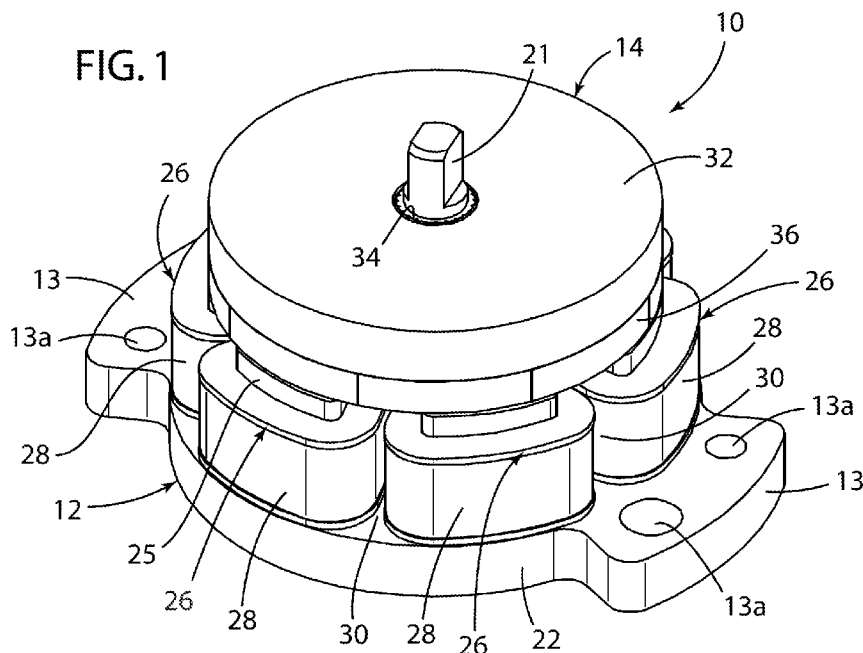




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(54) Title: AXIAL BRUSHLESS DC MOTOR WITH FRACTIONAL AND HOLD STEP FUNCTION



(57) Abstract: An axial brushless DC motor comprising a stator including a plurality of coils, a rotor including a magnet with a plurality of pairs of magnetic poles and adapted for movement relative to the stator in one or more full steps, and a coil phase circuit adapted for moving the rotor relative to the stator a fractional step less than the one or more full steps and/or holding the rotor at the fractional or one or more full steps.

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AXIAL BRUSHLESS DC MOTOR WITH FRACTIONAL AND HOLD STEP FUNCTION

Cross-Reference to Related Applications

5 This patent application claims priority and benefit of the filing date of and is a continuation-in-part of U.S. Patent Application Serial No. 15/017,237 filed on February 5, 2016, the disclosure and contents of which is expressly incorporated herein in its entirety by reference.

10 This patent application also claims priority and benefit of the filing date of U.S. Provisional Patent Application Serial No. 62/338,780 filed on May 19, 2016, the disclosure and contents of which is expressly incorporated herein in its entirety by reference.

Field of the Invention

15 The present invention relates generally to an electric motor and, in particular, to an axial brushless DC motor with fractional half, hold, and micro stepping functions.

Background of the Invention

20 The present invention is directed to an axial brushless electric motor of the type disclosed in United States Patent Publication No. 2016/0241107 to King et al., the entire disclosure and contents of which are incorporated herein by reference as though fully set forth herein.

 There remains a need for a more cost effective axial brushless motor.

25 The present invention satisfies this need by adding fractional half, hold, and micro step function elements to an axial brushless electric motor of the type disclosed in United States Patent Publication No. 2016/0241107 or the purpose of advantageously increasing resolution and reducing resonances.

30

Summary of the Invention

The present invention is generally directed to an axial brushless DC motor comprising a stator including a plurality of coils, a rotor including a magnet with a plurality of pairs of magnetic poles and adapted for movement relative to the stator in one or more full steps, and a coil phase circuit adapted for moving the rotor relative to the stator a fractional step less than the one or more full steps and/or holding the rotor at the one or more fractional or full steps.

In one embodiment, the coil phase circuit is a three phase circuit adapted to switch the orientation of one or more of the plurality of pairs of magnetic poles of the rotor during operation of the motor and hold the rotor at a half step between the one or more full steps.

In one embodiment, the coil phase circuit is a three phase coil circuit adapted to switch the orientation of one or more of the plurality of pairs of magnetic poles of the rotor during operation of the motor and hold the rotor at the fractional or one or more full steps.

In one embodiment, the coil phase circuit includes a one phase coil circuit, a motor bridge coupled to the one phase coil, a motor supply coupled to the motor bridge, a microprocessor coupled to the motor bridge, and a Hall Effect sensor coupled to the microprocessor for moving the rotor during the operation of the motor in micro steps between the one or more full steps.

In one embodiment, the coil phase circuit includes a plurality of coil circuit segments coupled together at a common junction that is coupled to ground for moving the rotor in micro steps during the operation of the motor between the one or more full steps.

The present invention is also directed to an axial brushless DC motor comprising a stator including a plurality of coils, a rotor including a magnet with a plurality of pairs of magnetic poles and adapted for movement relative to the stator in full step positions, and a coil phase circuit including first, second, and third coil phase segments connected in series at a common central connection point, each of the coil phase segments including a pair of coils configured in parallel, and current being adapted for flow through the coil phase circuit in a

manner adapted to switch the orientation of one or more of the plurality of pairs of magnetic poles of the magnet for moving the rotor relative to the stator a fractional step position less than the full step position and/or holding the rotor at the fractional step position or full step position.

