation, in FIGS. 10A-10F. FIG. 10A depicts a permanent magnet control component **150** in which pole pieces **152** and **154** are positioned adjacent the pole faces of permanent magnet **156** to provide two magnetic flux paths extending from opposite sides of the permanent magnet. Control coils **158** are positioned along each path. FIG. 10B depicts a permanent magnet control component **160** in which pole pieces **162** and **164** are positioned against the pole faces of permanent magnet **166** to provide two spaced, adjacent magnetic flux paths extending from the same side of permanent magnet **166**. Control coils **168** are positioned along each path. FIG. 10C depicts a permanent magnet control component **170** in which pole pieces **172** and **174** are configured so as to be positioned adjacent the pole faces of permanent magnet **176** so as to provide four flux paths, each flux path extending in a respective direction from permanent magnet **176**. Control coils **178** are also positioned along each path. FIG. 10D depicts another four path configuration of a permanent magnet control component **180** in which pole pieces **182**, **184** are configured and positioned to provide four flux paths for permanent magnet **186**, with a pair of spaced, adjacent flux paths extending from each side of permanent magnet **186**. Control coils **188** are positioned along each path. FIG. 10E depicts another four path configuration of a permanent magnet control component **190** in which all four flux paths formed by pole pieces **192**, **194** extend from one side of permanent magnet **196**. Again, control coils **198** are posi-

tioned along each flux path. FIG. 10F still further depicts a four path configuration of a permanent magnet control component 200 in which pole pieces 202, 204 extend to one side of permanent magnet 206, with pole piece 202 defining four flux paths and with pole piece 204 including a continuous return path. Control coils 208 are positioned along each path of pole piece 202. Many other variations are possible.

Accordingly, it is seen that a variety of different configurations of permanent magnet control components in accordance with the present invention are possible. The important considerations for division of permanent magnet flux in such permanent magnet control components include extending each pole piece to or beyond the outer perimeter of the pole face of the permanent magnet in each region where a flux path is intended and assuring that the pole face of the permanent magnet intersects each of the flux paths. It is not necessary for each pole piece to include the same number of path portions extending beyond the perimeter of the respective permanent magnet pole face as noted with reference to permanent magnet control component 200. Although two control coils are shown along each of the flux paths in FIGS. 10A–10E it is apparent from component 200 in FIG. 10F that one control coil positioned along a flux path is generally sufficient for purposes of the present invention. Further, although in the illustrated configurations each pole piece is positioned to contact a respective pole face of the permanent magnet, a small spacing between a pole piece and its adjacent permanent magnet pole face could be provided, particularly in applications where relative movement between the subject pole piece and the permanent magnet will occur.

In its simplest form a two path permanent magnet control component only requires one control coil positioned along one of the control paths to permit the magnetic flux of a permanent magnet to be switched between the two paths. In particular, a side view of such a two path component 210 is shown in FIG. 10G and includes a permanent magnet 211 pole pieces 212 and 213, and control coil 214 which may be connected to a suitable control circuit. By alternating energizing control coil 214 in an opposing manner and an aiding manner the magnetic flux of permanent magnet can be switched between the path including armature 215 and the path including armature 216. When control coil 214 is energized in an opposing manner the magnetic flux will traverse the path including armature 215 and when control coil 214 is energized in an aiding manner the magnetic flux will traverse the path including armature 216. Control coil 214 could also be placed at anyone of positions 217, 218, or 219 to achieve the flux path switching. Further, in the two coils embodiment shown in FIG. 10H control coil 217 is added. In such a device flux switching can be achieved by simultaneously energizing control coil 214 in a flux aiding manner and control coil 217 in a flux opposing manner, and by then simultaneously reversing the energization of the respective control coils 214 and 217.

Reference is made to FIGS. 11A–11F which depict devices similar to that of FIGS. 5–6 except that a bypass, formed of magnetic material, is provided in each case. In device 220 of FIGS. 11A–11C a bypass 222 is provided from pole piece 224 to pole piece 226 and is located between permanent magnet 228 and control coils 230, 232, with armature 234 located adjacent the ends of pole pieces 224, 226. In FIG. 11A with no coil energization, magnet flux components 236 and 237 travel as shown. When coils 230 and 232 are energized in an aiding or adding manner as in FIG. 11B, the result is permanent magnet magnetic flux components 236 and 237 traveling as shown, and with the

added magnetic flux component 238 from coils 230 and 232 also traveling as shown. Thus, in device 220 energizing the coils in an aiding manner results in an increased magnetic coupling force on armature 234. In FIG. 11C coils 230, 232 are energized in an opposing exceeding manner which results in permanent magnetic flux components 236 and 237 traveling as shown and excess magnetic flux component 238 traveling as shown. Thus, in device 220 energizing the coils in an opposing exceeding manner results in magnetic coupling force on armature 234, albeit smaller than that in the aiding exceeding case.

In device 240 of FIGS. 11D–11F a bypass 242 is provided between pole piece 244 and pole piece 246 but is located on an opposite side of permanent magnet 248 as compared to control coils 250, 252 and armature 254. Permanent magnet flux components 256 and 257 are shown for no coil energization in FIG. 11D. In FIG. 11E the paths of permanent magnet flux components 256 and 257, as well as excess coil magnetic flux 258, are shown when coils 250, 252 are energized in an aiding exceeding manner. In FIG. 11F the path of each magnetic flux component 256, 257, and 258 is shown when coils 230, 232 are energized in an opposed exceeding manner.

FIGS. 12A–12E depict a device 270 similar to that shown in FIGS. 7–9 except that bypasses 272 and 274 are provided from pole piece 276 to pole piece 278. Bypass 272 is located between permanent magnet 280 and control coils 282, 284 and bypass 274 is located between permanent magnet 280 and control coils 286, 288. Armatures 290 and 292 are also provided. When no coils are energized permanent magnet magnetic flux components 294, 296, 298, and 300 travel as shown in FIG. 12A.

If coils 282, 284 are energized in an opposing manner permanent magnet flux components 295, 297, and 299 travel as shown, with no flux component traversing the path which includes armature 290 and therefore no magnetic coupling force acting thereon. This would be the case for when coils 282, 284 are energized to the level where the coils magnetic flux just blocks, but does not exceed, the magnetic flux component 294 (FIG. 12A) from permanent magnet 280. If, however, coils 282, 284 are energized in an opposed exceeding manner an excess coil magnetic flux component 301 is produced which travels a path including armature 290 and bypass 272 results as shown in FIG. 12C.

Coils 286, 288 may be energized in an aiding manner such that all permanent magnet magnetic flux travels along the path which includes armature 292 as shown in FIG. 12D. If coils 286, 288 are energized in excess of the level of FIG. 12D then the excess magnetic flux component 304 traverses the path which includes armature 292 and bypass 274 as shown in FIG. 12E, thereby increasing the magnetic coupling force on armature 292 as compared to FIG. 12D. The advantage of incorporating such bypasses into permanent magnet control components in certain applications will become apparent below.

