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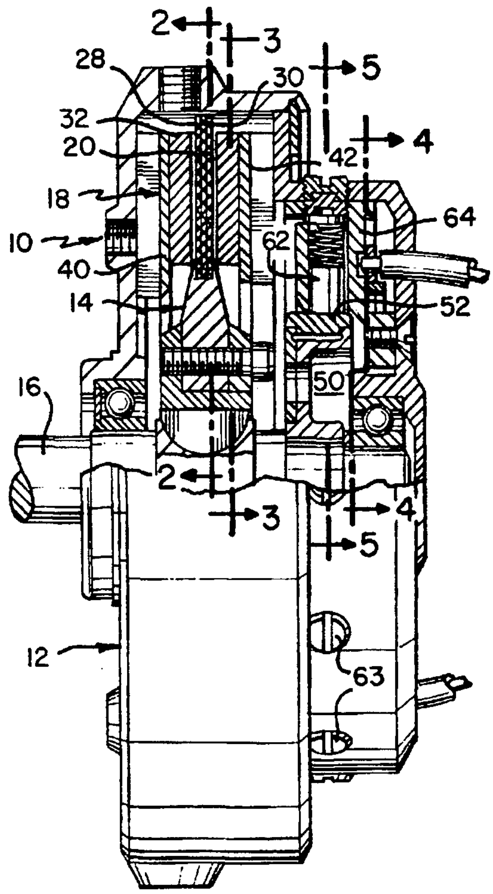
(54) Title: LOW SPEED, HIGH TORQUE ELECTROMECHANICAL MACHINE

(57) Abstract

An electromechanical machine (10) includes a field producing assembly (18) which is constructed so as to have an annular gap (20) circumferentially disposed about an axis of rotation and to produce a magnetic field across the gap (20) which varies circumferentially so as to have P periodic extremes of flux density. An electrical assembly includes N layers (28, 30, 32) each containing a circular array of C non-overlapping coils (22, 24, 26) with the coils in progressive layers circumferentially offset with respect to the coils of the preceding layer. The circumferential extent of the coils (22, 24, 26) is less than 360°/P, where C, P and N are integers, C > P, and N > 2. In a preferred embodiment, C/P > 1.5, and the coils (22, 24, 26) in different layers (28, 30, 32) are connected in series to form P, N-tuples of serially connected coils, with each N-tuple extending across all layers (28, 30, 32) and being connected progressively between adjacent commutator segments (52).



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LOW SPEED, HIGH TORQUE ELECTROMECHANICAL MACHINE

Field of the Invention

The present invention relates generally to electromechanical machines and, more particularly, concerns a high-efficiency machine, preferably a motor capable of high torque at low speed, making it an ideal device for motor vehicle applications.

Background of the Invention

Concern about the environment and the depletion of energy resources have long motivated the search for more efficient motor vehicles. A great deal of effort has been spent on producing electric vehicles and, particularly improved electric motors. This appears to be justified, as electric motors tend to be far more efficient than internal combustion engines.

One very efficient form of electromechanical machine is disclosed in my own U.S. Patents No. 4,390,805 and No. 4,605,873. Until now, it has proved difficult to obtain from such motors the power, torque and acceleration necessary for a motor vehicle. Some improvement of this nature is possible by utilizing a brushless configuration, but this normally requires controllers which significantly increase the total system size, weight and cost.

Broadly, it is an object of the present invention to provide an electric motor which produces sufficient torque and power to be useful in electric motor vehicles. The motor may be of the brush or brushless type and it should be sufficiently efficient to provide a driving range equivalent to existing motor vehicles.

In accordance with the present invention, an electromechanical machine includes a field producing assembly which is constructed so as to have an annular gap circumferentially disposed about an axis of rotation and to produce a magnetic field across the gap which varies circumferentially so as to have P periodic extremes of flux density. An electrical assembly includes N layers each containing a circular array of C non-overlapping coils, with the coils in progressive layers circumferentially offset with respect to the coils of the preceding layer. The circumferential extent of the coils is less than 360°/P, where C, P and N are integers, $C > P$, and $N > 2$. In a preferred embodiment, $C/P > 1.5$, and the coils in different layers are connected in series to form P, N-tuples of serially connected coils, with each N-tuple extending across all layers.

Brief Description of the Drawings

The foregoing brief description, as well further object, features and advantages of the present invention will be understood more completely from the following detailed description of a presently preferred, but nonetheless illustrative, embodiment of the present invention, with reference being had to the accompanying drawings, in which:

Figure 1 is a side view of an electric motor embodying the present invention, with the upper part being shown in section to reveal internal structural details;

Figure 2 is a rear view of the motor of Figure 1, with the upper part being shown in section along line 2-2 of Figure 1;

Figure 3 is a front view of the motor of Figure 1, with the upper part being shown in section along line 3-3 of Figure 1;

Figure 4 is a front view of the motor of Figure 1, with the upper part being shown in section along line 4-4 of Figure 1;

Figure 5 is a front view of the motor of Figure 1 with the upper part being shown in section along line 5-5 of Figure 1; and

Figure 6 is a schematic diagram illustrating the electrical circuit of the motor of Figure 1, including the wiring of the coils.