5 In one embodiment, the rotor is movable from a first driving position into a fractional step position less than the full step position by switching the flow of current from between the first and third coil phase segments through the common central connection point to between the second and third coil phase segments through the common central connection point.

10 In one embodiment, the rotor is movable from a first driving position into a full step hold position by switching the flow of current from between the first and third coil phase segments through the common central connection point to between the first and second coil phase segments and through the third coil phase segment through the common central connection point.

15 The present invention is also directed to an axial brushless DC motor comprising a stator including a plurality of coils, a rotor including a magnet and adapted for movement in full or fractional step position relative to the stator, and a coil phase circuit including first, second, and third coil phase segments coupled together in series at a common central connection point, each of the first,
20 second, and third coil phase segments including a pair of coils coupled in parallel, and energizable for moving the rotor between a first driving position and full or fractional step hold positions relative to the stator.

 In one embodiment, the rotor is movable between the first driving position and full or fractional hold positions relative to the stator by switching the flow of
25 current through the first, second, and third coil phase segments of the coil phase circuits.

 In one embodiment, the rotor is movable from the first driving position in which current flows through the first and third coil phase segments through the common central connection point to a fractional hold half step position in which
30 the flow of current has been switched to flow through the second and third coil phase segments.

In one embodiment, the rotor is movable from the first driving position in which current flows through the first and third coil phase segments through the common central connection point to a full step hold position in which the flow of current has been switched to flow through both of the first and second coil phase
5 segments and into the third coil phase segment through the common central connection point.

There are other advantages and features of this invention which will be more readily apparent from the following description of the embodiment of the invention, the drawings, and the appended claims.

10

Brief Description of the Drawings

In the accompanying drawings that form part of the specification, and in which like numerals are employed to designate like parts throughout the same:

FIG. 1 is a perspective view of an axial brushless DC motor incorporating
15 the fractional, micro, and hold step functions in accordance with the present invention;

FIG. 2 is a vertical cross-sectional view of the axial brushless DC motor shown in FIG. 1;

FIG. 2A is an exploded perspective view of the axial brushless DC motor
20 shown in FIG. 1;

FIG. 3A is a simplified plan view of the stator and position of the rotor of the axial motor in a first driving position of the rotor of the axial motor;

FIG. 3B is a schematic depicting the current flow through the stator coil phase circuit of the axial motor in the first driving position of the rotor of the axial
25 motor;

FIG. 3C is a schematic diagram of the rotor magnetic pole orientation of the axial motor in a first driving position of the rotor of the axial motor;

FIG. 4A is a simplified plan view of the stator and position of the rotor of the axial motor in a half step position of the rotor of the axial motor;

FIG. 4B is a schematic depicting the current flow through the stator coil phase circuit of the axial motor in the half step position of the rotor of the axial
30

motor;

FIG. 4C is a schematic diagram of the rotor magnetic pole orientation of the axial motor in the half step position of the rotor of the axial motor;

FIG. 5A is a simplified plan view of the stator and position of the rotor of the axial motor in a half step position of the rotor of the axial motor;

FIG. 5B is a schematic depicting the current flow through the stator coil circuit of the axial motor in the half step position of the rotor of the axial motor;

FIG. 5C is a schematic diagram of the rotor magnetic pole orientation of the axial motor in the half step position of the rotor of the axial motor;

FIG. 6A is a simplified plan view of the stator and position of the rotor of the axial motor in a full step hold position of the rotor of the axial motor;

FIG. 6B is a schematic depicting the current flow through the stator coil phase circuit of the stator of the axial motor in the full step hold position of the rotor of the axial motor;

FIG. 6C is a schematic diagram of the rotor magnetic pole orientation of the axial motor in the full step hold position of the rotor of the axial motor;

FIG. 7 is a block diagram of a micro stepping motor drive and stator coil phase circuit; and

FIG. 8 is a schematic diagram of a micro stepping stator coil phase circuit with a ground connection.

Detailed Description of the Embodiment

FIGS. 1, 2, and 2A depict an axial brushless DC motor 10 incorporating the fractional, hold, and micro step functions in accordance with the present invention and is of the type and structure disclosed in United States Patent Application Publication No. 2016/0241107 to King et al. and assigned to CTS Corporation, the entire disclosure and contents of which are incorporated and made part of this application as though fully set forth herein.

The axial brushless DC motor 10 comprises, among other elements as described in more detail in United States Patent Application Publication No. 2016/0241107 and incorporated herein by reference as though fully set forth

herein, a stator or stator assembly 12, a rotor or rotor assembly 14, an elongate and generally cylindrical sleeve bushing 16 defining an interior elongate through-hole 40, a ball bearing 18 mounted on a lower end of the sleeve bushing 16, a thrust bearing 20 mounted on an upper end of the sleeve bushing 16, and an
5 elongate motor shaft 21. In the embodiment shown, the axial brushless DC motor 10 is a three phase, eight pole, six slot axial brushless DC motor.