Reciprocating Motion

As mentioned above, controlling the path of magnetic flux from a permanent magnet can be useful in a variety of applications such as achieving reciprocating motion. In this regard, if the device 110 of FIGS. 7–9 is modified such that armatures 118 and 120 are fixed to a sliding shaft 320 as shown in FIGS. 13A–13C, and if the distance between the armatures is greater than the end to end length of pole pieces 114, 116, limited linear motion in two directions (left and right in FIGS. 13A–13C), and therefore linear reciprocating motion, can be achieved by the timed, alternate delivery of electrical signals to control coils 122, 124 and control coils

126, 128. By way of example, FIG. 13A represents the position of shaft connected armatures 118, 120 when coils 122, 124 are energized in an opposing manner to block the flux of permanent magnet 112 such that all magnetic flux traverses path 132 as shown and such that the resulting magnetic coupling force acts to the left as indicated by arrow 322. As shown in FIG. 13B when coils 122, 124 are de-energized the magnetic flux from permanent magnet 112 can again travel along path 130 through armature 118. However, due to the air gap 324 between armature 118 and pole pieces 114, 116 the reluctance along path 130 will be significantly greater than the reluctance along path 132. Accordingly, the amount of magnetic flux which flows along path 130 will be less than the amount of magnetic flux which flows along path 132 such that the magnetic coupling force on armature 118 acting to the right will be significantly less than the magnetic coupling force on armature 120 acting to the left as shown by arrows 326 and 328, which arrows are sized to represent the strength of the respective directional force. FIG. 13C represents the position of shaft connected armatures 118, 120 after coils 126, 128 are energized in a manner to oppose the flux of permanent magnet 112 such that all flux traverses path 130 and the resulting magnetic coupling force on armature 118, depicted by arrow 330, moves the shaft 10 connected armatures 118, 120 to the right.

Control coils 122, 124 and 126, 128 could also be energized in a flux aiding manner to achieve the same result. In such a device, FIG. 13A would represent coils 126, 128 energized to aid magnetic flux along path 132, FIG. 13B would again represent no coils energized, and FIG. 13C would represent coils 122, 124 energized to aid magnetic flux along path 130.

Thus, by alternately energizing and de-energizing control coils 122, 124 and 126, 128 a linear reciprocating motion of shaft connected armatures 118, 120 may be achieved. Further, such reciprocating motion may be achieved by energizing the coils in either an opposing or aiding manner. The magnetic coupling force exerted on a given armature when the control coils are energized to establish all magnetic flux along a single path which includes that armature is significantly greater than the magnetic coupling force which would be exerted on such armature by an identical energization of the control coils in the absence of the permanent magnet. This is demonstrated with reference to FIG. 14 which depicts a reciprocating device 340 in which only coils or electromagnets are utilized. As shown armatures 342 and 344 are connected by shaft 346, and each armature 342, 344 includes a respective U-shaped pole path piece 348, 350 which pole path pieces are mechanically connected by a non-magnetic material 352. Each pole path piece 348 and 350 has respective control coils 354, 356 and 358, 360 positioned therealong. By comparison with the device of FIGS. 13A–13C, if coils 358, 360 of device 340 are energized to cause magnetic flux flow in either direction, clockwise or counterclockwise, along path 362, the amount of electrical energy which would be required in order to achieve the same magnetic coupling force on armature 344 as achieved on armature 120 above in FIG. 13A would be twice that delivered to coils 122, 124 or 126, 128 in FIG. 13A. It is therefore demonstrated that by controlling or switching the flow of magnetic flux from a permanent magnet between at least two different paths results in greater coupling forces per unit of input electrical energy, and therefore that such control or switching will enable more work to be achieved per unit of input electrical energy.

As described above, if a coil is energized beyond the point where the magnetic flux produced by the coil aiding the amount of the permanent magnet's flux that is either opposed or aided, the extra magnetic flux needs a low reluctance path between the poles of the coil that produces the excess magnetic flux. If a complete low reluctance path is not provided for the excess magnetic flux there is little potential for taking advantage of the excess magnetic flux in terms of producing additional magnetic coupling forces. The path for such excess flux cannot be through a permanent magnet member. In assemblies which include an armature on each path, the armature will provide the necessary low reluctance path. Referring to FIG. 15, various components of the magnetic flux in device 110 (FIGS. 7–9) are depicted by numerals 380, 382, and 384 for the case when coils 122, 124 are energized to oppose the magnetic flux of permanent magnet 112 in an amount which exceeds the level of magnetic flux which permanent magnet 112 would cause to flow through armature 118 when no coils are energized. FIG. 15 is likewise representative of the case when coils 126, 128 are energized to aid the magnetic flux of permanent magnet 112 in an amount which exceeds the level of magnetic flux which permanent magnet 112 would cause to flow through armature 118 when no coils are energized. In particular, magnetic flux component 380 represents the magnetic flux of permanent magnet 112 which normally flows through the path including armature 120; magnetic flux component 382 represents the magnetic flux of permanent magnet 112 which is diverted by the opposing field of coils 122, 124 so as to traverse the path which includes armature 120; and magnetic flux component 384 represents the magnetic flux produced by coils 122, 124 which is in excess of the diverted magnetic flux 382. As shown, the excess magnetic flux 384 produced by coils 122, 124 traverses the path which includes armature 120 and bypasses permanent magnet 112 so as to also traverse the path which includes armature 118. Thus, the excess magnetic flux produced by coils 122, 124 adds to the permanent magnet flux traversing the path which includes armature 120, thus increasing the magnetic coupling force on armature 120, while at the same time providing a magnetic coupling force on armature 118.

In a reciprocating device where armatures 118 and 120 are connected by shaft 320 as shown in FIGS. 13A–13C and again in FIG. 16, excess magnetic flux 384 will increase magnetic coupling force 390 on armature 120 acting to the left. However, because such excess flux 384 also traverses the path which includes armature 118, such excess magnetic flux 384 also results in a magnetic coupling force 392 on armature 118 which acts to the right. Even though excess magnetic flux 384 traversing the path which includes an armature 118 has an opposite polarity to that which would traverse the path due to permanent magnet 112, the magnetic coupling force on armature 118 still acts to the right because armature 118 is not polarity sensitive, that is, armature 118 will be attracted regardless of the direction of the magnetic flux traversing the path. The overall effect is that a resultant force which is the difference between force 390 and force 392 will act on the shaft-connected armatures 118, 120. However, if armatures 118 and 120 were formed by permanent magnets having polarities as shown at the top and bottom of such armatures, the force acting on each armature would be in the same direction and therefore additive.

In this regard reference is made to FIG. 16B in which a two path device 371 having four control coils 373, 375, 377 and 379 is shown with the illustrated armatures being formed by permanent magnets 381 and 383 having polarities as shown. With no coils energized both permanent magnet

armatures **381** and **383** are attracted to the ends of pole pieces **385** and **387**. With coils **373**, **375** energized in an opposing manner and coils **377**, **379** energized in an aiding manner, the attractive force on permanent magnet armature **383** will generally increase and the attractive force on permanent magnet armature **381** will generally decrease. This is demonstrated with reference to the graph of FIG. **16C** which depicts a graph of the current flowing in the control coils on the x-axis versus the magnetic flux in gauss on the y-axis with line **389** representing the flux along the aiding side of device **371** and line **391** representing the flux along the opposing side of device **371**. As shown the magnetic flux on the coil opposing side decreases as the coil current increases and passed through zero at point **393**. After point **393** reverse magnetic flux begins to be produced and would result in a repelling force on permanent magnet armature **381**. In some applications particularly those where permanent magnet armatures and rotors are not utilized, it will be critical to recognize point **393** so that reverse magnetic flux is not produced. In this regard reference is made to FIGS. **16D** and **16E** in which use of Hall Effect switches **401** and **403** is incorporated to enable controlling the coil energizing current in situations where it is desirable to prevent reverse magnetic flux. As shown small bypasses **405** and **407** are provided with Hall Effect switches **401** and **403** disposed in gaps therealong, the switches being connected to control circuit **409**. As the flux traveling along the bypass path falls to zero the Hall Effect switch can be utilized to prevent further energization of the control coils so that no reverse flux is created.

