(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 July 2001 (26.07.2001)

PCT

(10) International Publication Number
WO 01/54255 A1

(51) International Patent Classification[7]: H02K 21/12, 21/00, 11/00, 1/12

(21) International Application Number: PCT/US01/01788

(22) International Filing Date: 18 January 2001 (18.01.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/487,418 20 January 2000 (20.01.2000) US

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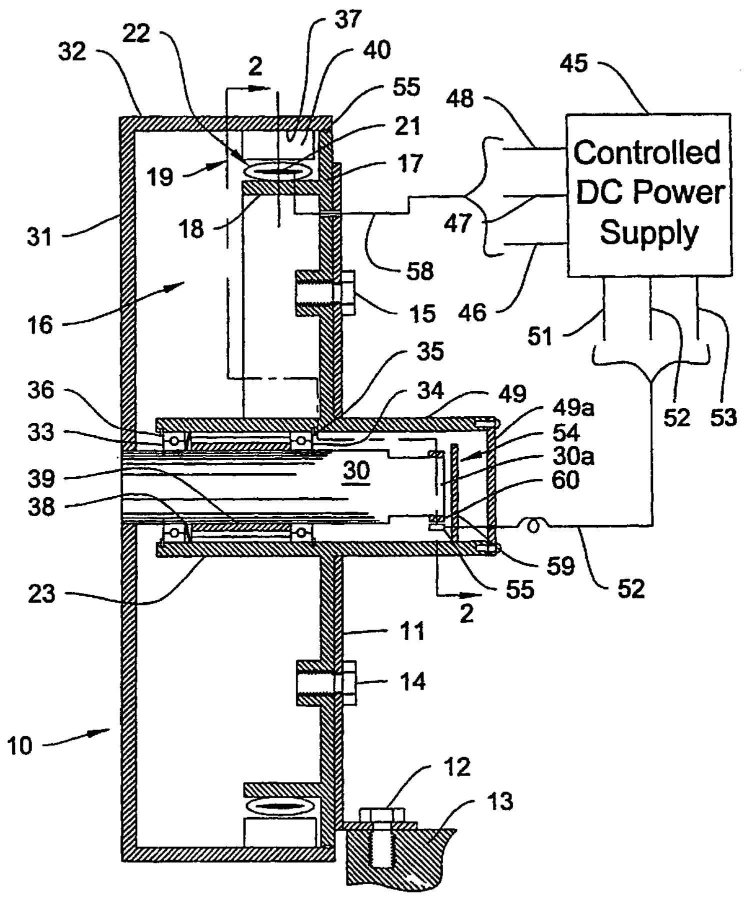
(81) Designated States *(national)*: CA, JP, KR, MX.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DIRECT DRIVE TOROIDALLY WOUND DC BRUSHLESS MOTOR



(57) Abstract: A hermetically sealed DC brushless motor (10) that has an external rotor. The motor includes a toroidally wound slotless stator (19). A controlled DC power supply (45) is coupled to coils (22). A shaft (30) for rotating within bearing (33, 34). A rotor housing (32) is connected by a rotor end housing (31). A rotary sealed (55) is positioned between the housing (32) and a support structure (17). The rotor structure (40) is comprised of no less than ten poles.

WO 01/54255 A1

DIRECT DRIVE TOROIDALLY WOUND DC BRUSHLESS MOTOR

TECHNICAL FIELD

This invention relates to toroidally wound brushless DC motors and more particularly to a hermetically sealed DC brushless motor having an annular slotiess toroidally wound stator and an external rotor for use in delivering a high torque, low speed rotary power output or a high torque high angular resolution output to a positioning system.

BACKGROUND ART

There are environments where high torque, low speed motors are particularly useful. One such environment involves traction drive motors for use in slow moving golf carts. Typical of many electric motor driven golf carts is the combination of a variable speed motor serially coupled through a gear train or belt and pulley system to the driving wheels of the cart. The need for gear trains or belt and pulley systems may be completely obviated by incorporating the subject invention within a driving wheel(s) of the cart.

Conveyor belt systems provide another environment where the systems typically involve motors which are connected by belt and pulley arrangements or gear trains that deliver power from the motor to a conveyor belt. The direct drive of the DC brushless motor of the subject invention utilizes an external rotor that directly cooperates with an underside of the conveyor belt and thereby avoids the need for intermediate belts and pulley or gear train assemblies. Automated assembly situations also frequently call for high torque and the ability to position a component with high angular resolution.

These automated assembly systems frequently call upon precision ground gears the mating teeth of which commonly experience mechanical backlash that create errors in the final angular position of a component part of the automated assembly system. The use of the instant invention provides precise angular positioning with great accuracy while simultaneously delivering high torque.

Direct drive motors that incorporate the invention routinely operate in conditions where moisture, dirt and other contaminants tend to invade the motor and interfere with the smooth functioning of the bearings. This problem is eliminated by the inventions inclusion of a hermetic seal between the motors external rotor and the motor's stator support frame.