The stator assembly 12 includes a flat base 22 in the form and shape of a disc defining a central through-hole or aperture 23, an interior circumferential shoulder 24 defined by the interior wall of the base 22 defining the central
10 through-hole 23 thereof, and a plurality of peripheral motor mounting brackets 13 each defining a plurality of motor mounting through-holes 13a.

In the embodiment shown, the base 22 is made from a powder metal. A plurality of stator armature posts 25, namely six in the embodiment of FIGS. 1, 2, and 3, protrude unitarily normally upwardly and outwardly from the interior face
15 of the base 22. In the embodiment shown, the armature posts 25 are generally triangular in shape and extend full circle around the central through-hole or aperture 23 in a spaced apart relationship relative to each other and the central through-hole or aperture 23.

The stator assembly 12 also includes a plurality of elongate thermoplastic
20 bobbins 26 mounted on the plurality of posts 25 respectively in a relationship with the plurality of bobbins 26 surrounding the plurality of posts 25 respectively.

A plurality of electrical coil packs 28 surround the plurality of bobbins 26 respectively. The bobbins 26 and the coil packs 28 are positioned on the base 22 relative to each other such that a slot or gap 30 is defined between each of
25 the bobbins 26 and coils 28. The embodiment shown defines six slots or gaps 30.

The rotor assembly 14 includes a flat base 32 in the form and shape of a disc defining a central through-hole or aperture 34. The base 32 is made from powder metal. A flat magnet 36 is seated against the exterior surface of the
30 bottom face 38 of the rotor base 32. In the embodiment shown, the magnet 36 is in the form and shape of a disc and defines a central through-hole or aperture

39 having a diameter greater than and spaced from the central through-hole or aperture 34 defined in the rotor base 32. In the embodiment shown, the magnet 36 is made of compression bonded Neo Ferrite magnetic material and is comprised of a plurality of pairs of N-S magnetic poles and, still more specifically,
5 a magnet 36 with eight alternating N-S poles.

The rotor assembly 14 and the stator assembly 12 are positioned relative to each other in an overlapping relationship with the exterior bottom face of the magnet 36 of the rotor assembly 14 positioned opposite, spaced from, and parallel to, the exterior top face of the armature posts 25, bobbins 26, and the
10 coils 28 of the stator assembly 12 and further in a relationship spaced from and parallel to the base 22 of the stator assembly 12. In this relationship, the two pairs of coils 28 (or four coils or two phases) are energized in response to the rotation of the rotor assembly 14 and the magnet 36 at any commutation stage.

The sleeve bushing 16, the bearings 18 and 20, and the motor shaft 21,
15 which is oriented in a relationship generally normal to the base 22 of the stator assembly 12 and the rotor assembly 14, are assembled in a relationship that allows for rotation of the rotor assembly 14 relative to the stator assembly 12 in response to the rotation of the motor shaft 21.

Specifically, in the embodiment shown, the lower end of the sleeve
20 bushing 16 extends into the aperture 23 defined in the base 22 of the stator assembly 12 and is seated against the shoulder 24 defined in the interior of the base 22 for mounting the sleeve bushing 16 in the center of the stator assembly 12 in a relationship with the sleeve bushing 16 extending generally normally upwardly and outwardly from the base 22 of the stator assembly 12 and further
25 in a relationship with the respective armature posts 25, bobbins 26, and electrical coil packs 28 surrounding and spaced from the sleeve bushing 16.

The motor shaft 21 extends through the interior of the sleeve bushing 16 and includes a lower end extending through the interior through-hole 23 defined in the base 22 of the stator 12 and thus is oriented and positioned in a
30 relationship normal to the base 22 of the stator assembly 12.

The ball bearing 18 and the thrust bearing 20 mount the motor shaft 21 to the sleeve bushing 16 for rotation relative to both the sleeve bushing 16 and the base 22 of the stator assembly 12.

Specifically, in the embodiment shown, the ball bearing 18 is located in
5 and positioned against a collar 42 formed at the lower end of the sleeve bushing 16 and surrounds a lower end of the motor shaft 21 for mounting the lower end of the motor shaft 21 to the lower end of the sleeve bushing 16 for rotation relative to both the lower end of the sleeve bushing 16 and the base 22 of the stator 12.

10 The thrust bearing 20 is seated in a collar 44 formed at the upper end of the sleeve bushing 16 and surrounds an upper end of the motor shaft 21 for mounting the upper end of the motor shaft 21 for rotation relative to the upper end of the sleeve bushing 16.

The base 32 of the rotor 14 is mounted to and surrounds an upper end of
15 the motor shaft 21. The magnet 36 is mounted to the underside of the base 32 of the rotor 14 and surrounds and is spaced from the upper end of the motor shaft 21.

In accordance with the present invention, the rotor 14 is designed to move
20 and rotate on the upper end of the motor shaft 21 relative to the stator 12 not only in the standard full steps but also in fractional half or micro steps with or without any feedback sensors as discussed in more detail below.

FIGS. 3B, 4B, 5B, and 6B depict the three phase coil circuit 50 of the
stator assembly 12 which, in the embodiment shown, is a generally "Y" shaped
25 circuit comprised of a phase U coil circuit segment 50a including a first pair of coils 28 arranged in parallel, a second phase W coil circuit segment 50b including a second pair of coils 28 arranged in parallel, and a third phase V coil circuit segment 50c including a third pair of coils 28 arranged in parallel.

