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(12) **United States Patent**  
**Flynn**

(10) **Patent No.:** **US 6,246,561 B1**  
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(54) **METHODS FOR CONTROLLING THE PATH OF MAGNETIC FLUX FROM A PERMANENT MAGNET AND DEVICES INCORPORATING THE SAME**

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(\*) 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.: **09/127,056**

(22) Filed: **Jul. 31, 1998**

(51) Int. Cl.<sup>7</sup> ..... **H02K 21/12**

(52) U.S. Cl. .... **361/147; 361/210**

(58) Field of Search ..... 361/143, 147, 361/206, 210

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*Primary Examiner*—Fritz Fleming

(74) *Attorney, Agent, or Firm*—Haverstock, Garrett and Roberts LLP

(57) **ABSTRACT**

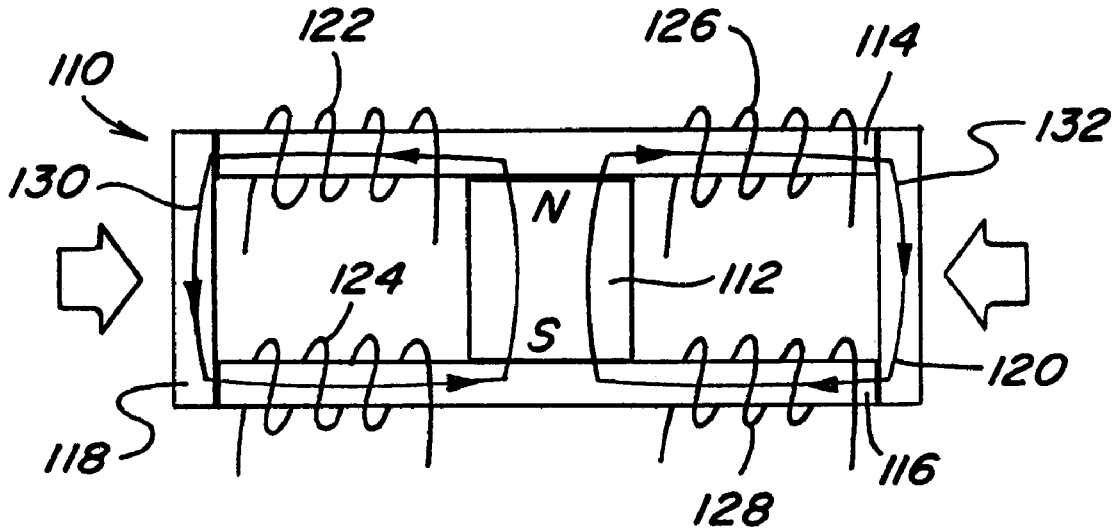
A permanent magnet device includes a permanent magnet having north and south pole faces with a first pole piece positioned adjacent one pole face thereof and a second pole piece positioned adjacent the other pole face thereof so as to create at least two potential magnetic flux paths. A first control 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.

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**42 Claims, 32 Drawing Sheets**



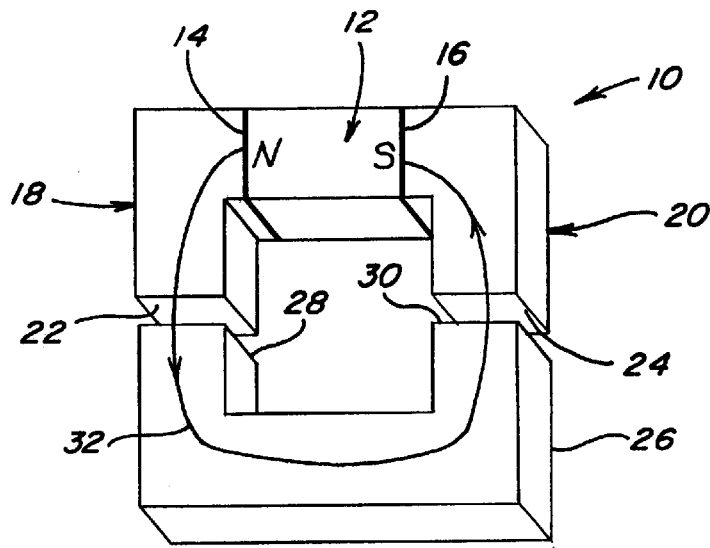


Fig. 1

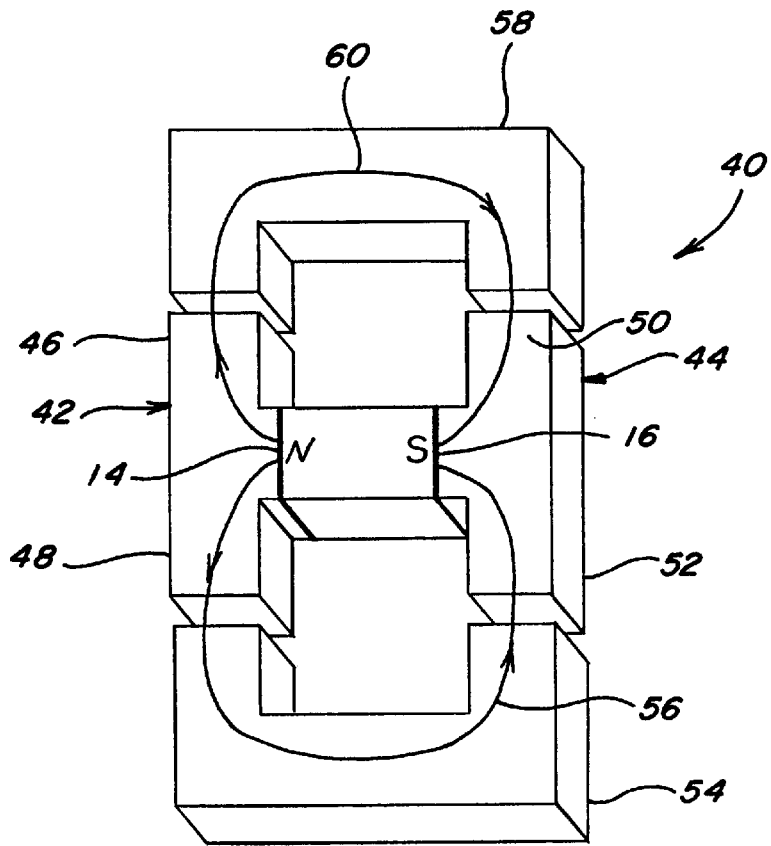


Fig. 2

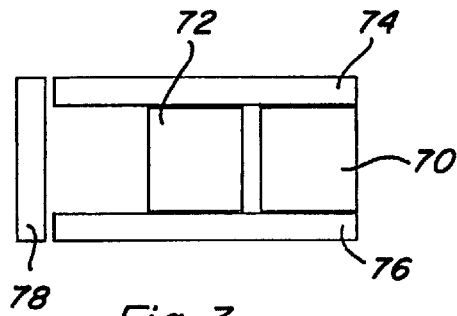


Fig. 3

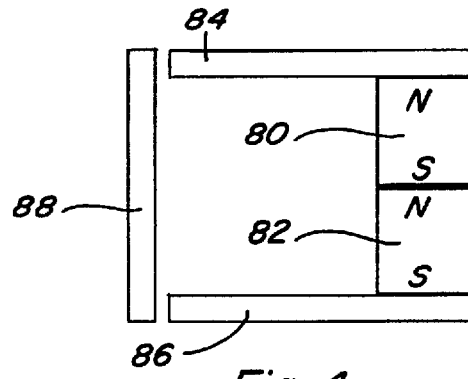


Fig. 4

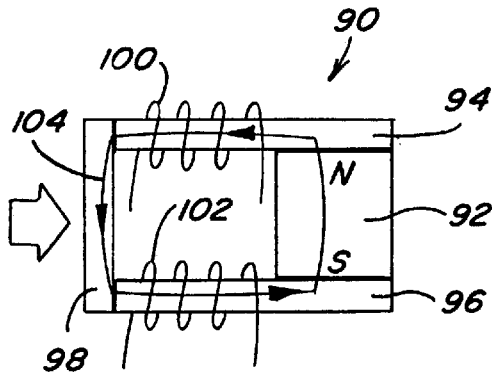


Fig. 5

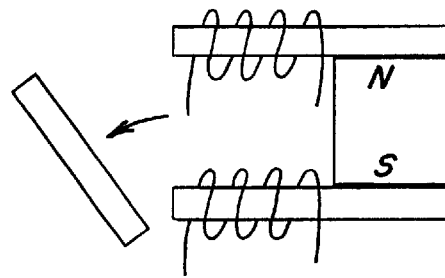


Fig. 6

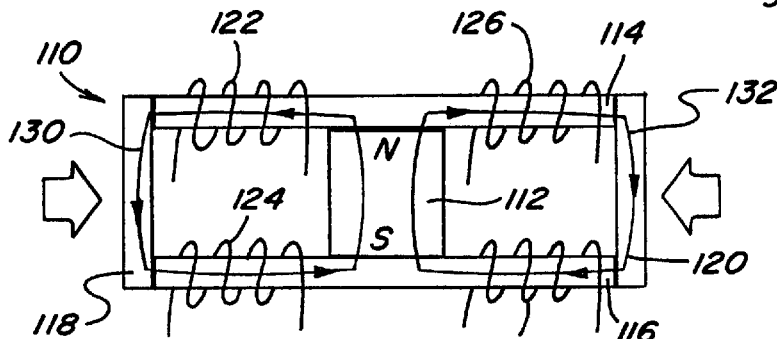


Fig. 7

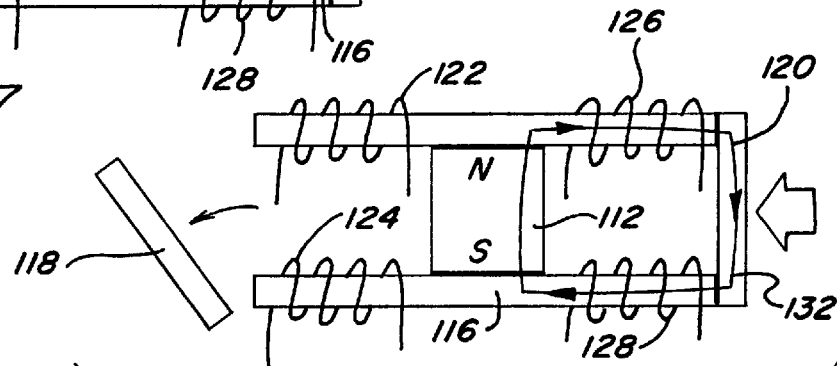


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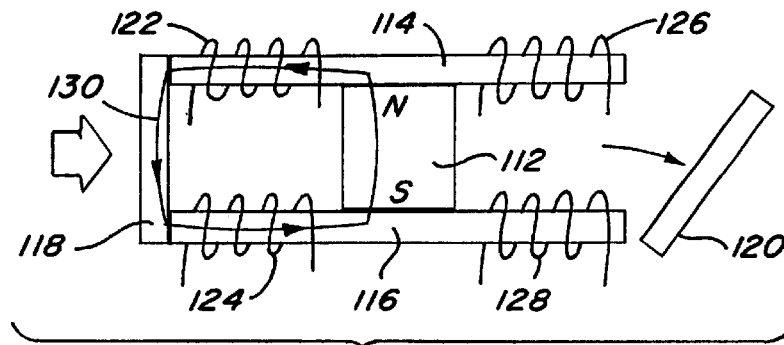


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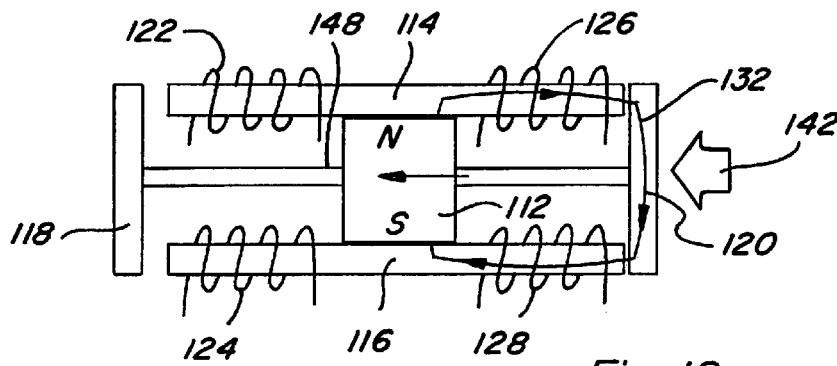


Fig. 10

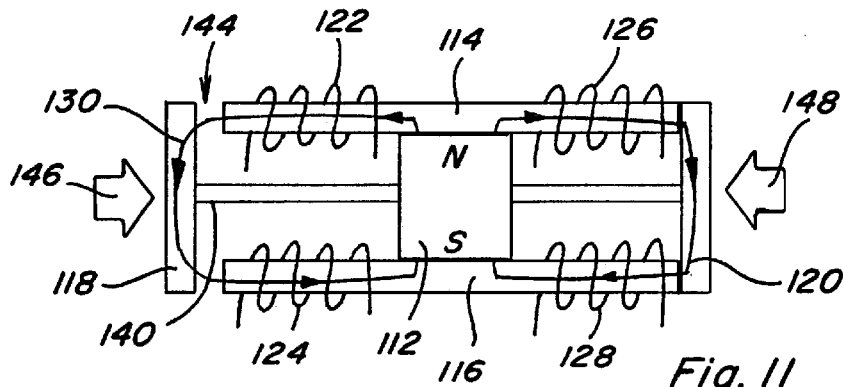


Fig. 11

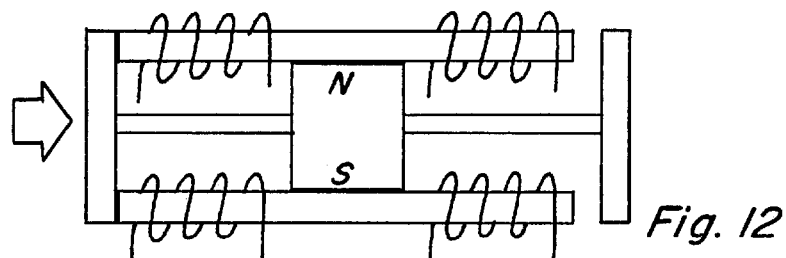


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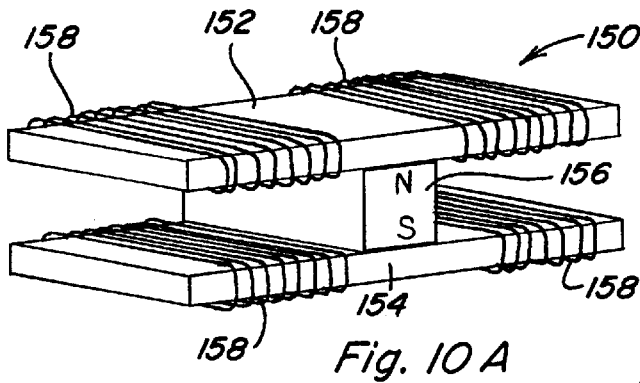