Detailed Description of the Preferred Embodiment

Turning now to the details for the preferred embodiment, Figures 1-5 illustrate a disc-type, permanent magnet motor 10 embodying objects and features of the present invention. In general overall construction, motor 10 resembles the motors of U.S. Patents Nos. 4,390,805 and 4,605,873. Accordingly, the disclosures of those patents are incorporated herein by reference, to the extent that they are relevant to the construction of motor 10. Motor 10 broadly comprises a housing 12; a disc-type rotor or armature assembly 14 mounted so as to rotate a drive shaft 16; and a stator assembly 18 providing a magnetic field across an annular gap 20, in which the rotor assembly 14 rotates. In operation, the stator assembly provides a circumferentially varying magnetic field across the annular thickness of gap 20. The portion of the rotor assembly 14 within the gap includes a plurality of windings which are provided with a periodically fluctuating electric current by means of a commutator or similar current switching device. As a result of interaction with the magnetic field, the rotor portion within gap 20 is forced into rotation, causing shaft 16 to rotate.

As best seen in Figures 1 and 2, in the preferred embodiment, rotor assembly 14 includes three layers of coils. In accordance with the invention, there may be more, but no fewer than three such layers. Each layer preferably includes sixteen non-overlapping coils in a circular arrangement, all of which are wound in the same direction, and all occupy equal arc sectors. In addition, the coils of each layer are circumferentially offset from the underlying layer by a fraction of a coil arc sector.

Thus, coil 22, a coil in the lowermost coil layer 28 in Figure 2 is offset from coil 24, a coil in the middle coil layer 30, which has been partially cut away to reveal the lower coil layer, and coil 24 is offset from coil 26, a coil in the uppermost coil layer 32 in Figure 2, which has been cut away to reveal the two lower coil layers. Preferably, coil 24 is circumferentially off-set by one-third of a coil arc sector from coil 22, and coil 26 is circumferentially off-set by one-third of a coil arc sector from coil 24. In the preferred embodiment, each layer of the armature includes sixteen non-overlapping coils. The armature is preferably nine inches in diameter and each coil is preferably made up of two layers of No. 19 wire.

In this preferred embodiment, all coils have the same number of turns. This is not essential, as the coils may have different numbers of turns, although it is preferable that each pair of diametrically opposite coils on the same rotor layer should have the same number of turns. Preferably, the wire used for winding has a thermoplastic or resin coating, for example epoxy, such that the turns can be fused together into a unified body. Additionally, the wound coils may be enclosed by a further epoxy layer to produce a durable, smooth or suitably textured, integrated winding structure, reducing windage losses. This arrangement also permits the armature coils to pass very close to the surfaces of the magnets on either side of the armature, thus allowing a greater density of copper winding in the gap 20 with a resultant increase in horsepower for a given size and corresponding increase in efficiency. The described coreless armature rotor is lightweight and utilizes no iron or ferrite materials, so that there is virtually no armature reaction, and no hysteresis effects, eddy losses, or necessity for advancing the commutator brushes under load conditions.

As best seen in Figures 1 and 3, stator assembly 18 comprises a circular array of permanent magnets in two opposed, spaced layers 40, 42, with the annular gap 20 being formed between the layers. In the preferred embodiment, there are ten equally spaced magnets in each layer, the magnets are wedge-shaped, and they are constructed to produce a substantially uniform magnetic field across the gap 20. In addition, adjacent magnets (e.g. 44, 46) on the same layer (e.g. 42) are magnetized so as to have opposite polarities (to produce oppositely directed fields perpendicular to the plane of Figure 3). Accordingly, as one progresses circumferentially about the layer 42, one encounters magnets of alternately opposite polarity, which produce alternately opposite extremes of polarity. Opposed magnets on layers 40 and 42 are constructed to have opposite polarities. Accordingly, the magnetic flux produced in the gap 20 is the sum of the magnetic flux produced by the opposed magnets. The overall effect of the permanent magnet structure is to produce a substantially uniform magnetic field across the gap 20, which fluctuates between alternately opposite extremes in polarity with circumferential position along the gap.

Although the preferred embodiment utilizes ten magnets on a layer, a greater or lesser number may be used. Preferably, the ratio between the number of coils C, per rotor layer and the number of magnetic extremes or poles, P, per station layer exceeds 1.5. This results in certain advantages in the construction, as explained more fully below.

In U.S. Patent No. 4,605,873, I disclosed a stator structure in which the permanent magnets in each layer are all of the same polarity, but are circumferentially spaced. The magnets of opposed layers are still of opposite polarity. Such a construction could be utilized in accordance with the present invention. It would produce a magnetic field in gap 20, having a fixed polarity which fluctuates between a maximum and minimum magnitude with circumferential displacement.

It is also possible to form the gap 20 by having only a single layer of permanent magnets and forming the opposite layer from a magnetic material, providing a flux return path for the magnetic flux produced by the magnets.

From the foregoing, those skilled in the art will appreciate that the disclosed structure of stator assembly 18 can take many alternative forms, all of which would work in the present invention.

Motor 10 also includes a commutator 50 which is mounted to rotate together with shaft 16 and, therefore, together with armature assembly 14. Commutator 50 preferably includes forty-eight commutator bars 52 (the same as the total number of coils in armature assembly 14), which are electrically isolated from each other and arranged in a circular array.