DISCLOSURE OF THE INVENTION

In the present invention there is provided a hermetically sealed DC brushiess motor that has an external rotor. The motor rotor delivers high torque at low speeds or high torque with high angular resol ution. The motor includes a toroidally wound slotless stator securely mounted on a support structure. The stator is made of a low magnetic core loss material molded in the shape of a ring having a plurality of coils wound thereon. A controlled DC power supply is coupled to the coils to energize the coils and provide a rotating magnetic field. A rotor support bearing is mounted on the support structure and is located within the stator. A rotor support shaft is mounted for rotation within the bearing. A cylindrical rotor housing is integrally connected by a rotor end housing to the rotor support shaft for rotation therewith. The cylindrical rotor housing is radially spaced away from and surrounds the stator. A rotary seal is positioned between the cylindrical rotor housing and the stator support structure to thereby establish a hermetically sealed environment within the motor as defined by the rotor end housing, the cylindrical rotor housing and the support structure. The cylindrical rotor housing has internally secured thereto an annular permanent magnet rotor structure comprised of no less than ten poles. The magnetic rotor structure is positioned between the cylindrical rotor housing and the stator.

It is therefore a primary object of the invention to provide a DC brushless motor wherein a cylindrical rotor housing having an integral end housing, an annular permanent magnetic pole structure, a rotary seal and support structure that cooperate with controlled DC power energized stator coils to provide a hermetically sealed motor that provides high torque rotary power from the cylindrical rotor housing to an output to be driven at a low speed or positioned with high angular resolution.

Another object of the invention is to provide a DC brushless motor that includes a direct external rotor drive ideally suited for use in a traction wheel structure of the type found in golf carts or similar vehicle.

Yet another object of the invention is to provide a hermetically sealed DC brushless motor that is provided with an external rotor output that directly engages a conveyor belt.

A further object of the invention is to provide a high angular resolution 20 output from a DC brushless motor that is essentially free from the affects of cogging.

BRIEF DESCRIPTION OF THE DRAWINGS

The description setforth above, as well as, other objects, features and advantages of the present invention, will be more fully appreciated by referring to the detailed description and the drawings that follow:

Figure 1 is a cross-section of a hermetically sealed DC brushless motor that embodies the invention.

Figure 2 is a section taken along line 2-2 IN Figure 1 and illustrates schematically the relative position of stator coils on a toroidal stator, permanent magnets secured to a cylindrical rotor, and rotor position sensors.

Figure 3 is a simplified developed view of a single rotor pole and associated toroidal stator coils as depicted in Figure 2.

Figure 4 shows in greater detail the nature of the electrical lead connections to the stator coils of Figures 2 and 3.

Figure 5 is an electrical schematic of the toroidal coils of Figs. 2-4 interconnected in a WYE configuration.

Figure 6 is a schematic block diagram illustrating the commutation circuitry for the motor in accordance with the invention.

Figure 7 illustrates a voltage wave form output of a Hall effect device.

Figure 8 depicts a traction drive wheel arrangement that embodies the invention.

Figure 9 illustrates schematically the subject invention in a conveyor belt drive environment.

Figure 10 illustrates a high angular resolution positioning arrangement that embodies the invention.

While the invention will be described in connection with certain preferred embodiments, there is no intent to limit it to those embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents as included within the spirit and scope of the invention as defined by the appended claims.

BEST MODE OF CARRYING OUT THE INVENTION

Reference is now made to FIG. 1 which is a cross-sectional view of a DC brushless motor 10 that embodies the invention. A brief description of the motor structure will be presented initially followed by an explanation of the dynamic electrical interaction of the motor components and related controls.

A motor support plate 11 is shown bolted securely to a motor support frame 13 by means of a bolt 12. A motor stator structure 17 is fastened to the motor support plate 11 by bolts 14, 15. The motor stator support structure 17 includes integrally formed therewith an annular rim 18 which extends into the motor interior cavity 16. A toroidally wound slotiess stator 19 includes an annular stator member 21 upon which are wound toroidal coils i.e., windings 22.

Centrally disposed in FIG. 1 is a tubular rotor bearing hub support 23 which is shown as an integral part of the motor stator support structure 17. A rotor support shaft 30 is secured to a rotor end housing 31 by means not shown. The rotor end housing 31 in turn structurally carries a cylindrical rotor housing 32 which is external to the toroidally wound slotless stator 19. The rotor support shaft 30 is mounted for rotation in rotor support bearings 33, 34. The bearings 33, 34 are shown with an aluminum spacer 39 and a bearing preload wave spring 38 positioned between them. Snap rings 35, 36 are shown at either end of the bearings 33, 34. Returning now to the cylindrical rotor housing 32 there is shown secured to an internal surface 37 an annular permanent magnet rotor structure 40, the details of which will be described more fully hereinafter.