Fig. 10 A

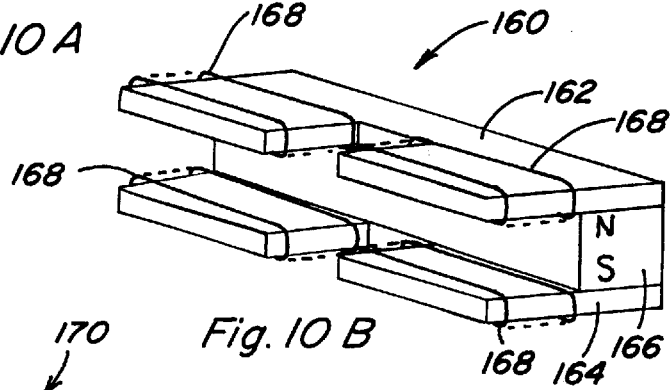


Fig. 10 B

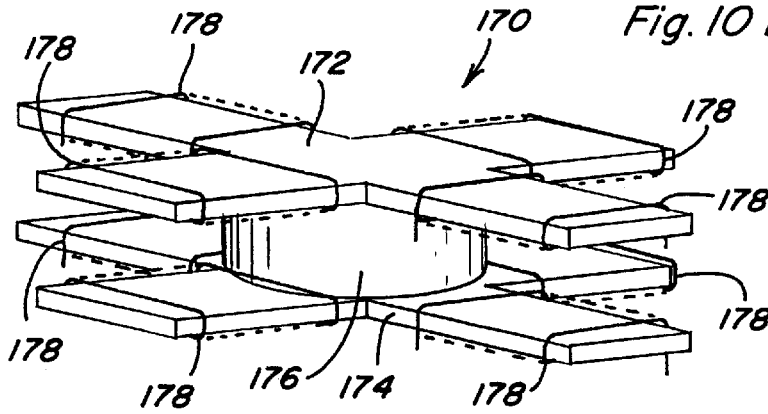


Fig. 10 C

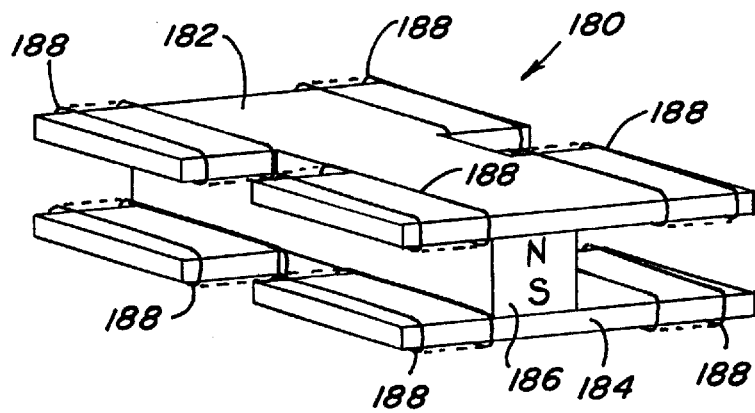


Fig. 10 D

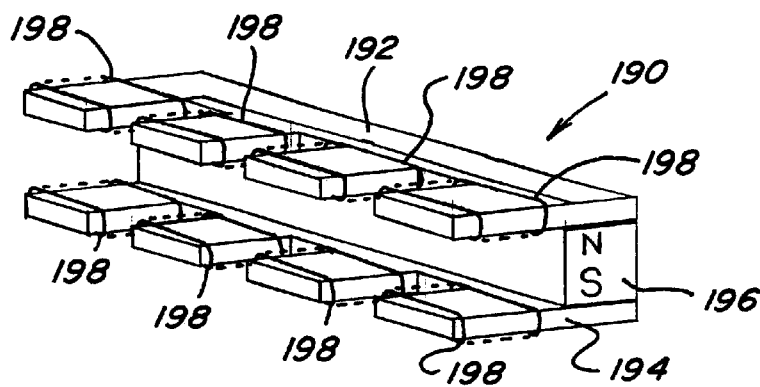


Fig. 10 E

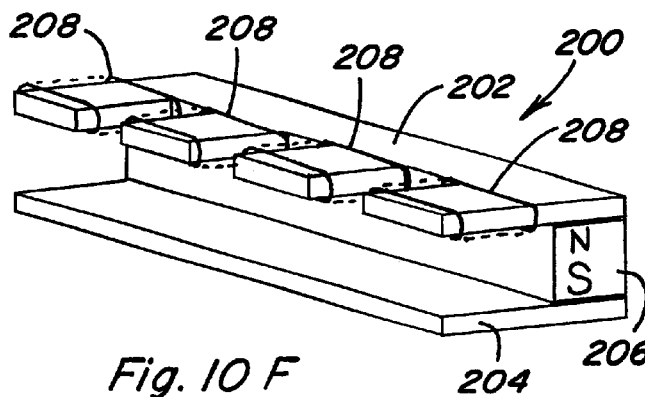


Fig. 10 F

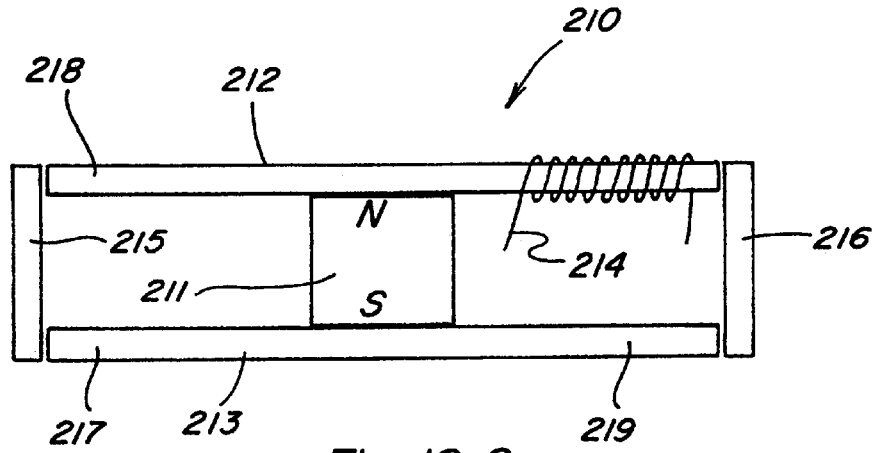


Fig. 10 G

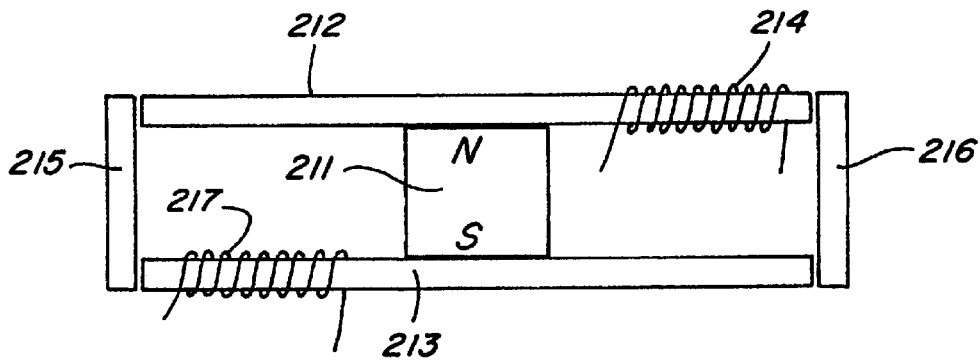


Fig. 10 H

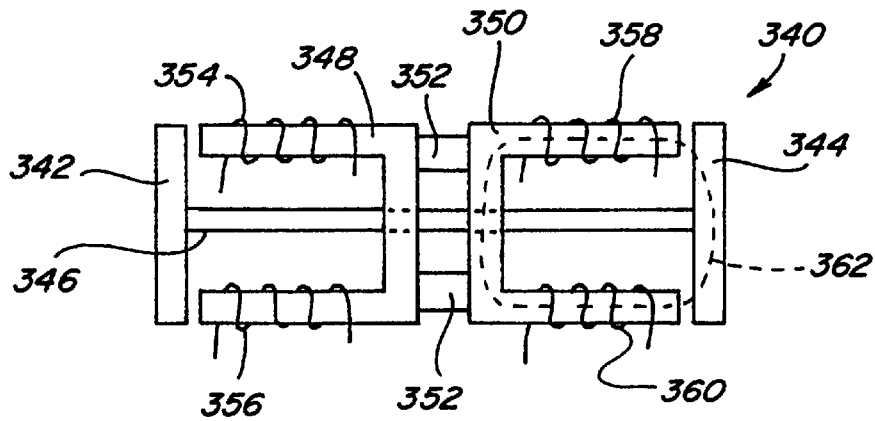


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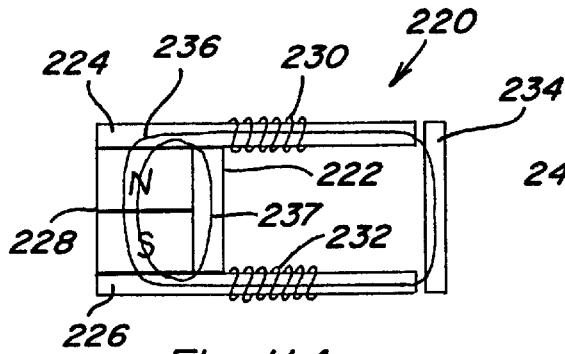


Fig. 11A

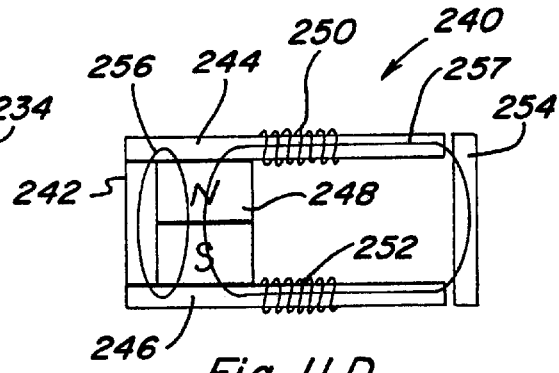


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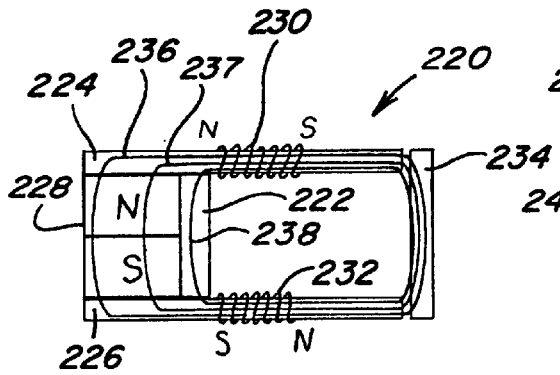


Fig. 11B

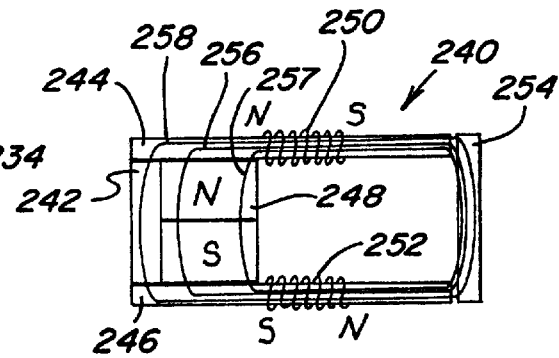


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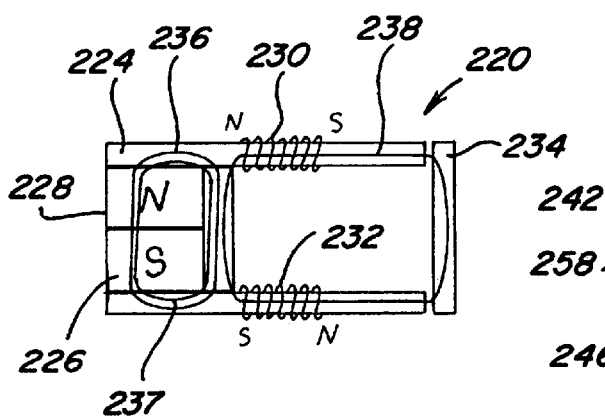


Fig. 11C

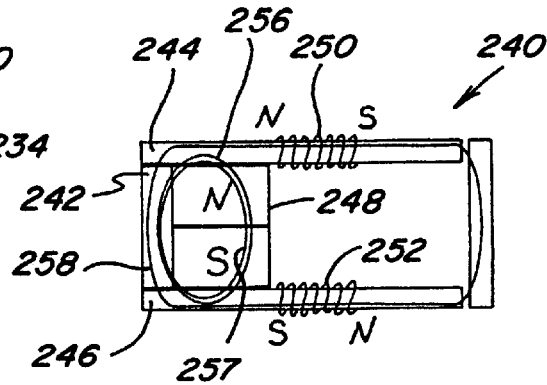
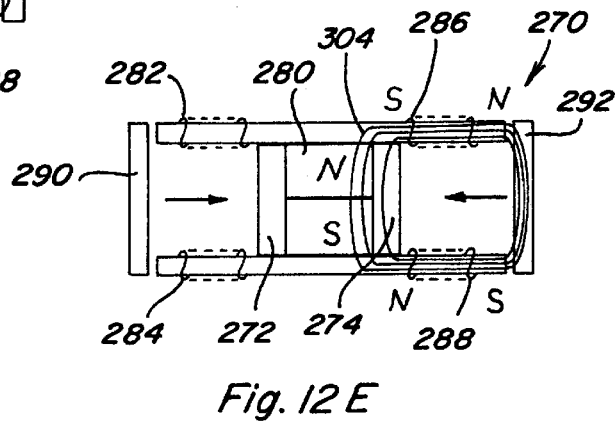
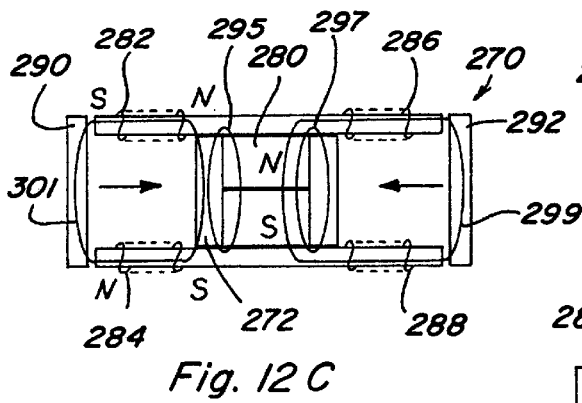
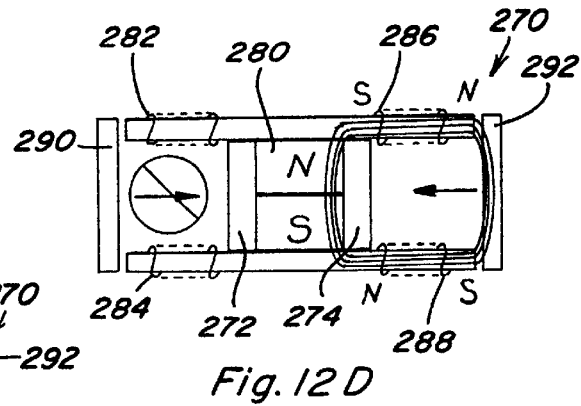
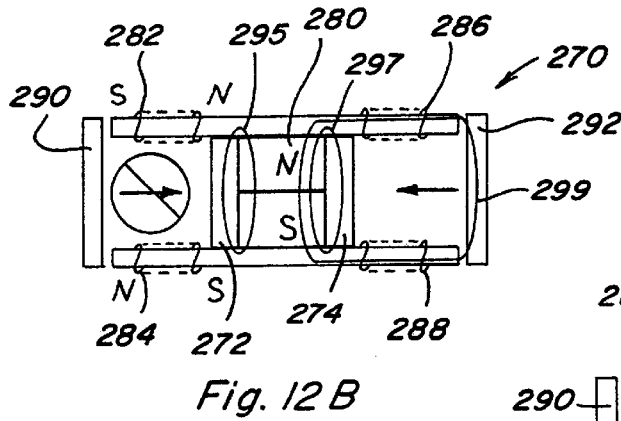
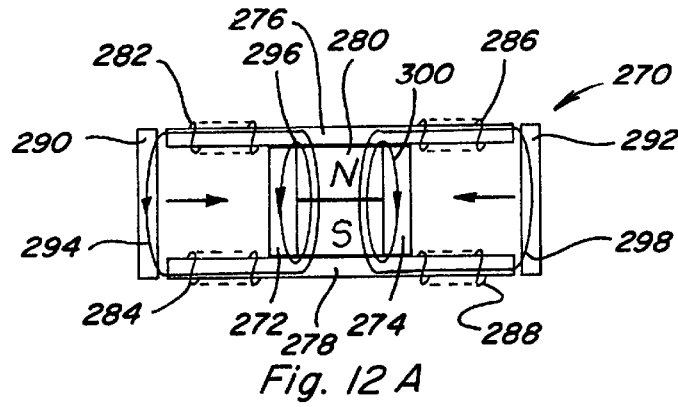


Fig. 11F





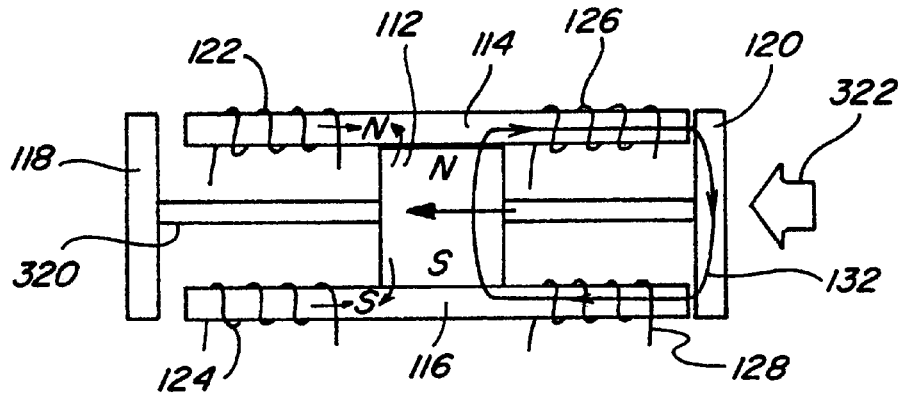


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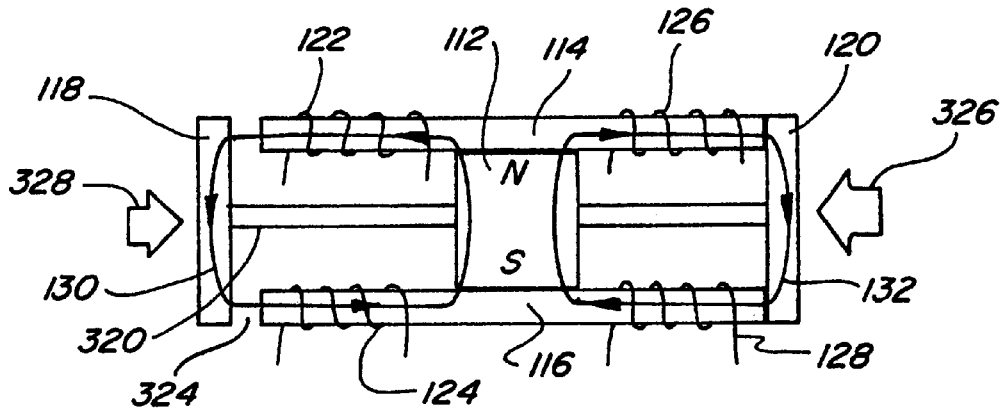


