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GB 1416430
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(54) **Electric motors**

(57) An electric, e.g. brushless D.C., motor comprises a rotor assembly 8 and a stator assembly 16. The rotor assembly 8 includes a rotational shaft 6 and a field magnet 11 shaped into a solid of revolution and fixed on the shaft 6. The stator assembly 16 includes an armature member 12 facing one of surfaces of the magnet 11 with a small air gap therebetween and a yoke member 25 facing another opposite one of the surfaces of the magnet 11. The field magnet 11 is formed of synthetic resin containing magnetic material. In a modification (Fig. 13, not shown) a yoke member (25) is mounted on the rotor (11). The motor may include a frequency detector assembly (60, Fig. 16, not shown).

FIG. 2

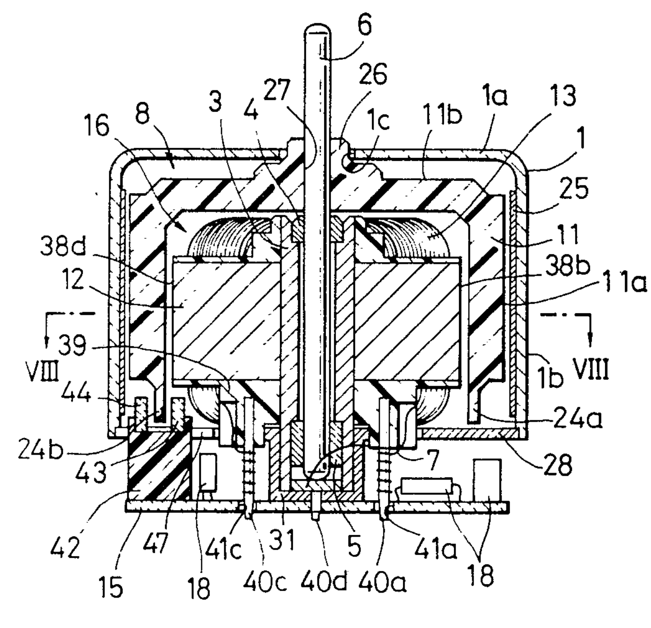

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FIG. 2

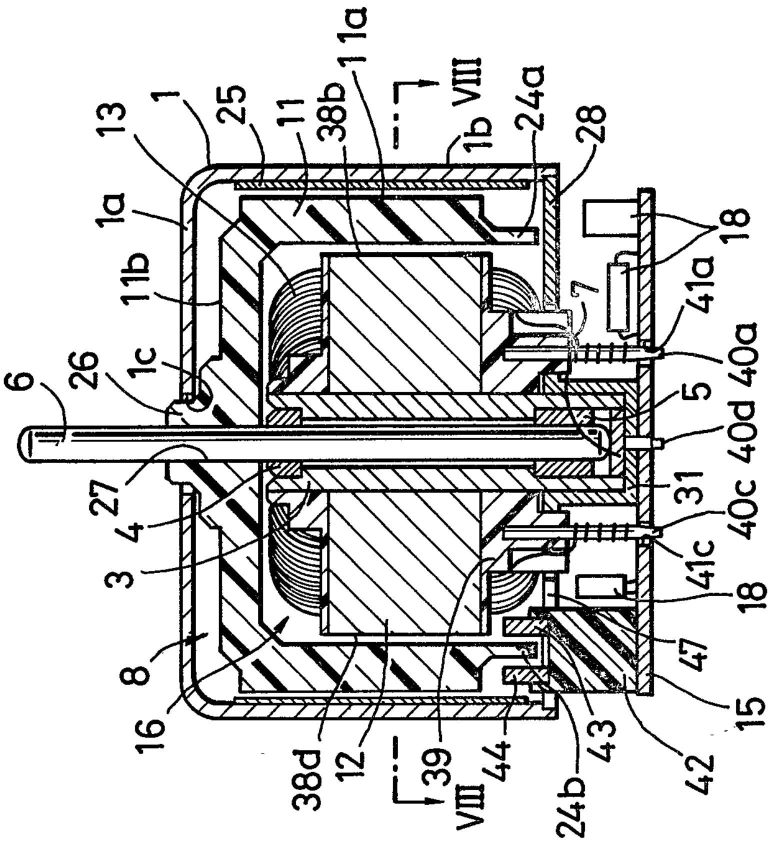

6
26
1c
1a
11b
13
1
25
11
38b
11a
VIII
1b
24a
28
18
41a
7
40a
5
40d
27
4
31
40c
3
41c
18
8
47
15
16
38d
12
39
44
43
24b
42
VIII

FIG. 1

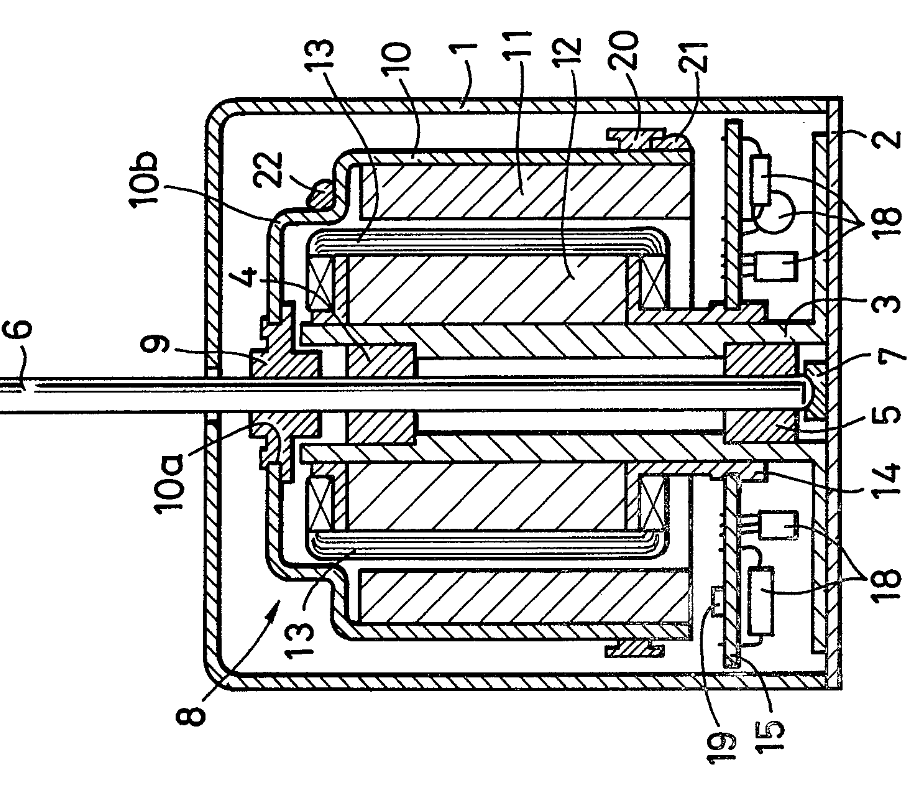

6
9
10a
10b
22
4
13
10
1
11
12
20
21
2
18
3
7
5
14
18
8
13
19
15

FIG. 3

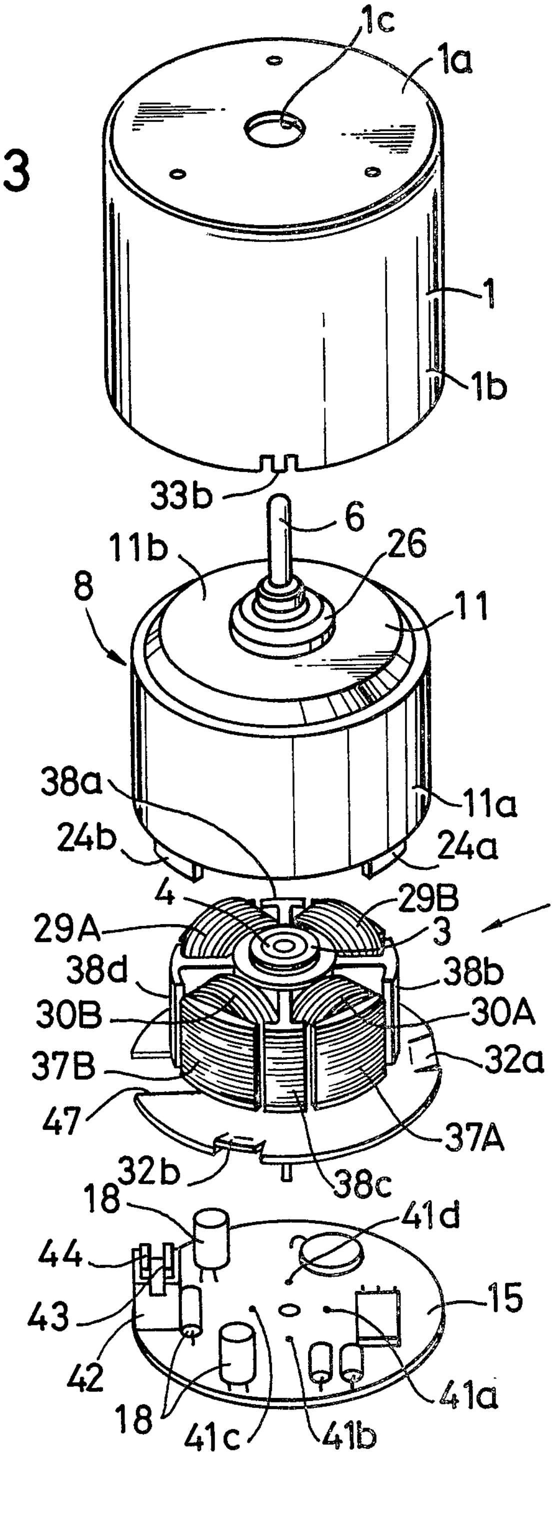

1c
1a
1
1b
33b
6
26
11b
8
11
38a
11a
24b
24a
4
29B
16
29A
3
38d
38b
30B
30A
37B
32a
47
37A
32b
38c
18
41d
44
15
43
42
41a
18
41c
41b