The phase U circuit 50a and coils 28 are coupled in series with both the
phase W and phase V circuits 50b and 50c and coils 28 at a common
30 connection point generally designated with the numeral 52.

FIGS. 3A, 3B, and 3C respectively depict the rotor position, three phase stator coil circuit 50, and rotor magnetic pole orientation of the motor 10 in a first start driving position of the rotor 14 of the motor 10.

5 More specifically, FIG. 3A depicts the rotor 14 and, more specifically the magnet 36 thereof, in a first start 7.5 degrees driving position, FIG. 3B depicts the energization and flow of current, generally designate by the letter I, through the phase U and phase W segments or sets of coils 28 of the stator coil phase circuit 50; and FIG. 3C depicts the rotor magnetic pole orientation resulting from the energization of the coils 28 as depicted in FIG. 3B.

10 FIGS. 4A, 4B, and 4C respectively depict the rotor position, three phase stator coil circuit 50, and rotor magnetic pole orientation of the motor 10 in a first half step holding position of the rotor 14 of the motor 10 relative to the stator assembly 12.

15 More specifically, FIG. 4A depicts the rotor 14, and more specifically the magnet 36 thereof, turned or rotated 7.5 degrees relative to the first driving position of the rotor 14 as shown in FIG. 3A in response to a switch from the FIG. 3C rotor magnetic pole orientation to the FIG. 4C rotor magnetic pole orientation resulting from a switch in the energization of the coils 28 from the FIG. 3B energization to the FIG. 4B energization where current, generally
20 designated by the letter I, flows through the phase V and phase W coils 28 of the coil phase circuit 50 rather than the phase U and W sets of coils as shown in FIG. 3B.

Still more specifically, in FIGS. 3A and 4A, the letters N and S designate the North and South poles of the magnet 36 of the rotor 14.

25 In FIG. 3B, the current, generally designated with the letter I, flows from and through the Phase U coil circuit segment 50a and into and through the Phase W coil circuit segment 50c via and through the common central connection point 52 while, in FIG. 4B, the current flow has been switched and flows from and through the Phase V coil circuit segment 50b, rather than the
30 Phase U coil circuit segment 50a as shown in FIG.3B, and into and through the

Phase W coil circuit segment 50c via and through the common central connection point 52.

In FIGS. 3C and 4C, the letters N, S, and O represent North, South, and neutral poles respectively of the magnet 36 of the rotor 14. In FIG. 3C, a pair of S magnetic poles are associated with the phase W and W1 coil circuit segment, a pair of N magnetic poles are associated with the phase U and U1 coil circuit segment, and a pair of O magnetic poles are associated with the phase V and V1 coil circuit segment. In FIG. 4C, the S magnetic poles are associated with the phase W and W1 coil circuit segment, the N magnetic poles are associated with the phase V and V1 coil circuit segment, and the O magnetic poles are associated with the phase U and U1 coil circuit segment.

In accordance with the present invention, the rotor 14 is held in the half step FIG. 4A position until the coil energization is switched from the FIG. 4B energization back into the FIG. 3B energization which results in a switch of the rotor magnetic pole orientation back from the FIG. 4C orientation to the FIG. 3C orientation to move or turn the rotor 14 another 7.5 degrees relative to the position of FIG. 4A to allow the rotor 14 to complete and finish its full 15 degree step rotation.

In accordance with the present invention, the addition of 7.5 degree fractional half step rotations of the rotor 14 between 15 degree full step rotations of the rotor 14 provides at least the following advantages: it improves system and motor performance by doubling resolution and reducing resonances; is a cost effective solution that eliminates the need for a motor with a higher number of full steps; and the position error is noncumulative.

The motor 10 is also adapted for full step holding in three phase mode as described below with reference to FIGS. 5A, 5B, 5C, 6A, 6B, and 6C.

FIGS. 5A, 5B, and 5C are similar to FIGS. 3A, 3B, and 3C and thus the earlier description of FIGS. 3A, 3B, and 3C is incorporated herein by reference with respect to FIGS. 5A, 5B, and 5C.

FIGS. 6A, 6B, and 6C depict the rotor 14 in its full step hold position following rotation thereof 15 degrees in response to a switch in the coil phase

energization circuit from the driving coil energization circuit depicted in FIG. 5B in which current, generally designated by the letter and reference I, flows from and through the phase U coil circuit segment 50a and through the phase W coil circuit segment 50c via and through the common junction point 52 to the coil energization circuit as depicted in FIG. 6B in which current, generally designated by the letter and reference 0.5I, flows from and through both the phase U and V coil circuit segments 50a and 50b respectively and into and through the phase W coil circuit segment 50c via and through the common junction point 52.

This switch in pattern of coil energization results in a change or switch in rotor magnetic pole orientation as depicted in FIG. 6C in which a pair of S poles are associated with the phase W and W1 coil circuit segment, a first pair of N poles are associated with the U and U1 coil circuit segment, and a second pair of N poles are associated with the phase V and V1 coil circuit segment.

Energization of the individual Phase U, V, and W coil circuit segments 50a, 50b, and 50c of the stator coil phase circuit 50 as depicted in FIG. 6B holds the rotor 14 in the position of FIG. 6A. A switch in the coil energization from the FIG. 6B energization back to the energization as depicted in FIG. 4B will release the hold on the rotor 14 and allow for another half step or full step rotation of the rotor 14 as described above.