Another embodiment of a device **400** which would provide reciprocating motion is shown in FIGS. **17A–17D** in which a permanent magnet control component **402** having two flux paths may be provided. A first pole piece **404** has two spaced, adjacent path portions **406** and **408** extending beyond the perimeter of the pole face of permanent magnet **410**, and a second pole piece **412** includes only one continuous portion **414** extending beyond the perimeter of the pole face of permanent magnet **410**, each path portion **406** and **408** of pole piece **404** being substantially aligned with at least a part of portion **414** of pole piece **412**. Control coil **416** is positioned along pole piece path portion **406** and control coil **418** is positioned along pole piece portion **408**. An armature **420** is positioned in the region between pole piece path portions **404**, **406** and pole piece portion **414** and is free to slide from side to side as shown by arrows **422** and **424**. A front view of component device **400** with no coils energized and armature **420** at a mid-point depicts flux flowing from the north pole face of permanent magnet **410**, through each of pole piece path portions **406** and **408**, through armature **420**, and returning to the south pole face through pole piece portion **414**. Thus, the magnetic flux divides equally along two paths. If coil **416** is energized in an aiding manner, or if coil **418** is energized in an opposing manner, all or a majority of the permanent magnets' magnetic flux can be made to flow through pole piece portion **406** such that a resulting magnetic coupling force on armature **420** causes it to move to the left as shown in FIG. **17C**.

Likewise, if control coil **416** is energized in an opposing manner, or if control coil **418** is energized in an aiding manner, all or a majority of the permanent magnet flux can be made to flow through pole piece path portion **408** such that a resulting magnetic coupling force on armature **420** causes it to move to the right as shown in FIG. **17D**. Accordingly, by alternately energizing and de-energizing coils **416** and **418** a reciprocating motion of armature **420** may be achieved.

Linear Motion

Referring now to FIGS. **18A–18E**, linear motion in accordance with the present invention is described. In particular, a permanent magnet control component **440** including a permanent magnet **442** with a pole piece **444** positioned against the north pole face thereof and a pole piece **446** positioned against the south pole face thereof is shown in an exploded view in FIG. **18A** and assembled in FIG. **18B**. Pole piece **444** includes five path portions **448A–448E** which extend beyond the perimeter of the north pole face of permanent magnet **442** to one side thereof and at respective positions along the length thereof, each path portion **448A–448E** including a respective control coil **450A–450E** positioned therearound. Pole piece **446** includes one portion **452** extending beyond the perimeter of the south pole face of permanent magnet **442** to the one side thereof, which portion **452** extends along the entire length of permanent magnet **442**. A plurality of armatures **454** define a path of relative movement between permanent magnet control component **440** and such armatures **454**, and by providing timed energization of given control coils **450A–450E** such relative movement can be achieved. The sequence of side views depicted in FIGS. **18C–18E** illustrate such relative movement, with coils **450A**, **450C** and **450E** being energized in an opposing manner simultaneously in FIG. **18C**, with coils **450A** and **450D** being energized simultaneously in an opposing manner in FIG. **18D**, and with coils **450B** and **450D** being energized simultaneously in an opposing manner in FIG. **18E**. In FIG. **18C**, magnetic flux will only flow along path portions **448B** and **448C** of pole piece **444** causing resultant magnetic coupling forces depicted by arrows **456**, **458** which act to move permanent magnet control component **440** to the left, assuming armatures **454** are fixed. Similarly, due to the timing of subsequent coil energization resultant magnetic forces depicted by arrows **460**, **462** in FIG. **18D** and arrows **464**, **466** in FIG. **18E** act to continue movement of permanent magnet control component **440** to the left. Thus, if permanent magnet control component **440** were fixed to a device or structure, controlled movement of the device or structure along the path defined by armatures **454** could be achieved. Conversely, if permanent magnet control component **440** were fixed and armatures **454** were located on a device or structure, controlled movement of the device or structure could also be achieved. It is also easily recognized that by varying the coil energization sequence and timing relative movement in the opposite direction can be achieved. Further, if the permanent magnet was doughnut shaped and the armatures were arranged in a circumferential pattern, rotary motion would likewise be achievable.

Rotary Motion

One embodiment of a rotary motion device or motor **500** which incorporates various permanent magnet flux control aspects of the present invention is shown in the exploded view of FIG. **19** and in the partial assembled view of FIG. **20**. Motor **500** includes a rotor assembly which includes a shaft **502** and associated upper bearing **504**, a non-magnetic disk member **506** mounted for rotation with shaft **502**, and a rotor pole piece **508** which is mounted for rotation with disk member **506** such as by the use of screws **510**. Rotor pole piece **508** includes a ring-shaped portion having two inwardly extending magnetic flux path portions **512A** and **512B**. A stator assembly of motor **500** includes a doughnut or ring-shaped permanent magnet **514** having an upwardly directed north pole face positioned adjacent and in close proximity to rotor pole piece **508**, and a downwardly directed south pole face positioned adjacent and in contact

with a stator pole piece **516**. Stator pole piece includes a ring-shaped portion having five inwardly projecting path portions **518A–518E**. Each path portion includes a respective winding post **520A–520E** extending therefrom and having a respective control coil **522A–522E** wound thereon. Stator pole piece faces **524A–524E** are positionable on respective winding posts **518A–518B** and, as shown in the partial assembly of FIG. **20**, are substantially aligned with the top surface of permanent magnet **514** so as to be positionable adjacent rotor path portions **512A** and **512B** when aligned therewith. Each of winding posts **518A–518E** and stator pole piece faces are formed of magnetic material, and although shown as separate pieces, an integral, one piece stator could be formed with similar winding posts and pole piece faces machined thereon. Lower bearing **526** is also shown.

FIGS. **21A–21E** illustrate top views of the partial assembly of FIG. **20** with magnetic flux shown. In FIG. **21A** magnetic flux travel when none of coils **522A–522E** are energized is depicted. Disregarding leakage flux, due to the low reluctance path provided by rotor pole piece path portions **512A** and **512B**, the majority of magnetic flux from the north pole face of permanent magnet **514** will travel radially inward along one of such path portions before passing downward through the stator assembly and returning to the south pole face of permanent magnet **514**. It is noted that rotor pole piece **508** includes two path portions and stator pole piece **516** includes five path portions such that rotor pole piece path portions **512A** and **512B** will always be skewed relative to the stator pole piece faces **524A–524E**. Only one rotor pole piece path portion can directly align with a stator pole piece face at a given time. By alternately energizing the control coils of each of the stator pole piece paths, rotary motion of the rotor may be achieved.