FIG. 4A

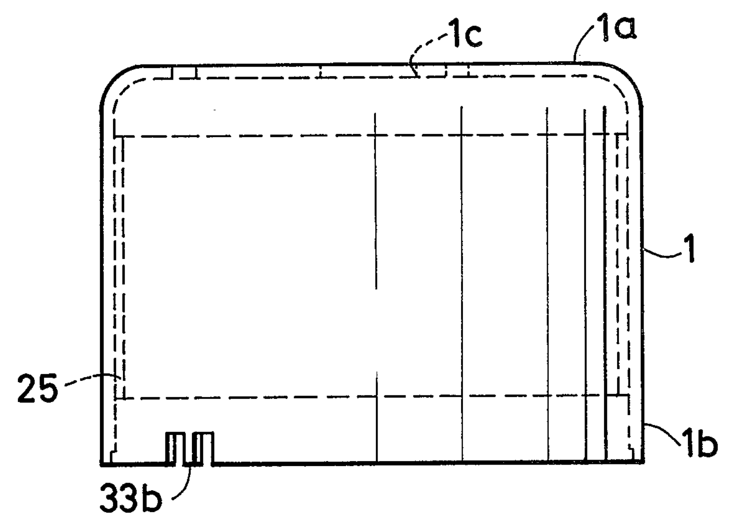


FIG. 4B

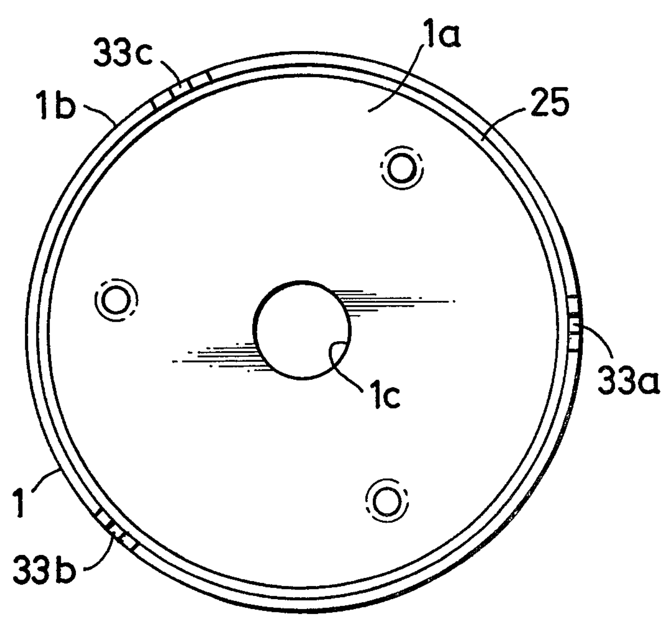


FIG. 5A

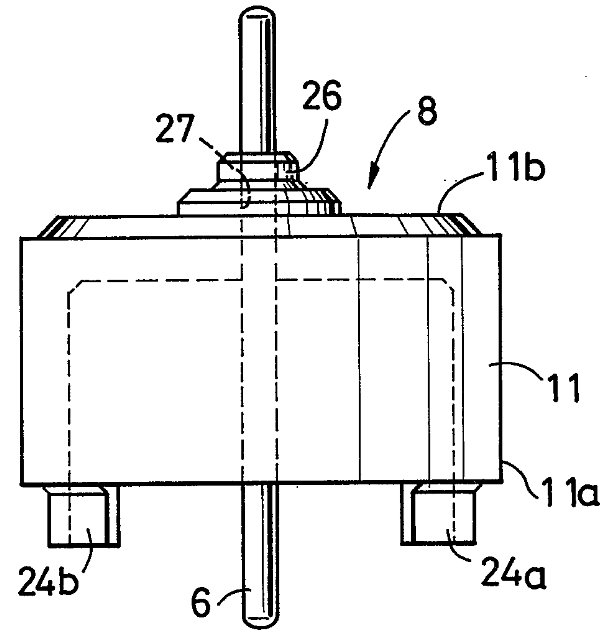


FIG. 5B

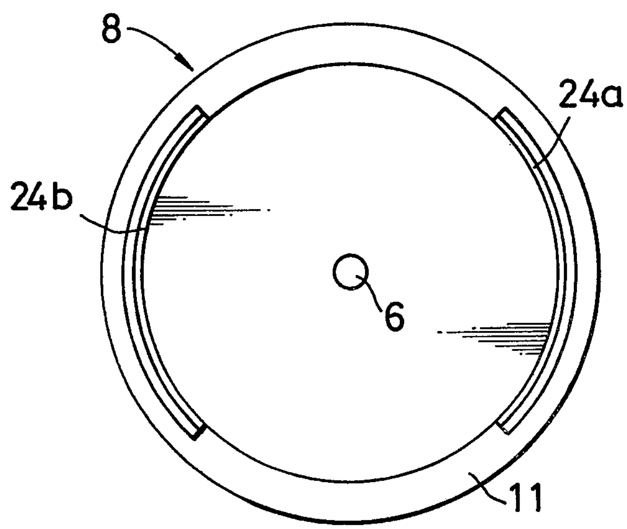


FIG. 6A

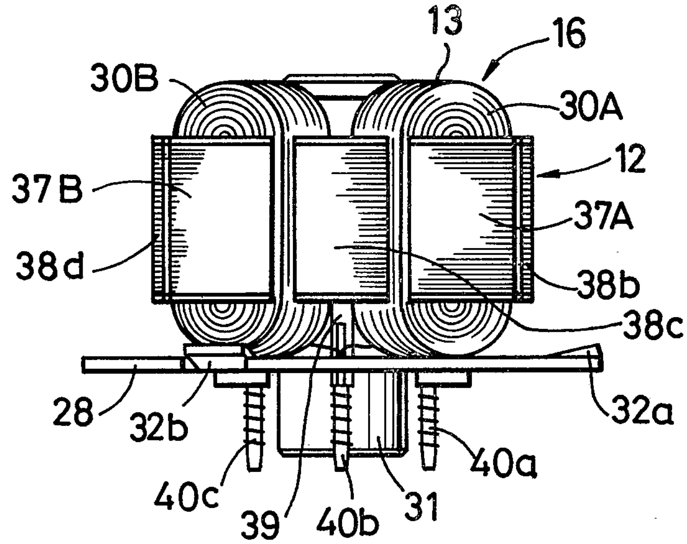

13
16
30B
30A
12
37B
37A
38d
38b
38c
28
32b
32a
40c
39
40b
31
40a

FIG. 6B

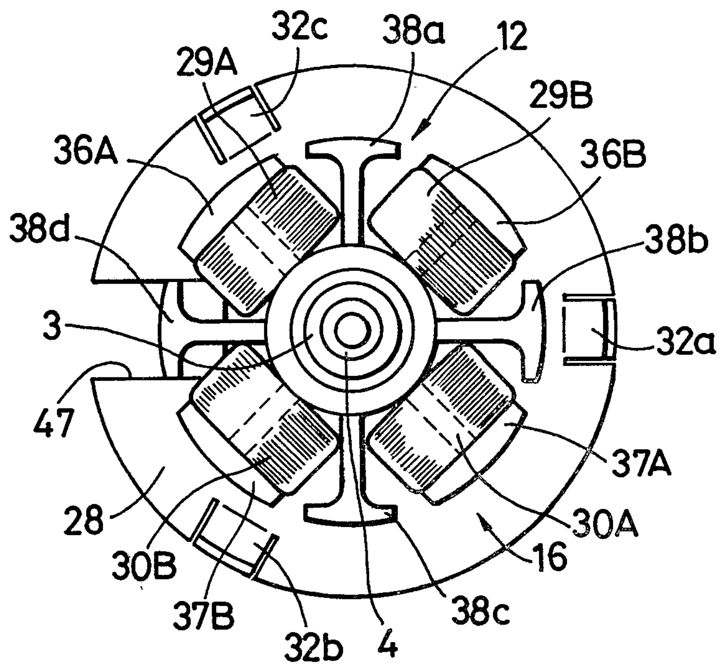

32c
38a
12
29A
29B
36A
36B
38d
38b
3
32a
47
37A
28
30A
16
30B
37B
32b
4
38c

FIG. 7

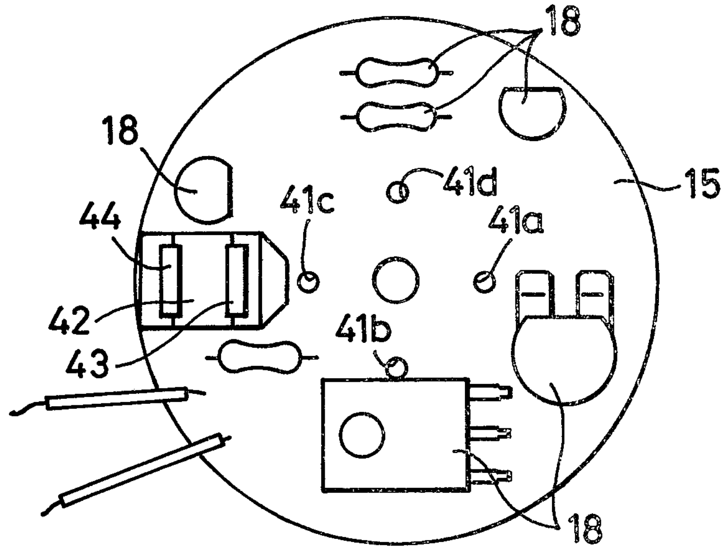

18
18
41d
15
41c
41a
44
42
43
41b
18

FIG. 8

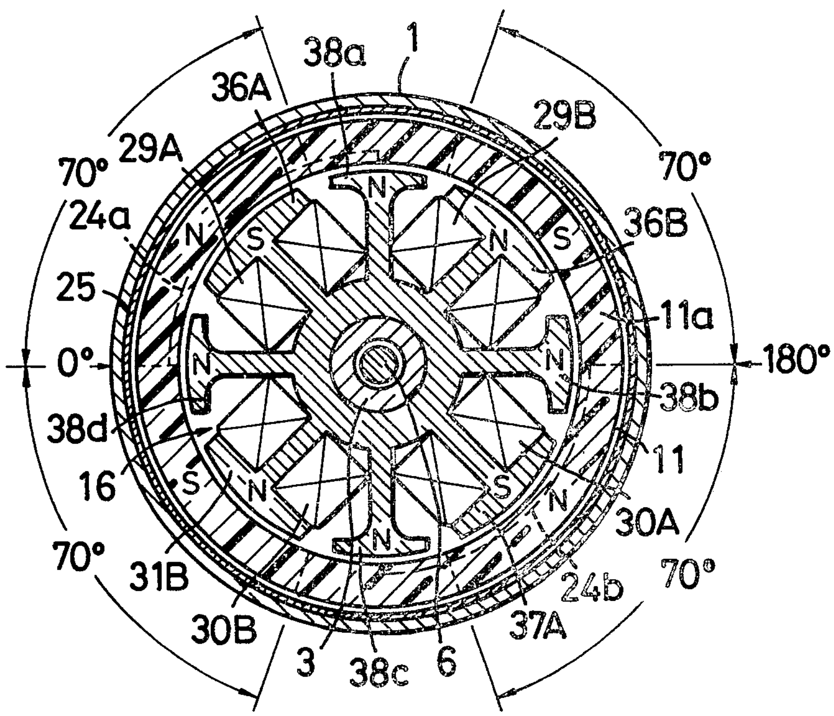

38a
1
36A
29B
70°
29A
70°
24a
36B
25
11a
0°
180°
38b
38d
11
16
30A
70°
31B
70°
24b
30B
37A
3
38c
6