At the right hand end of the rotor support shaft 30 there is provided a rotor position sensor 54 that includes a four pole bonded ferrite permanent magnet unit 60 that cooperates with three Hall effect devices, one of which 55 is shown on a circuit board 59. The details of the circuit board 59 manner of mounting in position sensor housing 49 are not shown In FIG. 1 only the electrical lead 52 from Hall effect device 55 is shown connected to a DC controlled power supply 45. The nature of the electrical connections of the remaining Hall effect devices will be explained in conjunction with the description of FIG. 6. A tubular shaped position sensor housing 49 surrounds the rotor position sensor 54. A position sensor cover 49a is secured as shown and provides protection from external contaminants.

A controlled DC power supply 45 is depicted electrically coupled to toroidal coils/windings 22 by electrical lead 58. Before moving onto FIG. 2 it should be recognized that the motor 10 is provided with a hermetic seal 55 where the cylindrical rotor housing 32 cooperates with the motor stator support structure 17. The seal 55 may take the form of an "o" ring. The hermetic sealing of the motor ideally suits the motor of this invention for use in environmentally hostile environments where there is a desire to maintain the motor interior cavity 16 with its rotor support bearings 33, 34 clean and free running.

Attention is now directed to FIG. 2 and FIG. 3 which sets forth graphically the structural relationship of the toroidally wound coils 22 mounted on the insulated annular stator member 21, as well as, the annular pen,nanent magnet rotor structure 40 secured to the internal surface 37 of the cylindrical rotor housing 32. It is important that each of the coils 22 are separated from each other by means of insulation space shown but not referenced. In order to facilitate the understanding of the invention only a few permanent magnets and related toroidal windings are illustrated. It is to be understood that permanent magnets and toroidal windings of the nature illustrated, although not shown, actually continues around the inside of the motor 10. The motor in this preferred embodiment of the invention is a 40 pole rotor which cooperates with 120 toroidal windings mounted on a slotiess annular stator 21. For purposes of explaining the electrodynamic operation of the motor, only two rotor poles 41, 42 and associated stator coils 24, 25, 26, 27, 28, 29 will be described in detail. Accordingly, the cylindrical rotor housing 32, to example has a pair of permanent magnets 41, 42 of the polarity shown bonded by any suitable means to the housing 32. These two magnets 41, 42 represent two poles and jointly occupy 18° of the cylindrical rotor housing 32. Immediately adjacent thereto are a set of six toroidal windings 24, 25, 26, 27, 28, 29 which are electrical interconnected as will be shown and explained with reference to FIGS. 4, 4a and 5.

The annular stator member 21 is preferably made of a low magnetic core loss material molded in the shape of a ring and is insulated with an epoxy coating for high voltage resistance. Materials Innovation, Inc. of West Lebanon, New Hampshire describe suitable soft magnetic (SM) materials for use in fabricating the annular stator member 21 in their data sheet 19801230012.0 dated November 2, 1998. The cylindrical rotor housing 32, as well as, the rotor end housing 31 is preferably made of low carbon steel.

FIG. 2 also illustrates the structural arrangement of the rotor position sensor 54. The rotor position sensor 54 includes a four pole bonded ferrite permanent magnet 60 mounted on the rotor end shaft 30a and Hall effect sensors H_1, H_2, H_3 referenced by numerals 55, 56, 57 are schematically shown disposed in an array with sensor H_2 displaced 60° from H_1 and sensor H_3 displaced 120° from H_1. The sensors are secured to the stationary position sensor housing by circuit board 59. It will be observed that in this 40 pole machine each of the coil/windings 24, 25, 26, 27, 28, 29 occupy 3° of the annular stator member 21. Hall effect sensor H_1 is positioned such that a radial line extending from and passing through the center of rotation of the rotor support shaft 30 also passes through the center of Hall effect sensor H_1. This radial line is displaced 1.5° from 0° top dead center as shown in FIG. 2. Accordingly, the radial line that passes through H_1 also passes through the center of coil 24, i.e., A^+, in FIGS. 3 and 4.

At this time it may be note worthy to mention that there are commercially available a variety of Hall effect sensors which may be utilized by the subject invention to detect the flux density of the magnetic field produced by the four pole bonded ferrite permanent magnet 60. For example, one such Hall effect sensor device which may be utilized as sensors 55, 56, 57 of the subject invention is a Model Number SS495A solid state Hall effect sensor manufactured by Honeywell Microswitch of Freeport, IL.

Now that the structural nature of the rotor permanent magnets 40, stator toroidal windings 22 and rotor position sensor 54 have been described attention will now be directed to FIGS. 2 to 7 to explain the electrical operation of the invention.

FIG. 3 represents a simplified developed view of a two rotor pole and associated toroidal coils shown in FIG. 2. In FIG. 4 only the six (6) toroidal coils 24, 25, 26, 27, 2 8, 29 the one hundred twenty (120) are shown mounted on annular stator member 21 and FIG. 4a illustrates in a schematic manner the nature of toroidal coil 24 and its cooperation with annular stator member 21. The electrical leads 20 depicted in FIG. 4 are shown schematically in FIG. 2 extending along the outer surface of the annular stator member 21.