In particular, referring to FIGS. **21B–21D**, an energizing sequence which results in such rotary motion is described. In FIG. **21B**, control coils **522A** and **522C** are energized in a permanent magnet flux opposing manner. Permanent magnet magnetic flux traveling along rotor pole piece path portion **512A** tends to traverse to stator pole piece face **524B** causing a magnetic coupling force indicated by arrow **526**. Likewise, permanent magnet flux traveling along rotor pole piece path portion **512B** tends to traverse to stator pole piece face **524D** causing a magnetic coupling force indicated by arrow **528**. The result is rotation of rotor pole piece **508** in a clockwise direction as indicated by arrow **530**.

Referring to FIG. **21C**, just after rotor pole piece path portion **512B** is no longer aligned with stator pole piece face **524D**, control coil **522C** is de-energized and control coil **522D** is energized in an opposing manner such that the permanent magnet flux traveling along rotor pole piece path **512B** tends to traverse to stator pole piece face **524E** resulting in magnetic coupling force indicated by arrow **532**. Control coil **522A** remains energized such that a magnetic coupling force indicated by arrow **534** results. Accordingly, clockwise rotation of rotor pole piece **508** is continued.

In FIG. **21D**, just after rotor pole piece path portion **512A** is no longer aligned with stator pole piece face **524B**, control coil **522A** is de-energized and control coil **522B** is energized in a permanent magnet magnetic flux opposing manner such that the permanent magnet magnetic flux traveling along rotor pole piece path **512A** tends to traverse to stator pole piece face **524C** such that a magnetic coupling force indicated by arrow **536** results. Control coil **522D** remains energized such that a magnetic coupling force indicated by arrow **538** results, and clockwise rotation of rotor pole piece **508** is continued.

As shown in FIG. **21E**, just after rotor pole piece path portion **512B** is no longer aligned with stator pole piece face **524E**, control coil **522D** is de-energized and control coil **522E** is energized in a permanent magnet magnetic flux opposing manner such that the permanent magnet magnetic flux traveling along rotor pole piece path **512B** tends to traverse to stator pole piece face **524A** such that a magnetic coupling force indicated by arrow **540** results. Control coil **522B** remains energized such that a magnetic coupling force indicated by arrow **542** results, and clockwise rotation of rotor pole piece **508** is continued.

Thus, by alternating energizing and de-energizing control coils **522A–522E**, in a predetermined timed sequence based upon rotation of the rotor assembly, continued rotation movement of rotor pole piece **508** may be achieved. Such an energization/de-energization scheme can be achieved utilizing circuitry common in the art, such as the control circuitry described in Applicant's U.S. Pat. Nos. 5,463,263 and 5,455,474, as well as various of the circuit configurations described herein below. Referring now to FIG. **22**, an assembled view of rotary motor **500** is shown including a housing or cover formed by an upper housing member **544** and a lower housing member **546**, with portions of each housing member cut away to expose motor structure described above. It is recognized that such housing members **544** and **546** should be formed of a non-magnetic material, and likewise that motor shaft **502** and bearings **504**, **526** should be formed of a non-magnetic material.

In another embodiment, a rotary motion device or motor **580** in accordance with the present invention is shown in an exploded perspective view in FIG. **23** and in an assembled perspective view in FIG. **24**. Two spaced permanent magnets **582** and **584** are positionable between stator pole pieces **586** and **588**. Stator pole piece **586** includes two path portions **590A** and **590B** extending away from permanent magnets **582**, **584** in opposite directions. Likewise, stator pole piece **588** includes two path portions **592A** and **592B** extending away from permanent magnets **582**, **584** in opposite directions and alignable respectively with stator pole piece path portions **590A** and **590B**. Control coils **594**, **596**, **598**, and **600** are each positioned along a respective stator pole piece path portion as shown. A non-magnetic shaft **602** includes a pair of like elongated rotor members **604** and **606**, formed of magnetic material, mounted at spaced locations thereon and being angularly oriented with respect to each other, shaft **602** passing between spaced permanent magnets **582** and **584**. Non-magnetic end cap members **608** and **610** are attachable to the ends of stator pole pieces **586** and **588** and are configured for receiving shaft **602** and respective bearings **612** and **614**.

The ends of respective stator pole pieces **506** and **508** are configured for a given desired coupling relationship with rotor members **604** and **606**. For example, as shown in the exemplary end views of FIGS. **25A** and **25B**, with end cap **608** removed, the end of stator pole piece **586** may include an arcuate portion **616** which is configured to create a variable reluctance air gap **618** with elongate rotor member **604**. The end of stator pole piece **588** includes an arcuate portion **620** which is likewise configured to create a variable reluctance air gap **622** with rotor member **604**. In particular, portion **594** includes a circumferential curvature **618** which has a center point offset below the axis of rotation of shaft **602** and rotor member **604** as indicated by circle **624** shown in shadow. Similarly, portion **620** includes a circumferential radius of curvature which has a center point offset above the axis of rotation of shaft **602** and rotor member **604**. When magnetic flux is passing along the path which includes a

given end of the assembly, maximum coupling between the rotor member and stator pole pieces occurs when the rotor is positioned as shown in FIG. 25B. Accordingly, the illustrated rotor member and stator pole piece configurations in and of themselves do not provide any skewing to the direction of rotation of the rotor assembly.

In this regard, various configurations for the rotor and ends of the stator pole pieces are shown in the end views of FIGS. 26–28, which configurations provide skewing the direction of rotation. In particular, in device 620 of FIG. 26 a rotor member 622 having notches 624 and 626, which notches provide for greater magnetic coupling with the stator pole pieces 628 and 630 at corners 632 and 634 such that rotation is skewed in the clockwise direction. If notches were instead located at corners 632 and 634, skewed rotation in the counterclockwise direction would be the result. In device 620 such counterclockwise rotation could also be achieved by removing rotor 622 from shaft 636, flipping it end to end, and replacing it on shaft 636.

In the device 640 of FIG. 27, a portion 642 of the arcuate end portion of stator pole piece 644 is removed and a portion 646 of the arcuate end portion of stator pole piece 648 is removed. This configuration results in greater magnetic coupling between rotor member 650 and stator pole piece 644 at corner 652, and greater magnetic coupling between rotor member 650 and stator pole piece 648 at corner 654, such that rotation is skewed in the counterclockwise direction. Clockwise rotation could be achieved by instead modifying the opposite side of stator pole pieces 644 and 648.

FIG. 28 depicts an end view of a device 660 in which the axis 662 of the arcuate end portion of upper stator pole piece 664 and lower stator pole piece 666 is placed at an angle A as shown. This configuration creates an unequal variable reluctance air gap where opposite corners of rotor member 668 are closer to stator pole pieces 664 and 666. Further, the angle at which maximum magnetic coupling between rotor member 668 and stator pole pieces 664 and 666 occurs is retarded by angle A. Rotation would be in the counterclockwise direction for the illustrated configuration.