FIG. 9

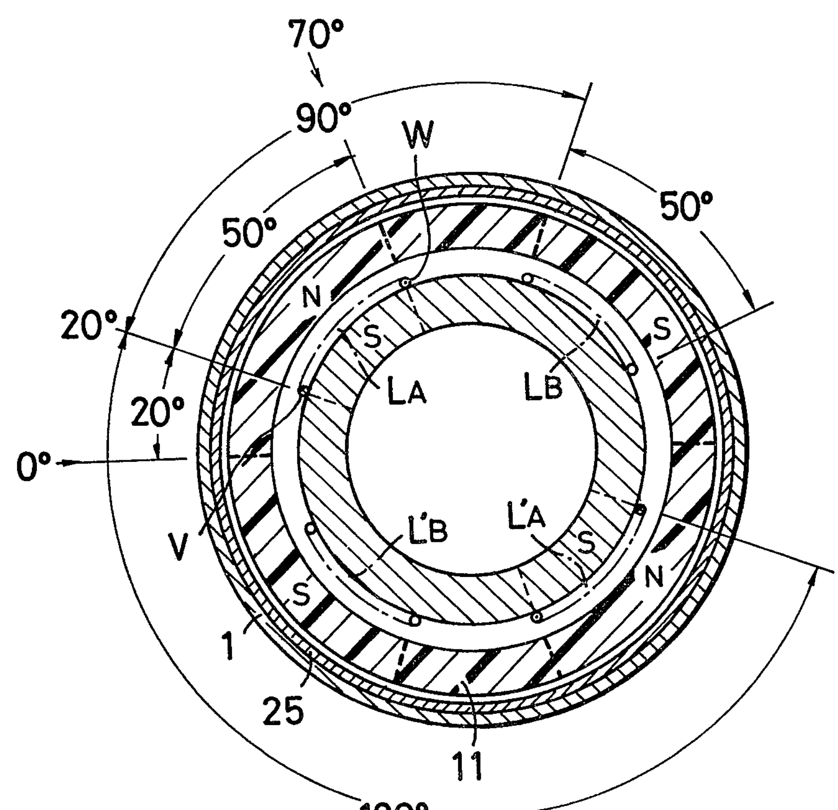


FIG. 10A

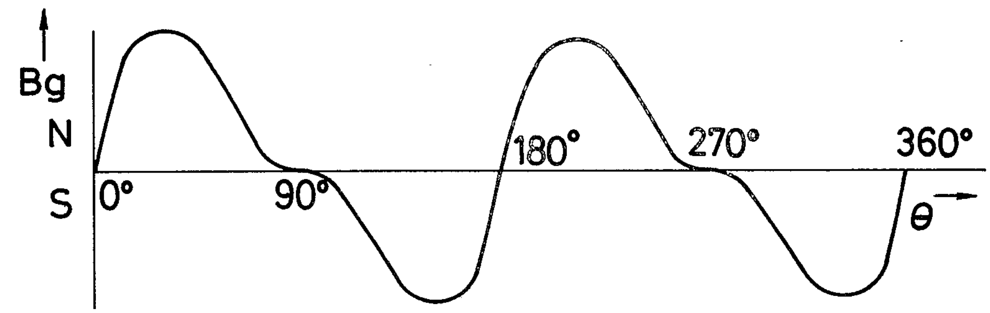


FIG. 10B

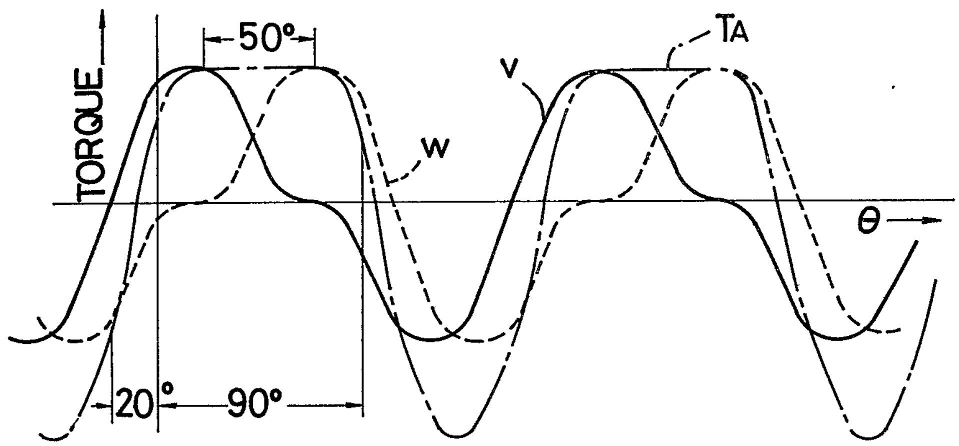


FIG. 10C

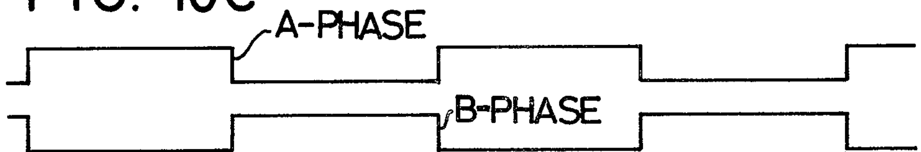


FIG. 10D

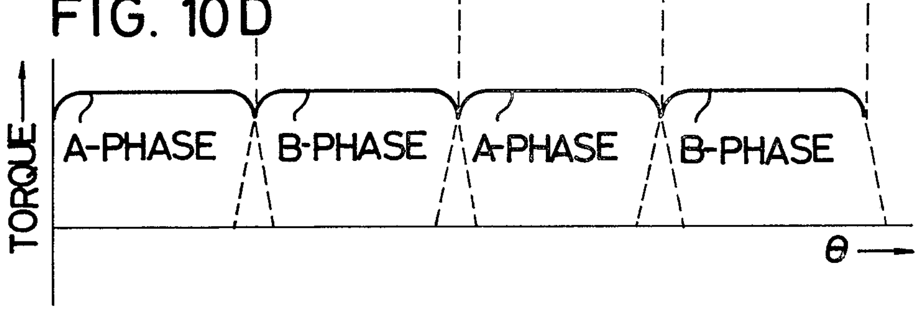


FIG. 11

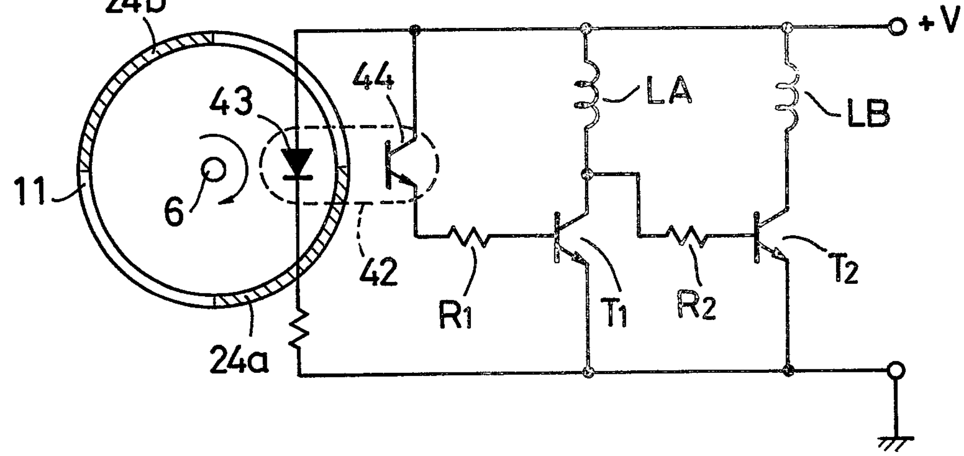

24b
43
44
11
6
42
24a
LA
LB
+V
R1
T1
R2
T2

FIG. 12

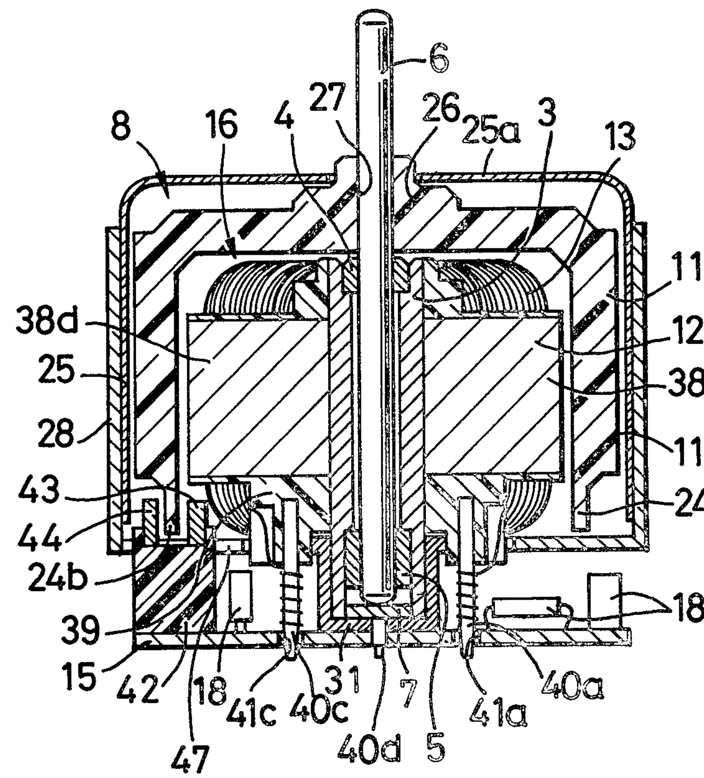

6
8
16
4
27
26
25a
3
13
11
12
38d
38b
25
28
11a
43
24a
44
24b
18
39
15
42
18
41c
40c
31
7
5
41a
40a
40d
47

FIG. 13

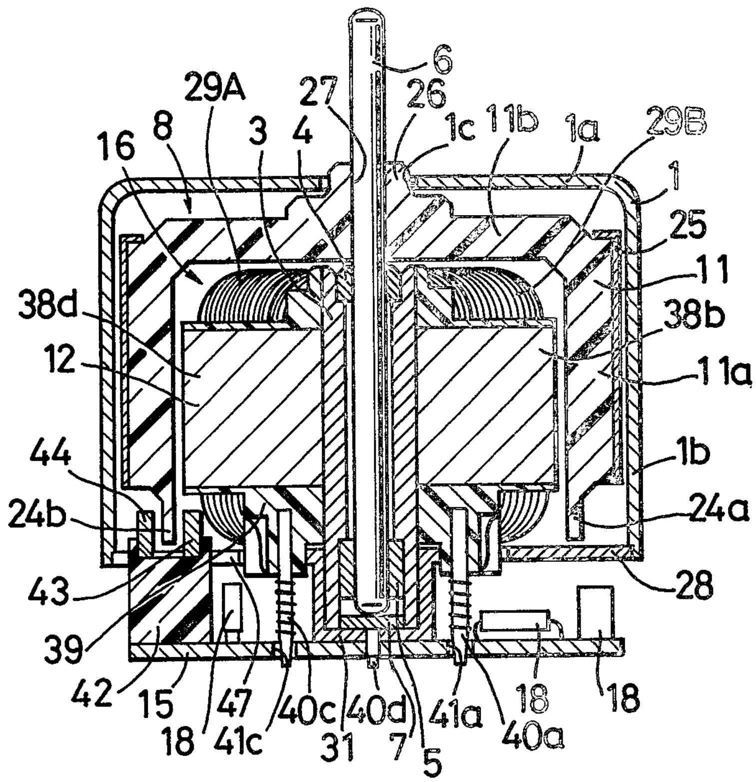

6
27
26
29A
1c
11b
1a
29B
16
8
3
4
1
25
11
38d
38b
12
11a
44
1b
24b
24a
43
28
39
42
15
47
40c
40d
41a
18
18
18
41c
31
7
40a
5