The motor 10 of the present invention is also adapted for micro instead of half step movement between full steps.

In accordance with one embodiment, the micro stepping of the rotor 14 may be accomplished by separating the three connected coil energization phases and circuits depicted in FIGS. 3B, 4B, 5B, and 6B into three separate coil energization phases or circuits 100 as depicted in FIG. 7 and each including a one phase coil circuit 102 including a pair of coils 28 coupled in parallel; a motor bridge 104 coupled to the one phase coil circuit 102; a motor supply 106 coupled to the motor bridge 104; a microprocessor 108 coupled to the motor bridge 104; and a Hall Effect sensor(s) 110 coupled to the microprocessor 108.

In accordance with another embodiment, the micro stepping of the rotor 14 may be accomplished by the addition of a ground connection generally

designated by the numeral 150 in FIG. 8 at the common point 52 of the three phase coil circuit 50 depicted in FIG. 8 which is otherwise identical in structure to the three phase coil circuit depicted in FIGS. 3B, 4B, 5B, and 6B.

In accordance with these embodiments, if each input phase current is
5 driven by sine and cosine waveforms, then the motor 10 can operate in a synchronous manner and micro-stepping is a technique that will increase motor resolution by controlling both the direction and amplitude of the current in each phase and, more specifically, by making the current flow through the phase coils a fraction of either full on current in one direction or full on current in the opposite
10 direction. Since sine and cosine micro-stepping are the most common forms, but other waveforms can be used as well.

Numerous variations and modifications of the axial brushless DC motor described above may be effected without departing from the spirit and scope of the novel features of the invention. It is thus understood that no limitations with
15 respect to the structure or stepping function of the axial brushless DC motor illustrated herein is intended or should be inferred. It is, of course, intended to cover by the appended claims all such modifications as fall within the scope of the claims.

20

CLAIMS

We claim:

1. An axial brushless DC motor comprising:
5 a stator including a plurality of coils;
a rotor including a magnet with a plurality of pairs of magnetic poles and adapted for movement relative to the stator in one or more full steps; and
a coil phase circuit adapted for moving the rotor relative to the stator a fractional step less than the one or more full steps and/or holding the rotor at the
10 one or more fractional or full steps.
2. The axial brushless DC motor of claim 1, wherein the coil phase circuit is a three phase circuit adapted to switch the orientation of one or more of the plurality of pairs of magnetic poles of the rotor during operation of the motor
15 and hold the rotor at a half step between the one or more full steps.
3. The axial brushless DC motor of claim 1, wherein the coil phase circuit is a three phase coil circuit adapted to switch the orientation of one or more of the plurality of pairs of magnetic poles of the rotor during operation of
20 the motor and hold the rotor at the fractional or one or more full steps.
4. The axial brushless DC motor of claim 1, wherein the coil phase circuit includes a one phase coil circuit, a motor bridge coupled to the one phase coil, a motor supply coupled to the motor bridge, a microprocessor coupled to the
25 motor bridge, and a Hall Effect sensor coupled to the microprocessor for moving the rotor during the operation of the motor in micro steps between the one or more full steps.
5. The axial brushless DC motor of claim 1, wherein the coil phase
30 circuit includes a plurality of coil circuit segments coupled together at a common junction that is coupled to ground for moving the rotor in micro steps during the

operation of the motor between the one or more full steps.

6. An axial brushless DC motor comprising:
a stator including a plurality of coils;
5 a rotor including a magnet with a plurality of pairs of magnetic poles and adapted for movement relative to the stator in full step positions; and
a coil phase circuit including first, second, and third coil phase segments connected in series at a common central connection point, each of the coil phase segments including a pair of coils configured in parallel, and current being
10 adapted for flow through the coil phase circuit in a manner adapted to switch the orientation of one or more of the plurality of pairs of magnetic poles of the magnet for moving the rotor relative to the stator a fractional step position less than the full step position and/or holding the rotor at the fractional step position or full step position.

15
7. The axial brushless DC motor of claim 6, wherein the rotor is movable from a first driving position into a fractional step position less than the full step position by switching the flow of current from between the first and third coil phase segments through the common central connection point to between
20 the second and third coil phase segments through the common central connection point.