By way of review and in accordance with this invention a brushless DC motor is constructed without stator winding slots. The stator magnetic material is in the form of a ring and the windings have a toroidal configuration about the ring. Preferably as is shown in FIG. 5 the winding includes 120 segments connected into a WYE circuit configuration. In the left hand side of FIG. 5 there is shown schematically the WYE circuit configuration that corresponds to the six (6) coils shown in FIGS. 3 and 4. In this embodiment as noted earlier there are groups of six (6) coils interconnected as shown. Accordingly, there are twenty (20) groups of six (6) coils that comprise the motor winding structure.

Attention is now directed to FIG. 6 which is a schematic block diagram illustrating the manner in which the DC power supply 45 is controlled by means of the dynamic interaction of the stator coil windings and rotor position sensor 54.

The controlled DC power supply 45 includes a battery 43 coupled by way of leads 44, 44a to a unit designated as a sine drive 50. The sine drive 50 delivers electrical power to the stator coil windings 22 by means of electrical leads 46, 47, 48. The sine drive 50 receive three sine wave inputs on leads 51 52, 53 from Hall effect devices 55, 56, 57.

FIG. 7 illustrates the sine wave nature of the Hall effect devices output that are delivered to the sine drive 50 where they are used to provide rotor position information and amplified and delivered over leads 46, 47, 48 to energize the windings 22 and provide a rotating magnetic field. It is this rotating magnetic field that cooperates with the annular permanent magnet pole structure 40 carried by the cylindrical rotor housing 32 that creates the high torque output. It should be readily appreciated that the sine drive 50 may include integrated circuitry that in a known manner controls the nature of the sine wave output signals on leads 46, 47, 48 and therefore the motor rotor 32 output characteristics.

The flat compact nature of the DC motor of the subject invention coupled with the direct drive nature of the external cylindrical rotor housing 32 ideally suits the motor for use in a traction wheel of a vehicle such as a golf cart.

FIG. 8 depicts the hermetically sealed DC brushless motor 10 mounted in a rim 62 of a traction wheel that includes a pneumatic tire 63 mounted thereon. A vehicle body 64 is shown secured to the motor stator support structure 17 by means of a wheel support housing 65. Locating the vehicle drive motor in a traction wheel of, for example, a golf cart completely eliminates the need for drive gear trains or belt and pulley mechanisms to be carried within the vehicle.

FIG. 9 shows yet another embodiment of the invention where the motor 10 embodying the invention is shown with its cylindrical rotor housing 32 engaging an underside 66 of a conveyor belt 67.

A DC motor that embodies the invention is especially useful when the outer diameter of the cylindrical rotor housing is between four and forty inches.

FIG. 10 shows the DC motor 10 embodying the invention in a high angular resolution positioning environment where the rotor end housing 31, here shown horizontally disposed, included thereon a component 67 to be precisely rotated through a preset angle between a first position indicated by arrow 68 and a second position indicated by arrow 69.

CLAIMS:

1 . A DC brushiess motor having an external rotor for use in high torque, low speed or high torque, high angular resolution positioning environments, said motor comprising;

(a) a toroidally wound slotiess stator securely mounted on a support structure the stator being made of a low magnetic core loss material molded in the shape of a ring having a plurality of coils wound thereon;

(b) a controlled DC power supply coupled to the coils to energize the coils and provide a rotating magnetic field;

(c) a rotor support bearing mounted on the support structure and within the stator;

(d) a rotor support shaft mounted for rotation within the bearing;

(e) a cylindrical rotor housing integrally connected by a rotor end housing to the rotor support shaft for rotation therewith, the cylindrical rotor housing radially spaced away from and surrounding the stator;

(f) the cylindrical rotor housing having internally secured thereto an annular permanent magnet rotor structure comprised of nodes than 10 poles, the rotor structure positioned between the cylindrical rotor housing and the stator.

(g) the cylindrical rotor housing and its end housing, the annular permanent magnetic pole structure cooperating with the controlled DC power energized stator coils to provide a motor that provides high torque rotary power from the cylindrical rotor housing to an output to be driven at a low speed or positioned with high angular resolution.

2. The DC brushless motor of claim 1 wherein the rotor support shaft has secured thereto for rotation therewith a multi-pole permanent magnet means.

3. The DC brushless motor of claim 2 wherein the controlled DC power supply includes a battery power sine wave amplification means in combination with and electrically coupled to outputs of Hall effect devices that detect flux density of magnetic fields produced by the rotating multi-pole permanent magnet means, the Hall effect device each producing a sine wave signal to provide rotor position infon-nation to produce an amplified sine wave output by the sine wave amplification means, the sine wave amplification means having a plurality of outputs electrically coupled to the coils mounted on the ring shaped stator.

4. The DC brushless motor of claim 3 wherein the rotating multi-pole magnet means has four poles and there are three Hall effect devices.

5. The DC brushiess motor of claim 4 which includes in combination a vehicle traction wheel mounted upon the cylindrical rotor housing to be driven thereby.

6. The DC brushless motor of claim 4 which includes in combination a continuous belt having an underside that engages an outer surface of the cylindrical rotor housing and is driven thereby.