FIG. 14

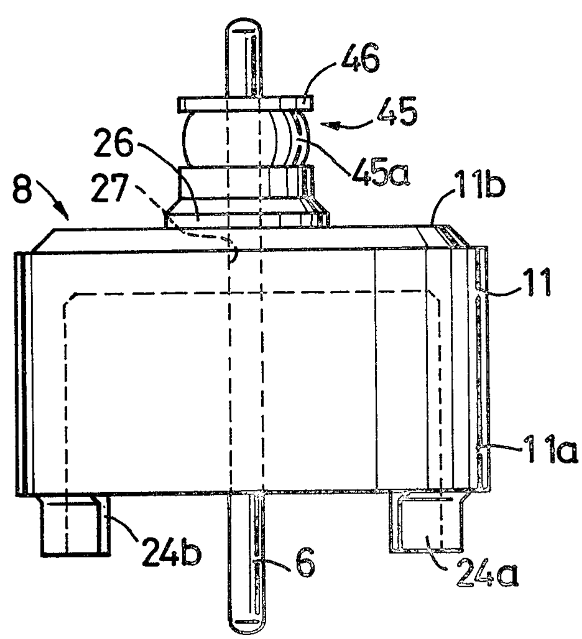

46
45
26
45a
8
27
11b
11
11a
24b
6
24a

FIG. 15

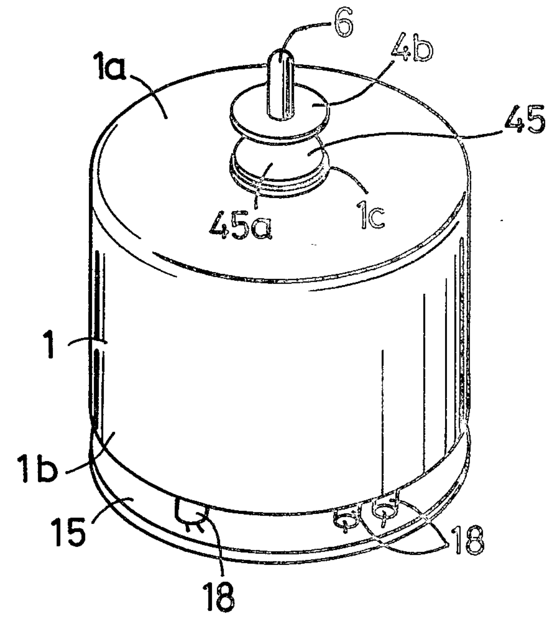

6
4b
1a
45
45a
1c
1
1b
15
18
18

FIG. 16

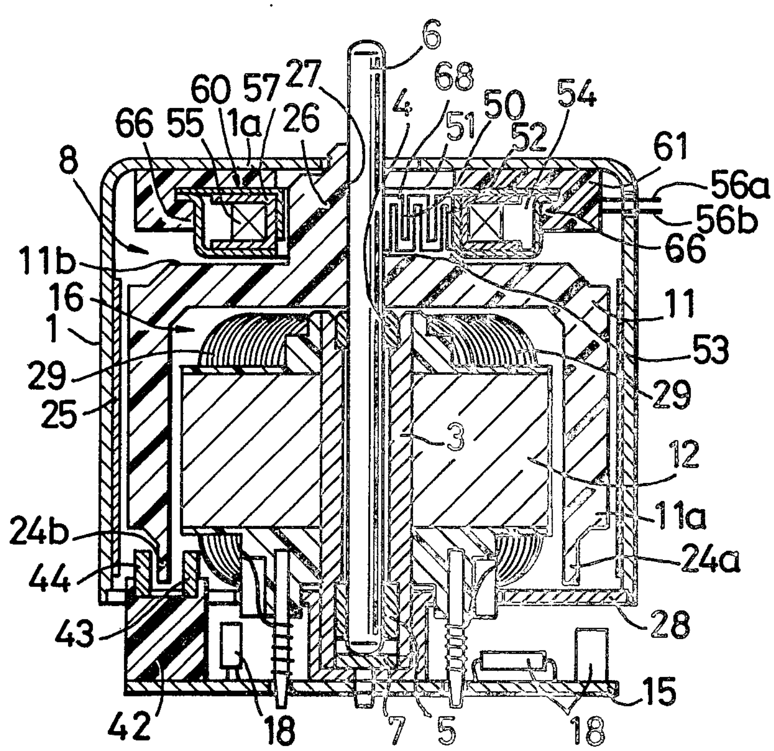

6
27
68
60
57
4
50
54
66
55
1a
26
51
52
61
8
56a
56b
66
11b
16
11
1
53
29
29
25
3
12
11a
24b
24a
44
43
28
15
42
18
7
5
18

FIG. 17

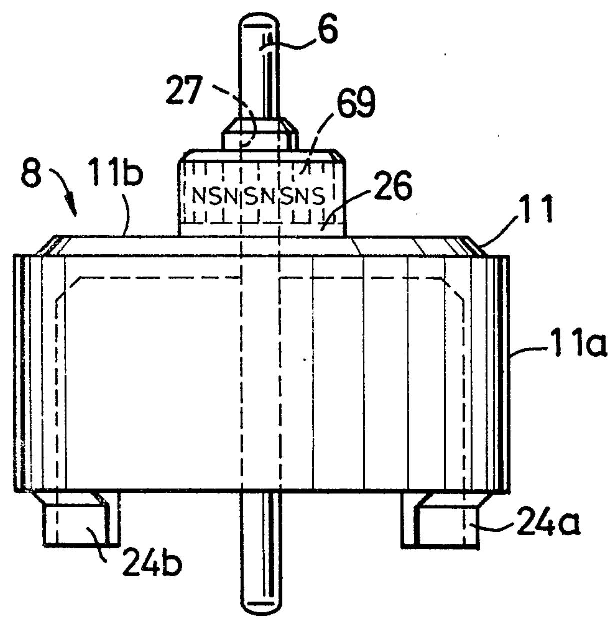


FIG. 18

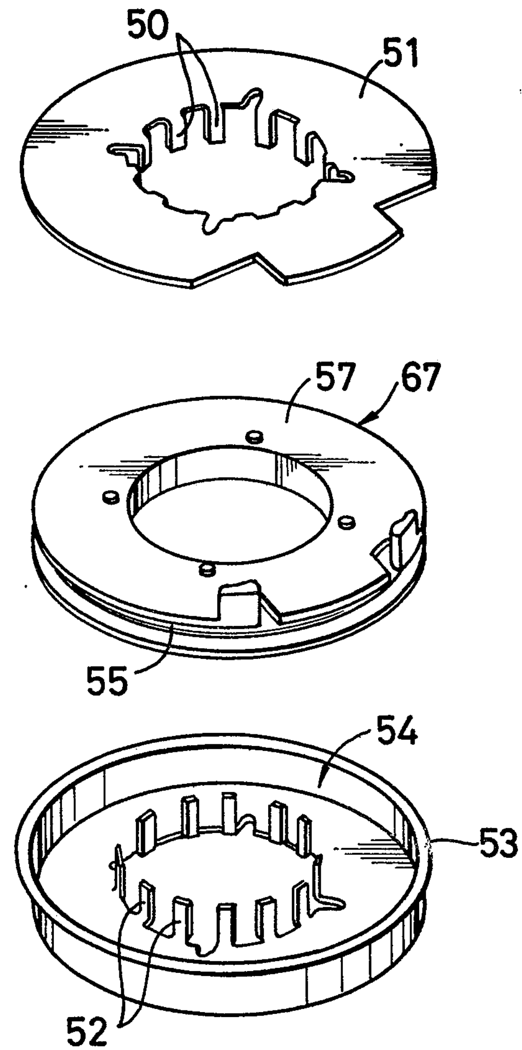


FIG. 19

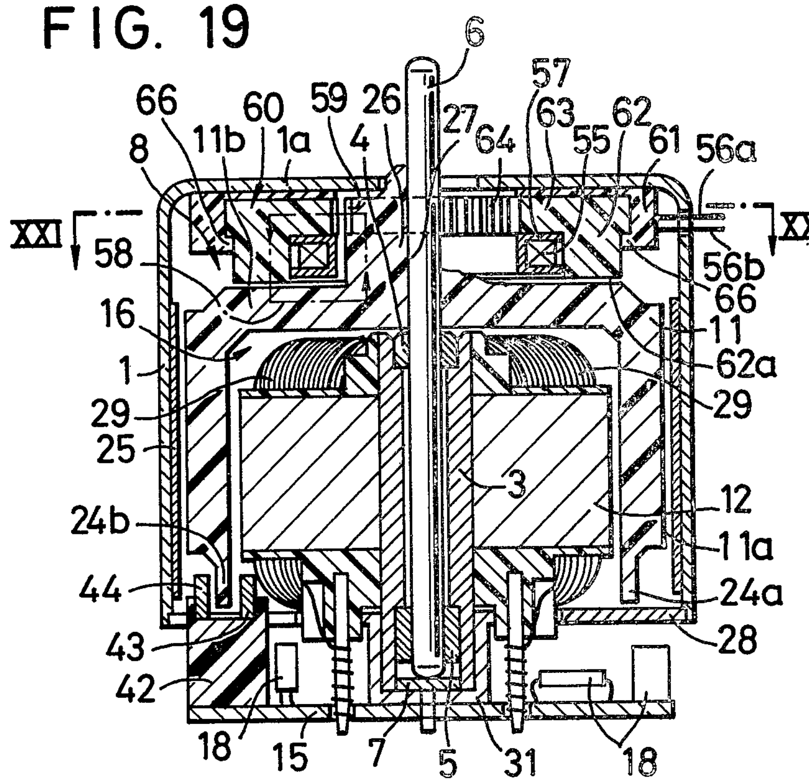

6
66
60
59
26
27
4
64
57
63
55
62
61
56a
8
11b
1a
XXI
XXI
58
56b
66
16
11
1
62a
29
29
25
3
12
24b
11a
44
24a
43
28
42
18
15
7
5
31
18