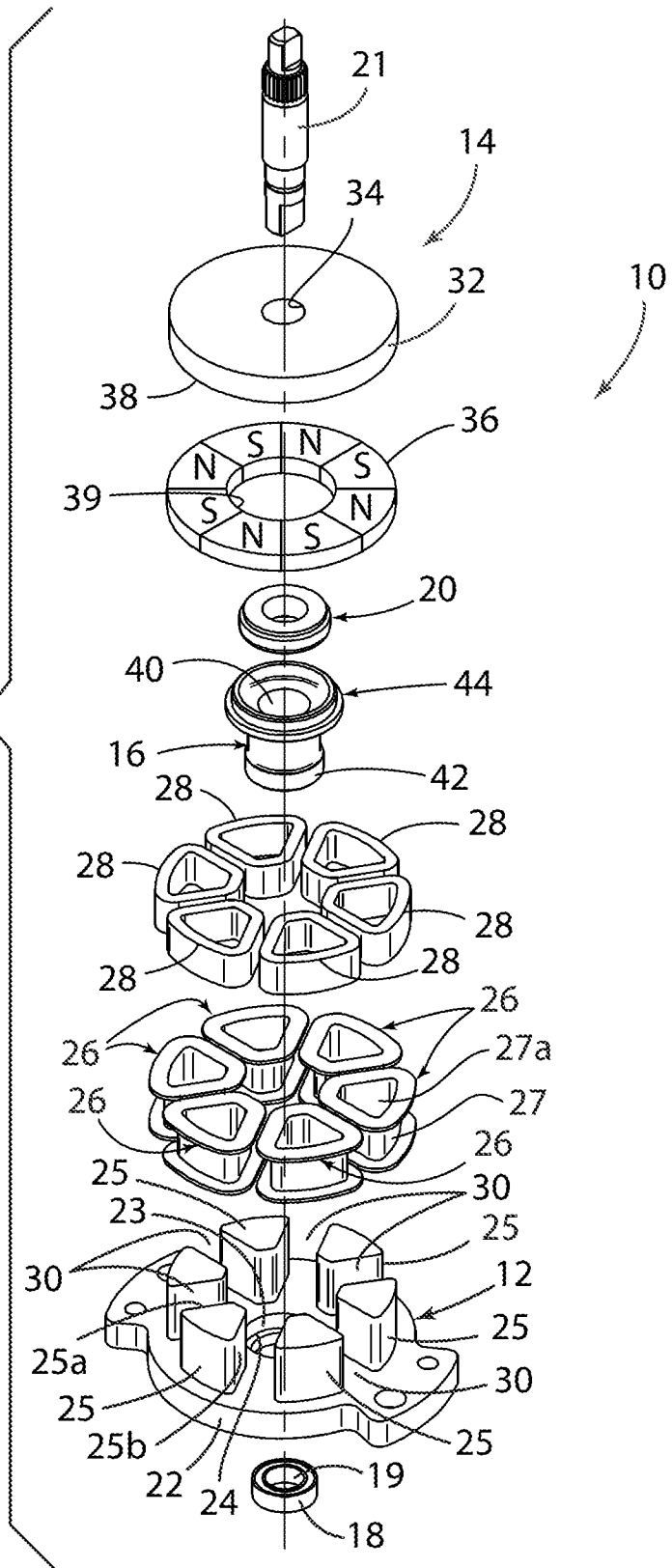
8. The axial brushless DC motor of claim 6, wherein the rotor is movable from a first driving position into a full step hold position by switching the
25 flow of current from between the first and third coil phase segments through the common central connection point to between the first and second coil phase segments and through the third coil phase segment through the common central connection point.

30

9. An axial brushless DC motor comprising:
a stator including a plurality of coils;
a rotor including a magnet and adapted for movement in full or fractional step position relative to the stator;
- 5 a coil phase circuit including first, second, and third coil phase segments coupled together in series at a common central connection point, each of the first, second, and third coil phase segments including a pair of coils coupled in parallel, and energizable for moving the rotor between a first driving position and full or fractional step hold positions relative to the stator.
- 10
10. The axial brushless DC motor of claim 9, wherein the rotor is movable between the first driving position and full or fractional hold positions relative to the stator by switching the flow of current through the first, second, and third coil phase segments of the coil phase circuits.
- 15
11. The axial brushless DC motor of claim 10, wherein the rotor is movable from the first driving position in which current flows through the first and third coil phase segments through the common central connection point to a fractional hold half step position in which the flow of current has been switched to
- 20 flow through the second and third coil phase segments.
12. The axial brushless DC motor of claim 10, wherein the rotor is movable from the first driving position in which current flows through the first and third coil phase segments through the common central connection point to a full
- 25 step hold position in which the flow of current has been switched to flow through both of the first and second coil phase segments and into the third coil phase segment through the common central connection point.
- 30