Referring again to motor 580 of FIGS. 23–25, rotary motion of such device is depicted in the end views of FIG. 29A–29D. In each end view the end cap has been removed to show rotation of the rotor members and in each of FIGS. 29A–29D an end view depicting rotor member 604 and an end view depicting rotor member 606 are shown side-by-side. In FIG. 29A, rotor member 604 is defined as being at zero degrees and rotor member 606 is defined as being at ninety degrees. Control coils 594, 598 are energized in a permanent magnet magnetic flux aiding manner such that no magnetic flux passes through stator pole piece path portions 590B and 592B. This allows rotor member 606 to move out of its ninety degree position and the magnetic coupling between rotor member 604 and stator pole piece path portions 590A and 592A will cause rotation to the position shown in FIG. 29B and then FIG. 29C. When rotor member 604 reaches the ninety degree position shown in FIG. 29D control coils 594, 598 are de-energized and control coils 596, 600 are energized in a permanent magnet magnetic flux aiding manner causing rotation to continue due to the magnetic coupling between rotor member 606 and stator pole piece path portions 590B and 592B. Thus, by alternately energizing the control coils of each path with every ninety degree rotation of rotor members 604 and 606, continuous rotary motion is achieved.

The initial direction of rotation can be controlled by the circuit means used to energize control coils 594, 598 and 596, 600, which circuit means includes circuitry for detect-

ing the angular position of the rotor members. In particular, if rotor members 604 and 606 are at rest in the position shown in FIG. 29A, and coils 594, 598 are energized in an aiding manner, rotation may be clockwise or counterclockwise. If the desired direction is clockwise but upon energization of coils 594, 598 the rotor members begin to move counterclockwise, the detection circuitry will immediately de-energize coils 594, 598 and energize coils 596, 600 so that the counterclockwise direction is achieved.

Further, bypasses around permanent magnets 582 and 584 could be provided in rotary motion device 580, such as those shown in FIG. 12, and rotor members 604 and 606 could be formed by permanent magnets so as to take advantage of energizing the control coils in an exceeding manner.

A third embodiment of a rotary motion device or motor 650 is shown in the exploded partial perspective view of FIG. 30 and in the assembled partial perspective view of FIG. 31. In motor 650 the stator assembly includes a control component 651 including a permanent magnet 652 having a stator pole piece 654 positioned adjacent one pole face thereof and a stator pole piece 656 positioned adjacent the opposite pole face thereof. Stator pole piece 654 includes a path portion 658A extending to one side of permanent magnet 652 and a path portion 658B extending to the one side thereof and spaced from first path portion 658A. Control coils 660 and 662 are positioned along respective stator pole piece path portions 658A and 658B. Likewise, stator pole piece 656 includes path portions 664A and 664B which extend in a similar manner therefrom so as to be aligned with stator path portions 658A and 658B respectively. Control coils 666 and 668 are positioned along respective stator pole piece path portions 664A and 664B. Positioned opposite and facing control component 651 is a like control component 670 including permanent magnet 672, stator pole piece 674 with path portions 676A and 676B having respective control coils 678 and 680, and stator pole piece 682 with path portions 684A and 684B having respective control coils 686 and 688. The end of each of the pole piece path portions 658A, 658B, 664A, 664B, 676A, 676B, 684A, and 684B is of a generally arcuate configuration.

A rotor assembly of motor 650 includes a non-magnetic shaft 700 having a permanent magnet rotor member 702 mounted thereon for rotation therewith. Permanent magnet rotor member 702 is generally ring-shaped and segmented to include distinct north and south pole faces which reverse about every ninety degrees therearound. When assembled the top and bottom surfaces of permanent magnet rotor member 702 align with pole pieces 654, 656, 674, and 682 of the stator assembly and are preferably configured such that a minimal gap between the outer surface of permanent magnet rotor member 702 and the arcuate surfaces of the pole piece path portions is provided.

Rotation of device 650 can be achieved by controlled, timed energizing and de-energizing of control coils 660, 662, 666, 668, 678, 680, 686, and 688. Exemplary rotation is demonstrated with reference to the top views of FIGS. 32A–32B which depict counterclockwise rotation of permanent magnet rotor member 702 through one-hundred eighty degrees. In FIG. 32A stator pole piece path portion 658A of component 651 is active and stator pole piece path portion 658B is not active, which may be achieved by energizing control coil 660 in a permanent magnet magnetic flux aiding manner or by energizing control coil 662 in a permanent magnet magnetic flux opposing manner. Stator pole piece path portion 676B of component 670 is active and stator pole piece path portion 676A is not active, which may be achieved by energizing control coil 680 in a permanent

magnet magnetic flux aiding manner or by energizing control coil 678 in a permanent magnet magnetic flux opposing manner. Thus, portions 690 and 692 of permanent magnet rotor member 702, which both have a north magnetic polarity, will be repelled by the north polarity of stator pole piece path portions 658A and 676B aligned therewith. Portions 694 and 696 of permanent magnet rotor member 702, both of which have a south magnetic polarity, will be attracted to the active path portions 658A and 676B. At the instant that rotor member portion 694 becomes aligned with stator pole piece path portion 658A, as shown in FIG. 32B, all coils are de-energized such that all pole piece path portions will be active as shown. Pole piece path portions 658B and 676A are then kept active while pole piece path portions 658A and 676B are made inactive. This is achieved by energizing control coils 662 and 678 in a permanent magnet magnetic flux aiding manner or by energizing control coils 660 and 680 in a permanent magnet magnetic flux opposing manner. Rotor member portions 690 and 692 will again be repelled by the north polarity of path portions 658B and 676A aligned therewith such that rotation of permanent magnet rotor 702 is continued. In FIG. 32D all coils are shown de-energized when rotor portion 692 aligns with pole piece path portion 658A. By continuing this timed sequence of energization and de-energization of the control coils, continued rotary movement is achieved. As explained above, the initial direction of rotation can be controlled by circuit means which detects the initial direction of permanent magnet rotor 702 and immediately alters the coil energization scheme if the initial direction is incorrect.

A side view of assembled motor 650 is shown in FIG. 33 and includes an upper housing or enclosure portion 710, a bottom housing portion 712, upper bearing 714, and a lower bearing 716.

A fourth embodiment of a rotary motion device or motor 740 is illustrated in FIGS. 34–39. Motor 740 includes five stator control components 742A–742E positioned around a ring shaped permanent magnet rotor member 744 (FIG. 36). As shown with reference to component 742A in FIG. 37 each stator component 742A includes a permanent magnet 746A with an upper pole piece 748A positioned adjacent one pole face thereof and a lower pole piece 750A positioned adjacent the opposite pole face thereof. Control coils 752A, 754A are positioned along respective pole pieces 748A, 750A. A bypass 756A extends from pole piece 748A to pole piece 750A and is positioned between permanent magnet 746A and control coils 752A, 754A. Alternatively, bypass 756A could be provided on the opposite side of permanent magnet 746A as shown in FIG. 38. Although not shown, it is anticipated that permanent magnet rotor member 744 would be mounted on an axis for rotation therewith and that a motor housing or enclosure could be provided, such as shown in relation to motor 650 of FIG. 33.