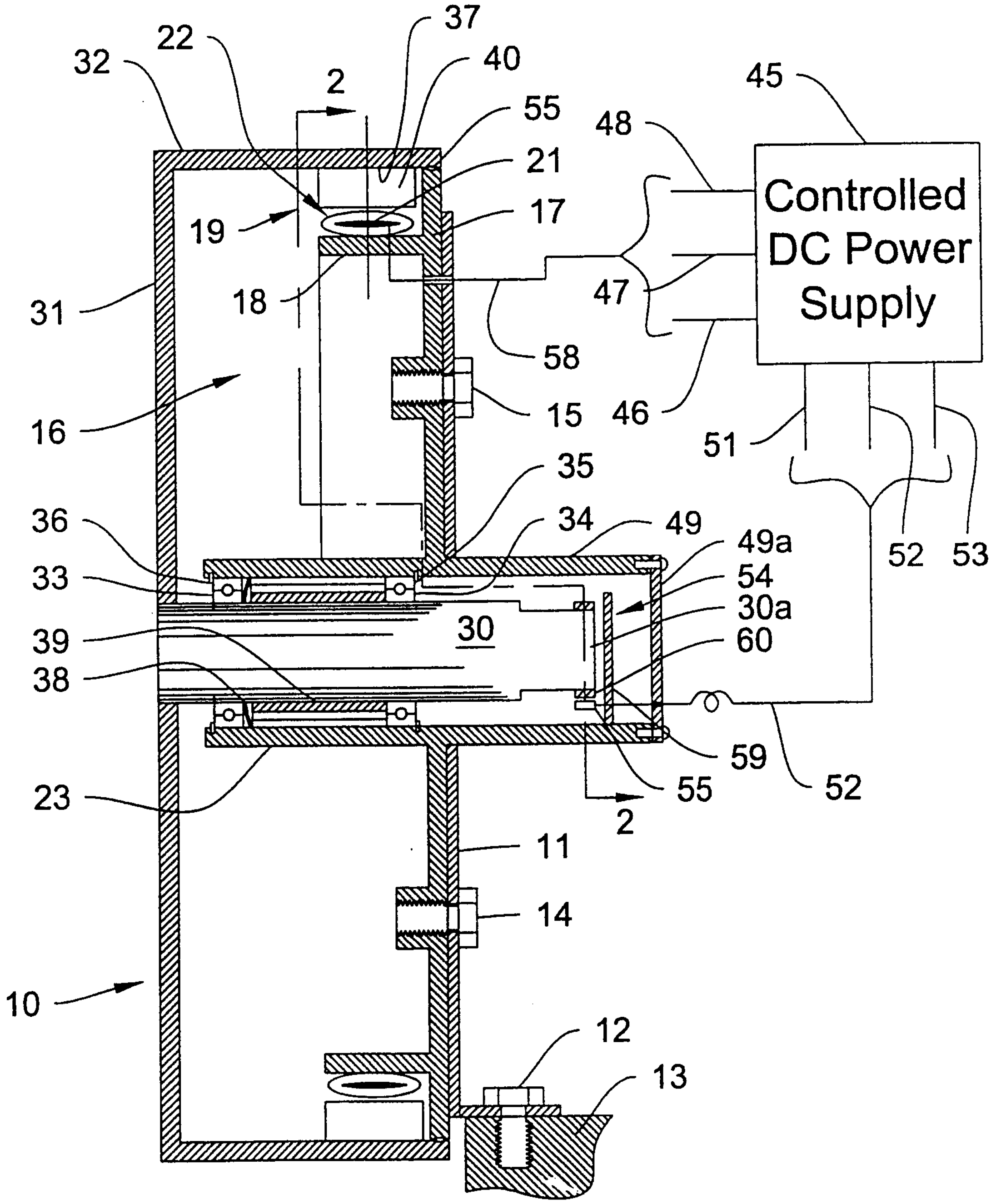
7. The DC brushless motor of claim 4 which includes in combination a component secured to the rotor end housing for angular rotation therewith from one angular position to another.

8. The DC brushless motor of claim 4 wherein the cylindrical rotor housing has an outside diameter of between 4 and 40 inches.

9. The DC brushless motor of claim 1 wherein a rotary seal is positioned between the cylindrical rotor housing and the stator support structure

to thereby establish a hermetically sealed environment within the motor as defined by the rotor end housing the cylindrical rotor housing and the support structure.