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FIGURE 2A



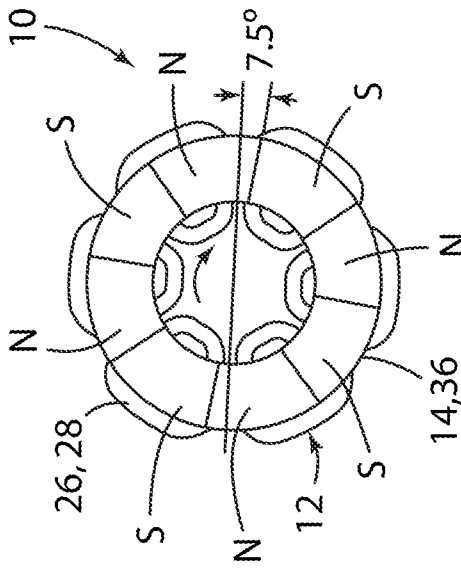


FIG. 3A

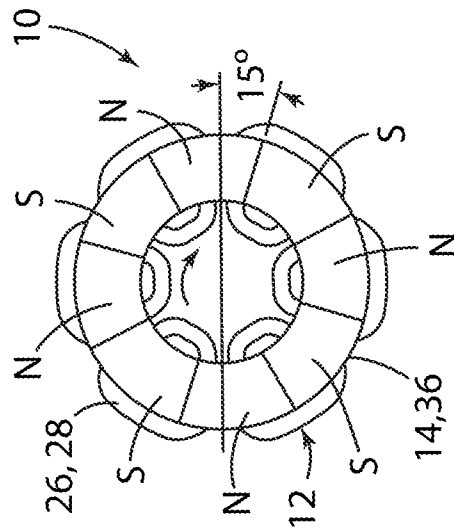


FIG. 4A

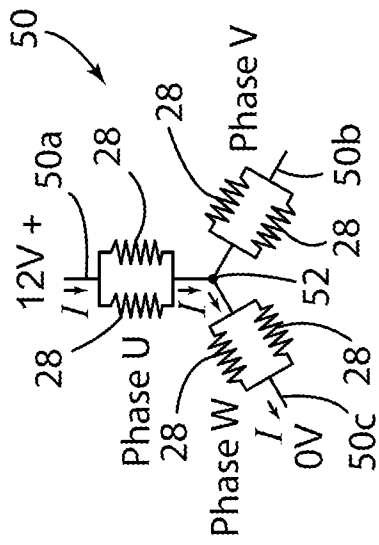


FIG. 3B

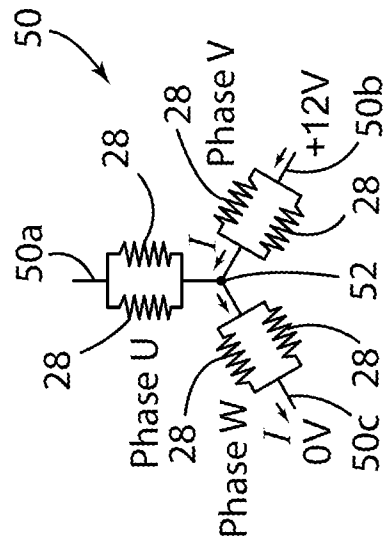


FIG. 4B

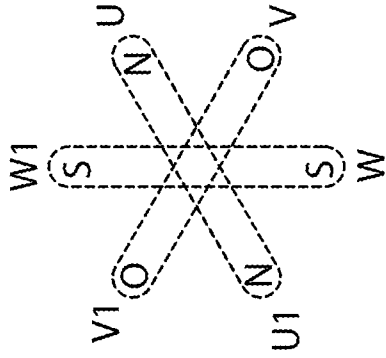


FIG. 3C

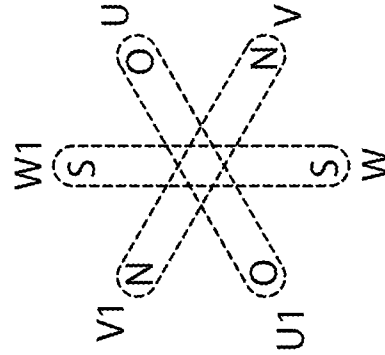


FIG. 4C

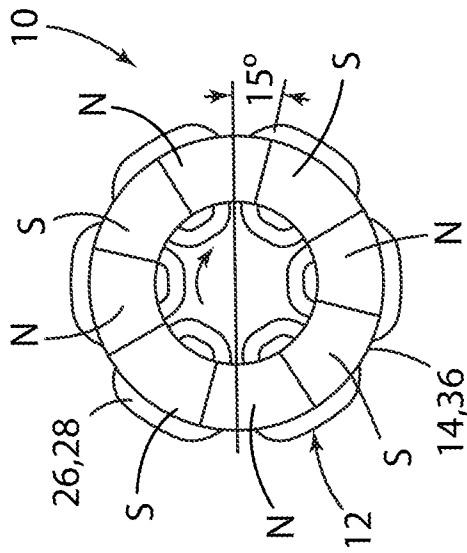


FIG. 5A

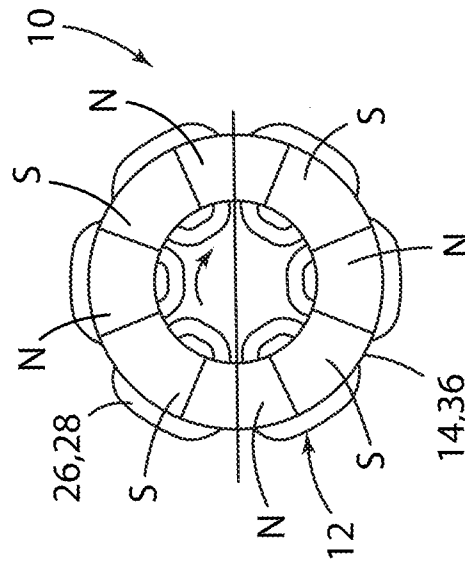


FIG. 6A

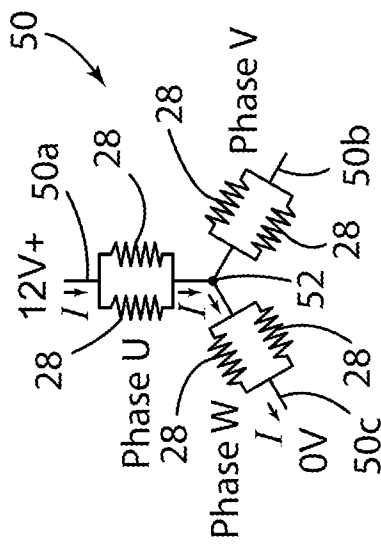


FIG. 5B

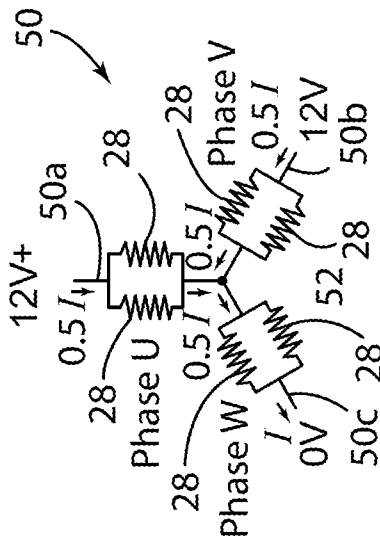


FIG. 6B

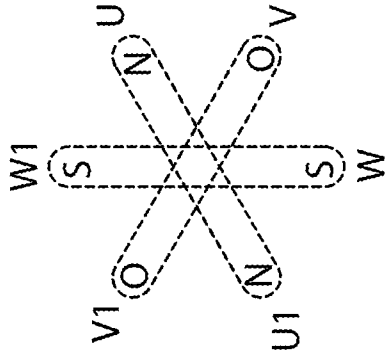


FIG. 5C

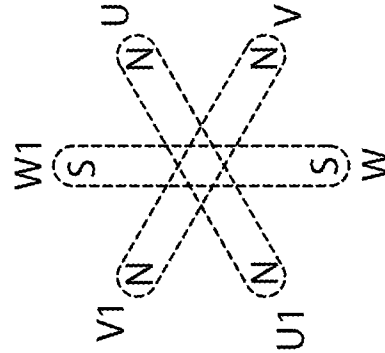


FIG. 6C

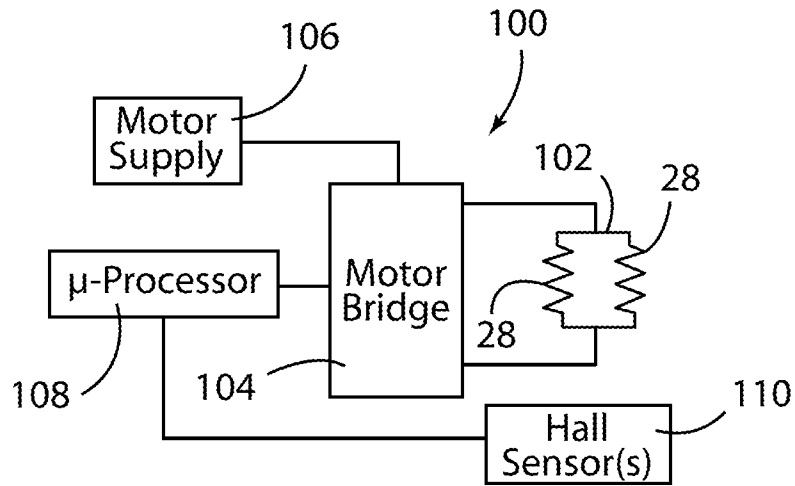


FIG. 7

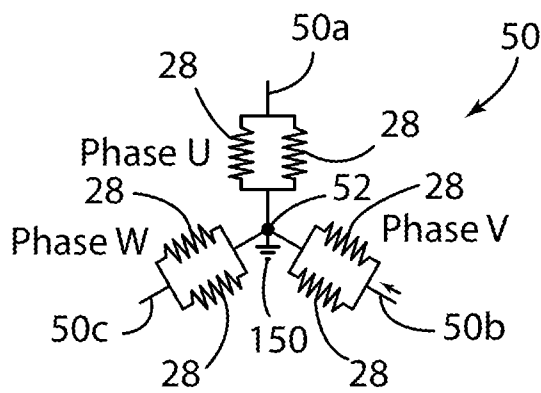


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/032807

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02K21/24 H02K11/33 H02P8/42
ADD.
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)
H02K H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 223 255 A (GOLDMAN GARY S ET AL) 16 September 1980 (1980-09-16)	1-12
Y	column 4, line 36 - column 6, line 19; figures 2-6 column 6, line 20 - column 8, line 36; figures 7,8	7-10