Fig. 13 B

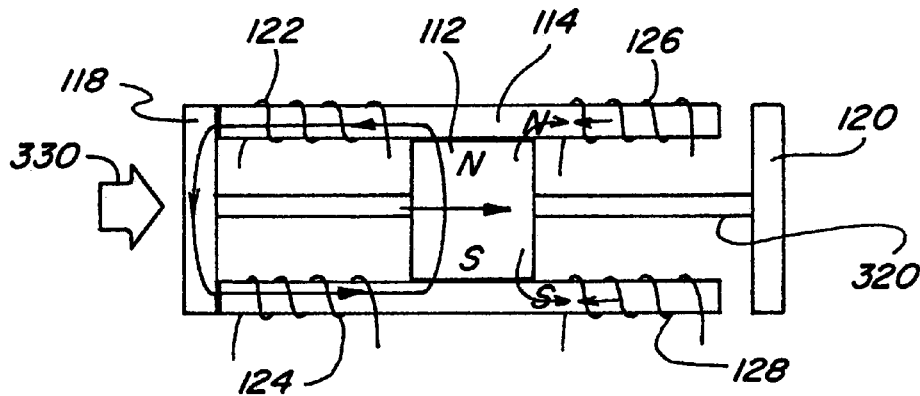


Fig. 13 C

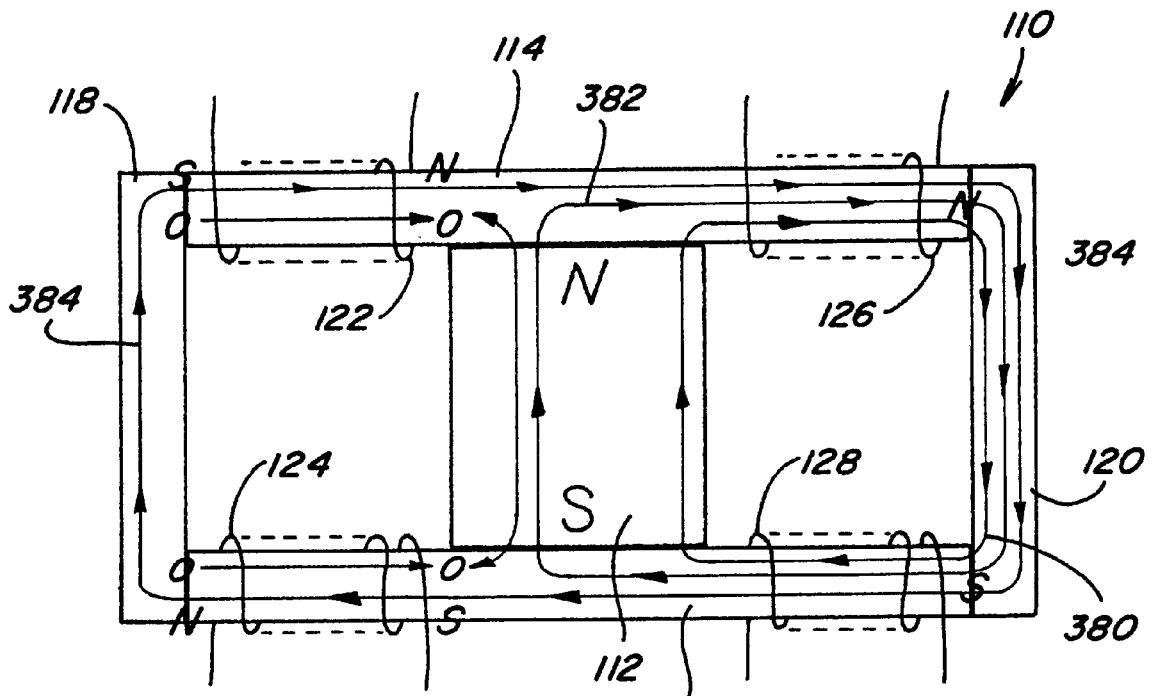


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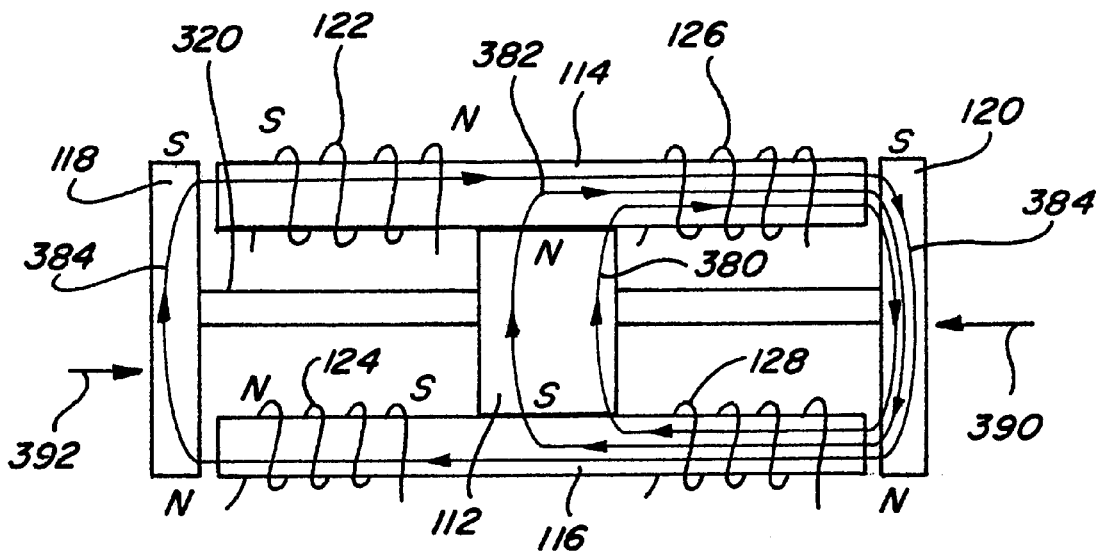


Fig. 16 A

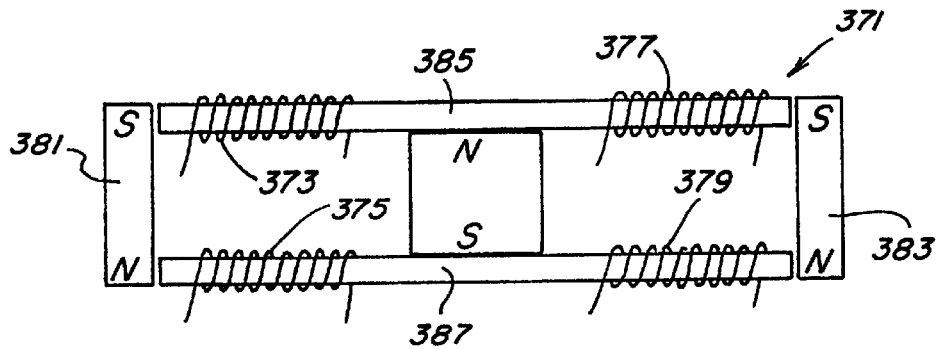


Fig. 16 B

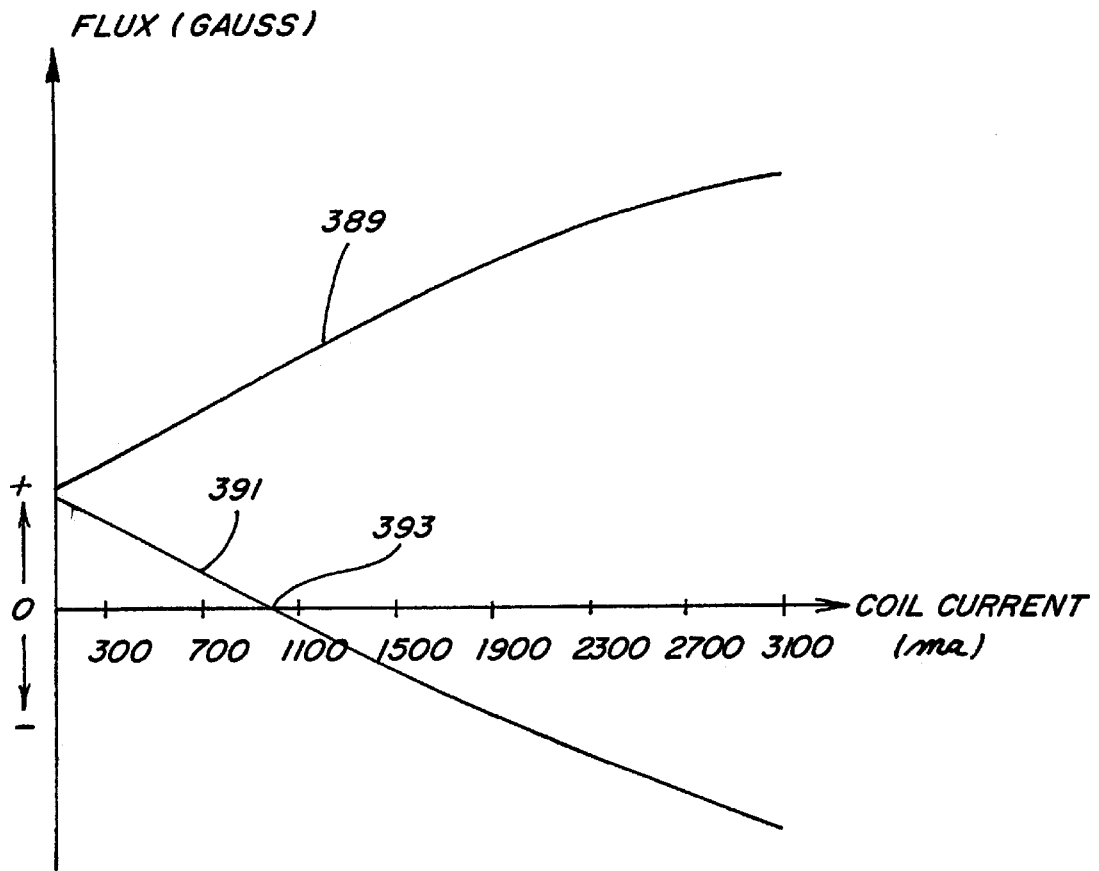


Fig. 16 C

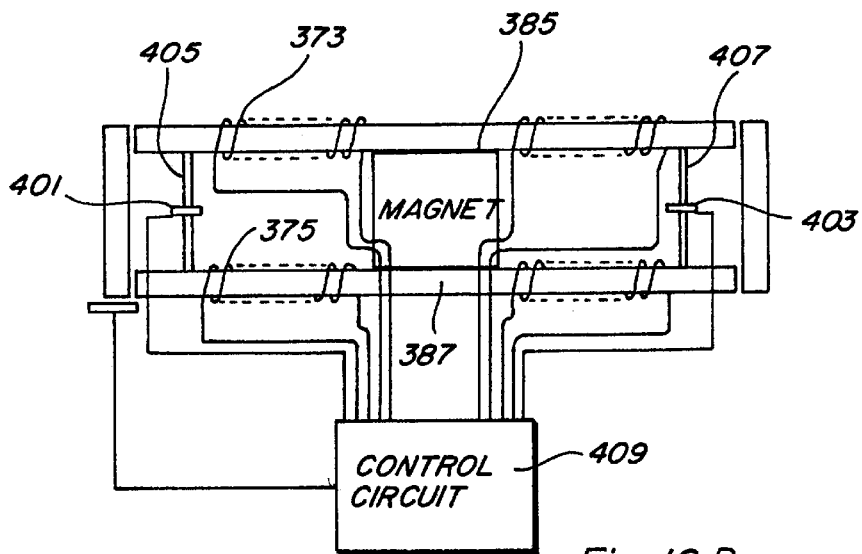


Fig. 16 D

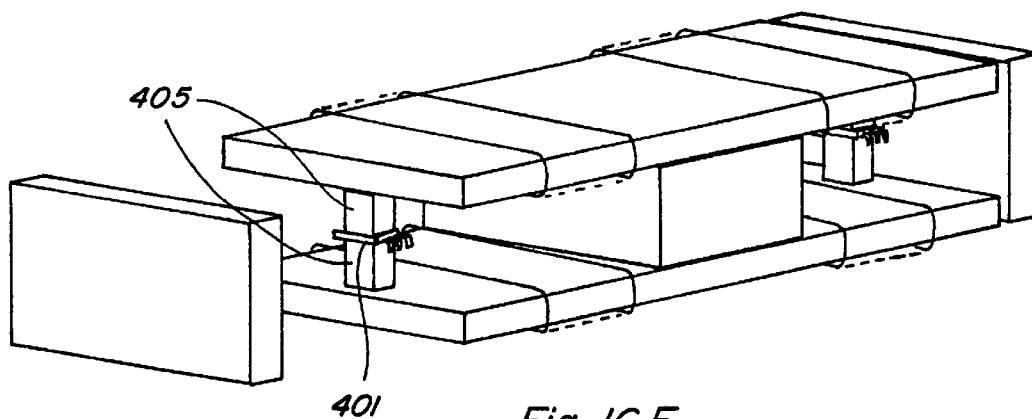


Fig. 16 E

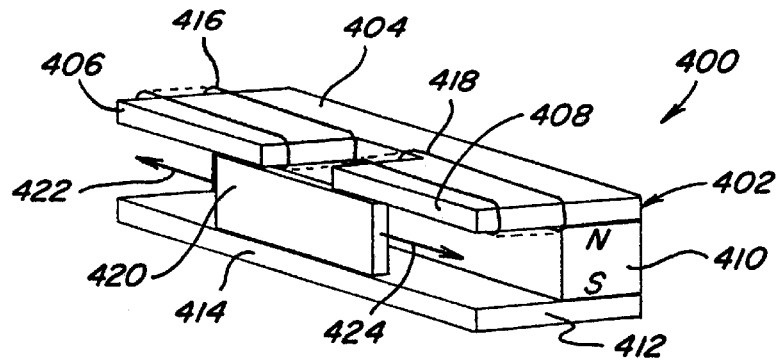


Fig. 17A

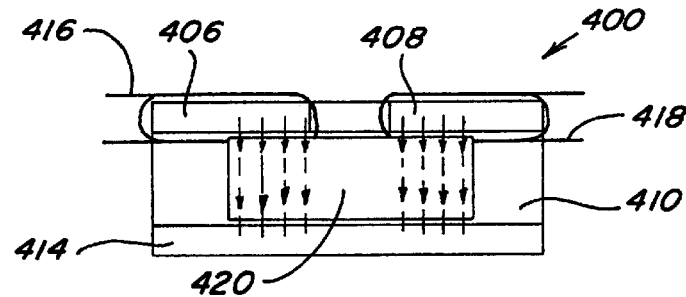


Fig. 17B

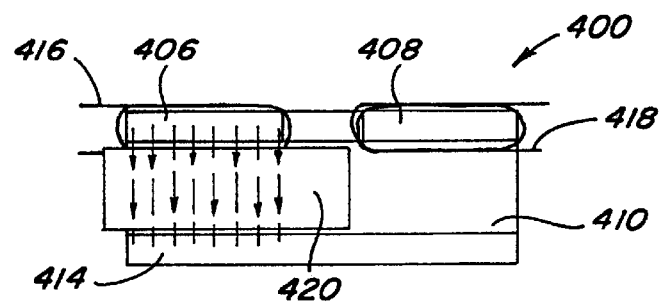


Fig. 17 C

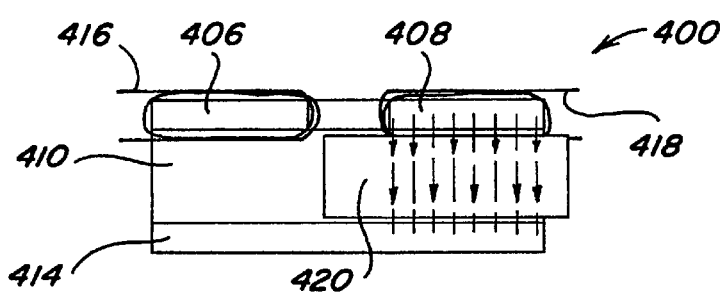


Fig. 17 D

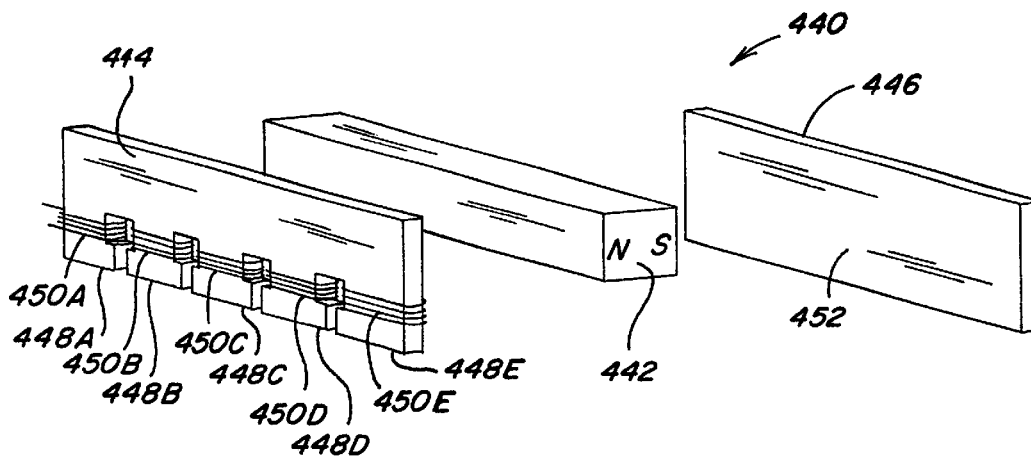


Fig. 18 A

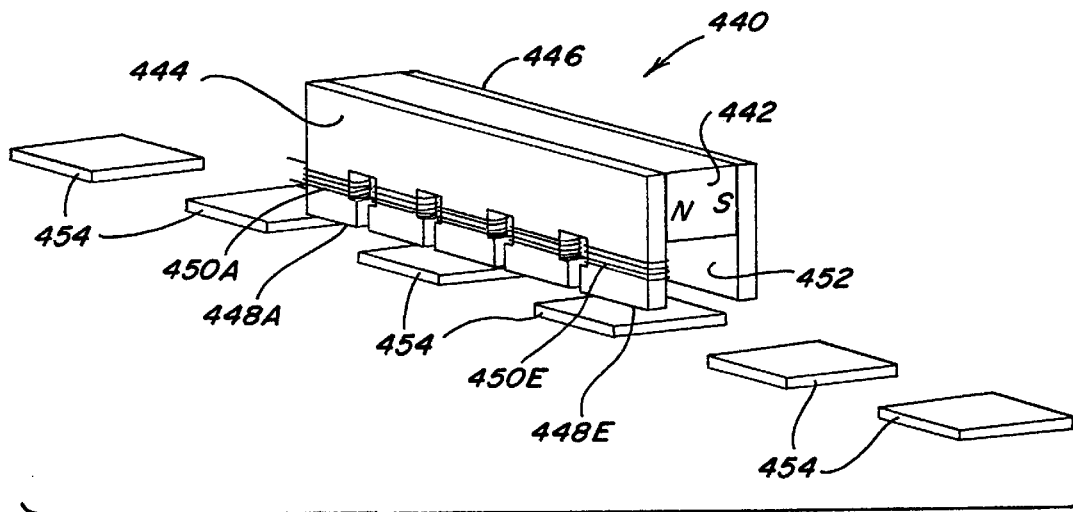


Fig. 18B

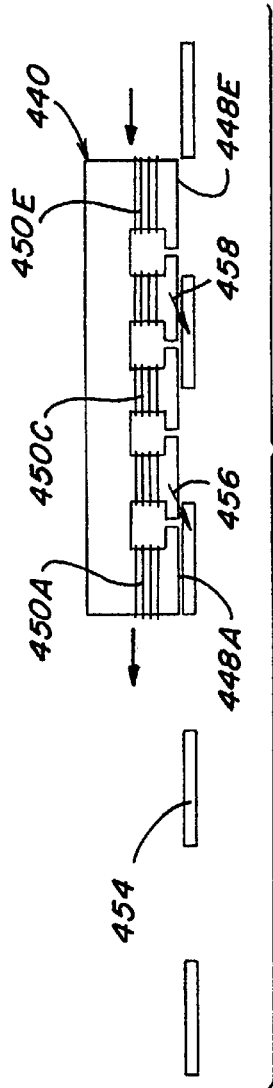


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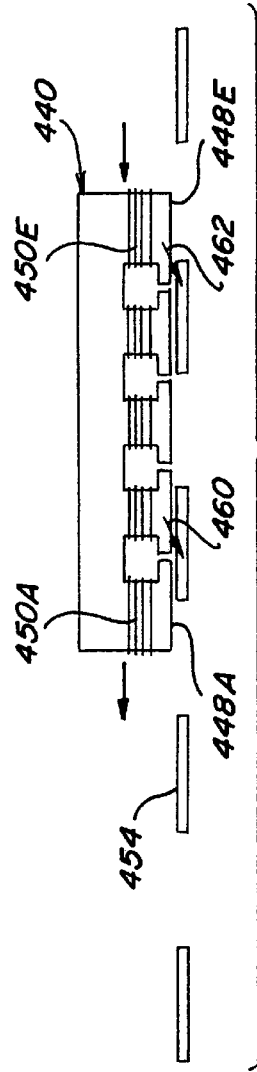