Fig. 1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22
40
32
2
55
48
45
21
Controlled
DC Power
Supply
19
17
31
18
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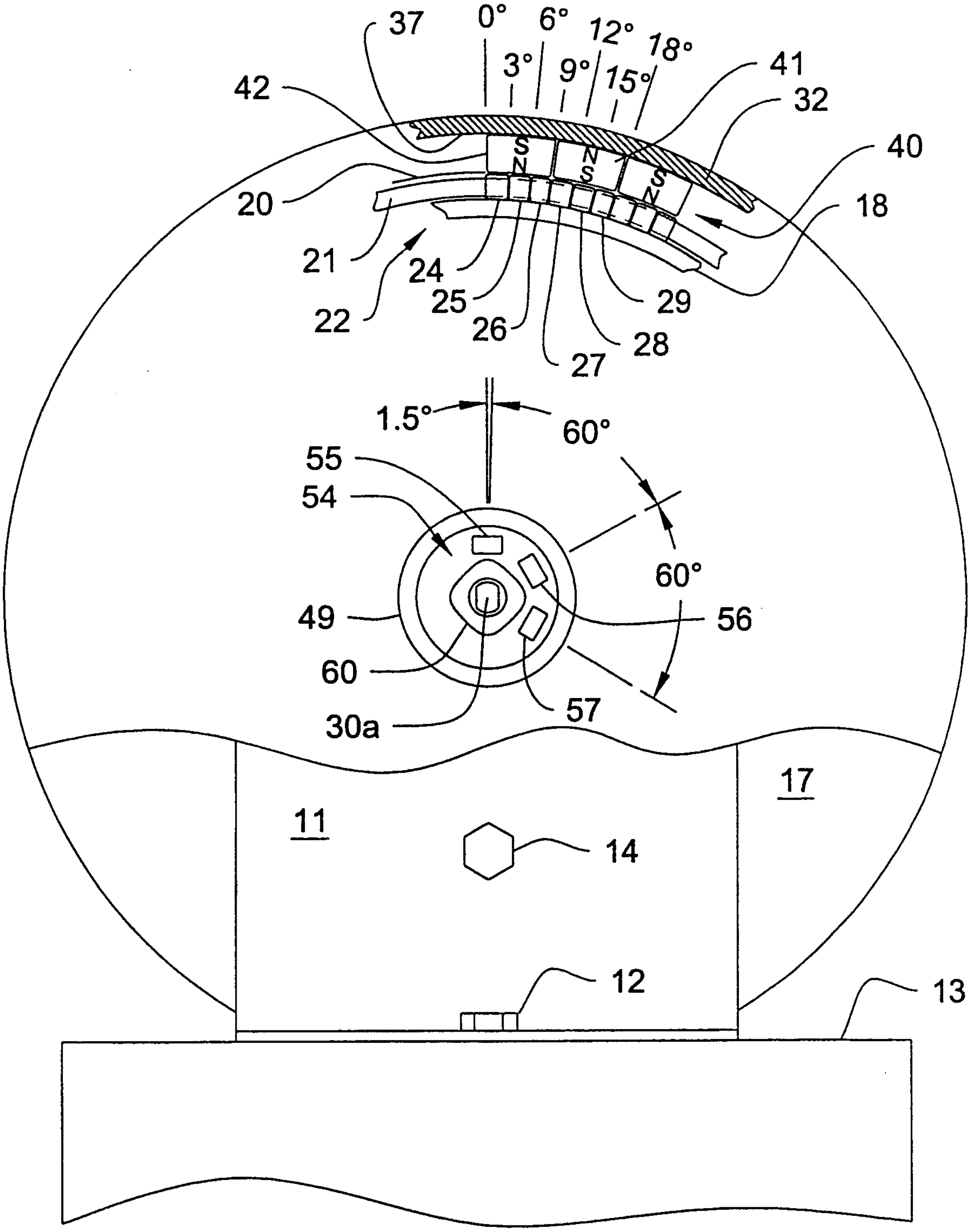
58
16
15
46
51
35
36
34
49
49a
52
53
33
54
30a
39
30
60
38
59
52
23
55
2
11
14
10
12
13

Fig. 2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12°
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S
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18
21
24
22
25
26
27
28
29
1.5°
60°
55
54
60°
49
56
60
30a
57
17
11
14
12
13