A plurality of brush holders 60 are mounted so that each of the brush holders is radially aligned with one of the permanent magnets of stator assembly 18. Within each brush holder 60, an electrically conductive brush 62 is mounted for radial sliding movement and is spring-biased toward the commutator bars 52 of commutator 50 into electrical contact therewith. Threaded caps 63 afford access to brushes 62 and permit adjustment of brush contact tension. Also mounted in housing 12 are connecting rings 64 and 66, which are connected to opposite sides of the battery (not shown) which powers motor 10. As will be appreciated from Figures 4 and 5, alternate ones of brush holders 60 are electrically connected to ring 64, and the remaining brush holders are connected to ring 66. Adjacent brushes are therefore connected, through their respective holders, to opposite sides of the battery, and they provide electric power to the commutator segments 52 by making contact therewith. As explained more fully below, the coils of armature assembly 14 are also connected to the commutator segments 52, so that operating electric current is provided to them via the brushes 62.

Figure 6 is a schematic diagram illustrating the electric circuit of motor 10. The figure illustrates a portion that circuit comprising 10 coils. The coils are shown schematically in three different sizes, with the large coils representing coils on lower layer 28, the small coils representing coils in the intermediate layer 30, and the medium sized coils representing coils in the upper layer 32. Coil sizing is just a schematic expedient, since all coils would typically be the same size. Each coil is connected to two adjacent ones of the commutator segments 52. In addition, the coils are connected in serial triplets through the layers. Thus, coil 22 in lower layer 28 is in series with coil 24 in intermediate layer 30, which is in series with coil 26 in upper layer 32. Coil 26, is in turn, in series with a coil in lower level 28, which starts the next triplet. The coils therefore form a series string of serially connected triplets.

Each of the brushes 62 is radially aligned with one of the permanent magnets. Thus, brush 62-1 is aligned with permanent magnet 44 and brush 62-2 is aligned with permanent magnet 46. As can be seen in Fig. 6, adjacent brushes are connected to opposite polarities of the battery which powers the motor and contain a series circuit of coils between them.

This arrangement serves to maintain 10 parallel conducting paths among the coils. Any coil which is in radial alignment with a magnet (e.g. coil 22' in Fig. 6) will be shortcircuited by having its commutator segments short-circuited together by the corresponding brush (e.g. the brush 62-2), which is aligned with the magnet. As a result, there is no induction in any coil which is in precise radial alignment with a magnet. This eliminates arcing at the brushes, leading to longer component life, and the possibility of operating the machine at higher speeds and, therefore, higher efficiency. It should also be noted that a minimum of four commutators segments separate each pair of full voltage brush contact points. Accordingly, it is possible to obtain greater power by using substantially higher voltages than in previous motors of this type, without the risk of shorting or ring-fire due to fragments or particles between segments.

Generalizing the preceding description, the machine includes a magnetic field producing assembly, which was disclosed as a stator, but could equally well be the rotating component. This field assembly produces a magnetic field across an annular gap which varies circumferentially in the gap so as to have P periodic extremes of flux density. In the preferred embodiment, the periodic extremes were produced by oppositely poled permanent magnets. An electrical assembly includes N layers, each including a circular array of C non-overlapping coils in the gap, and the coils in successive layers are progressively annularly offset from the coils in preceding layers. A commutator is provided with N*C contact segments in a circular array and is contacted by P brushes, each of which is aligned with one of the magnetic poles. Adjacent brushes are attached to opposite sides of the power supply. Each coil of the electrical member is connected between adjacent contact segments and the coils are serially connected to the coil layers to form N-tuples of coils connected in series. With this arrangement, the brushes define P parallel circuits of serially connected coils. In addition, there are at least (N*C/P)-2 segments between each pair of full voltage brush contact points.

A preferred embodiment of the invention has been disclosed for illustrative purposes, those skilled in the art will appreciate that many additions, modifications, and substitutions, in addition to those specifically discussed, are possible, without departing from the scope and spirit of the invention as defined by the accompanying claims. For example, those skilled in the art would readily realize that the role of the stator and rotor assemblies could readily be reversed. That is, the magnetic field producing assembly could become a rotor and the electrical assembly could remain stationary.

WHAT IS CLAIMED IS

1. An electromechanical machine comprising:

a field producing assembly constructed to include an annular gap circumferentially disposed about an axis of rotation and including means for producing a magnetic field in across said gap which varies circumferentially so as to create P periodic extremes of flux density;

an electrical assembly including N layers each having a circular array of C non-overlapping coils, the coils of progressive layers being at circumferentially offset positions with respect to the coils of a preceding layer and having a circumferential annular extent which is less than 360°/P; and

means mounting said field producing assembly and said electrical assembly for relative rotation about said axis;

where C, P and N are integers, with C>P and N>2.

2. An electromechanical machine in accordance with Claim 1, wherein coils in different layers are connected in series to form a plurality of N-tuples of serially connected coils each extending across said N layers.

3. An electromechanical machine in accordance with Claim 2 wherein said N-tuples of coils are connected in series.

4. An electromechanical machine in accordance with Claim 1 further comprising switching means for shortcircuiting each coil when its center is aligned with an extreme of magnetic flux density in said gap, while enabling current flow through all other coils which are not so aligned.

5. An electromechanical machine as in Claim 3, further comprising:

a commutator mounted non-rotatably with respect to the electrical assembly and rotatably with respect to the field producing assembly, said commutator having N*C of commutator segments each coupled to a respective end of one coil in one layer and also to a respective end of one coil in another layer, and P brushes engaging said commutator, said brushes being interconnected to provide P parallel conducting pathways among said coils for shorting P coils when each of said P coils is centrally aligned with one of said extremes of magnetic flux density in said gap.