Fig. 18D

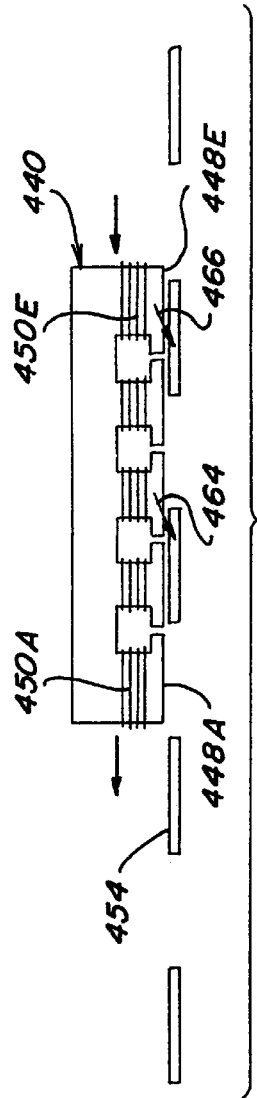


Fig. 18E



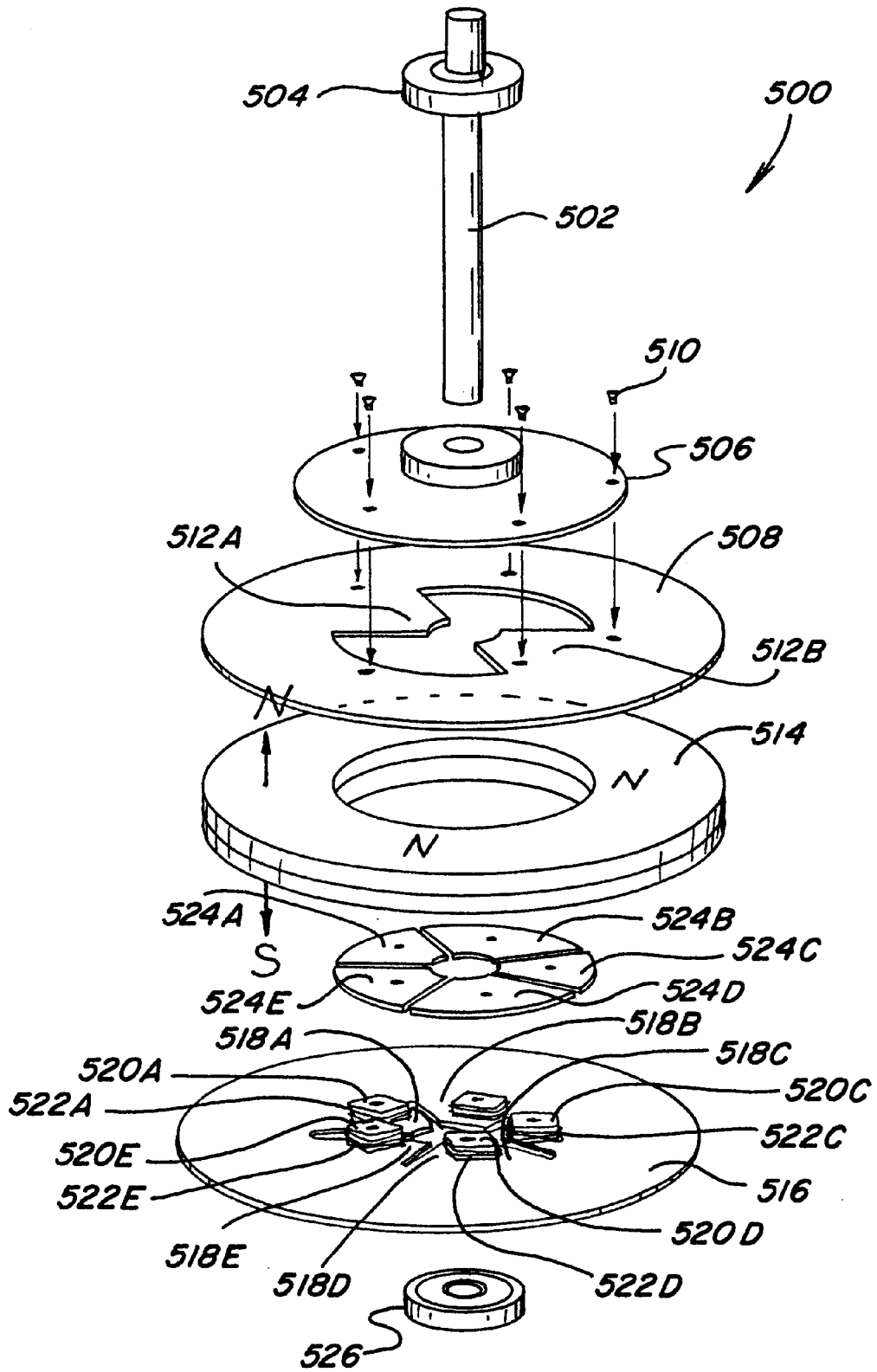


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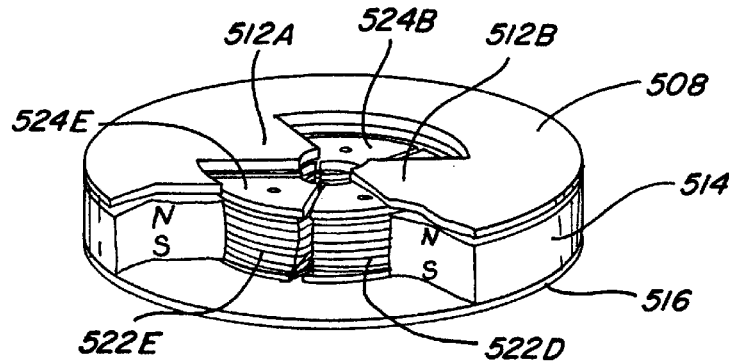


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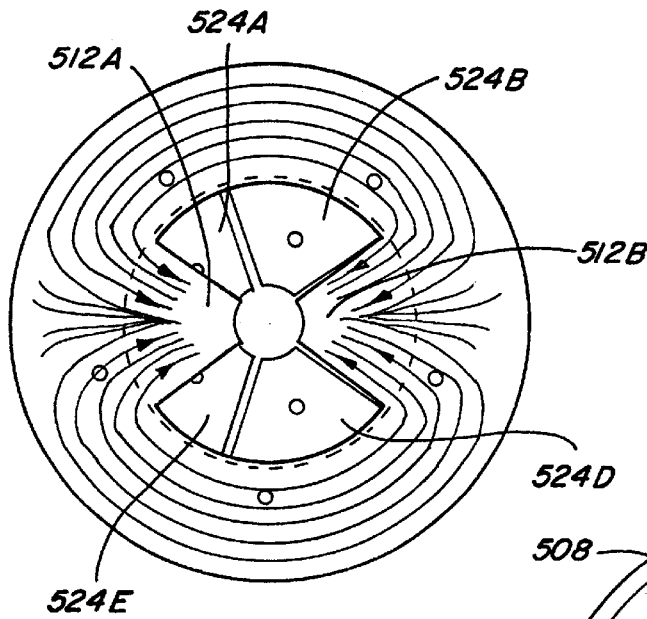


Fig. 21A

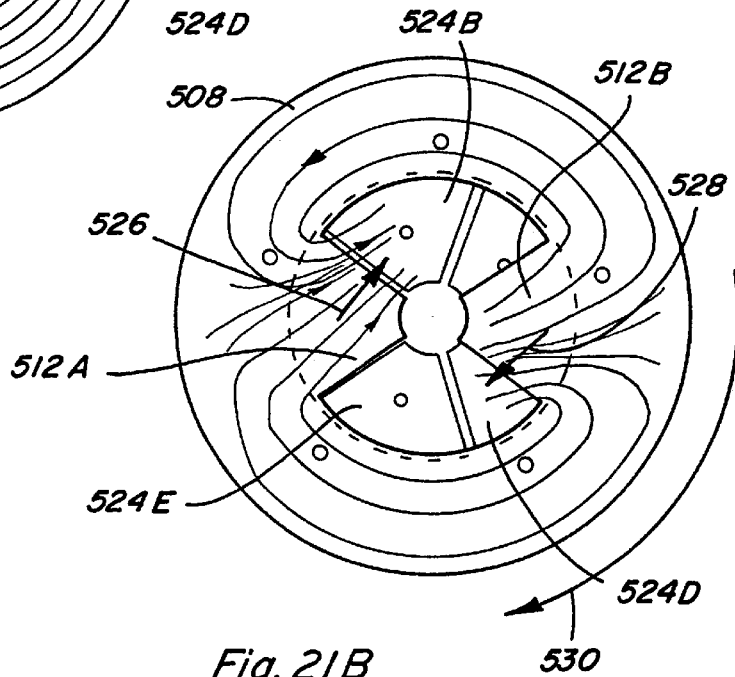


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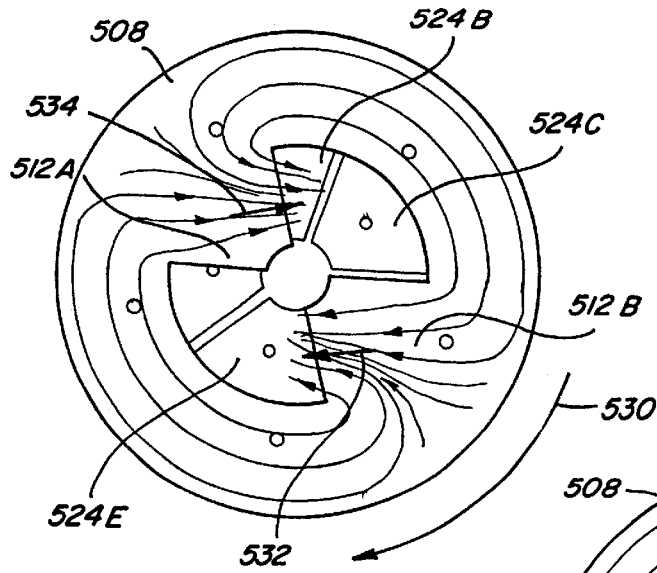


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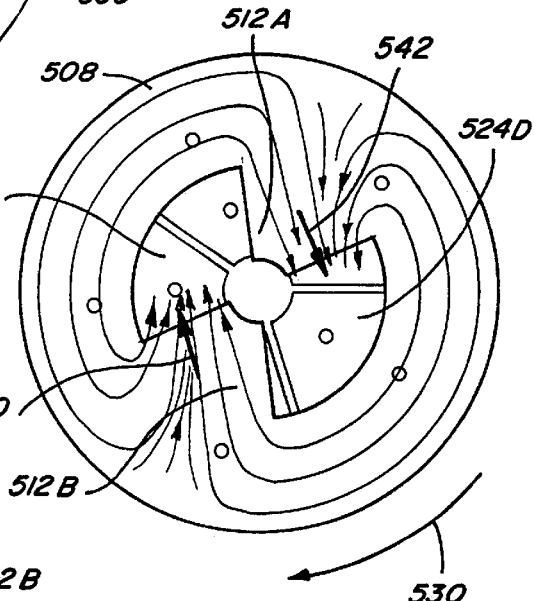


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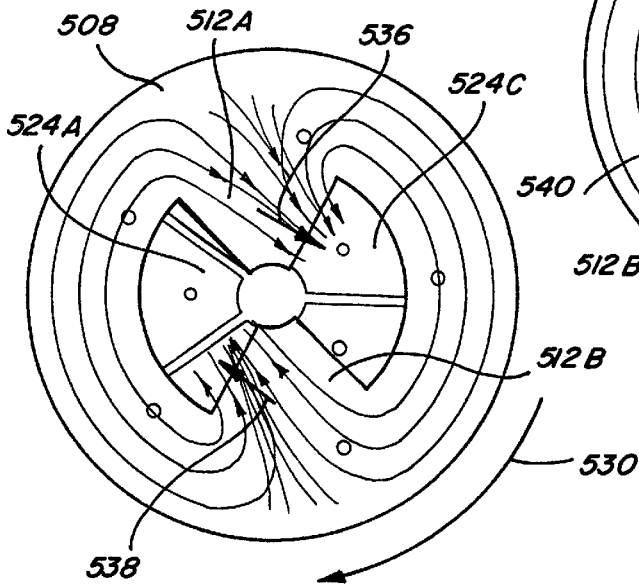


Fig. 21D



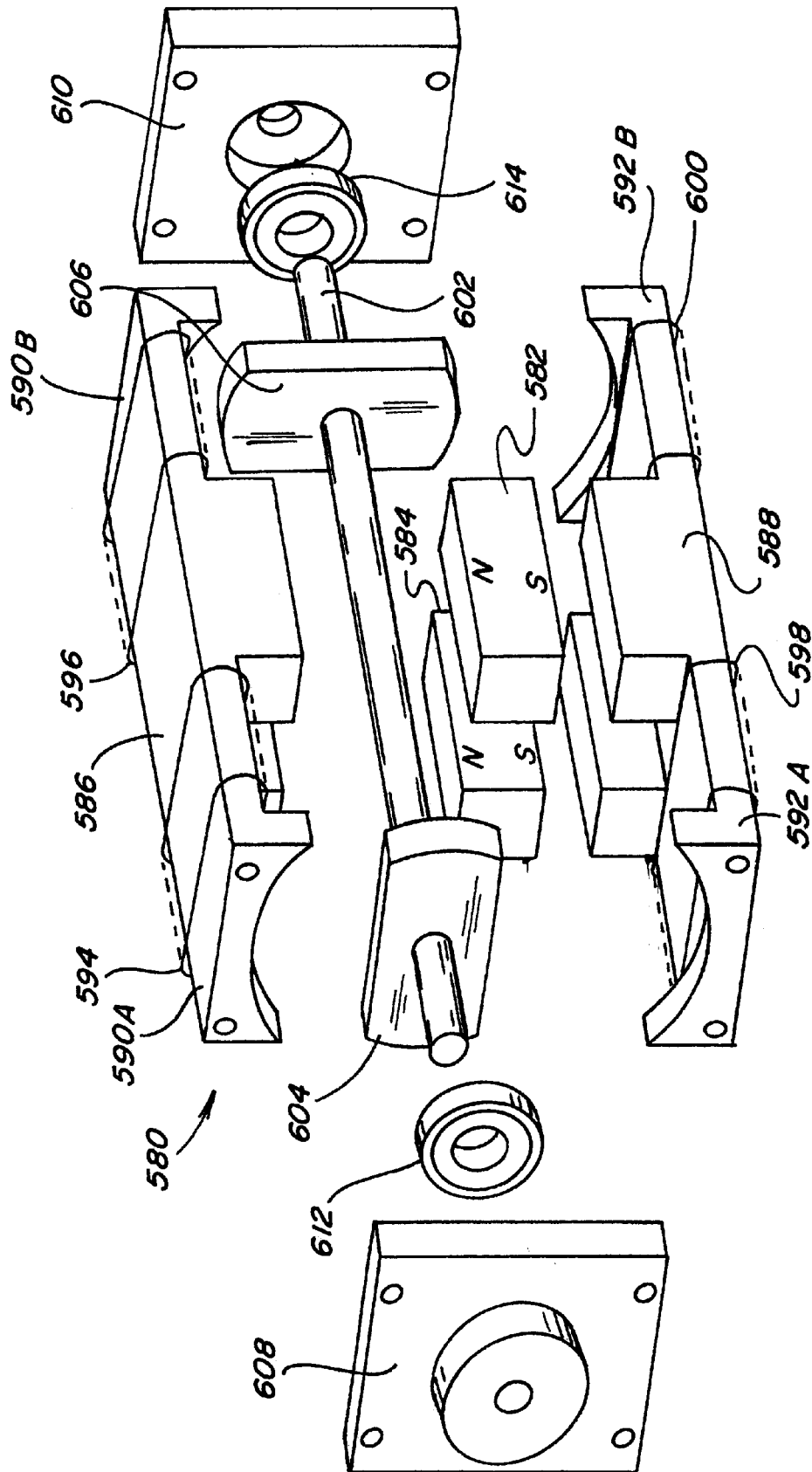


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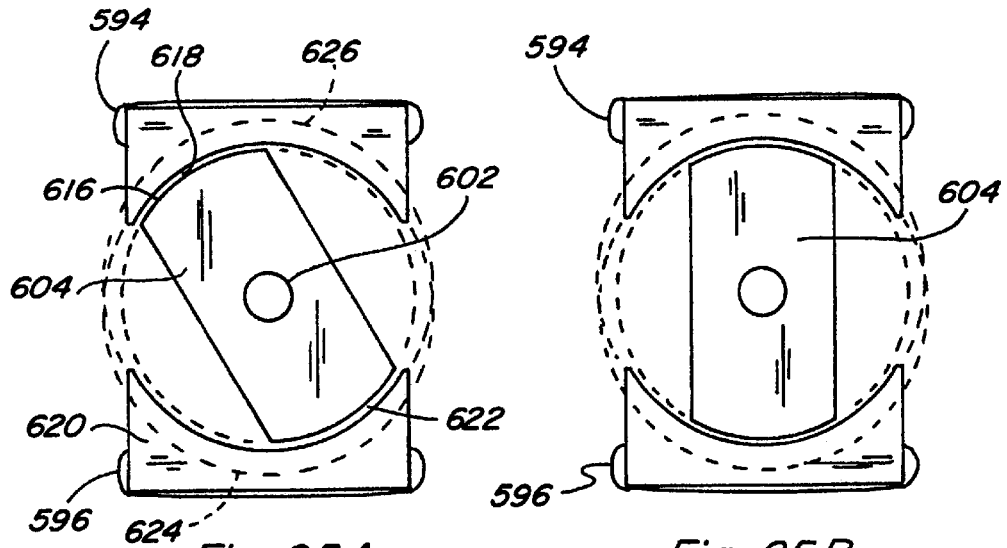