Fig. 3

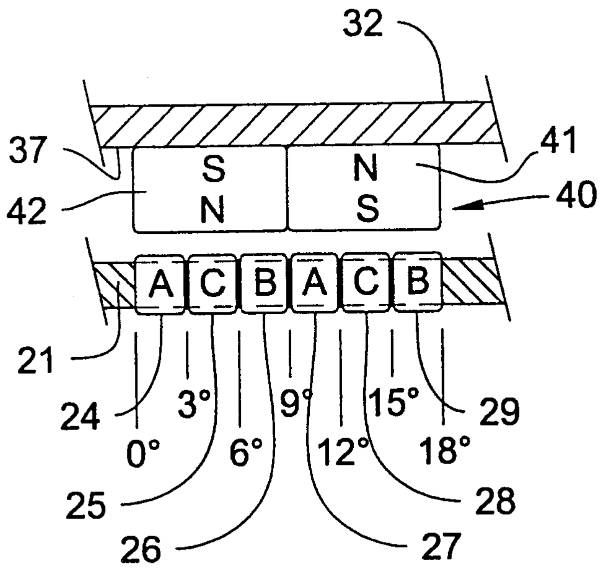


Fig. 4

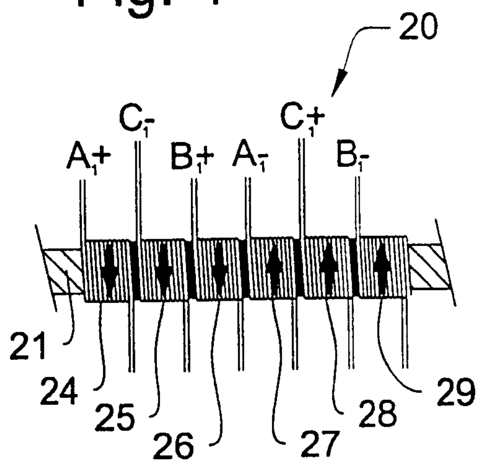


Fig. 4a

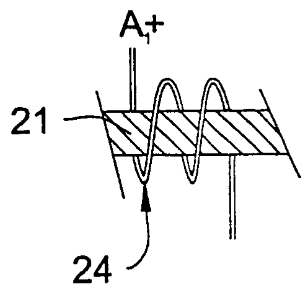


Fig. 5

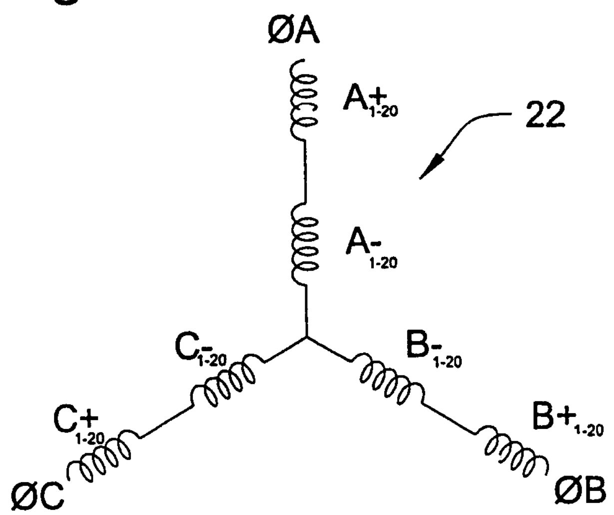
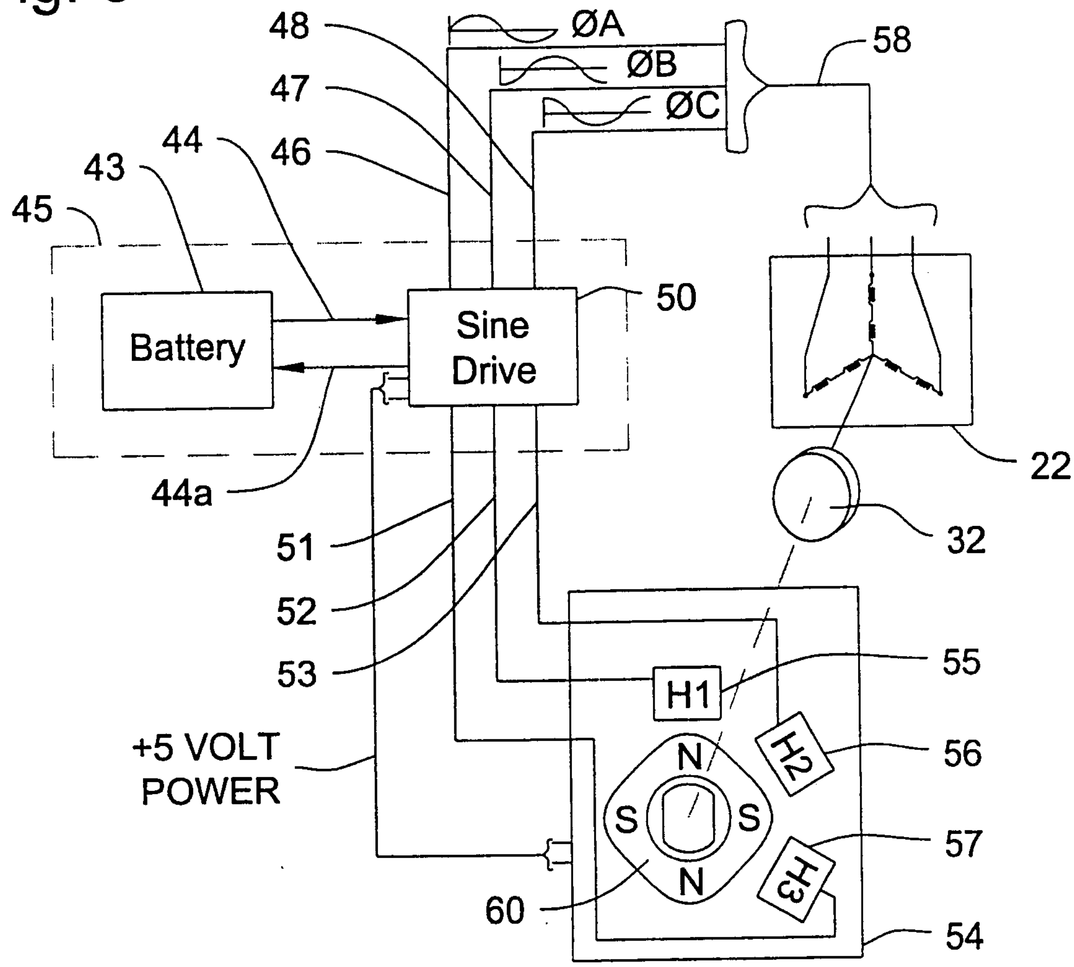