Referring to the top views of FIGS. 39A–39D, rotary motion of rotor member 744 is depicted by the sequence of views. Regions 770 and 772 in FIGS. 39A–39D represent the magnetic north regions of the top of permanent magnet rotor 744. In FIG. 39A control coils 752E and 752C are energized in a permanent magnet aiding and exceeding manner such that regions 770 and 772 of permanent magnet rotor 744 are repulsed by components 742E and 742C while permanent magnet motor regions 774 and 776 are attracted by components 742E and 742C. The resultant coupling forces act to move permanent magnet rotor in a counterclockwise direction to the location shown in FIG. 39B. Just after permanent magnet rotor region 772 passes the point shown in FIG. 39C, control coil 752B is energized in a

permanent magnet aiding and exceeding manner, while control coils 752E and 752C also remain energized, and counterclockwise rotation of permanent magnet rotor 744 is continued. Just after permanent magnet rotor region 772 passes by control component 742C control coil 752C is de-energized, while control coils 752E and 752B remain energized, so as to continue counterclockwise rotation. Then, just after permanent magnet rotor region 770 reaches the location shown in FIG. 39D control coil 752D is energized in a permanent magnet flux aiding and exceeding manner, while coils 752E and 752B remain energized, so as to continue counterclockwise rotation. Thus, as in the other embodiments, repeated and timed energization and de-energization of the control coils produces the desired rotational movement.

In terms of controlling the energization of coils in the devices described above, various electronic control circuit/switching means and electromechanical control circuit/switching machines are depicted in FIGS. 40–44. In circuit 800 of FIG. 40 a given coil 802 is placed in series between an electrical energy source 804 and a power mosfet 806. An LED 808 is connected to electrical energy source 804 through resistor 810 and is positioned to impinge upon a phototransistor 812 which is connected in series with resistor 814. A control input of mosfet 806 is connected between phototransistor 812 and resistor. Accordingly, when LED 808 activates phototransistor 812 the voltage drop across resistor 814 activates, or turns ON, mosfet 806 and coil 802 is energized. Timed energization of coil 802 is provided by mounting an interrupter 816, such as shown in FIG. 42, to the shaft 816 of the motor device to be controlled, such that as interrupter 814 rotates with shaft 816 coil 802 is alternately energized and de-energized. In a device with a plurality of coils a corresponding plurality of LED/photoreistor pairs may be provided.

In circuit 820 of FIG. 41 a coil 822 is positioned between electrical energy source 824 and power mosfet 826. A hall switch 828 is connected in series with resistor 830. Hall switch 828 is also connected to the control input of mosfet 826 through resistor 832. In a given device hall switch 828 would be positioned to react to a change in magnetic flux so as to control the ON/OFF switching of mosfet 826, and thus the alternate energization and de-energization of coil 822.

In FIG. 43 a circuit 840 for controlling two coils in an opposite manner is provided such that when coil 842 is energized coil 844 is de-energized, and such that when coil 842 is de-energized coil 844 is energized. Both coils 842 and 844 are connected in series between electrical energy source 846 and respective power mosfets 848 and 850. An LED 852 and phototransistor 854 arrangement is provided, LED connected in series with resistor 856 and phototransistor connected in series with resistor 858. When LED 852 turns phototransistor 854 ON the voltage drop across resistor 858 turns mosfet 848 ON and coil 842 is energized. At that time the voltage applied at the control input of mosfet 850 will be low and therefore mosfet 850 will be OFF and coil 844 will be de-energized. When interrupter 814 blocks LED 852, phototransistor 854 is turned OFF and mosfet 848 is likewise turned OFF. The control input of mosfet 850 is therefore pulled high through resistor 860 and mosfet 850 is turned ON such that coil 844 is energized.

In a FIG. 44 a system 870 including member 872 mounted on rotating shaft 874 is provided, with the left side of member 872 being alternately conductive at 876 and non-conductive at 878. Coils 880 and 882 are connected to respective brushes 884 and 886 which are positioned to contact member 872 during rotation thereof. Member 872 is

connected through brush **890** to power supply **888**. Thus, coils **880** and **882** will alternately be energized and de-energized as the respective brushes thereof contact the conductive and non-conductive portions of member **872**.

Any of such circuit means, variations thereof, or other circuit means may be used to provide the timed energization of the control coils in the various embodiments of the present invention.

From the preceding description of the illustrated embodiments, it is evident that the objects of the invention are attained. Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is intended by way of illustration and example only and is not to be taken by way of limitation.

For example, although the magnetic flux control techniques of the present invention have been discussed as applicable mainly to various motive applications, such magnetic flux control techniques are also useful in static applications.

Power Conversation

Referring to FIGS. **45A-45C** there is shown the permanent magnet device **900** of FIGS. **45A-45C** that has two magnetic flux paths provided by rectangular pole piece **902** which includes upper portion **904** and lower portion **906** each positioned against a respective pole face of permanent magnet **910**. Unlike the device of FIGS. **7-9**, fall away armatures are not provided. Rather, fixed armatures in the form of integral pole piece portions **912** and **914** extend from upper portion **904** to lower portion **906** completing the two flux paths in a permanent manner. Control coils **916, 918** are provided along one flux path and control coils **920, 922** are provided along the other flux path, such control coils acting as primary windings in device **900**. One coil **924** is positioned around pole piece portion **912** and another coil **926** is positioned around pole piece portion **914**, such coils **924, 926** acting as secondary windings in device **900**.

In FIG. **45A** coils **916, 918** are energized in a permanent magnet magnetic flux aiding manner so as to couple with all the magnetic flux of permanent magnet **910**. All magnetic flux flows along path **930** as shown and thus couples with coil **924**. In FIG. **45B** no coils are energized and the permanent magnet magnetic flux splits evenly between paths **930** and **932**, coupling with both coil **924** and coil **926**. In FIG. **45C** coils **920, 922** are energized in a permanent magnet magnetic flux aiding manner such that all magnetic flux traverses path **932** and couples with coil **926**. In FIG. **45D** no coils are energized as in FIG. **45B**. By continuously alternately energizing and de-energizing coils **916, 918** and **920, 922** in such a manner energy conversion is achieved due to the coupling with coils **924** and **926**. The magnetic flux in the integral pole piece portions **912** and **914**, and thus the flux coupling with respective coils **924** and **926**, varies by a factor of twice the amount of magnetic flux generated by energizing coils **916, 918** and **920, 922**.

The construction shown in FIGS. **45A** and **45X** are similar to the construction shown in FIGS. **7** and **47**. The difference in both cases relates to replacing the two flux paths and armatures with one continuous flux path. The arrangement in FIG. **7** has one permanent magnet and four coils and the arrangement in FIG. **47** has two permanent magnets and two coils. Although the physical aspects of the two arrangements and the details of the flux control vary, the control method for varying the permanent magnets flux are similar and will be described simultaneously and only differences will be pointed out.

With continuous flux paths the static flux from the permanent magnet or magnets is useless. However, if the static

flux of the permanent magnet confined to the flux paths were modified to be time varying it would have utility for electromagnetic induction devices for power conversion like transformers and power inverters. However, the same basic method for controlling the flux of a permanent magnet to provide linear and rotary motion can also be applied to time varying the static flux from the permanent magnetic. The construction shown in FIG. **45X** utilizes four control coils and a single permanent magnet and the construction shown in FIG. **45A** uses two control coils and two permanent magnets. The flux that would normally be supplied by a primary winding is supplied by the static flux of the permanent magnet or magnets and the control coils convert this static flux into a time varying flux in a novel way. Both arrangements use two secondary coils, the secondary coils are placed in the region of the continuous flux path that would be occupied by an armature or rotor in the linear or rotary arrangements. The regions of the flux paths that perform work are the same in all cases.