Fig. 25A

Fig. 25B

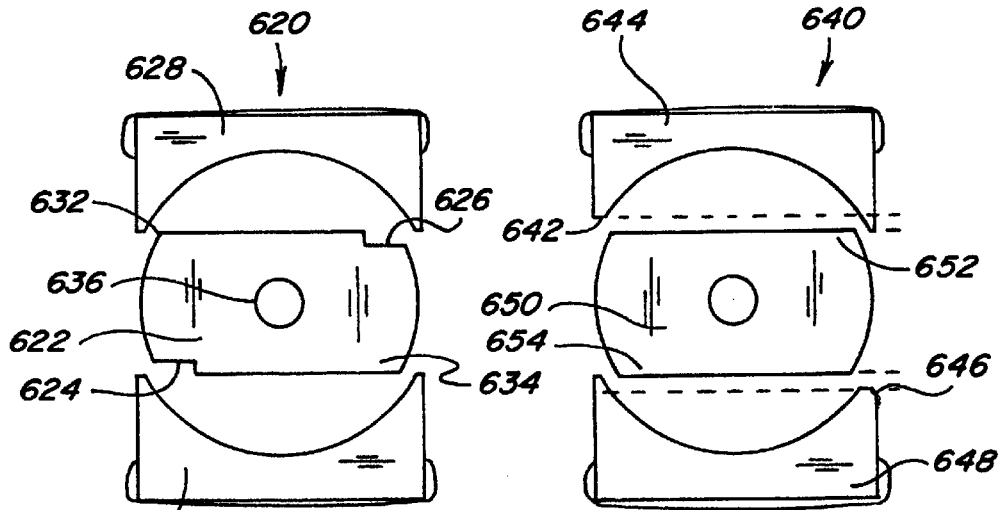


Fig. 26

Fig. 27

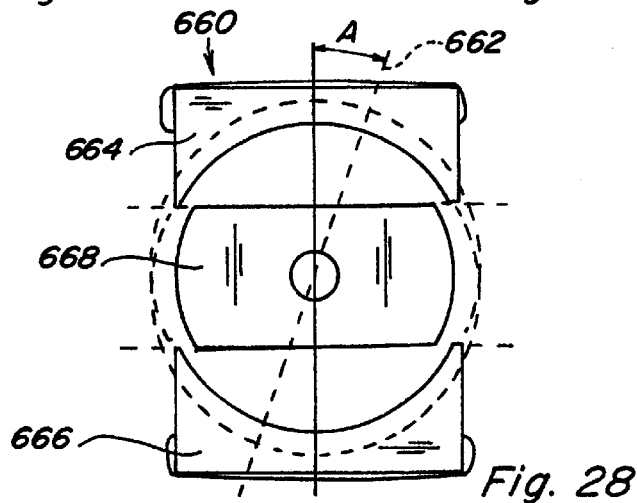


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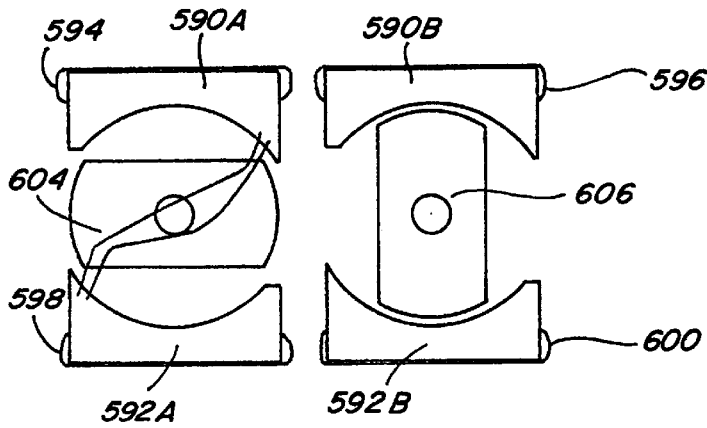


Fig. 29A

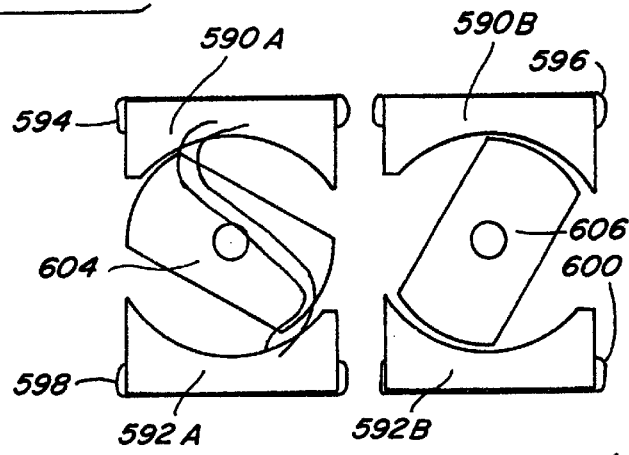


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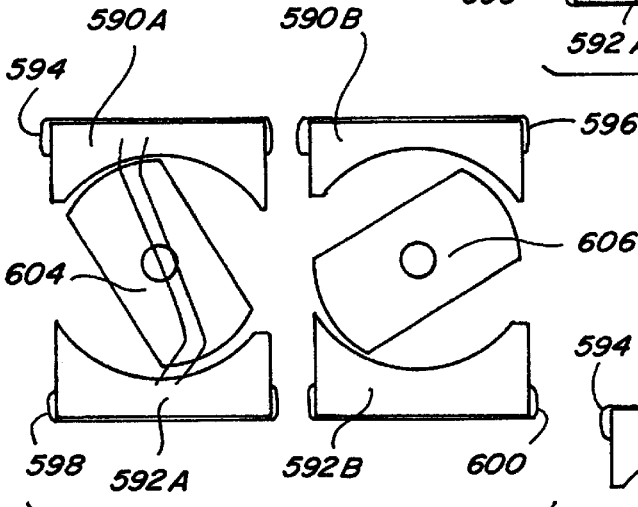


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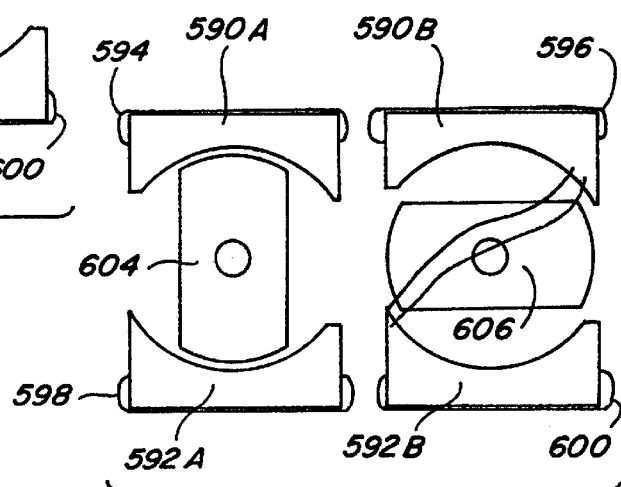
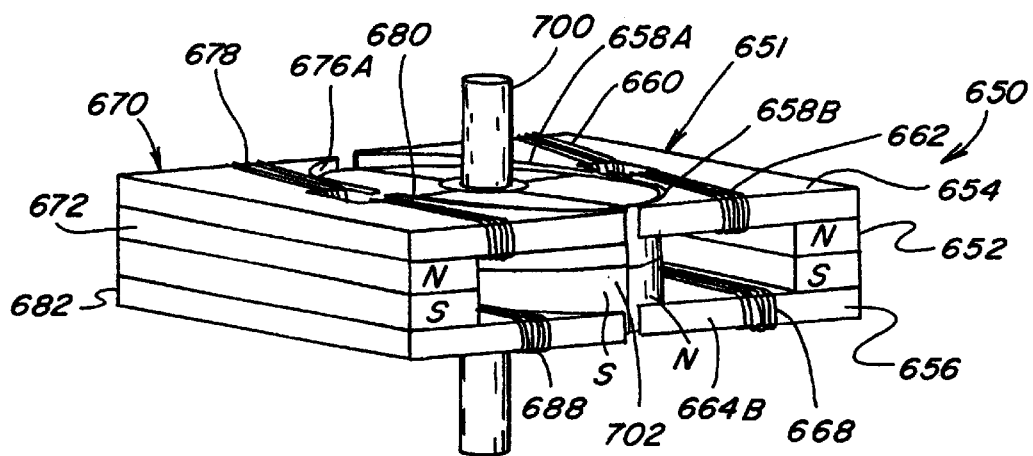
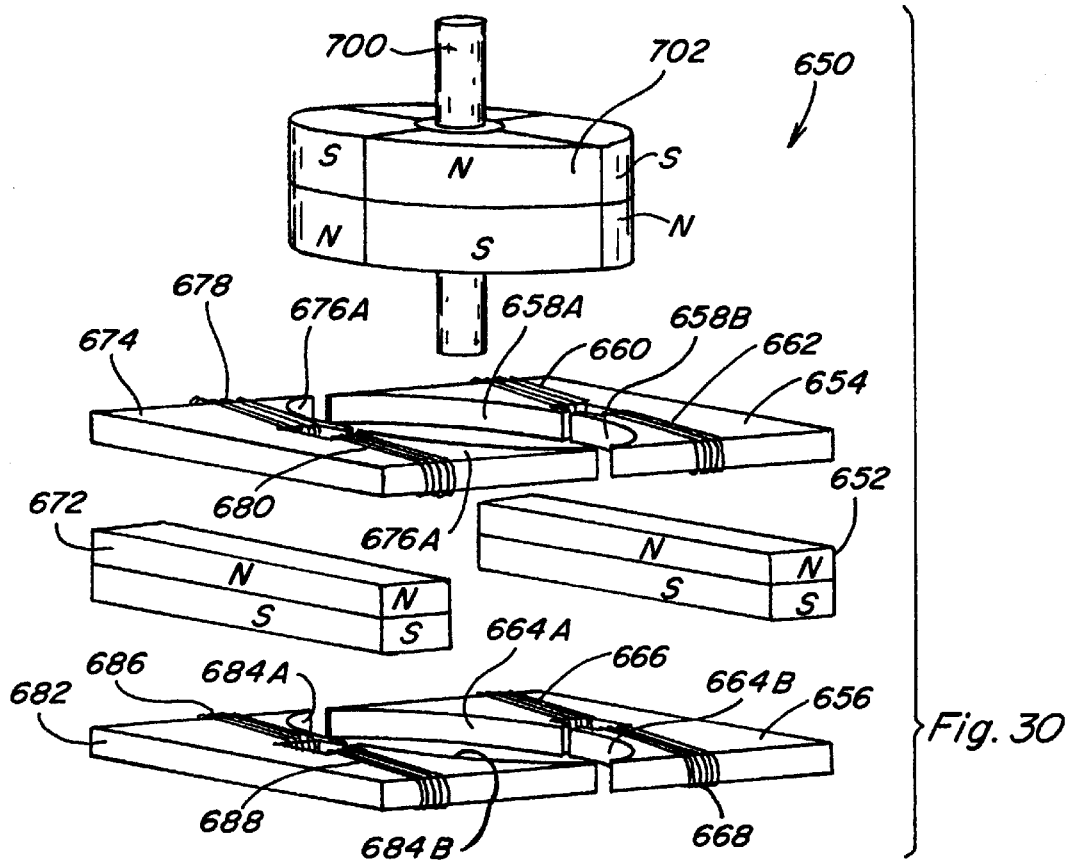


Fig. 29D





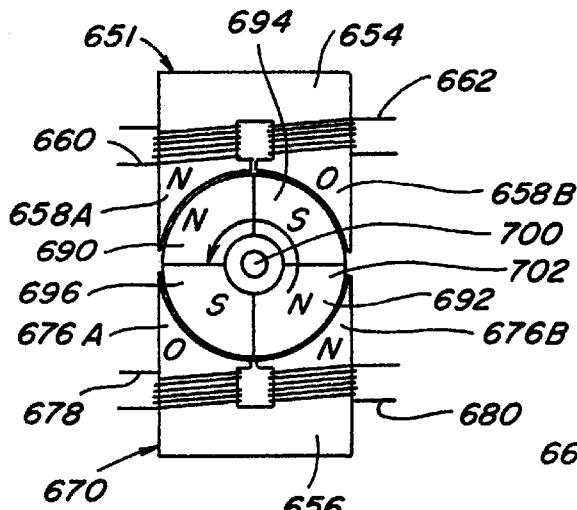


Fig. 32A

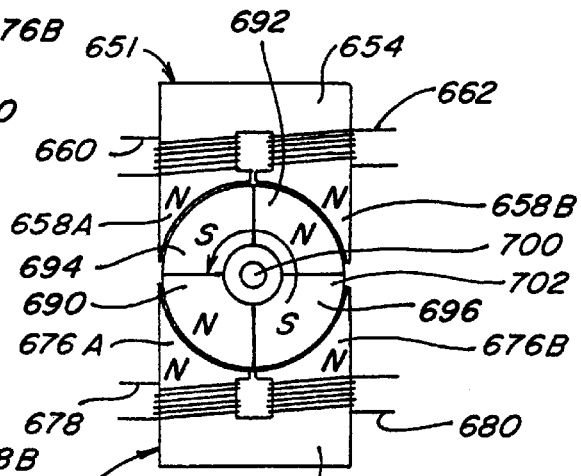


Fig. 32 B

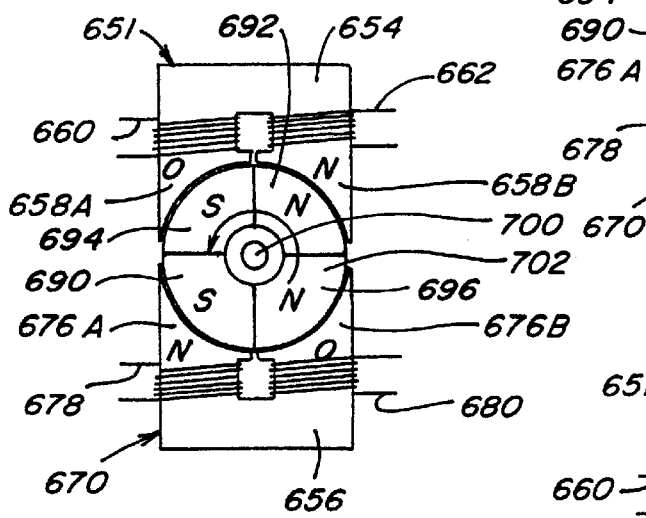


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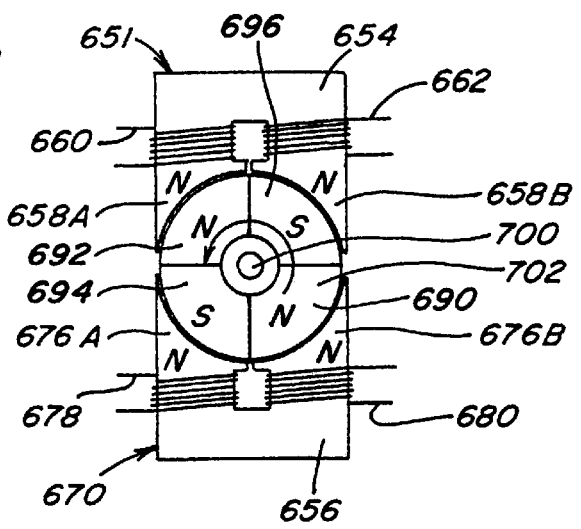


Fig. 32 D

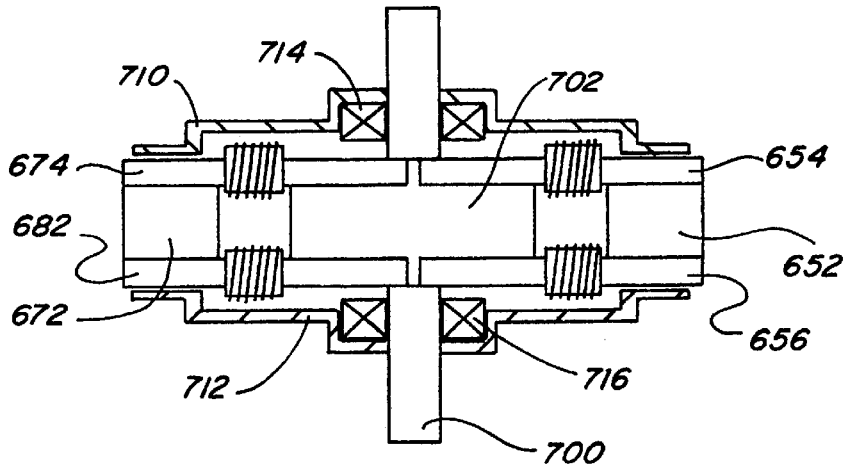


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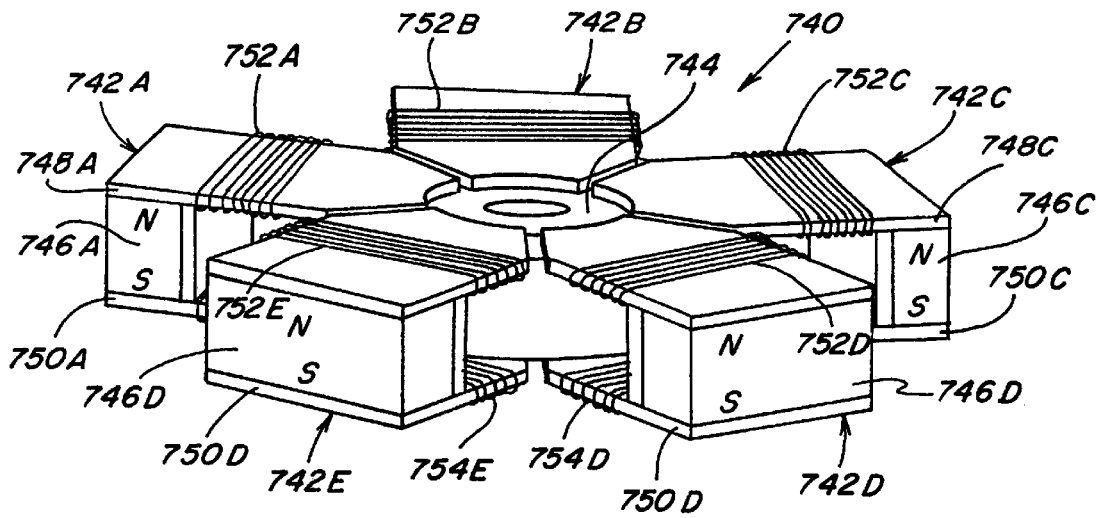