6. An electromechanical machine as in Claim 3 further comprising:

a commutator mounted so as to be non-rotatable with respect to the electrical assembly and rotatable with respect to the field assembly, said commutator having N*C conductive and electrically isolated commutator segments spaced in a substantially circular arrangement, each of said P coils being connected between a pair of adjacent commutator segments;

P brushes positioned in spaced arrangement so as to contact each of said commutator segments in turn during operation of said machine, each of said P brushes being dimensioned to be wider than a non-conductive region between adjacent commutator segments, each of said brushes being radially aligned with respect to a corresponding one of said extremes of magnetic flux density so that the pair of adjacent commutator segments corresponding to a single coil are shortcircuited by one of said P brushes when said coil is centrally aligned with a corresponding flux density extreme in said gap.

7. An electromechanical machine as in Claim 1 wherein said field assembly further comprises first and second magnetic field members disposed about a common axis and spaced axially apart to form a gap therebetween, at least one of said field members comprising a magnet structure for providing an axially directed flux field across said gap distributed to provide a circular array of periodic extremes of magnetic flux density.

8. An electromechanical machine as in Claim 7, including a commutator mounted non-rotatably with respect to said electrical assembly and rotatably with respect to said field producing assembly.

9. An electromechanical machine as in Claim 8, further including P brushes engaging said commutator, said brushes being connected to provide P parallel conducting pathways among the coils of the electrical assembly and for short-circuiting P coils when each of said P coils is centrally aligned with one of said extremes of magnetic flux density in said gap.

10. An electromechanical machine as in claim 8, wherein each coil is connected between two adjacent segments of said commutator.

11. An electromechanical machine including a pair of power line terminals and comprising:

a stator element and a rotor element, said rotor element being mounted in spaced, opposed relationship to said stator element for rotation relative thereto;

a substantially circular array of magnetic-poles of alternately opposite polarity mounted on one of said elements;

at least three substantially circular arrays of coils mounted on the other of said elements in different layers, the coils defining C groups of coils with each coil in a group occupying a different layer, each group of coils being connected in a series circuit; and

switching means synchronized to a rotation of said rotor element for connecting and disconnecting said series circuits of said groups of coils between said power terminal pair in a predetermined sequence and with a predetermined reversing polarity; where C is an integer.

12. An electromechanical machine as in Claim 11 wherein there are N layers of coils, said switching means comprising:

a commutator mounted non-rotatably with respect to the roto-element and rotatably with respect to the stator, said commutator having N*C of commutator segments each coupled to a respective end of one coil in one layer and also to a respective end of one coil in another layer, and P brushes engaging said commutator, said brushes being interconnected to provide P parallel conducting pathways among said coils; where N and P are integers, with C>P and N>2.

13. An electromechanical machine as in Claim 11 wherein there are N layers of coils, said switching means comprising:

a commutator mounted so as to be non-rotatable with respect to the rotor element and rotatable with respect to the stator element, said commutator having N*C conductive and electrically isolated commutator segments spaced in a substantially circular arrangement, each of said coils being connected between a pair of adjacent commutator segments;

P brushes positioned in spaced arrangement so as to contact each of said commutator segments in turn during operation of said machine, each of said brushes being dimensioned to be wider than a non-conductive region between adjacent commutator segments, each of said brushes being radially aligned with respect to a corresponding one of said magnetic poles so that the pair of adjacent commutator segments corresponding to a single coil are shortcircuited by one of said P brushes when said coil is centrally aligned with a corresponding magnetic pole.

14. An electromechanical machine comprising:

rotor and stator elements

one of said rotor and stator elements comprising two parallel members spaced apart to form a gap therebetween, each member having a circular array of P magnetic poles of alternatively opposite polarity (P being an even integer), each pole of each of said members occupying a pole arc sector of the circular array of substantially the same extent and being aligned opposite an opposite polarity pole of the other member;

the other of said rotor and stator elements being positioned between said two parallel members, and having a non-overlapping circular array of C coils in each of at least three layers thereof, C being an integer greater than P;

the circular array of C coils in each layer being angularly offset relative to the circular arrays of C coils on the other layers;

each coil of each layer occupying a coil arc sector unique from the coil arc sector of every other coil on the same layer, each of said coil arc sectors having substantially the same arcuate extent and being smaller than a pole arc sector; and

a switching device synchronized with said rotor element.

15. An electromechanical machine as in Claim 14 wherein there are N layers of coils, said switching device comprising:

a commutator mounted non-rotatably with respect to the rotor element and rotatably with respect to the stator element, said commutator having N*C of commutator segments each coupled to a respective end of one coil in one layer and also to a respective end of one coil in another layer, and P brushes engaging said commutator, said brushes being interconnected to provide P parallel conducting pathways among said coils.

16. An electromechanical machine as in Claim 14 wherein there are N layers of coils, said switching device comprising:

a commutator mounted so as to be non-rotatable with respect to the rotor element and rotatable with respect to the stator element, said commutator having N*C conductive and electrically isolated commutator segments spaced in a substantially circular arrangement, each of said coils being connected between a pair of adjacent commutator segments;

P brushes positioned in spaced arrangement so as to contact each of said commutator segments in turn during operation of said machine, each of said brushes being dimensioned to be wider than a non-conductive region between adjacent commutator segments, each of said brushes being radially aligned with respect to a corresponding one of said magnetic poles so that the pair of adjacent commutator segments corresponding to a single coil are shortcircuited by said brush when said coil is centrally aligned with a corresponding magnetic pole.