In all cases the control coils can either be wired in series or parallel and the secondary coils can be either wound in series or parallel. More than one secondary coil or secondary coils with multiple taps can be placed in the working regions and further multiple flux paths can be utilized with one or more secondary coils placed in each of the working regions. This is made obvious by the disclosures of the linear and rotary devices herein and based on the fact that the working regions of the flux paths are identical.

FIGS. **45X** and **45A** also show the paths of the static flux of the permanent magnet or magnets when no current is flowing in the control coils. In the arrangement shown in FIG. **45X** the flux from the single permanent magnet divides between the two working areas of the flux path. In the arrangement of FIG. **45A** all of the flux of one of the permanent magnets passes through one of the working regions and all of the flux of the second permanent magnet passes through the other working region. Each of the working regions in both cases are occupied by secondary coils.

FIGS. **45Y** and **45B** show the control coils energized with the polarity shown with respect to the polarity of the permanent magnet or magnets included. In FIG. **45Y** the opposing coil blocks the passage of flux from the permanent magnet and the aiding coil couples with the flux of the permanent magnet and therefore all of the flux of the permanent magnet passes through one working region as shown. In FIG. **45A** the opposing side of the coil blocks the passage of flux from the permanent magnet on the opposing side of the coil and the aiding side of the coil couples with the flux of the other permanent magnet and therefore all of the flux of both the permanent magnets passes through the working region as shown.

FIGS. **45Z** and **45C** show the control coils energized with a polarity opposite of that shown in FIGS. **45Y** and **45B**. The same action occurs and results in all of the permanent magnet or magnets path flux passing through the opposite working regions.

By alternating the polarity of the control coils during one cycle, one working region experiences an increasing flux and the opposite region experiences a decreasing flux and during the next cycle the opposite occurs. This results in the induction of a voltage in the secondary coils that is decided by the magnitude of the change in flux in the working region and the time in which this change occurs. The novelty of this discovery is that the primary flux inducing the voltage in the secondary coils is supplied by the permanent magnet or magnets and is far greater than the flux supplied by the control coils.

Further, in the rotary motion devices of FIGS. 31 and 34, it is not necessary that respective rotor members 702 and 744 be formed of permanent magnets. Each could take the form shown in FIG. 46 where sections 950 and 952 are formed of magnetic material such as soft iron and sections 954 and 956 are formed by a non-magnetic filler material.

FIGS. 47 and 48 show another embodiment 1000 of the subject device. The embodiment 1000 includes two spaced permanent magnets 1002 and 1004 each of which has its north pole adjacent the upper surface and its south pole adjacent the lower surface. A magnetizable bridging member 1006 extends across and makes contact with the north magnetic poles of the magnets 1002 and 1004 and another magnetizable bridging member 1008 makes contact with the south magnetic poles of the two permanent magnets 1002 and 1004. The members 1006 and 1008 extend slightly beyond the opposite sides of the respective permanent magnets 1002 and 1004 and a pair of spaced armature members 1010 and 1012 are positioned to move into and out of engagement with the ends of the members 1006 and 1008. Coils 1014 and 1016 are mounted respectively on the members 1006 and 1008 in the space between the permanent magnets 1002 and 1004, and the armatures 1010 and 1012 are shown connected together by a rod 1018 which enables them to move backwards and forwards into engagement with the respective members 1006 and 1008 when different voltages are applied to the respective coils 1014 and 1016. In FIGS. 47, the coils 1014 and 1016 are energized as shown with the coil 1014 having its north magnetic end to the left and its south magnetic end to the right and the opposite is true of the coil 1016. In FIG. 48, the voltage applied to the respective coils 1014 and 1016 is reversed so that the polarity of the left end of coil 1014 is south and the polarity of the opposite end of the same coil 1014 is a north magnetic pole. The reverse is true of the coil 1016. It is to be noted in FIGS. 47 and 48 that the relationship of aiding and opposing is indicated on the figures to indicate the relationship when the coils are energized. For example, in FIG. 47 when the coils are energized as shown the relationship is opposing for the permanent magnet 1002 and is aiding with respect to the permanent magnet 1004. The reverse is true when the voltage on the coils is reversed as shown in FIG. 48. By properly timing the voltage on the respective coils the movement of the armature is controlled. The same principles can be applied to produce rotating movement as shown in FIG. 42.

FIG. 49 shows another embodiment 1030 of the subject invention using principles similar to those described in connection with FIGS. 47 and 48. The embodiment 1030 includes a plurality, three being shown, of stationary members 1032, 1034 and 1036. The details of these members are better shown in FIG. 50 which shows the details of the member 1036. This member includes a pair of permanent magnets 1038 and 1040, each of which has magnetizable members mounted adjacent opposite sides thereof as in the previous construction. The members 1042 and 1044 also have coils 1046 and 1048, respectively, and the coils are energized as described in connection with FIGS. 47 and 48 to produce aiding and opposing magnetism. The construction shown in FIG. 49 may have three stator portions as shown or it may have more stator portions as desired. The rotor 1050 is positioned in the space between the members 1032, 1034 and 1036 and includes a permanent magnet portion part of which has its north magnetic pole on the surface as shown and the other parts has its south magnetic pole in the same surface as shown. The permanent magnets 1038 and 1040 on the stators interact with the permanent

magnets on the rotor to produce the rotating motion and is controlled by the energizing of the coils.

FIG. 51 is a perspective view of stacked laminated pole pieces designed for another preferred embodiment of a rotary motor 1100 which uses the principles disclosed herein. Motor embodiment 1100 contains two pole piece stacks 1110 and 1120, made of laminated pole pieces 1120. All pole pieces 1102 in either of the stacks 1110 and 1120 have identical shapes, thickness, and construction, to minimize manufacturing costs; the sole difference between stacks 1110 and 1120 is their orientation, facing each other and separated by permanent magnets 1130 and 1140, which are oriented with their north and south faces positioned as shown in FIG. 51.

A first magnet-contacting surface 1112 of stack 1110 is placed adjacent to (and preferably in direct contact with) the north face of permanent magnet 1130. A second magnet-contacting surface 1114 in stack 1110 is placed adjacent to (and preferably in direct contact with) the north face of the other permanent magnet 1140. Similarly, first and second magnet-contacting surfaces 1122 and 1124 of stack 1120 are placed adjacent to (and preferably in direct contact with) the south faces of permanent magnets 1130 and 1140, as shown in FIG. 51. For convenience, stack 1110 is referred to below as the "north stack", and stack 1120 is referred to below as the "south stack".

An electromagnetic coil 1116, capable of carrying timed pulses of current under the control of an electronic control means, is wrapped around the coil-wrapped portion 1118 of north stack 1110. A similar electromagnetic coil 1126 is wrapped around the coil-wrapped portion 1128 of south stack 1120.