FIG. 20

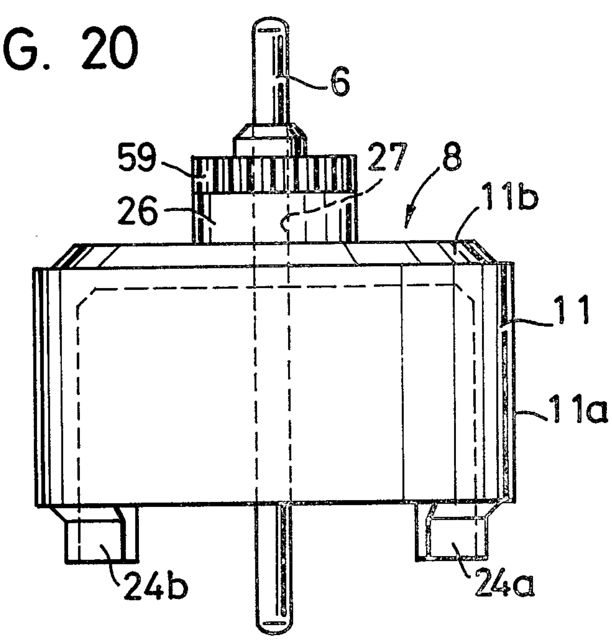

6
59
27
8
26
11b
11
11a
24b
24a

FIG. 21

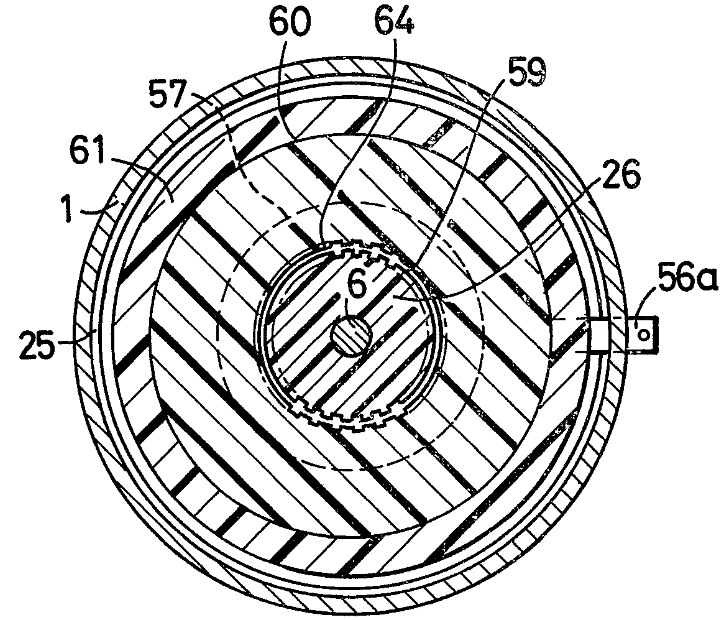

60
64
59
57
61
26
1
56a
6
25

FIG. 22

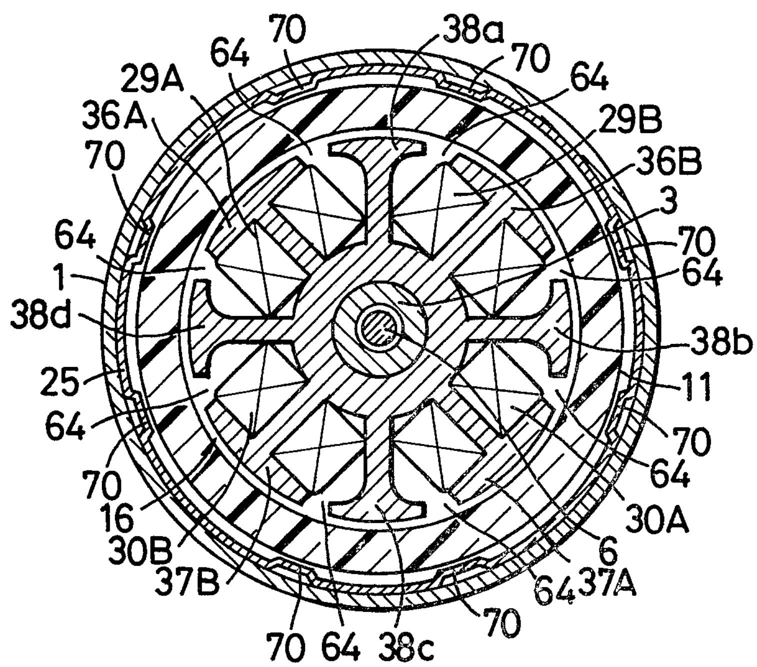

70
38a
64
70
64
29A
36A
29B
36B
70
3
64
70
1
64
38d
38b
25
11
64
70
70
64
16
30A
30B
6
37B
64
37A
70
64
38c
70

FIG. 23

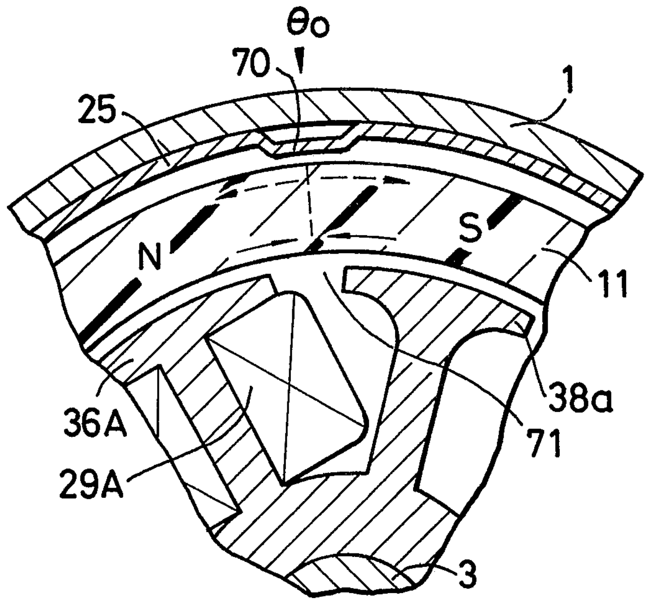


FIG. 24A

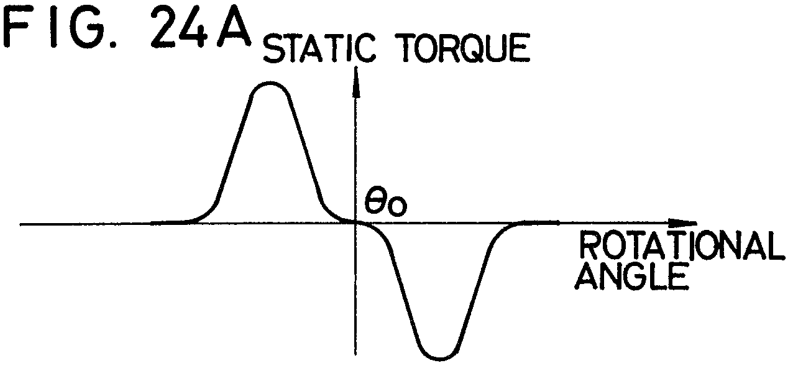
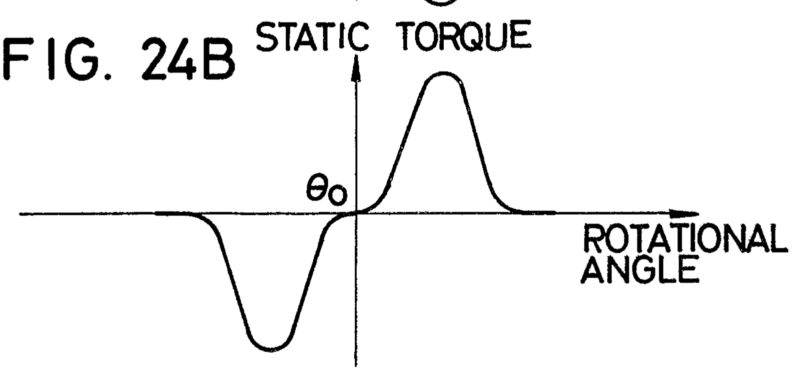


FIG. 24B



SPECIFICATION

Electric motors

This invention relates to electric motors, and more particularly, but not exclusively, to brushless *dc* motors.

In a conventional brushless *dc* motor, a cylindrical ceramic ferrite magnet or arcuate ceramic ferrite magnets are provided for a rotor assembly. In an outer-rotor type brushless *dc* motor, such ceramic ferrite magnets are fixed by adhesive on the inner surface of a cup-shaped rotor yoke made of a material of high permeability, such as soft steel plate. The rotor assembly is heavy and has a lage moment of inertia, which is very disadvantageous for a small inertia motor.

Moreover, the ferrite magnets, rotor yoke or other elements forming the rotor assembly must be accurately machined so that the rotor assembly has good rotary dynamic balance. This increases the cost of the elements of the rotor assembly.

Since the ferrite magnets are fixed by adhesive on the inner wall of the rotor yoke, assembly is slow and the rotor assembly is apt to lose the rotational dynamic balance during the assembly process, so necessitating the subsequent provision of weights to regulate the rotary dynamic balance.

Moreover, a device such as a frequency generator for detecting rotational speed or a mechanical element for torque transmission may be attached to the rotary shaft of the motor, and a motor including such a device becomes large and complicated, further increasing the assembly time.

According to the present invention there is provided an electric motor comprising:

a rotor assembly including a rotational shaft and a field magnet shaped as a solid of revolution, said field magnet being fixed on the shaft; and

a stator assembly including an armature member facing one of the surfaces of said magnet with a small air gap therebetween and a yoke member facing another opposite one of the surfaces of said magnet with a small air gap therebetween.

According to the present invention there is also provided an electric motor comprising:

a rotor assembly including a rotational shaft and a field magnet shaped as a solid of revolution, said field magnet being moulded of synthetic resin containing magnetic material and fixed on the shaft; and

a stator assembly including an armature member facing one of the surfaces of said magnet with a small air gap therebetween.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a vertical sectional view of a conventional outer-rotor type brushless *dc* motor;

Figures 2 to 11 represent one embodiment of 4-pole alternate phase brushless *dc* motor according to the invention;

Figure 2 is a vertical sectional view of the motor;

Figure 3 is an exploded perspective view of the motor;

Figure 4A is a side view of a motor case;

Figure 4B is a bottom view of the motor case;

Figure 5A is a side view of a rotor assembly;

Figure 5B is a bottom view of the rotor assembly;

Figure 6A is a side view of a stator assembly;

Figure 6B is a top plan view of the stator assembly;

Figure 7 is a top plan view of a circuit board;

Figure 8 is a cross-sectional view taken on the line VIII–VIII in Fig. 2;

Figure 9 is a schematic view showing a part of the motor;

Figure 10A is a graph showing a magnetic flux distribution formed by the rotor magnet of the motor;

Figure 10B is a graph for explaining the composite rotational torque imparted by A-phase coils;

Figure 10C is a waveform diagram showing change-over currents for the A-phase and B-phase;

Figure 10D is a graph showing the rotational torque of the motor;

Figure 11 is a circuit diagram of one example of a drive circuit for the motor;

Figure 12 is a vertical sectional view of an electric motor showing a modification of the yoke;

Figure 13 is a vertical sectional view of an electric motor showing another modification of the yoke;

Figure 14 is a side view of the rotor showing a modification thereof;

Figure 15 is a perspective view of the motor having the rotor of Fig. 14;

Figures 16 to 18 show another embodiment of *dc* motor according to the invention;

Figure 16 is a vertical sectional view of the motor provided with a frequency generator for detecting rotational speed;

Figure 17 is a side view of the rotor assembly of Fig. 16;

Figures 19 to 21 show a modification of the motor provided with a frequency generator;

Figure 19 is a vertical sectional view of the motor according to this modification;

Figure 20 is a side view of a rotor assembly of the motor;

Figure 21 is a cross-sectional view taken on the line XXI–XXI in Fig. 19;

Figure 22 is a cross-sectional view of the motor showing another modification of the yoke;

Figure 23 is a partially enlarged view of Fig. 22;

Figures 24A and 24B are a graph showing static torque of the motor of Fig. 22.