Fig. 6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ØA
ØB
ØC
58
47
44
46
43
45
Battery
Sine
Drive
50
22
44a
32
51
52
53
55
H1
+5 VOLT
POWER
H2
56
N
S
S
N
H3
57
60
54

Fig. 7

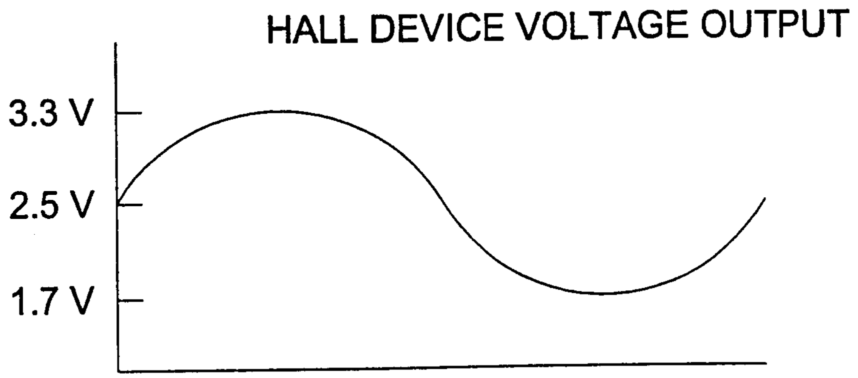

HALL DEVICE VOLTAGE OUTPUT
3.3 V
2.5 V
1.7 V
POSITION

Fig. 8

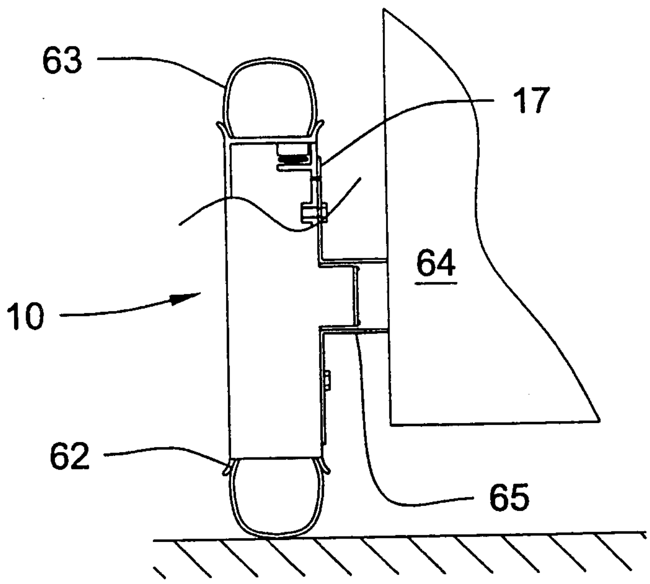


Fig. 9

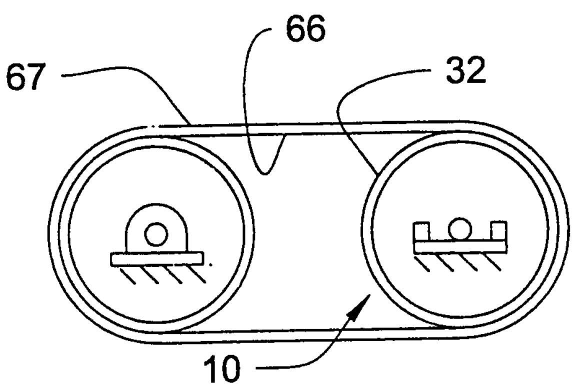
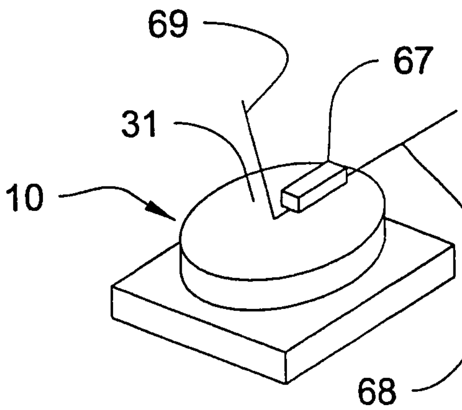


Fig. 10



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/01788

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H02K 21/12, 21/00, 11/00, 1/12
US CL :310/156, 152, 68B, 254
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 310/156, 152, 68B, 254

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,289,066 A (CLARK) 22 February 1994 (22.02.1994), col. 4, lines 29-64, fig. 1A and 1B.	1-3
Y ----- A	US 4,373,148 A (GUTZ) 08 February 1983 (08.02.1983), col. 2, lines 33-55, fig. 1. Col. 2, lines 56-63.	1-3 ----- 3-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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15 MARCH 2001

Date of mailing of the international search report
18 APR 2001

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