The currents which are passed in a timed manner through "north coil" 1116 and "south coil" 1126 created timed and alternating electromagnetic fields which cause the magnetic fluxes from both of the two permanent magnets 1130 and 1140 to repeatedly shift back and forth between two alternating flux-carrying pathways.

A rotor assembly 1160, which can be made either from a stack of laminated pieces 1162 as shown, or using solid construction as desired, is shown in perspective view in FIG. 51. Rotor 1160 is positioned inside the space formed by the north stack 1110 and the south stack 1120. Rotor device 1160 is provided with (i) a means, such as the non-circular slot 1164, allowing the torque exerted on the rotor device 1160 to drive a shaft that is mounted within the slot 1164; and, (ii) a plurality of peripheral extensions 1166 which are angularly spaced to match the flux paths 1152 of the north stack and 1158 of the south stack when rotor 1160 in proper angular alignment.

Flux-carrying pathways are shown in FIG. 52, which comprises FIGS. 52A through 52D, showing various different flux paths (under the control of north coil 1116 and south coil 1126) at different positions of the rotor 1160.

When the current passing through north coil 1116 creates an electromagnetic field in the direction shown in FIG. 52A, this electromagnetic field directs the north pole fluxes from both the permanent magnets 1130 and 1140 through the first path portion 1156 of the north stack through the rotor 1160 by means of the rotor extensions 1166 and to the first path portion 1154 of the south stack. This exerts a rotational torque on rotor 1160 until rotor extensions 1166 align perfectly with the first path portions 1156 and 1154 of the north stack and south stack, respectively, as shown in FIG. 52A.

Proper timing and direction of the current pulses which pass through the north coil 1116 and the south coil 1126, are

controlled by means of an electronic control system that is triggered by the rotor 1160 angular position with respect to the flux path positions. The timing is such that the current direction is reversed when the magnetic attraction at the first path portions 1156 and 1154 is near its maximum, such as shown in FIG. 52A.

FIG. 52B shows the result of angular momentum of the rotor 1160 carrying the rotor beyond the point of maximum attraction after the current direction is reversed; thus allowing rotor rotation to continue in its previous direction.

After the direction of the current has been reversed, as shown in FIGS. 53B and 52C, the electromagnetic field directs the south pole fluxes from both the permanent magnets 1130 and 1140 through the second path portion 1158 of the south stack through the rotor 1160 by means of the rotor extensions 1166 and to the second path portion 1152 of the north stack. Torque is produced until the rotor extensions 1166 align perfectly with the second path portions 1158 and 1152 of the south stack and north stack respectively, as shown in FIG. 52D. At this time, the current direction is reversed and the cycle is repeated continuously, thus allowing torque on the rotor assembly 1160 at all (or essentially all) times and all positions in its rotation.

One of the advantages of the rotary motor embodiments 1100 shown in FIGS. 51-53 is that the torque which it can generate can be increased by increasing the length of the motor, without requiring any increase in the diameter of the motor. This is due to the fact that increasing the length of a motor having this design will increase the area of the north and south faces of the two permanent magnets 1130 and 1140, even when its diameter is held constant. Accordingly, this motor offers potentially high torque-to-diameter ratios, in situations suited for a motor that is long but narrow.

Other applications and advantages of the devices and methods of the present invention exist and various modifications are possible, and therefore the present invention is not intended to be limited to the specific examples disclosed herein. Accordingly, the spirit and scope of the invention are to be limited only by the terms of the appended claims.

What is claimed is:

1. A device for producing rotary motion, comprising:

a rotor assembly including a shaft which defines an axis of rotation for the assembly, a rotor mounted on the shaft for rotation therewith, the rotor having a plurality of rotor extension portions circumferentially-spaced and extending in a radial outward manner away from the shaft;

a stator assembly circumferentially surrounds at least a portion of the rotor which includes the rotor extension portions, the stator assembly including:

- (a) at least two spaced permanent magnets, each having north and south pole faces, the north pole faces being in substantial alignment on opposite sides of the rotor assembly and the south pole faces being in substantial alignment on opposite sides of the rotor assembly,
- (b) at least one north-field pole piece, comprising:
 - (i) a first magnet face positioned adjacent to the north pole face of a first permanent magnet,
 - (ii) a second magnet face positioned adjacent to the north pole face of a second permanent magnet,
 - (iii) at least one first north-field stator extension and at least one second north-field stator extension, wherein the first and second north field stator extensions are separated from each other by a

north-field bridge portion, and wherein both of the first and second north-field stator extensions extend toward the rotor;

- (iv) said north-field bridge portion positioned between the first and second north-field stator extensions; and,
- (v) a north-field control coil, surrounding the north-field bridge portion positioned between the first and second north-field stator extensions, and having a predetermined number of turns to allow the north-field control coil, as alternating voltage is applied to it in a cyclical manner, to direct essentially all of the north magnetic field emanating from the north faces of both the first and second permanent magnets, through each of the first and second north-field stator extensions, in an alternating manner which is coordinated with rotation of the rotor;
- (c) at least one south-field pole piece, comprising:
 - (i) a first magnet face positioned adjacent to the south pole face of a first permanent magnet,
 - (ii) a second magnet face positioned adjacent to the south pole face of a different permanent magnet,
 - (iii) at least one first south-field stator extension and at least one second south-field stator extension, wherein the first and second south field stator extensions are separated from each other by a south-field bridge portion, and wherein both the first and second south-field stator extensions extend toward the rotor;
 - (iv) said south-field bridge portion positioned between the first and second south-field stator extensions;

and,

- (v) a south-field control coil surrounding the south-field bridge portion positioned between the first and second south-field stator extensions, and having a predetermined number of turns to allow the south-field control coil, as alternating voltage is applied to it in a cyclical manner, to direct essentially all of the south magnetic field emanating from the south faces of both the first and second permanent magnets, through each of the first and second south-field stator extensions, in an alternating manner which is coordinated with rotation of the rotor; and,

means for connecting each of the north-field and south-field control coils to a source of electric energy and a switching means which, in combination, are capable of energizing the north-field and south-field control coils in a predetermined timed manner correspond to positions of the plurality of circumferentially-spaced outwardly-extending portions of the rotor during rotation thereof.

2. The device of claim 1 wherein said at least one north-field pole piece is provided as a laminated stack having a first magnet face and a second magnet face, each magnet face being pressed against a north pole face of a permanent magnet, and wherein said at least one south-field pole piece is provided as a laminated stack having a first magnet face and a second magnet face, each magnet face being pressed against a south pole face of a permanent magnet.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,342,746 B1
DATED : January 29, 2002
INVENTOR(S) : Charles J. Flynn

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

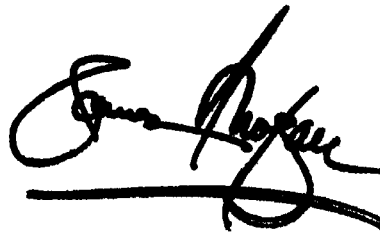
Column 12,

Line 24, "18" should be -- 118 --.

Signed and Sealed this

Fourth Day of June, 2002

Attest:

A handwritten signature in black ink, appearing to read "James E. Rogan", with a long horizontal flourish underneath.

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office