Before discussing the embodiments of the invention, various problems associated with prior art motors will be described. Referring initially to Fig. 1, there is illustrated an outer-rotor type brushless *dc* motor. A cylindrical cup-shaped motor case 1 is provided with a disc-like cover plate 2 for the opening portion thereof. A cylindrical support member 3 is mounted on the central portion of the cover plate 2. One end of a central, axial hole of the support member 3 is provided with a bearing 4, and the other opposite end of the hole is provided with a bearing 5. A rotatable motor shaft 6 is rotatably supported by bearings 4 and 5 and a thrust bearing 7 attached on the central portion of the cover plate 2.

A cup-shaped rotor yoke 10 is fixed to an upper portion of the shaft 6 through a boss 9. A cylindrical or arcuate permanent magnets 11 are secured to the inner cylindrical side wall of the yoke 10. A rotor assembly 8 formed of the yoke 10 and the magnets 11 encircles and rotates about a stator assembly formed of a cylindrical stator core 12. The core 12 is made of high permeability material such as ceramic ferrite, and is fixed to the outer side wall of the support member 3. The coils 13 which may, for example, be three-phase, are arranged on the cylindrical outer surface of the core 12, spaced apart from each other by a predetermined angle.

An annular circuit board 15 is attached on the lower part of the support member 3 with a cylindrical insulating member 14 therebetween. Circuit elements 18 forming a motor drive circuit are attached on the back of the circuit board 15. A position sensing element 19 is provided on the surface of the circuit board 15 for the purpose of sensing the rotational position of the rotor 8. The drive circuit operates in response to the output of the sensing element 19 selectively to energize the coils 13, whereby the motor is rotated.

In the conventional brushless *dc* motor of Fig. 1, the rotor yoke 10 for supporting the magnets 11 is made of a material of high permeability, such as soft steel iron to reduce the reluctance of the magnetic path. Therefore, the rotor assembly 8 is heavy and shows a large moment of inertia. That is very disadvantageous for a small inertia motor.

The magnets 11 must be accurately ground to produce good rotational dynamic balance of the rotor assembly 8 about the shaft 6. Moreover, the yoke 10 must be accurately machined to obtain a good rotational dynamic balance, and especial accuracy is necessary for a hole 10*a* for fixing the boss 9 through which the yoke 10 is secured to the shaft 6.

Further, since the magnets 11 are fixed on the inner wall by means of adhesive or a force fit, the assembly 8 rotor is apt to lose rotational dynamic balance. Therefore, a ring material 20 of "T" cross-section is attached on the cylindrical outer wall of the yoke 10, as shown in Fig. 1. After the rotor assembly 8 has been assembled, a small amount of weight material 21 composed of lead powder and adhesive compound is selectively attached in the space formed between the yoke 10 and the ring material 20 to adjust the rotational dynamic balance. Alternatively, or in combination with this, a small amount of weight material 22 is selectively attached in the space formed by the stepped corner 10*b* of the bottom of the yoke 10.

It will be understood that the motor of Fig. 1 requires much assembly time for fixing the magnets 11 or much adjustment time for producing the rotational dynamic balance.

The foregoing problems associated with the motor of Fig. 1 can be avoided with embodiments of the invention, one embodiment in the form of a 4-pole alternate phase brushless *dc* motor being shown in Figs. 2 to 11, in which like reference numerals identify corresponding elements in Fig. 1. Fig. 2 is a vertical cross-section of the motor, and Fig. 3 is an exploded perspective view of the motor.

As shown in Figs. 2 and 3, the brushless *dc* motor to be described comprises a cylindrical motor case 1, a rotor assembly 8, a stator assembly 16 and a circuit board 15.

Figs. 4A and 4B respectively show side and bottom views of the motor case 1. The case 1 is drawn into a cup-shape from, for example, a soft steel plate. A small hole 1*c* is formed at the centre of the bottom 1*a* of the case 1, through which the shaft 6 passes. A cylindrical magnetic path material forming a yoke 25 is fixed on the inner side wall of the case 1. The yoke 25 may be made of a silicon steel plate which is cut into a rectangle having a width as long as the inner perimeter of the case 1. The yoke 25 is secured to the inner side wall of the case 1 with its drawback force taken up by the elasticity of the silicon steel plate. The yoke 25 may be attached to the case 1 by forming several turns in spiral. Alternatively, a cylindrically formed high permeability ferrite yoke or so-called "soft ferrite" or other high permeability material may be secured in the case 1.

The yoke 25 is stationary and opposite to the rotor assembly 8, while the corresponding yoke 10 in the conventional motor of Fig. 1 rotates. Thus, the rotor assembly 8 of this embodiment has no yoke.

Figs. 5A and 5B respectively show side and bottom views of the rotor assembly 8, which comprises a magnet 11 and a rotational shaft 6. The magnet 11 is formed of plastics magnetic material, that is a mixture of thermosetting resin or thermoplastic resin and ferrite powder. The plastics magnetic material is formed into a cup-shaped solid of revolution comprising a cylindrical portion 11*a* and a bottom 11*b*, by means of injection moulding. A boss portion 26 having a centre hole 27 is formed at the centre of the bottom 11*b* of the magnet 11 to secure the shaft 6 by force fitting. The magnet 11 may alternatively be formed of rubber magnetic material.

On the lower end of the cylindrical portion 11*a* of the magnet 11, a pair of arcuate shutter blades 24*a* and 24*b* are formed along the circumferential edge of the cylindrical portion 11*a*, spaced apart from each other by 180°. That is, shutter blades 24*a* and 24*b* are diametrically opposite to each other. Each shutter blade 24*a* and 24*b* has a central angle of 90° alternately to interrupt the light path of a photo-coupler 42 described hereinafter for 90°, for generating a change-over signal for alternate energization of 180 electric degrees.

The shaft 6 provided with the magnet 11 is rotatably supported on the centre of the stator assembly 16 by the bearings 4 and 5, as shown in Fig. 2. Thus, the rotor assembly 8 rotates in the cylindrical space formed between the stator assembly 16 and the yoke 25 provided on the inner side wall of the case 1. A small gap is provided between the outer circumferential surface of the cylindrical portion 11*a* of the magnet 11 and the inner circumferential surface of the yoke 25. A small gap is also provided between the inner circumferential surface of the cylindrical portion 11*a* of the magnet 11 and the surfaces of salient poles of the stator assembly 16.

Figs. 6A and 6B respectively show side and plan views of the stator assembly 16. The stator assembly 16 comprises a base plate 28, a cylindrical support member 3, a stator core 12 and two phases of coils of which one phase is formed by a pair of coils 29A and 30A and another phase is formed by a pair of coils 29B and 30B. The base plate 28 is formed of a disc-like steel plate having a cylindrical recess 31 at the centre thereof. Bent-up portions 32*a*, 32*b* and 32*c* are formed on the peripheral edge of the base plate 28 at intervals of 120° to form recesses thereon. Click portions 33*a*, 33*b* and 33*c* are formed on the circumferential edge of the case 1 at intervals of 120°. When assembling the motor, the click portions 33*a*, 33*b* and 33*c* are bent inwardly at the corresponding bent-up portions 32*a*, 32*b* and 32*c* to fix the case 1 to the base plate 28.

The cylindrical support member 3 is mounted in the recess 31 of the base plate 28 by force fitting. The bearings 4 and 5 and a thrust bearing 7 are provided in the cylindrical hole of the support member 3. The laminated iron core 12 is secured on the outer cylindrical surface of the support member 3. The core 12 has 8 poles of salient-pole configuration, as shown in Fig. 6B. Slots for winding coils are formed between each salient pole. Each pole-face of four salient poles 36A, 36B, 37A and 37B at intervals of 90° extends over central angles of about 50°. Coils 29A, 29B, 30A and 30B are respectively wound on the salient poles 36A, 36B, 37A and 37B. Each pole-face of four salient poles 38*a*, 38*b*, 38*c* and 38*d* arranged between the salient poles 36A, 36B, 37A and 37B extends over central angles of about 30°. Coils are not wound on the salient poles 38*a*, 38*b*, 38*c* and 38*d*, which operate as auxiliary poles.

Alternate "A-phase" and "B-phase" are formed by the coils. "A-phase coil" is formed by the coils 29A and 30A which are separated from each other by 180° and are connected in series with each other. "B-phase coil" spaced apart from the A-phase coil by a circumferential dimension equal to 90° is formed by coils 29B and 30B, which are separated from each other by 180° and are connected in series with each other. Two pairs of leads of these A and B-phase coils are connected to conductive patterns on the circuit board 15, through four terminal rods 40*a* to 40*d* mounted axially on an annular insulating material 39 for insulating the coils from the core 12.

The circuit board 15, as viewed in Fig. 7, is provided with four through holes 41*a* to 41*d*, each positionally corresponding to terminal rods 40*a* to 40*d*. When assembling the motor, the terminal rods 40*a* to 40*d* are passed through the holes 41*a* to 41*d* to be connected with the conductive patterns on the back of the circuit board 15 by means of solder, whereby the circuit board 15 is secured to the stator assembly 16.

A photo-coupler 42 is mounted on the circuit board 15. The photo-coupler 42 includes a light emitting element 43 and a light sensing element 44, which are opposite to each other. The photocoupler 42 passes through a rectangular notch 47 of the base plate 28 and extends to the rotational locus of the shutter blades 24*a* and 24*b* of the magnet 11, as shown in Fig. 2. The shutter blades 24*a* and 24*b* rotate across the light path between the light emitting element 43 and the light sensing element 44 of the photo-coupler 42, so the light emitted from the light emitting element 43 is interrupted every 180°, intermittently for a duration of 90°, which generates a change-over signal for alternate energization over an electric angle of 180°. The photo-coupler 42 is arranged at the middle position between the A-phase coil 29A and the B-phase-coil 30B, that is, at the same circumferential position as the centre of the salient pole 38*d*.