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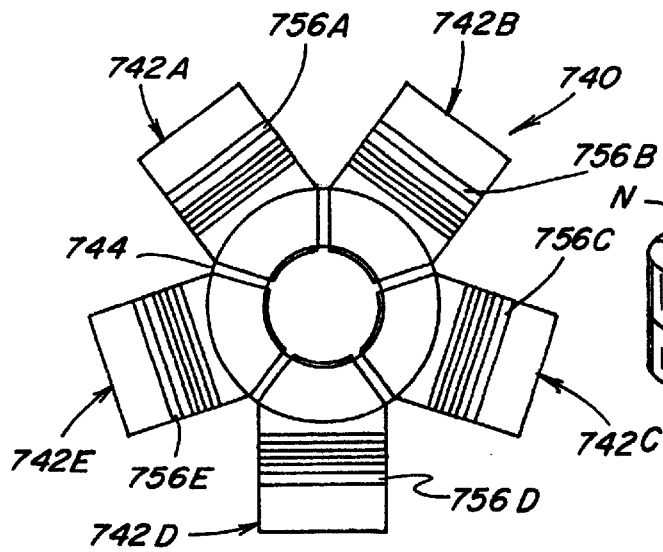


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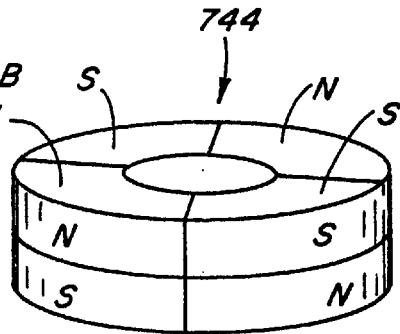


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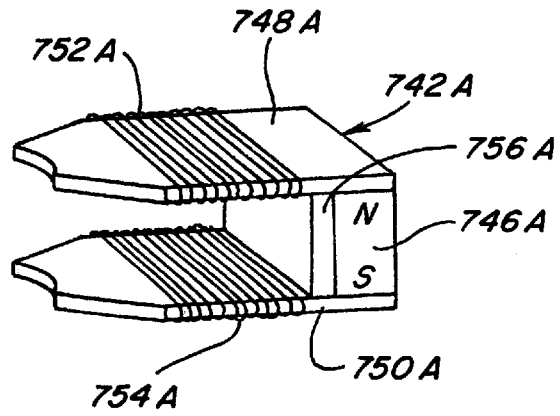


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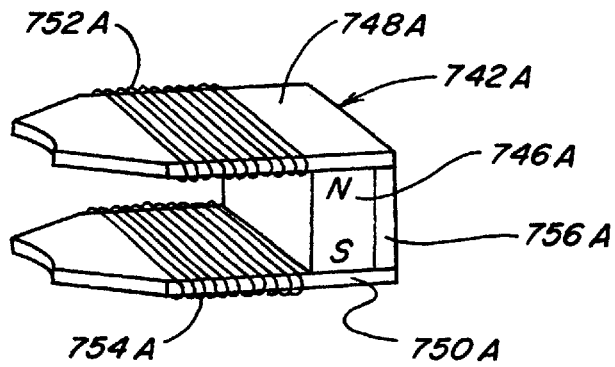
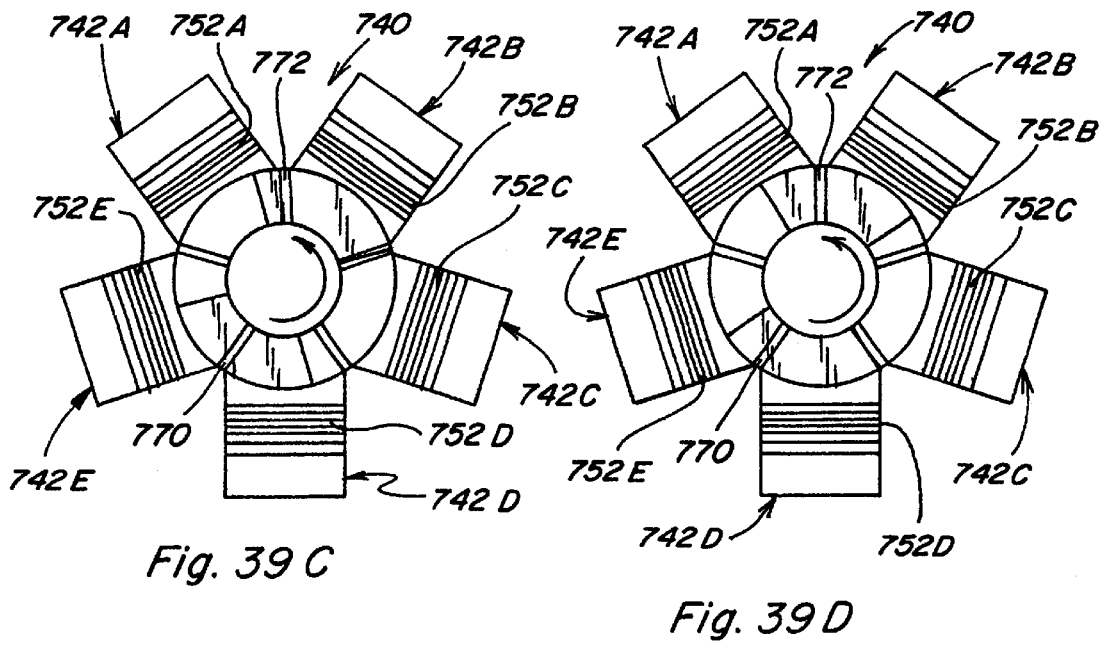
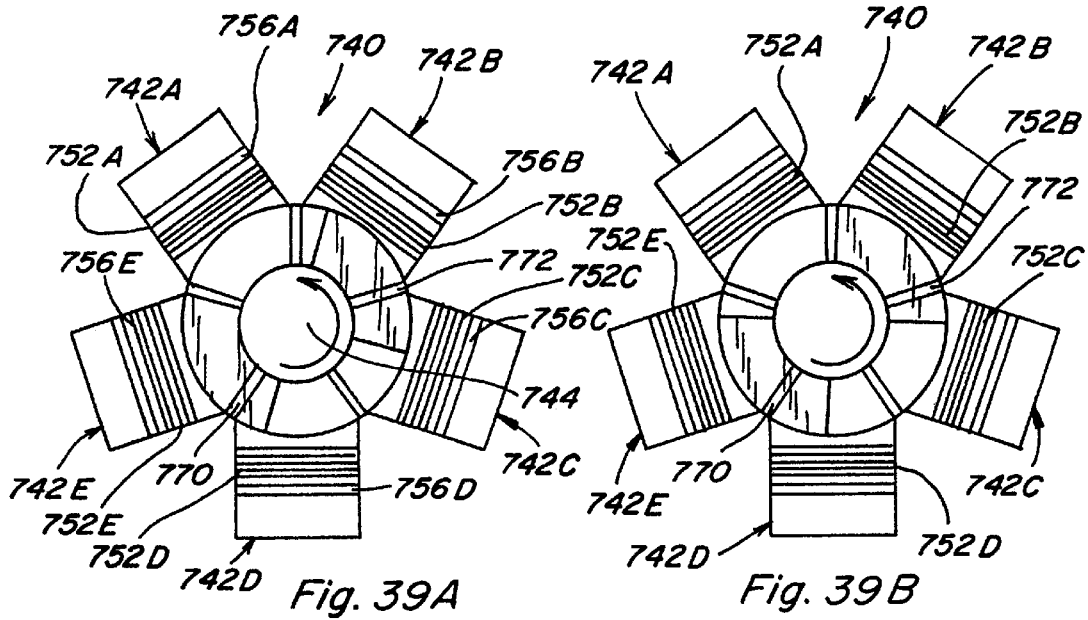