17. An electromechanical machine in accordance with Claim 14, wherein coils in different layers are connected in series to form a plurality of N-tuples of serially connected coils each extending across said N layers of coils.

18. An electromechanical machine in accordance with Claim 17 wherein said N-tuples of coils are connected in series.

19. An electromechanical machine as in Claim 18 wherein there are N layers of coils, said switching device comprising:

a commutator mounted non-rotatably with respect to the rotor element and rotatably with respect to the stator element, said commutator having N*C of commutator segments each coupled to a respective end of one coil in one layer and also to a respective end of one coil in another layer, and P brushes engaging said commutator, said brushes being interconnected to provide P parallel conducting pathways among said coils.

20. An electromechanical machine as in Claim 18 wherein there are N layers of coils, said switching device comprising:

a commutator mounted so as to be non-rotatable with respect to the rotor element and rotatable with respect to the stator element, said commutator having N*C conductive and electrically isolated commutator segments spaced in a substantially circular arrangement, each of said coils being connected between a pair of adjacent commutator segments;

P brushes positioned in spaced arrangement so as to contact each of said commutator segments in turn during operation of said machine, each of said brushes being dimensioned to be wider than a non-conductive region between adjacent commutator segments, each of said P brushes being radially aligned with respect to a corresponding one of said magnetic poles so that the pair of commutator segments corresponding to a single coil are shortcircuited by one of said P brushes when said coil is centrally aligned with a corresponding magnetic pole.