Next, the operation of the *dc* motor shown in Figs. 2 to 7 will be described.

The magnet 11 of the rotor assembly 8 includes two circumferentially arranged pairs of magnetic poles, as shown in Fig. 8, which is a cross-sectional view taken on line VIII–VIII in Fig. 2. One pair of poles comprises an N-pole and an S-pole, together subtending an angle of 70° on both sides of a positional angle corresponding to one edge of the shutter blade 24*a*, that is, the positional angle 0° of Fig. 8. Another pair of poles comprises an N-pole and an S-pole, together subtending an angle of 70° on both sides of a positional angle corresponding to one edge of the shutter blades 24*b*, that is, the positional angle of 180°. Remaining arcuate, cylindrical parts of the magnet 11 are not magnetized. The magnetic density in the air gap between the inner cylindrical surface of the magnet 11 and the surfaces of the salient poles is as shown in Fig. 10A. The curve of Fig. 10A shows the magnetic flux distribution about the axis of the motor in a clockwise rotary path starting from the positional angle 0° of Fig. 8.

As shown in Fig. 10A, the polarity of the magnetic flux density changes abruptly at positional angles of 0°, 180°, 260°... Moreover, the flux density is reduced to zero in the vicinities of positional angles of 90°, 270°..., corresponding to the non-magnetized arcuate portions of the magnet 11.

When the "A-phase" coils 29A and 30A are energized, corresponding to the salient poles 36A and 37A being excited, for example, to S-pole, an N-pole appears on each of the remaining salient poles 36B, 37B, 38*a*, 38*b*, 38*c* and 38*d*. Fig. 9 is an equivalent schematic view of Fig. 8. The magnetic flux generated by the salient poles 36A and 37A excited to S-pole is substantially equivalent to the flux generated by virtual coils L_A and L'_A of Fig. 9 which are propounded by equivalent magnetic shell theory. The positive and negative path portions V and W of the virtual coil L_A or L'_A are separated from each other by a circumferential dimension of about 50° which is equal to the central angle of 50° of each pole-face of the salient poles 36A and 37A. Virtual equivalent coils L_B and L'_B may also be propounded for "B-phase". The "A-phase" virtual coil L_A or L'_A is spaced by a circumferential dimension equal to 90° from the virtual coil L_B or L'_B.

The rotational torque of the motor is generated by the magnetic flux from the magnet 11 which links the current flowing through the virtual coils L_A, L'_A or L_B, L'_B. The positive path portion V of the A-phase coil is located at a positional angle of 20° apart from the positional angle of 0° representing the position of the photo-coupler 42. The negative path portion W of the A-phase coil is phase shifted by 50° from the positive path portion V. Thus, if it is assumed that the coil L_A is energized for a complete 360° rotation, then the rotational torque generated by the magnetic flux distribution linking the current of the positive path V appears as shown by a solid curve *v* in Fig. 10B. This rotational torque curve is seen to be phase-shifted by 20° in relation to the flux distribution curve of Fig. 10A. The rotational torque generated by the magnetic flux which links negative current flowing through the negative path W appears as shown by a broken curve *w*. This rotational torque curve *w* is seen to be a negative, or inverted version of the curve *v* and to be phase-shifted by 50° in relation to the curve *v*.

The total torque which is generated by the positive path V and the negative path W of the A-phase coil L_A is equal to the sum of the curves *v* and *w*. The overall torque is as shown by a dot-dash curve T_A, which exhibits a trapezoidal waveform having position range over a rotational angle greater than 90°, or 180 electrical degrees. The overall torque generated by the B-phase coil L_B exhibits a version of the curve T_A, phase-shifted by a rotational angle of 90° in relation to the curve T_A. Therefore, when the A-phase coil L_A (the coils 29A and 30A) and the B-phase coil L_B (the coils 29B and 30B) are energized alternately for a duration of 180 electrical degrees for each, with energizing current having waveforms shown in Fig. 10C, a continuous positive rotational torque is generated throughout 360 electrical degrees, as shown by the torque curve of Fig. 10D.

A motor drive circuit shown in Fig. 11 selectively energizes the "A-phase coil" L_A and "B-phase coil" L_B. As described above, the switching signal of Fig. 10C is generated by the photo-coupler 42 in which the light path between the light emitting element 43 and the light sensing element 44 is interrupted by the shutter blades 24*a* and 24*b*. The light emitting element 43 may be a light emitting diode and the light sensing element 44 may be a photo-transistor, as illustrated in Fig. 11. When the light path of the photo-coupler 42 is not interrupted by the shutter blade 24*a* or 24*b*, the photo-transistor 44 turns on. A base current is supplied to a drive transistor T_1 from the photo-transistor 44 through a resistor R_1, which turns on the transistor T_1. Thus, the "A-phase" coil L_A is energized for a duration of 180 electric degrees. When the transistor T_1 is put into the on-state, another drive transistor T_2 is kept off, as the base of the transistor T_2 is connected to the collector of the transistor T_1 through a resistor R_2.

When the light path of the photo-coupler 42 is interrupted by the shutter blade 24*a* or 24*b*, the photo-transistor 44 turns off. Thereby, the transistor T_1 is put into the off-state to raise the collector potential thereof up to a high level. A base current flows into the transistor T_2 through the coil L_A and the resistor R_2 to turn on the transistor T_2. As a result, the "B-phase" coil L_B is energized for the duration of the remaining 180 electric degrees.

As above described, in the brushless *dc* motor of this embodiment, the magnet 11 is moulded into a cup-shape with plastics magnetic material and the yoke 25 is stationary, being faced close to the surface of the magnet 11, so that the moment of inertia can be substantially reduced. Moreover, the magnet 11 is moulded into the shape of a rotational solid having accurate dimensions, so that the adjustment time for regulating the rotational dynamic balance of rotor can be eliminated.

Next, a modification of the yoke 25 will be described referring to a vertical-sectional view of the motor in Fig. 12. In this modification, the base member 28 is formed into a cup-shape. The yoke 25 is also formed into a cup-shape having a central hole 25*a*. The yoke 25 is secured to the inner cylindrical wall of the base member 28 with their cylindrical portions overlapped with each other. The cup-shaped yoke 25 serves as a casing of the motor, which effectively reduces leakage magnetic fluxes out of the motor from the magnet 11, when the yoke 25 is made of a silicon steel plate or the like.

Another modification of the yoke 25 is shown by a vertical sectional view of the motor in Fig. 13. In the modification of Fig. 13, the cylindrical yoke 25 is attached on the outer circumferential surface of the cylindrical portion 11*a* of the magnet 11 by adhesive. The yoke 25 may be made of a silicon steel plate as in the embodiment of Fig. 2. Alternatively, a cylindrical formed high permeability ferrite yoke or so-called "soft ferrite" or other sintered yoke material may be attached to the cylindrical portion 11*a* of the magnet 11 by force fitting. It differs from the motor of Fig. 1 in that the yoke 11 is not a constructional part of the rotor. Mechanical strength is not required for the yoke 25, which, thereby, may be made light in weight by reducing the thickness thereof. Thus, the moment of inertia of the rotor can be reduced.

Next, a modification of the magnet 11 will be described with reference to Figs. 14 and 15, respectively showing a side view of the rotor assembly 8 and a perspective view of the motor. In the modification shown in Figs. 14 and 15, a pulley portion 45 having a flange 46 is formed to drive a flat belt, adjacent to the boss portion 26 of the magnet 11 by means of monoblock moulding with moulding material for the magnet. Alternatively, the contact surface 45*a* of the pulley 45 may be machined to the shape of Fig. 14. Other machine elements, such as a spur gear, helical gear or cam, may be formed on the boss portion 26 of the magnet 11 integrally therewith. Alternatively, other machine elements such as a worm gear may be provided on the boss portion 26 of the magnet 11 by means of insert moulding.

Next, a modified embodiment of the motor in which a frequency generator for detecting the rotational speed of the motor is provided, will be described with reference to Figs. 15 to 18 respectively showing a vertical sectional view of the motor, a side view of the rotor assembly, and an exploded perspective view of the frequency detecting part.

The boss portion 26 of the magnet 11 is circumferentially divided to provide 12 poles on a magnetized portion 69, as shown in Fig. 17. An annular frequency detector assembly 60 is attached on the bottom 1*a* of the case 1 through a support member 61 to encircle the boss portion 26, as shown in Fig. 16. The shupport member 61 is provided with a plurality of resilient click portions 66 projecting inwardly on the inner peripheral edge at predetermined circumferential intervals. The frequency detector 60 is fixed to the case 1 by the click portions 66.

The frequency detector assembly 60 comprises an annular upper yoke 51, a coil assembly 67 and a cup-shaped lower yoke 54, as shown in Fig. 18. The upper yoke 51 and the lower yoke 51 are made of high permeability material such as a soft iron sheet, which is punched and then pressed to form a number of comb teeth 50 and 52 (for example, 20 teeth) formed perpendicularly on the inner circumferential edge of each annular opening thereof at regular intervals. When the detector 60 is assembled, the comb teeth 50 and 52 are alternately arranged on a virtual cylindrical surface, as shown in Fig. 16. The outer circumferential edges of the upper and lower yokes 51 and 53 are connected with each other to form a magnetic path.

An annular space 54 formed between the upper and lower yokes 51 and 53 is provided with the coil assembly 67 which includes an annular bobbin 57 having a channel section. A detecting coil 55 is circumferentially wound on the bobbin 57. Therefore, the magnetic path formed by the upper and lower yokes 51 and 53 and the coil 55 link together. The magnetic path forms an open magnetic circuit including air gaps 48 formed between alternately arranged comb teeth 50 and 52. Thereby, the detector 60 picks up the magnetic flux from the magnetized portion 69 on the cylindrical surface of the boss portion 26 of the magnet 11, through the air gaps 48. Thus, a detecting signal having a frequency depending on the rotational speed of the motor is obtained from the detecting coil 55.

The comb teeth 50 and 52 of the upper and lower yokes 51 and 52 face the circumferential surface of the magnetized portion 69 of the boss portion 26 of the magnet 11 with a small gap therebetween. The N-poles and S-poles of the magnetized portion 69 alternately oppose the alternately arranged comb teeth 50 and 52 in accordance with the rotation of the rotor. A magnetic flux passes through in one direction in the magnetic path extending from the comb teeth 50 of the upper yoke 51 to the connecting edges of the upper and lower yokes 51 and 53, and then to the comb teeth 52 of the lower yoke 53, and then the flux passes through in the counter direction in the magnetic path. As a result, a voltage having a frequency proportional to the rotational speed of the rotor is developed across a pair of leads of the coil 55 linking with the magnetic path. The voltage is led out as a frequency detecting signal through terminals 56*a* and 56*b* to a speed servo circuit.