Fig. 38



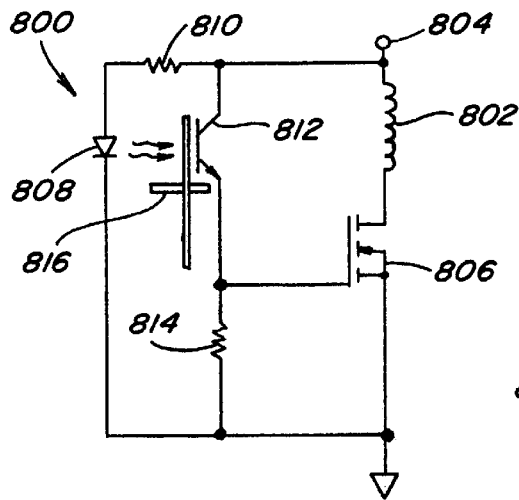


Fig. 40

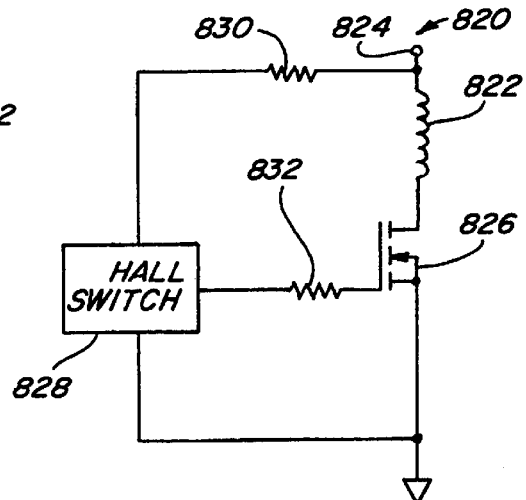


Fig. 41

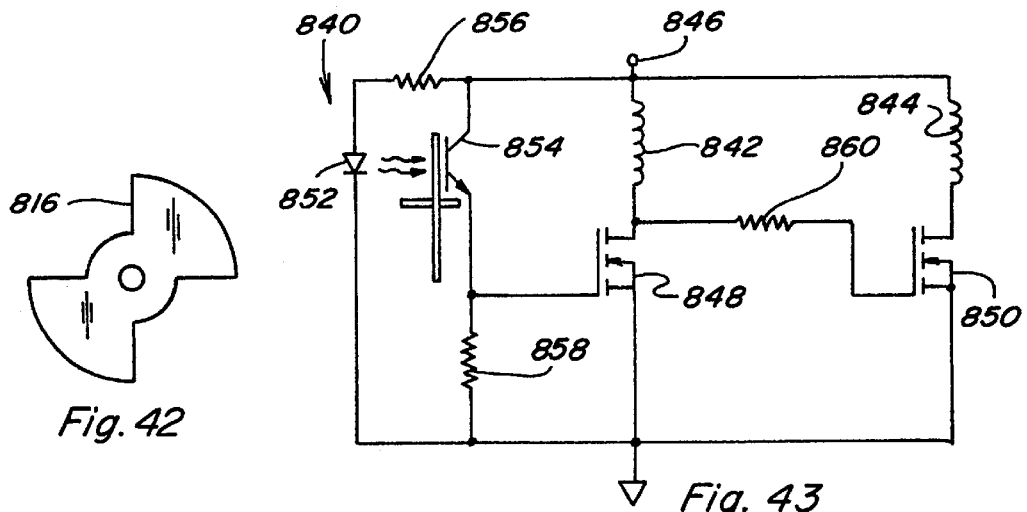


Fig. 42

Fig. 43

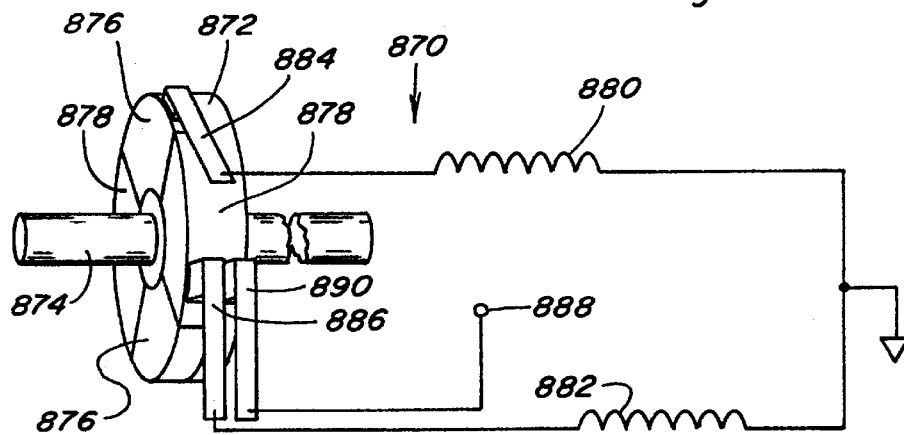


Fig. 44

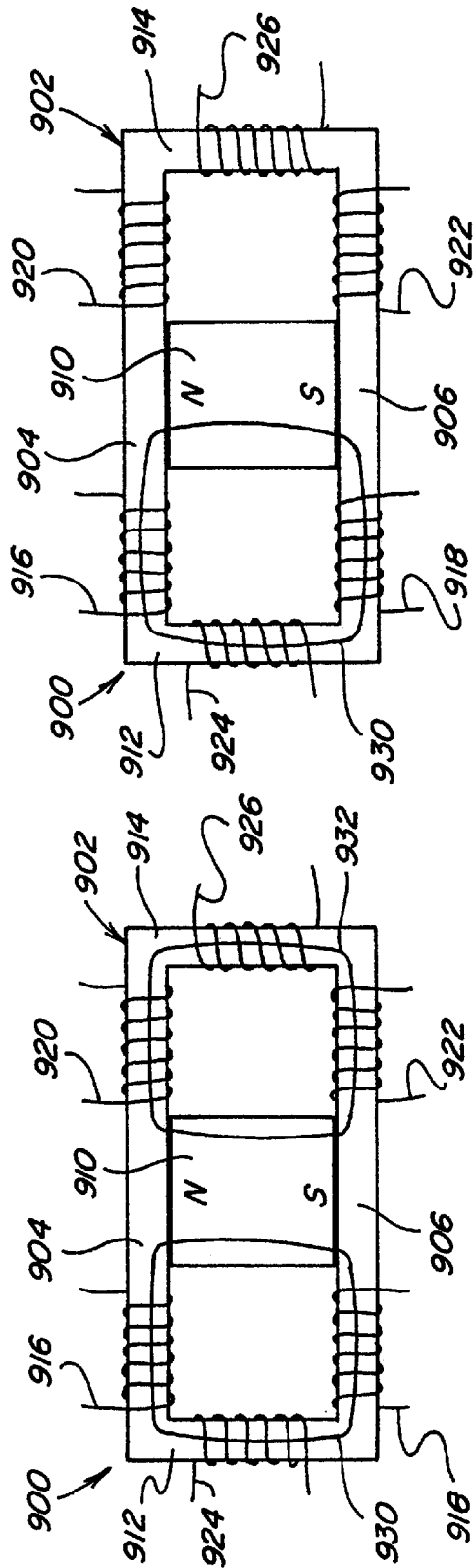


Fig. 45A

Fig. 45B

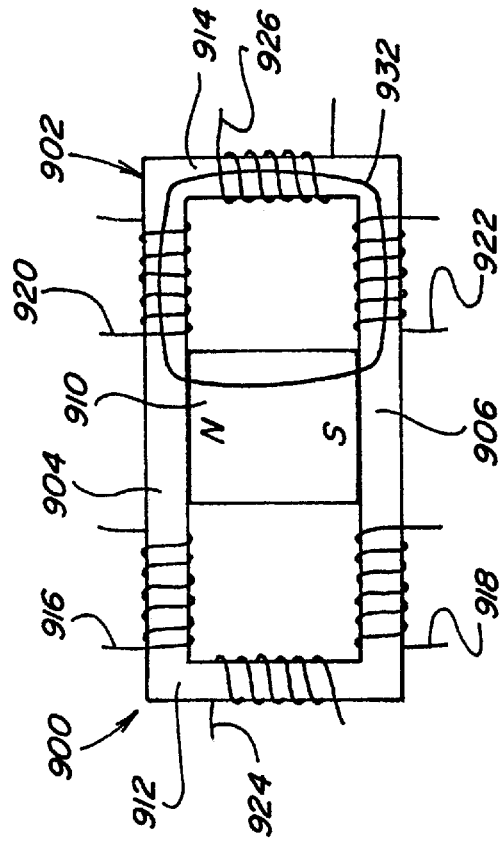


Fig. 45C

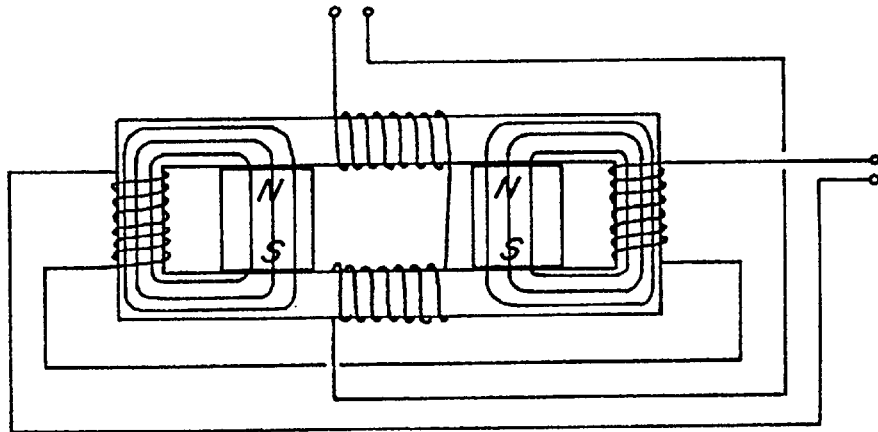


Fig. 45 X

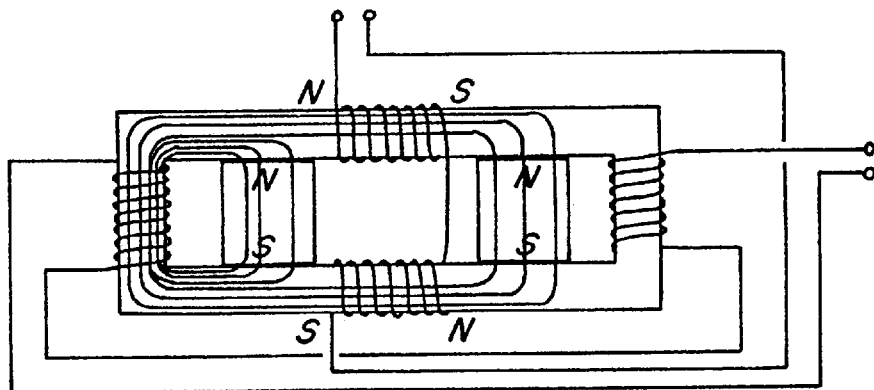


Fig. 45 Y

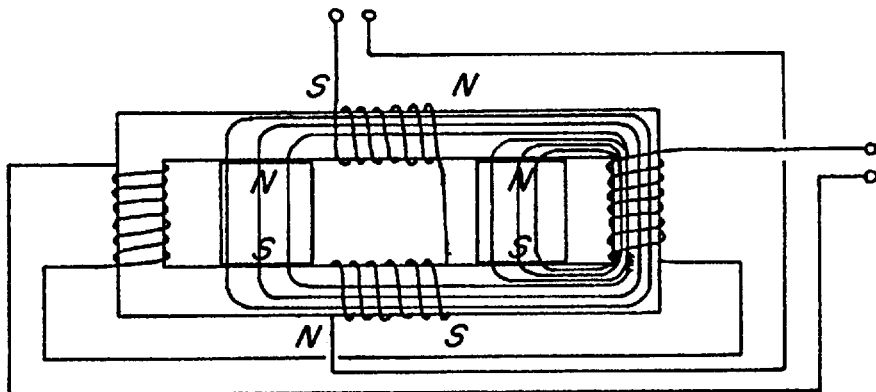


Fig. 45 Z

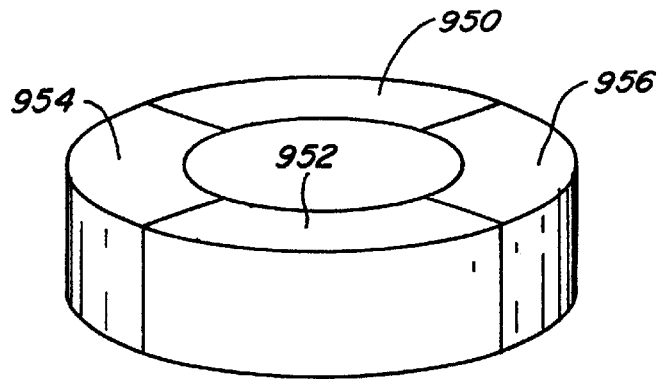


Fig. 46

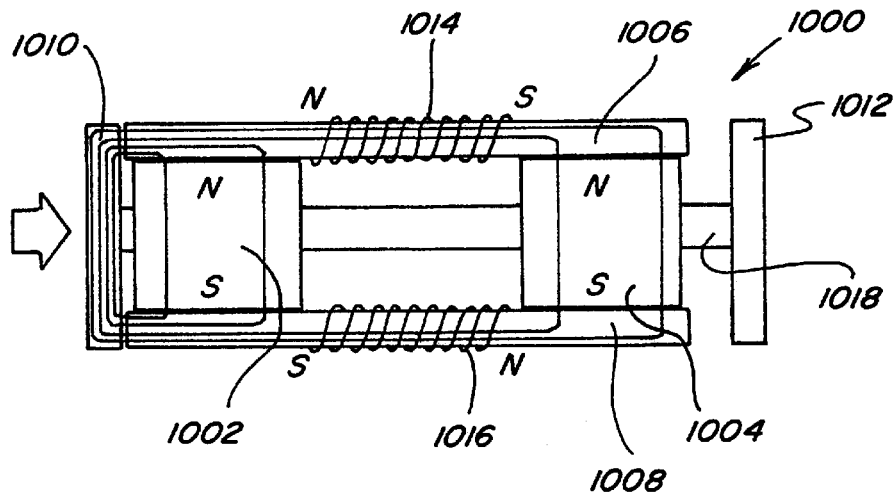


Fig. 47

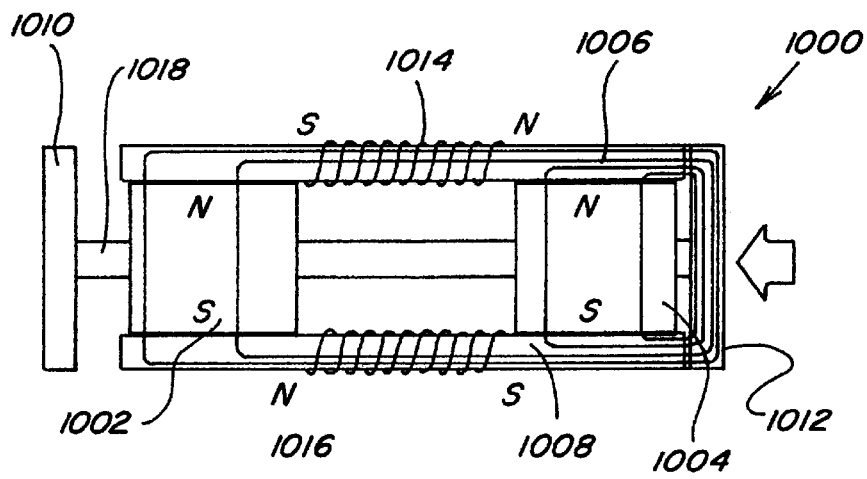


Fig. 48



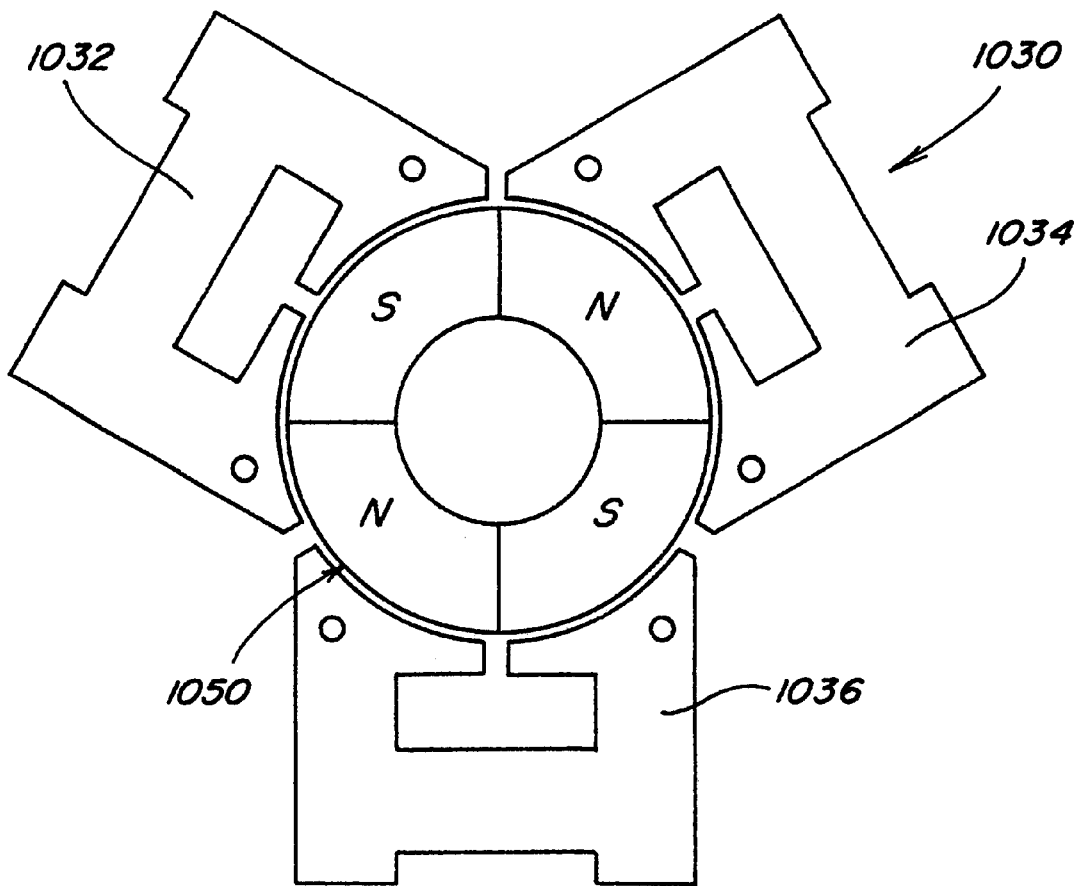


Fig. 49

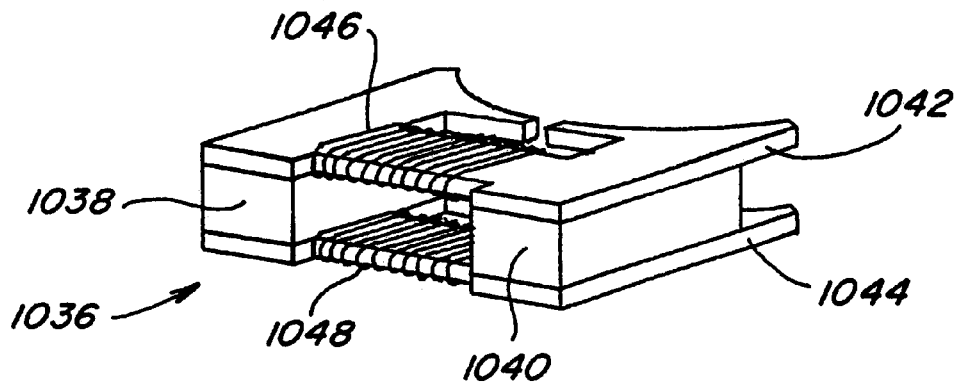


Fig. 50

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

## FIELD OF THE INVENTION

This invention relates generally to permanent magnet devices and more particularly, to a permanent magnet control component in which the flow of flux from a permanent magnet is controlled between two or more flux paths by utilizing timed delivery of electrical signals through one or more coils placed along at least one of the flux paths. Such permanent magnet control components may take on a variety of configurations facilitating use of such components in a variety of applications including applications involving the production of reciprocating, linear, and rotary motion and power conversion. Several novel permanent magnet rotary motion devices of motor constructions which operate by controlling the path of magnetic flux from one or more permanent magnets are described, such permanent magnet rotary motor constructions having increased efficiency and more desirable torque characteristics as compared to many currently used motors.

## BACKGROUND OF THE INVENTION

Magnetic force of attraction is commonly used in a variety of types of permanent magnet devices including both linear and rotary motors. In the field of such permanent magnet devices there is a continuous pursuit of increased efficiency and reduced complexity.

Accordingly, an object of the present invention is to provide a permanent magnet control component in which the path of a given level of permanent magnet flux can be controlled by a lesser level of electromagnetic flux.

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

Still another object of the present invention is to provide permanent magnet control components and motor constructions in which flux path control is provided by energizing an electromagnet to oppose the magnetic flux of one or more permanent magnets.

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

Yet another object of the present invention is to provide permanent magnet motor constructions with improved operating characteristics.

## SUMMARY OF THE INVENTION

These and other objects of the invention are attained by an apparatus which, in one aspect, is a permanent magnet device, comprising a permanent magnet having north and south pole faces, a first pole piece, a second pole piece, a first control coil, a second control coil, and circuit means, the first pole piece positioned adjacent the north pole face of the permanent magnet and including a first path portion, a second path portion and a third portion, the first path portion extending beyond a perimeter of the north pole face and the second path portion extending beyond the perimeter of the

north pole face to define first and second flux paths for magnetic flux emanating from the north pole face of the permanent magnet, the first path portion of the first pole piece connected to the second path portion of the first pole piece by the third portion which extends across the north pole face of the permanent magnet, the second pole piece positioned adjacent the south pole face and including a first path portion and a second path portion, the first path portion extending beyond a perimeter of the south pole face and substantially aligned with the first path portion of the first pole piece, the second path portion extending beyond the perimeter of the south pole face and substantially aligned with the second path portion of the first pole piece, the first control coil positioned around the first path portion of the first pole piece, the second control coil positioned around the second path portion of the first pole piece, the circuit means connected to each of the first control coil and the second control coil to alternately energize the first coil and the second coil in a timed sequential manner.

Another aspect of the present invention provides a method for controlling the path of magnetic flux from a permanent magnet which involves placing a first pole piece adjacent a first pole face of the permanent magnet so as to have at least first and second path portions extending beyond a perimeter of the first pole face. A second pole piece is placed adjacent a second pole face of the permanent magnet so as to include at least one portion which substantially aligns with the first and second path portions of the first pole piece. A first control coil is placed along and around the first path portion of the first pole piece and a second control coil is placed along and around the second path portion of the first pole piece. The first control coil is repeatedly energized in a permanent magnet magnetic flux opposing manner so as to prevent magnetic flux of the permanent magnet from traversing the first path portion of the first pole piece, and the second control coil is repeatedly energized in a permanent magnet magnetic flux opposing manner so as to prevent magnetic flux of the permanent magnet from traversing the second path portion of the first pole piece.

Yet another aspect of the present invention provides a method for controlling the path of magnetic flux from a permanent magnet by placing a first pole piece adjacent a first pole face of the permanent magnet so as to have at least first and second path portions extending beyond a perimeter of the first pole face. A second pole piece is placed adjacent a second pole face of the permanent magnet so as to include at least one portion which substantially aligns with the first and second path portions of the first pole piece. A first control coil is placed along and around the first path portion of the first pole piece, and a second control coil is placed along and around the second path portion of the first pole piece. The following steps are alternately performed in a repeated manner:

- (i) energizing the first control coil in a permanent magnet magnetic flux aiding manner so as to couple with substantially all magnetic flux of the permanent magnet such that substantially no magnetic flux of the permanent magnet traverses the second path portion of the first pole piece when the first control coil is so energized; and
- (ii) energizing the second control coil in a permanent magnet magnetic flux opposing manner so as to couple with substantially all magnetic flux of the permanent magnet such that substantially no magnetic flux of the permanent magnet traverses the first path portion of the first pole piece when the second control coil is so energized.

A further aspect of the present invention provides method for controlling the path of magnetic flux from a permanent magnet by placing a first pole piece adjacent a first pole face of the permanent magnet so as to have at least first and second path portions extending beyond a perimeter of the first pole face, and placing a second pole piece adjacent a second pole face of the permanent magnet so as to include at least one portion which substantially aligns with the first and second path portions of the first pole piece. A first control coil is placed along and around the first path portion of the first pole piece, and a second control coil is placed along and around the second path portion of the first pole piece. The following steps are alternately performed in a repeated manner:

- (i) energizing the first control coil in a permanent magnet magnetic flux aiding manner so as to couple with substantially all magnetic flux of the permanent magnet such that substantially no magnetic flux of the permanent magnet traverses the second path portion of the first pole piece when the first control coil is so energized; and
- (ii) energizing the second control coil in a permanent magnet magnetic flux opposing manner so as to couple with substantially all magnetic flux of the permanent magnet such that substantially no magnetic flux of the permanent magnet traverses the first path portion of the first pole piece when the second control coil is so energized.

#### BRIEF DESCRIPTION OF THE INVENTION

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, 10A–10H are perspective views of various embodiments of permanent magnet control components which include two or more magnetic flux paths;

FIGS. 11, 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. 12, 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–E are a side view of 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 movement thereof;

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;

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.

## DETAILED DESCRIPTION OF THE DRAWINGS

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 16, 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 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  $F_{T26}$  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  $F_{T54}$  can be determined as:

$$F_{T54}=(B/2)2A/\mu_0=B^2A/4\mu_0=F_{T26}/4.$$

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 B 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  $B_r$ , the flux density can only be increased from  $B_r$  to  $B_{max}$  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  $B_{max}$ . 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 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 positioned 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 **20** 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 618 includes a circumferential curvature 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 detecting 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/photoresistor 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 Conversion

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 posi-

tioned 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 alternatingly 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.

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 permanent magnet device, comprising a permanent magnet having north and south pole faces, a first pole piece, a second pole piece, a first control coil, a second control coil, and circuit means, the first pole piece positioned adjacent the north pole face of the permanent magnet and including a first path portion, a second path portion and a third portion, the first path portion extending beyond a perimeter of the north pole face in one direction and the second path portion extending beyond the perimeter of the north pole face in another direction to define first and second flux paths for magnetic flux emanating from the north pole face of the permanent magnet, the first path portion of the first pole piece connected to the second path portion of the first pole piece by the third portion which extends across the north pole face of the permanent magnet, the second pole piece positioned adjacent the south pole face and including a first path portion and a second path portion, the first path portion extending beyond a perimeter of the south pole face and substantially aligned with the first path portion of the first pole piece, the second path portion extending beyond the perimeter of the south pole face and substantially aligned with the second path portion of the first pole piece, the first

control coil positioned around the first path portion of the first pole piece, the second control coil positioned around the second path portion of the first pole piece, the circuit means connected to each of the first control coil and the second control coil to alternately energize the first coil and the second coil in a timed sequential manner.

2. The permanent magnet device as set forth in claim 1, wherein the first control coil and the second control coil are alternately energized in a permanent magnet magnetic flux aiding manner.

3. The permanent magnet device as set forth in claim 1, wherein the first control coil and the second control coil are alternately energized in a permanent magnet magnetic flux opposing manner.

4. The permanent magnet device as set forth in claim 1, further comprising a rotor member mounted on a shaft for rotation therewith, the rotor member sized, shaped, and positioned to extend substantially from the first path portion of the first pole piece to the first path portion of the second pole piece during at least some part of its rotation.

5. The permanent magnet device as set forth in claim 4, wherein the rotor member is formed by at least one permanent magnet.