FIG. 2

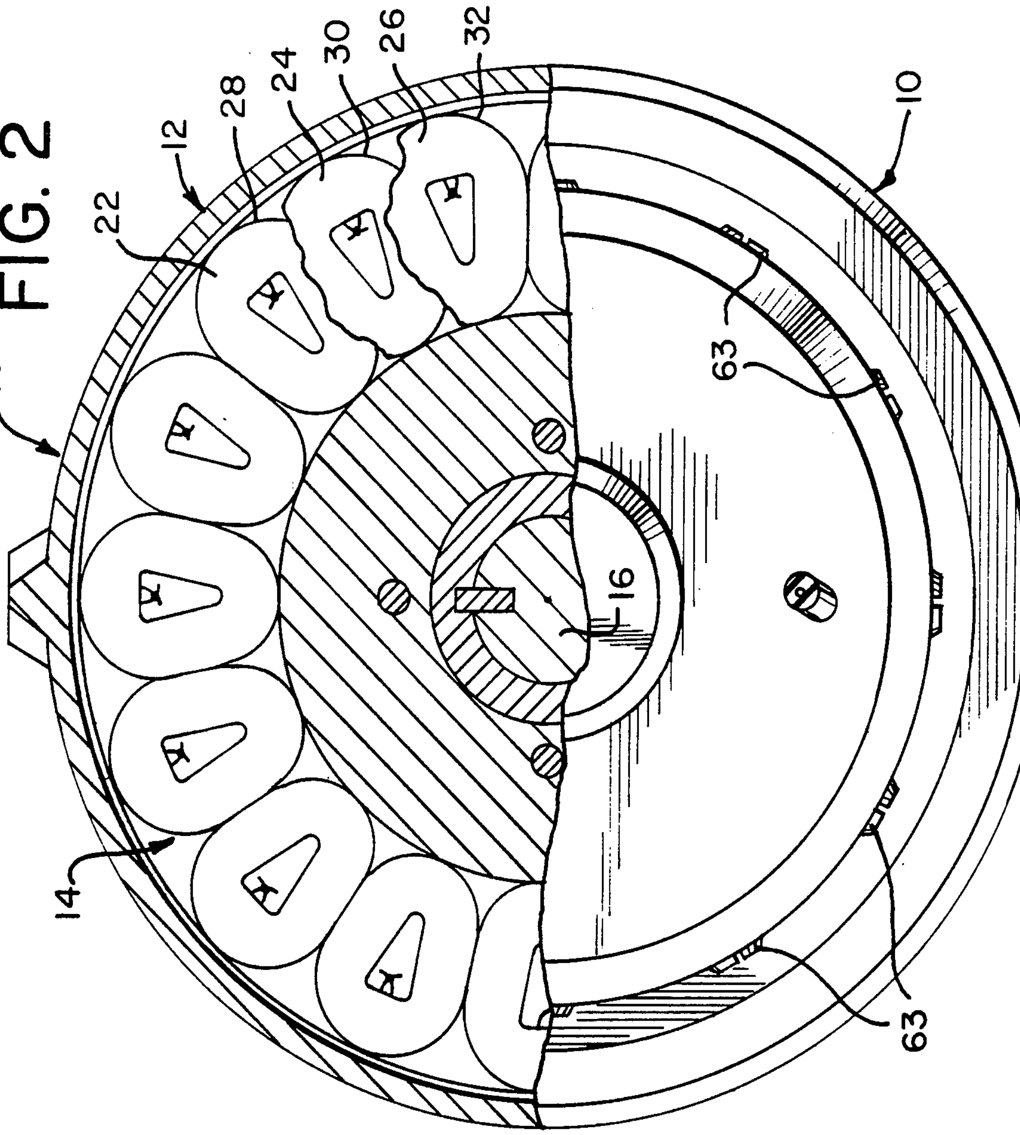


FIG. 1