X	DE 10 2013 109877 A1 (ZF LENKSYSTEME GMBH [DE]) 12 March 2015 (2015-03-12) paragraph [0040] - paragraph [0045]; figures 1-6 paragraph [0046] - paragraph [0048]; figures 1-4,7,8 paragraph [0050] - paragraph [0059]; figures 10-19	1-4,6-12
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 13 July 2017	Date of mailing of the international search report 20/07/2017
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Zavelcuta, Florin
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/032807

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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X	US 6 348 751 B1 (JERMAKIAN JOEL B [US] ET AL) 19 February 2002 (2002-02-19) column 7, line 63 - column 9, line 48; figure 1 column 18, line 60 - column 23, line 7; figures 5-23 -----	1-4
X	WO 2015/189121 A2 (MMT SA [CH]) 17 December 2015 (2015-12-17) paragraph [0030] - paragraph [0035]; figures 1-4 paragraph [0051] - paragraph [0053]; figures 13-17 -----	1-7,9-11
X	US 5 514 923 A (GOSSLER SCOTT E [US] ET AL) 7 May 1996 (1996-05-07) column 4, line 12 - column 5, line 19; figures 1-3 -----	1,4
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Y	US 2007/138983 A1 (DE FILIPPIS PIETRO [IT] ET AL) 21 June 2007 (2007-06-21) paragraph [0001] - paragraph [0021]; figures 1-3 -----	7-10

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International application No PCT/US2017/032807

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