Another modification of the motor having another type of frequency generator is illustrated in Figs. 19 to 21, which respectively show a vertical-sectional view of the motor, a side view of the rotor assembly and a cross-section taken on the line XXI–XXI of Fig. 19. The motor of this modiciation is provided with a frequency generator of so-called "variable reluctance type". As shown in Figs. 20 and 21, a number of spur gear-like teeth 59 are formed on the cylindrical surface of the boss portion 26 of the magnet 11. An annular frequency detector assembly 60 is attached on the bottom 1*a* of the case 1 through a support member 61 to encircle the boss portion 26. The support member 61 is provided with a plurality of resilient click portions 66 projecting inwardly on the inner peripheral edge at predetermined circumferential intervals. The frequency detector 60 is fixed to the case 1 by the click portions 66.

The frequency detector assembly 60 includes an annular yoke 62 formed of high permeability material, such as sintered "soft ferrite" or plastics material including "soft ferrite" powder. The yoke 62 has an inwrdly projecting flange portion 63, on the inner circumferential surface of which a number of spur gear-like teeth 64 are formed. The teeth 64 have the same pitch as the teeth 59 formed on the cylindrical surface of the boss portion 26 of the magnet 11, as shown in Fig. 21.

The teeth 59 of the boss portion 26 and the teeth 64 of the yoke 62 face each other with a small gap therebetween. The lower surface 62*a* or the yoke 62 and the upper surface of the bottom 11*b* of the magnet 11 axially face each other with a small gap therebetween. Accordingly, a magnetic path 58 shown by a dot-dash line in Fig. 19 is formed to extend through the boss portion 26, the bottom 11*b* of the magnet 11 and the yoke 62.

A detecting coil 55 is circumferentially provided on the lower surface of the flange portion 63 of the yoke 62, linking the magnetic path 58. The detecting coil 55 is circumferentially wound on a bobbin 57 having a channel section, in the same manner as Fig. 18. The boss portion 26 of the magnet 11 is axially magnetized to form magnetic flux passing in the magnetic path 58 shown by the dot-dash line of Fig. 19, the flux linking with the coil 55. When the rotor rotates, each top of the teeth 59 of the boss portion 26 alternately faces to each top and bottom of the teeth 64 of the yoke 62, so the length of the air gap between the boss portion 26 and the yoke 62 is alternately changed in accordance with the rotational speed of the rotor. As a result, the reluctance of the magnetic path 58 varies, which changes the magnetic flux linking with the coil 55. Thus, a voltage having a frequency proportional to the rotational speed of the rotor is developed in the coil 55. The voltage is led out as a frequency detecting signal through terminals 56*a* and 56*b* to a speed servo circuit.

The boss portion 26 of the magnet 11 may be magnetized in the radial direction at the teeth 59 to provide magnetic flux for frequency detection. In this modification, the shaft 6 may be included in a part of the magnetic path. Moreover, in this embodiment, the yoke 62 may be moulded of plastics magntic material such as used for the magnet 11. Alternatively, an annular magnetic member may be inserted into a part of the magnetic path 58 without such magnetization on the boss portion 26 or the yoke 62.

Next, another modification of the yoke 25 attached to the inner cylindrical surface of the case 1 will be described with reference to Figs. 22, 23, 24A and 24B, respectively, showing a cross-section of the motor, a partially enlarged view of Fig. 22, and waveforms of static torques imparted to the rotor.

Generally, in a *dc* motor provided with slots each having a full opening or a half opening as in this embodiment, the magnetic reluctance between the rotor and stator becomes larger in the rotational annular range of such opening of each slot. For example, in Fig. 23, the magnetic reluctance increases in the angular range of an opening 71 formed between the salient poles 36A and 38*a*. In this case, when a boundary of magnetic polarity of the magnet 11 passes in the vicinity of the opening 71, the magnetic flux distribution between the rotor and the stator is disturbed, which causes unsteady rotation including "jerky movement" at every rotational angle of the openings. That is to say, the rotor has a tendency always to stop in the de-energized condition when one of the boundaries of the magnetic polarity of the magnet 11 is at the angular position θ_0 representing the centre of the opening 71. This tendency is caused by two small static torques, opposite to each other, which are imparted to the rotor to stop at the balancing point θ_0, as shown by two solid arrows in Fig. 23. The static torques are illustrated in a graph in Fig. 24A which shows the intensity and direction of static torque with the abscissa as the rotational angle in the vicinity of the balancing point θ_0. As shown in Fig. 24A, static torques in positive and negative directions are imparted to the rotor on both sides of the rotational angle θ_0, which causes unsteady rotation of the rotor, vibration of the motor or ripple of rotational torque.

In the motor of this modiciation, the change of magnetic reluctance between the rotor and the stator is compensated by the yoke 25 provided in a stationary position closely opposite to the rotor magnet 11, so that the static torques can be reduced. As shown in Fig. 22, axially extending projections 70, each facing inwardly to the magnet 11, are formed on the cylindrical surface of the yoke 25, at each angular position corresponding to the opening 71 between the salient poles.

Magnetic reluctance is reduced in the angular range of each projection 70, which compensates for the increased reluctance in the angular range of each opening 71 of the slot. Thus, a substantially uniform reluctance is obtained throughout the rotary path in the air gap between the rotor and the stator. In this construction, counter static torques as shown by dotted arrows in Fig. 23 are imparted to the rotor by projections 70, so that the rotor rotates away from the positional angle θ_0 in the de-energized condition of the motor.

The counter static torques, as shown in Fig. 24B, appear in reverse polarities to the graph of Fig. 24A. Accordingly, the static torques imparted by the opening 71 and the projection 70 cancel each other. As a result, the unsteady rotation, vibration and torque ripple of the motor are eliminated.

Various other modifications can of course be made. For example, the invention may be applied to an inner rotor-type brushless *dc* motor or to an axial air gap type brushless *dc* motor in which the rotor and the stator are axially facing to each other. Moreover, the invention may be applied to the other types of rotational electric machine having a rotational field magnet, such as a synchronous motor or a tachometer.

CLAIMS

1. An electric motor comprising:

a rotor assembly including a rotational shaft and a field magnet shaped as a solid of revolution, said field magnet being fixed on the shaft; and

a stator assembly including an armature member facing one of the surfaces of said magnet with a small air gap therebetween and a yoke member facing another opposite one of the surfaces of said magnetic with a small air gap therebetween.

2. A motor according to claim 1 wherein said field magnet is moulded with synthetic resin containing magnetic material.

3. A motor according to claim 1 wherein said field magnet has a boss portion and a centre hole about the rotational axis thereof, the field magnet being fixed on the shaft in said boss portion by means of adhesive or force fitting.

4. A motor according to claim 2 wherein said field magnet has a machine element provided integrally therewith, about the rotational axis thereof, for transmission of rotational torque.

5. A motor according to claim 2 wherein said field magnet has at least one shutter segment formed integrally therewith by moulding, a light emitter element and a light sensing element are provided in said stator assembly and said shutter segment rotates across the light path formed between said light emitting element and said light sensing element, whereby a rotational position of the rotor is detected by said light sensing element.

6. A motor according to claim 2 wherein a number of circumferentially arranged first teeth are formed on a part of said field magnet, a stationary detecting means including a number of circumferentially arranged second teeth facing said first teeth with a small air gap therebetween and a detecting coil is provided and a magnetic flux generating means is provided in a part of a magnetic path including said air gap, whereby magnetic flux linking to the detecting coil changes by the rotation of said first teeth so that a signal having a frequency in accordance with the rotational speed of the rotor is obtained from said detecting coil.

7. A motor according to claim 2 wherein a partial, circumferential surface of said field magnet is magnetized to form a plurality of circumferentially arranged magnetic poles, and a stationary detecting means including a plurality of circumferentially arranged comb teeth segments facing said magenetic poles with a small gap therebetween and a detecting coil linking to a magnetic path which includes a plurality of air gaps formed between each of said comb teeth segments is provided, whereby the magnetic flux produced by said magnetic poles is detected by said comb teeth segments so that a signal having a frequency in accordance with the rotational speed of the rotor is obtained from said detecting coil.

8. An electric motor comprising:

a rotor assembly including a rotational shaft and a field magnet shaped as a solid of revolution, said field magnet being moulded of synthetic resin containing magnetic material and fixed on the shaft; and

a stator assembly including an armature member facing one of the surfaces of said magnet with a small air gap therebetween.

9. A motor according to claim 8 wherein said stator assembly further includes a yoke member facing another opposite one of the surfaces of said magnet with a small air gap therebetween.

10. A motor according to claim 8 wherein said field magnet is provided with a yoke member thereon.

11. A motor according to claim 8 wherein said field magnet has a boss portion and a centre hole about the rotational axis thereof, the field magnet being fixed on the shaft in said boss portion by means of adhesive or force fitting.

12. A motor according to claim 8 wherein said field magnet has a machine element provided integrally therewith, about the revolutionary axis thereof, for transmission of rotational torque.

13. A motor according to claim 8 wherein said field magnet has at least one shutter segment formed integrally therewith by moulding, a light emitting element and a light sensing element are provided in said stator assembly and said shutter segment rotates across the light path formed between said light emitting element and said light sensing element, whereby a rotational position of the rotor is detected by said light sensing element.

14. A motor according to claim 8 wherein a number of circumferentially arranged first teeth are formed on a part of said field magnet, a stationary detecting means including a number of circumferentially arranged second teeth facing said first teeth with a small air gap therebetween and a detecting coil is provided and a magnetic flux generating means is provided in a part of a magnetic path including said air gap, whereby magnetic flux linking to the detecting coil changes by the rotation of said first teeth so that a signal having a frequency in accordance with the rotational speed of the rotor is obtained from said detecting coil.

15. A motor according to claim 8 wherein a partial, circumferential surface of said field magnet is magnetized to form a plurality of circumferentially arranged magnetic poles, and a stationary detecting means including a plurality of circumferentially arranged comb teeth segments facing said magnetic poles with a small gap therebetween and a detecting coil linking to a magnetic path which includes a plurality of air gaps formed between each of said comb teeth segments is provided, whereby the magnetic flux produced by said magnetic poles is detected by said comb teeth segments so that a signal having a frequency in accordance with the rotational speed of the rotor is obtained from said detecting coil.

16. An electric motor substantially as hereinbefore described with reference to Figs. 2 to 11 of the accompanying drawings.

17. An electric motor substantially as hereinbefore described with reference to Figs. 2 to 11 as modified by Fig. 12 of the accompanying drawings.

18. An electric motor substantially as hereinbefore described with reference to Figs. 2 to 11 as modified by Fig. 13 of the accompanying drawings.

19. An electric motor substantially as hereinbefore described with reference to Figs. 2 to 11 as modified by Figs. 14 and 15 of the accompanying drawings.

20. An electric motor substantially as hereinbefore described with reference to Figs. 16 to 18 of the accompanying drawings.

21. An electric motor substantially as hereinbefore described with reference to Figs. 19 to 21 of the accompanying drawings.

22. An electric motor substantially as hereinbefore described with reference to Figs. 22 and 23 of the accompanying drawings.

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