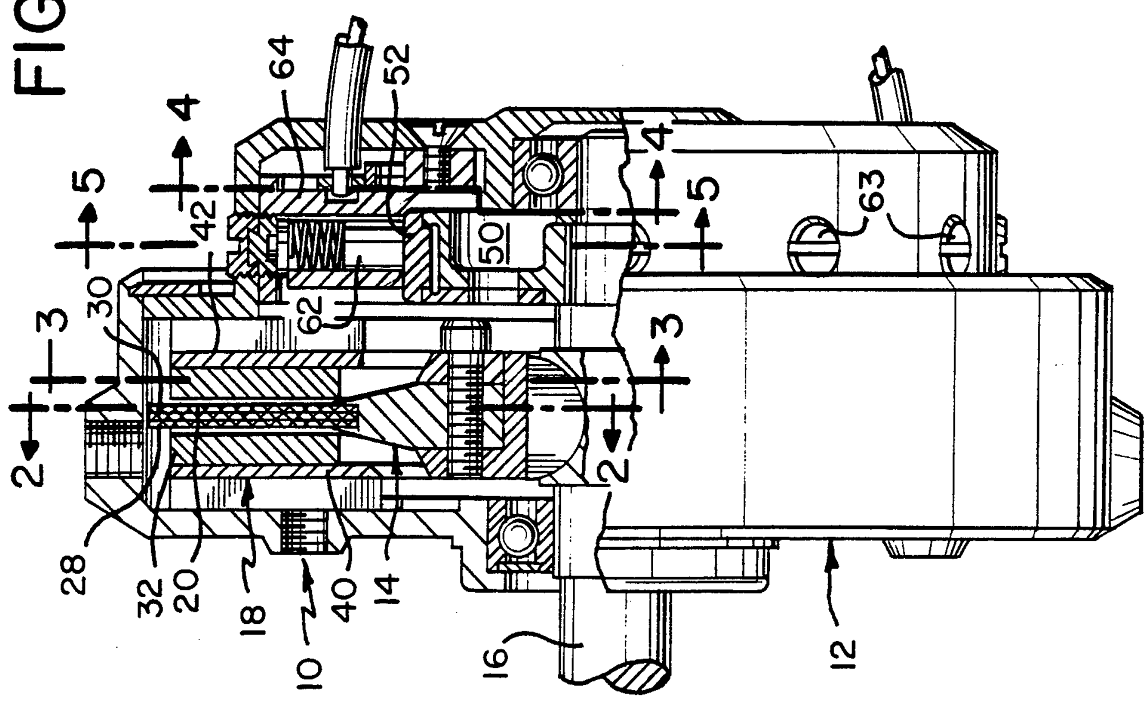
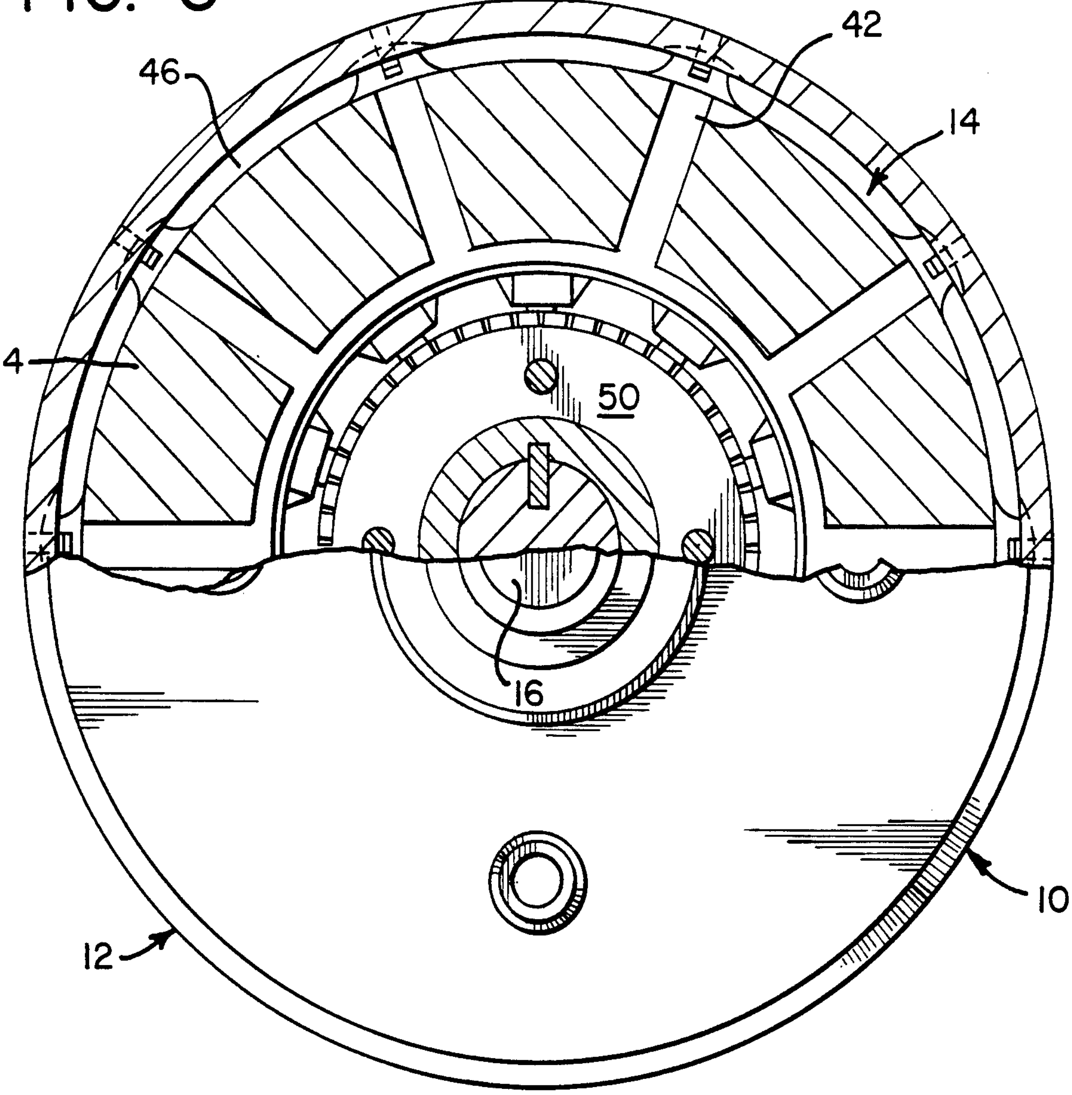