6. The permanent magnet device as set forth in claim 1, wherein the second path portion of the first pole piece and the second path portion of the second pole piece are positioned alongside the first path portion of the first pole piece and the first path portion of the first pole piece.

7. The permanent magnet device as set forth in claim 1, further comprising a first bypass extending from the first path portion of the first pole piece to the first path portion of the second pole piece, one end of the first bypass positioned adjacent the first path portion of the first pole piece and between the permanent magnet and the first control coil.

8. The permanent magnet device as set forth in claim 6, further comprising a second bypass extending from the second path portion of the first pole piece to the second path portion of the second pole piece, one end of the second bypass positioned adjacent the second path portion of the first pole piece and between the permanent magnet and the second control coil.

9. The permanent magnet device as set forth in claim 1, further comprising a plurality of armatures arranged to define a path of movement, wherein the second path portion of the first pole piece and the second path portion of the second pole piece are positioned alongside the first path portion of the first pole piece and the first path portion of the second pole piece, and wherein all of such pole piece path portions include an end face positioned adjacent the path of movement defined by the plurality of armatures.

10. The permanent magnet device as set forth in claim 1, wherein the first control coil and the second control coil are simultaneously energized one in a permanent magnet magnetic flux aiding manner and one in a permanent magnet magnetic flux opposing manner.

11. The permanent magnet device as set forth in claim 1, further comprising two shaft connected armatures positionable adjacent the ends of the first and second pole pieces, wherein each of the armatures is formed by a permanent magnet.

12. The permanent magnet device of claim 1 further comprising a first fixed armature extending between the first path portion of the first pole piece to the first path portion of the second pole piece and a second fixed armature extending between the second path portion on the first pole piece to the second path portion of the second pole piece.

13. The permanent magnet device of claim 12 where a first secondary coil is wrapped around the first fixed arma-

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ture and a second secondary coil is wrapped around the second fixed armature.

14. The permanent magnet device of claim 13 including circuit means connected to the control coils to control the energizing thereof to produce a varying flux in the armatures and to induce voltage in the secondary coils.

15. The permanent magnet device of claim 1 wherein there are at least two permanent magnets each having north and south pole faces, the first pole piece being positioned extending between the north pole faces of the permanent magnets and the second pole piece positioned extending between adjacent south pole faces of the permanent magnets.

16. A method for controlling the path of magnetic flux from a permanent magnet, the method comprising the steps of:

- (a) placing a first pole piece adjacent a first pole face of the permanent magnet so as to have at least first and second path portions extending beyond a perimeter of the first pole face;
- (b) placing a second pole piece adjacent a second pole face of the permanent magnet so as to include at least one portion which substantially aligns with the first and second path portions of the first pole piece;
- (c) placing a first control coil along and around the first path portion of the first pole piece;
- (d) placing a second control coil along and around the second path portion of the first pole piece;
- (e) repeatedly energizing the first control coil in a permanent magnet magnetic flux opposing manner so as to prevent magnetic flux of the permanent magnet from traversing the first path portion of the first pole piece; and
- (f) repeatedly energizing the second control coil in a permanent magnet magnetic flux opposing manner so as to prevent magnetic flux of the permanent magnet from traversing the second path portion of the first pole piece.

17. The method as set forth in claim 16 wherein the energization of steps (e) and (f) take place in a simultaneous manner.

18. A method for controlling the path of magnetic flux from a permanent magnet, the method comprising the steps of:

- (a) placing a first pole piece adjacent a first pole face of the permanent magnet so as to have at least first and second path portions extending beyond a perimeter of the first pole face;
- (b) placing a second pole piece adjacent a second pole face of the permanent magnet so as to include at least one portion which substantially aligns with the first and second path portions of the first pole piece;
- (c) placing a first control coil along and around the first path portion of the first pole piece;
- (d) placing a second control coil along and around the second path portion of the first pole piece; and
- (e) alternately performing the following steps in a repeated manner:
  - (i) energizing the first control coil in a permanent magnet magnetic flux aiding manner so as to couple with substantially all magnetic flux of the permanent magnet such that substantially no magnetic flux of the permanent magnet traverses the second path portion of the first pole piece when the first control coil is so energized; and

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- (ii) energizing the second control coil in a permanent magnet magnetic flux opposing manner so as to couple with substantially all magnetic flux of the permanent magnet such that substantially no magnetic flux of the permanent magnet traverses the first path portion of the first pole piece when the second control coil is so energized.

19. A method for controlling the path of magnetic flux from a permanent magnet the method comprising the steps of:

- (a) placing a first pole piece adjacent a first pole face of the permanent magnet so as to have at least first and second path portions extending beyond a perimeter of the first pole face;
- (b) placing a second pole piece adjacent a second pole face of the permanent magnet so as to include at least one portion which substantially aligns with the first and second path portions of the first pole piece;
- (c) placing a first control coil along and around the first path portion of the first pole piece;
- (d) placing a second control coil along and around the second path portion of the first pole piece; and
- (e) alternately performing the following steps in a repeated manner:
  - (i) simultaneously energizing the first control coil in a permanent magnet magnetic flux aiding manner and the second control coil in a permanent magnet flux opposing manner; and
  - (ii) simultaneously energizing the first control coil in a permanent magnet flux opposing manner and the second control coil in a permanent magnet magnetic flux aiding manner.

20. A rotary motion device, comprising a rotor assembly including a shaft which defines an axis of rotation of the assembly, a rotor pole piece mounted for rotation with the shaft, the rotor pole piece including an outer ring portion having at least two path portions extending inwardly from a periphery of the outer ring portion;

a stator assembly including a permanent magnet having a generally ring-shaped configuration, a first pole face of the permanent magnet positioned adjacent the outer ring portion of the rotor pole piece, the stator assembly further comprising a stator pole piece including an outer ring portion positioned adjacent a second pole face of the permanent magnet and having a plurality of path portions extending inwardly from the periphery, each path portion further including a respective portion which extends toward a plane defined by the first pole face of the permanent magnet and alignable with each of the rotor pole piece path portions at certain rotational positions of the rotor pole piece, each path portion including a control coil positioned therealong;

and circuit means connected to each of the coils and including a source of electrical energy and switch means for energizing respective ones of the control coils in a predetermined timed sequence based upon rotation of the rotor assembly.

21. A rotary motion device, comprising:

a rotor assembly including a shaft which defines an axis of rotation of the assembly, a pair of spaced elongated rotor members mounted on the shaft at spaced locations thereon and angularly oriented with respect to each other, each of the elongated rotor members formed of a magnetic material;

a stator assembly including a permanent magnet having opposed first and second pole faces, a first pole piece

positioned adjacent the first pole face and a second pole piece positioned adjacent the second pole face, each pole piece including a respective first path portion extending beyond a perimeter of its adjacent pole face and having an arcuate shaped end portion, the first path portion of the first pole piece aligned with the first path portion of the second pole piece, each pole piece further including a respective second path portion extending beyond the perimeter of its adjacent pole face in a direction opposite to that of the first path portions and having an arcuate shaped end portion, the second path portion of the first pole piece aligned with the second path portion of the second pole piece, at least one of the first path portions of the first pole piece and the first path portion of the second pole piece including a control coil mounted on at least one of the pole pieces, at least one of the second path portions of the first pole piece and the second path portion of the second pole piece including a control coil mounted on at least one of the pole pieces,

wherein the rotor assembly extends from end to end of the stator assembly such that the elongate members are aligned with the arcuate shaped end portions of the path portions of the pole pieces;

and circuit means connected to each of the coils and including a source of electrical energy and switch means for energizing respective ones of the control coils in a predetermined timed sequence based upon rotation of the rotor assembly.

**22.** A rotary motion device comprising:

a rotor assembly including a shaft which defines an axis of rotation of the assembly, a ring-shaped rotor member mounted for rotation with the shaft, the ring-shaped rotor member including a plurality of distinct circumferential regions;

a stator assembly including a first permanent magnet, a first pole piece positioned against a first pole face and a second pole piece positioned against a second pole face, the first pole piece including at least a first path portion extending beyond a perimeter of the first pole face, the second pole piece including at least a first path portion extending beyond a perimeter of the second pole face, the first path portion of the first pole piece aligned with the first path portion of the second pole piece, at least a portion of the ring-shaped rotor member positioned between the first path portion of the first pole piece and the first path portion of the second pole piece, at least one of the first path portions of the first pole piece and the first path portion of the second pole piece including a first control coil positioned at a point intermediate the first permanent magnet and the ring-shaped rotor member;

and circuit means connected to the first control coil and including a source of electrical energy and switch means for energizing the first control coil in a predetermined timed manner based upon rotation of the rotor assembly.

**23.** The rotary motion device as set forth in claim **22**, wherein the ring-shaped rotor member is formed by a permanent magnet having distinct circumferential regions of opposite polarity.

**24.** The rotary motion device as set forth in claim **23**, wherein the first pole piece includes a second path portion spaced from and extending adjacent to the first path portion, the second pole piece including a second path portion spaced from and extending adjacent to the first path portion such

that the second path portion of the first pole piece is aligned with the second path portion of the second pole piece, at least a portion of the ring-shaped permanent magnet rotor member positioned between the second path portion of the first pole piece and the second path portion of the second pole piece, at least one of the second path portions of the first pole piece and the second path portion of the second pole piece having a second control coil mounted on at least one of the pole pieces at a point intermediate the first permanent magnet and the ring-shaped permanent magnet rotor member, the second control coil connected to the circuit means so as to be energized in a predetermined timed manner based upon rotation of the rotor assembly.

**25.** The rotary motion device as set forth in claim **22**, wherein the stator assembly further comprises a second permanent magnet, a third pole piece positioned adjacent a first pole face of the second permanent magnet and a fourth pole piece positioned adjacent a second pole face of the second permanent magnet, the third pole piece including at least a first path portion extending beyond a perimeter of the second permanent magnet first pole face, the fourth pole piece including at least a first path portion extending beyond a perimeter of the second permanent magnet second pole face, the first path portion of the third pole face aligned with the first path portion of the fourth pole piece, at least a portion of the ring-shaped permanent magnet rotor member positioned between the first path portion of the third pole piece and the first path portion of the fourth pole piece, at least one of the first path portions of the third pole piece and the first path portion of the fourth pole piece including a third control coil mounted on at least one of the pole pieces at a point intermediate the second permanent magnet and the ring-shaped permanent magnet rotor member, the third pole piece including a second path portion spaced from and extending adjacent to the first path portion the fourth pole piece including a second path portion spaced from and extending adjacent to the first path portion thereof such that the second path portion of the third pole piece is aligned with the second path portion of the fourth pole piece, at least a portion of the ring-shaped permanent magnet rotor member positioned between the second path portion of the third pole piece and the second path portion of the fourth pole piece, at least one of the second path portions of the third pole piece and the second path portion of the fourth pole piece including a fourth control coil mounted on at least one of the pole pieces at a point intermediate the second permanent magnet and the ring-shaped permanent magnet rotor member, wherein each of the third and fourth control coils are connected to the circuit means so as to be energized in a predetermined timed manner based upon rotation of the rotor assembly.

**26.** A device for producing rotary motion comprising:

a rotor assembly including a shaft which defines an axis of rotation for the assembly, a ring-shaped rotor member mounted for rotation with the shaft, the ring-shaped rotor member having a plurality of distinct circumferentially positioned regions extending around the axis, a stator assembly including a first permanent magnet, a first pole piece positioned against the first pole face of the first pole piece and a second pole piece positioned against a second pole face of the first pole piece, the first pole piece including at least a first path portion extending beyond a perimeter of the first pole face, the second pole piece including at least a first path portion extending beyond the perimeter of the second pole face, the first path portion of the first pole piece aligned with the first path portion of the second pole piece, at

least a portion of the ring-shaped rotor member positioned between the first path portion of the first pole piece and the first path portion of the second pole piece, at least one of the first path portions of the first pole piece and the first path portion of the second pole piece including a first control coil mounted on at least one of the pole pieces at a point intermediate the first permanent magnet and the ring-shaped rotor member; and circuit means connected to the first control coil and including a source of electrical energy and switch means for energizing the first control coil in a predetermined timed manner based upon position of the rotor assembly during rotation of the rotor assembly.

27. The device for producing rotary motion of claim 26 wherein the circuit means includes means for timing the energizing of the first control coil includes means for adjusting the timing thereof.

28. The device for producing rotor motion of claim 26 including means to vary the flux generated in the first and second pole pieces.

29. A device for handling the flux between two separate permanent magnets each of which has a north magnetic pole adjacent one side face and the south magnetic pole adjacent to the opposite side face, the north and south side pole faces respectively of both magnets being substantially in alignment, a first member in surface-to-surface contact with the north magnetic faces of the spaced permanent magnets, a second member in surface-to-surface contact with the south magnetic faces of the spaced permanent magnets, first and second armatures each positioned adjacent opposite ends of the first and second permanent magnets and adjacent to opposite ends of the spaced members, a coil mounted on each of the members in the space between the adjacent permanent magnets, and means for applying voltages of predetermined polarities across the respective coils to change the magnetic coupling between the permanent magnets and between the armatures.

30. A device for producing rotational movement comprising:

a rotor having a shaft rotatable about the axis thereof, a member constructed of permanent magnets mounted on the shaft, said member having circumferential portions some of which have a north magnetic pole and others a south magnetic pole adjacent to the same side thereof, the opposite surface of the permanent magnet member having north magnetic poles opposite the south magnetic poles and south magnetic poles opposite the north magnetic poles, a stator having a plurality of circumferentially spaced portions each of which includes at least one permanent magnet and a pair of members mounted adjacent opposite sides of the permanent magnets, the members being positioned adjacent to the periphery of the rotor permanent magnet member and means on the member adjacent each opposite side of the stator permanent magnet for mounting a coil, and means for energizing the coil on each stator portion in sequence to produce magnetic coupling force between the stator and the rotor in a direction to produce rotating motion of the rotor.

31. A device including a rotating member and a stationary member, each having a permanent magnet portion positioned to produce magnetic coupling force therebetween in predetermined positions thereof, the rotor including a shaft rotatable about its axis and the permanent magnet extending around the shaft and formed by a plurality of adjacent portions of permanent magnet material whereby adjacent portions have their north and south magnetic pole faces on

opposite sides of the rotor permanent magnet, a plurality of stator members each stator member having at least one permanent magnet having a north magnetic pole adjacent one side and a south magnetic pole adjacent to the opposite side, a pair of members positioned adjacent respective opposite sides of the stator permanent magnet in position to extend to adjacent the rotor permanent magnet whereby a flux path is formed between the members and the stator and rotor permanent magnets, a coil mounted on each member of the stator and means for applying a voltage of predetermined polarity to each of said coils to control the flux through a path between the permanent magnets and to control the coupling force between the permanent magnets on the stator and the permanent magnets on the rotor.

32. A motion producing device comprising at least one permanent magnet having a north pole opposite and spaced from a south pole, a pair of spaced substantially parallel members adjacent respectively the north and south poles of the at least one permanent magnet and extending outwardly to substantially aligned opposite edges, a flux supporting member positioned adjacent the respective opposite edges of each pair of parallel members, a coil on selected ones of the parallel members, and a source of electrical energy connected to each of the coils for energizing the coils to change the flux in the parallel members and in the flux supporting members.

33. The motion producing device of claim 32 wherein there are at least two spaced permanent magnets extending between the parallel members.

34. The motion producing device of claim 32 wherein one of said pair of parallel members is subdivided into a plurality of sidewardly extending portions extending to one of said opposite side edges, at least one of said coils being positioned on at least one of said sidewardly extending portions.

35. The motion producing device of claim 34 wherein there are coils on a plurality of respective ones of the sidewardly extending portions.

36. The motion producing device of claim 32 wherein the permanent magnet and the parallel members are annular in shape.

37. The motion producing device of claim 32 including a by-pass member extending between the pair of spaced substantial parallel members adjacent one side of the permanent magnet.

38. A permanent magnet device comprising at least two permanent magnets each having north and south pole faces, a first pole piece, a second pole piece, a first control coil, a second control coil and circuit means, the first pole piece positioned adjacent the north pole faces of the at least two permanent magnets and including a first path portion, a second path portion and a third path portion, the first path portion extending beyond the perimeter of the north pole faces and the second path portion extending beyond the perimeter of the north pole faces to define first and second flux paths for magnetic flux emitting from the north pole faces of the at least two permanent magnets, the first path portion of the first pole piece connected to the second path portion of the first pole piece by a third portion which extends across the north pole face of the at least two permanent magnets, the second pole piece positioned adjacent to the south pole faces of the at least two permanent magnets and including a first path portion and a second path portion, the first path portion extending beyond a perimeter of the south pole faces and substantially aligned with the first path portion of the first pole piece, the second path portion extending beyond the perimeter of the south pole faces and substantially aligned with the second path portion of the first



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pole piece, the first control coil positioned around the first path portion of the first pole piece, the second control coil positioned around the second path portion of the first pole piece, and the circuit means connected to each of the first control coil and the second control coil to alternately energize the first coil and the second coil in a timed sequential manner.

**39.** The permanent magnet device of claim **38** further comprising a first fixed armature extending between the first path portion of the first pole piece to the first path portion of the second pole piece and a second fixed armature extending between the second path portion of the first pole piece to the second path portion of the second pole piece.

**40.** The permanent magnet device of claim **39** where a first secondary coil is wrapped around the first fixed arma-

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ture and a second secondary coil is wrapped around the second fixed armature.

**41.** The permanent magnet device of claim **40** including circuit means connected to the control coils to control the energizing thereof to produce a varying flux in the armatures and to induce voltage in the secondary coils.

**42.** The permanent magnet device of claim **38** wherein there are at least two permanent magnets each having north and south pole faces, the first pole piece being positioned extending between the north pole faces of the permanent magnets and the second pole piece positioned extending between the south pole faces of the permanent magnets.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 6,246,561 B1  
DATED : June 12, 2001  
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 3.

Line 53, "Figs 10, 10A-H" should be -- Figs. 10A-H --.

Line 56, "Figs 11, 11A-F" should be -- Figs. 11A-F --.

Line 61, "Figs 12, 12A-E" should be -- Figs. 12A-E --.

Column 4.

Line 4, "Figs. 16A-E" should be -- Fig. 16 --.

Signed and Sealed this

Twenty-ninth Day of January, 2002

Attest:



Attesting Officer

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