FIG. 3



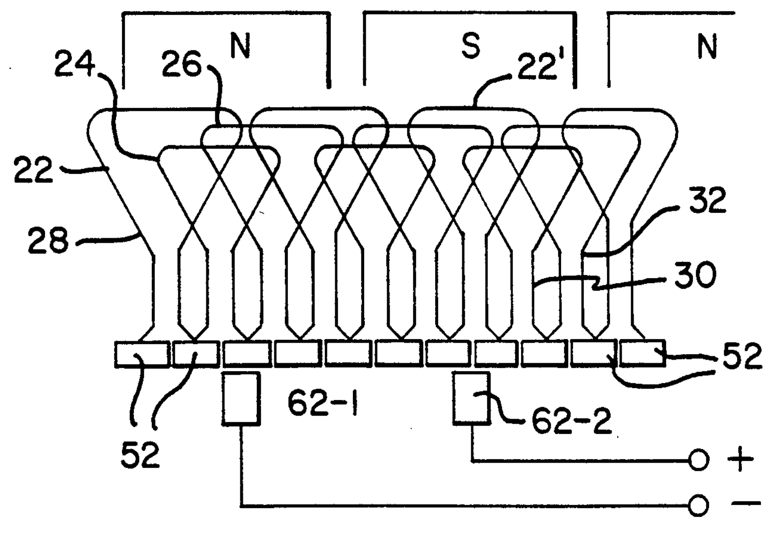


FIG. 6

FIG. 4

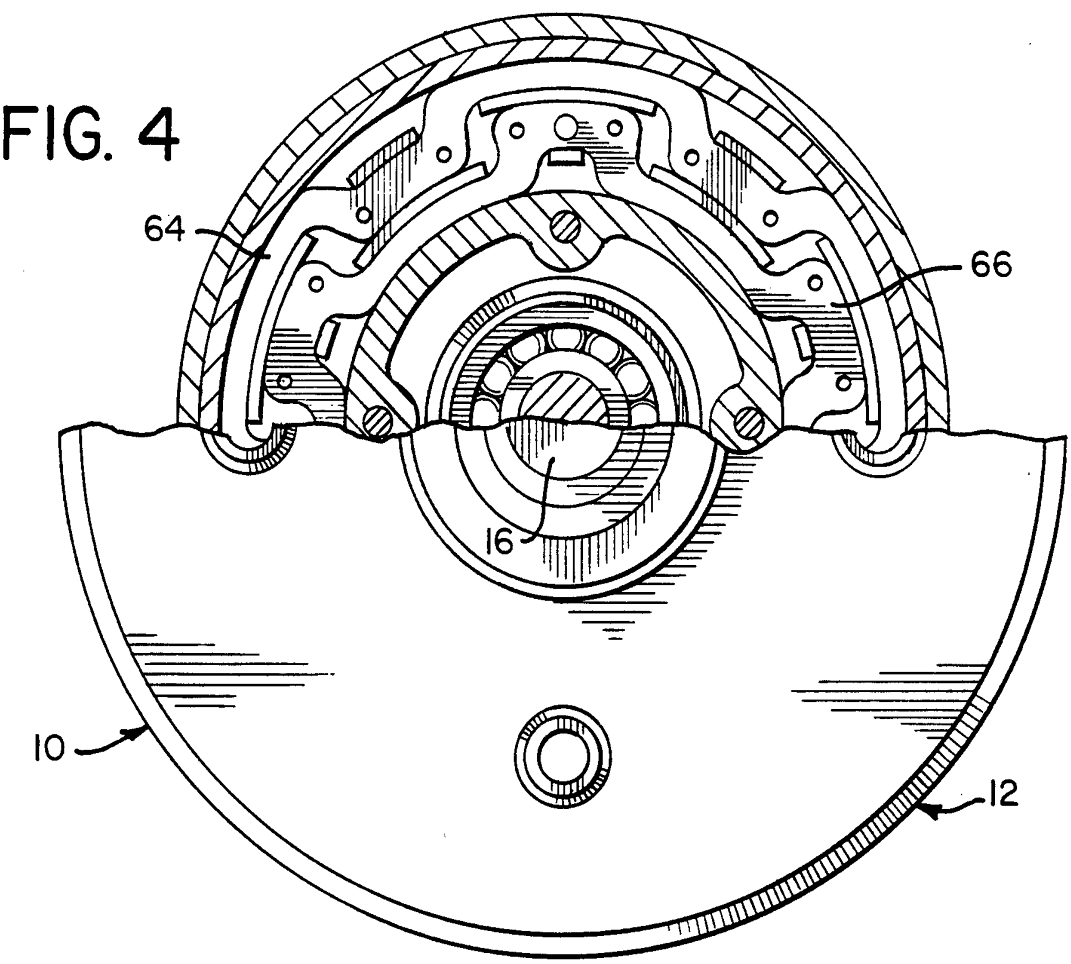
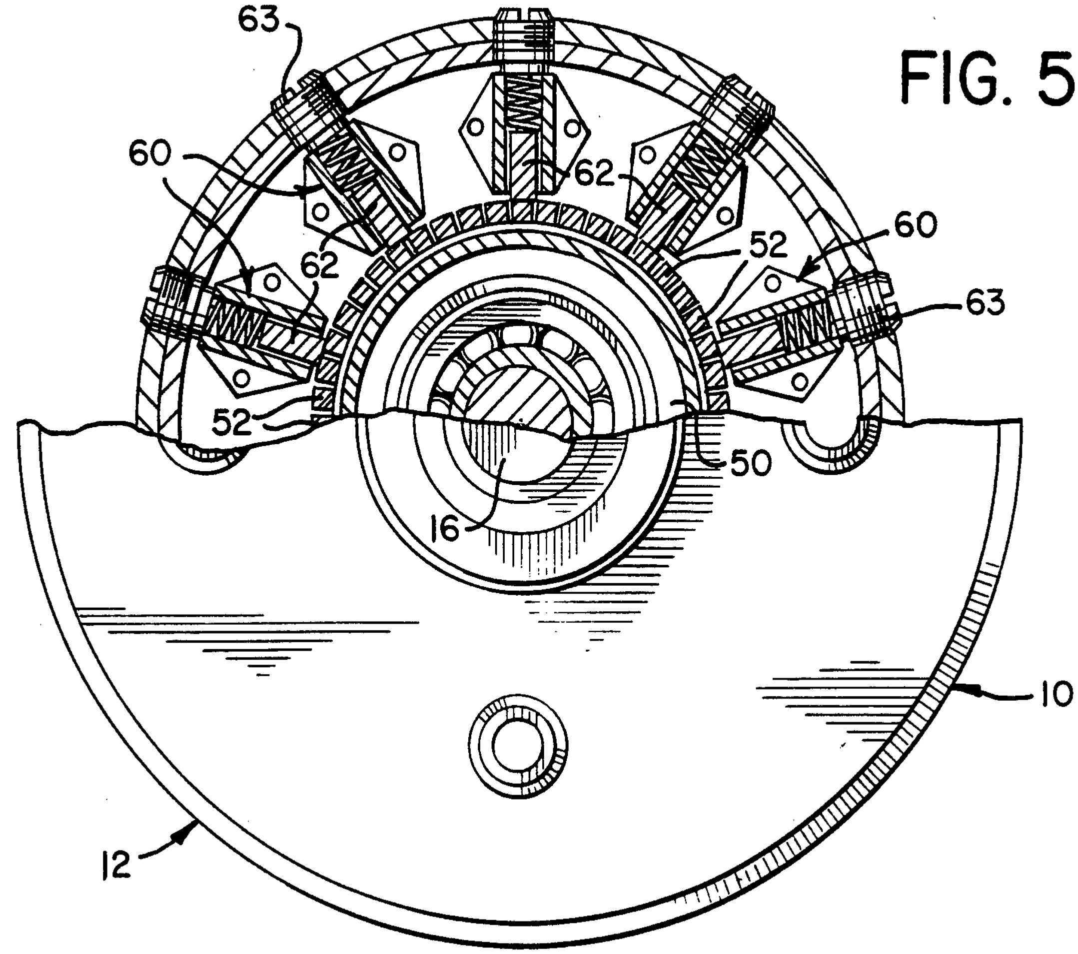


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/08078

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H02K 3/00, 1/22
US CL :310/198,268
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. : 310/198,268

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

H02K 21/26,3/00,3/04,13/04,1/22, 310/154, 179, 198, 206, 208,234,268

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A, 4,390,805 (HAHN) 28 June 1983 (see column 2, lines 22-37)	1-20
Y	US,A, 4,605,873 (HAHN) 12 August 1986 (see column 3, line 68 and column 4, lines 1-10)	1-20
Y	US,A, 4,319,152 (VAN GILS) 09 March 1982 (see column 4, lines 35-41)	1-20
Y	US,A, 4,463,276 (NAKAMURA) 31 July 1984 (see column 1, lines 57-68 and column 8, lines 1 and 2)	1-20

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

* Special categories of cited documents:

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Date of the actual completion of the international search
19 OCTOBER 1994

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