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SPECIFICATION

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BACKGROUND OF THE INVENTION

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Be it known that we, Lincoln M. Jore and
Matthew B. Jore, citizens of the United States of
America, and residing at Ronan, Montana 59864, have
invented an improvement in a

CONDUCTOR OPTIMIZED AXIAL FIELD ROTARY ENERGY DEVICE

of which the following is a

This application claims the benefit of provisional
application Serial No. 60/445,884, filed February 7,
2003.

The present invention relates to an optimized axial
field rotary energy device which can be either used as a
motor for converting electrical energy to motion or a
generator for converting rotary motion to electrical
energy. This invention includes a stator formed by
stacking a plurality of printed circuit boards wherein
the electrical components are arranged for maximum power
and efficiency.

Axial air gap brushless motors with layered disk
stators are known, such as U. S. Pat. No. 5,789,841 to

1 Wang. The stator winding in Wang utilizes wires
2 interconnected in a wave or lap configuration. These
3 motors were of relatively large size and difficult to
4 manufacture.

5 Further, axial field electric machines utilizing
6 printed circuit board stators are also known such as
7 shown in U.S. Pat. No. 6,411,002 to Smith et al.

8 The present invention provides a rotary energy
9 device for operating with multi-phase electrical power.
10 The device is generally flat and relatively thin and
11 provides a motor which can be used with many tools and
12 appliances in use today, such as electric drills, power
13 saws, weed eaters, electric bicycles, washers and dryers.
14 The device according to the present invention is designed
15 to minimize electrical resistance and to minimize eddy
16 and loop current. The electromagnetic inductance is
17 enhanced by minimizing the gap between the rotor magnets
18 and the stator circuits and further since the motor is
19 constructed of printed circuit boards, the manufacturing
20 costs are substantially minimized.

21

22 SUMMARY OF INVENTION

23 The present invention provides an axial rotary
24 energy device which is arranged in a multi-phase electric
25 current configuration. The device includes a rotor
26 having a plurality of permanent magnet poles secured
27 thereto and further includes a stator formed by stacking
28 a plurality of printed circuit board working conductor

1 layers together with a plurality of printed circuit board
2 connecting layers. The stator having at least one
3 working conductor layer for each phase of the electric
4 current and at least one connecting conductor layer
5 associated with one working conductor layer. The working
6 conductor layer and the connecting conductor layer each
7 having radial conductors extending from an inner diameter
8 through-hole to an outer diameter through-hole. A
9 plurality of via conductors are provided for electrically
10 connecting selected ones of the radial connectors of the
11 connecting conductor layer to selected ones of the radial
12 connectors of the working conductor layers through the
13 through-holes.

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15 DESCRIPTION OF THE DRAWINGS

16 In order that the invention may be clearly
17 understood and readily carried into effect, a preferred
18 embodiment of the invention will now be described, by way
19 of example only, with reference to the accompanying
20 drawings wherein:

21 Fig. 1 is a partially exploded view of a stator,
22 with parts broken away, used with the present invention;

23 Fig. 2 is a view of the stator shown in Fig. 1 with
24 further parts broken away;

25 Fig. 3 is a view of the stator shown in Fig. 2 with
26 further parts broken away;

27 Fig. 4 is an exploded view of an energy device
28 according to the present invention;

1 Fig. 5 is a cross-sectional view of an energy device
2 according to the present invention;

3 Fig. 6 is a plan view of a first working conductor
4 layer used with the stator shown in Fig. 1;

5 Fig. 6A is a plan view of the first working
6 conductor layer shown in Fig. 6 with details of the
7 conductor pattern removed;

8 Fig. 7 is a plan view of a first connecting
9 conductor layer used with the stator shown in Fig. 1;

10 Fig. 8 is a plan view of a second working conductor
11 layer used within the stator shown in Fig. 1;

12 Fig. 9 is a plan view of a second connecting
13 conductor layer used within the stator shown in Fig. 1;

14 Fig. 10 is a plan view of a third working conductor
15 layer used within the stator shown in Fig. 1;

16 Fig. 11 is a plan view of a third connecting
17 conductor layer used with the stator shown in Fig. 1;

18 Fig. 12 is a plan view of a separate conductor layer
19 used within the stator according to the present
20 invention;

21 Fig. 13A is an exploded cross-sectional view showing
22 a method of construction in the stator layers;

23 Fig. 13B is a cross-sectional view showing the
24 stacked stator layers shown in Fig. 13A;

25 Fig. 13C is a cross-sectional view as shown in Fig.
26 13B with plated through-holes;

1 Fig. 14 is a detail view of a radial conductor used
2 with the conductor layers according to a first embodiment
3 of the present invention;

4 Fig. 15 is a detail view showing radial conductors
5 of six conductor layers connected in parallel according
6 to the present invention;

7 Fig. 16 is a plan view of the first working
8 conductor layer shown in Fig. 6;

9 Fig. 17 is a plan view of the first connecting
10 conductor layer shown in Fig. 7 with highlighting;

11 Fig. 18 is a plan view of a conductor layer
12 according to a second embodiment of the present
13 invention;

14 Fig. 19 is a detail view of a radial conductor used
15 with the conductor layers according to a third embodiment
16 of the present invention;

17 Fig. 20 is a detail view of a radial conductor used
18 with the conductor layers according to a fourth
19 embodiment of the present invention;

20 Fig. 21 is a detail view of a radial conductor used
21 with the conductor layers according to a fifth embodiment
22 of the present invention;

23 Fig. 22 is a detail view of a radial conductor used
24 with the conductor layers according to a sixth embodiment
25 of the present invention;

26 Fig. 23 is a detail view of a radial conductor used
27 with the conductor layers according to a seventh
28 embodiment of the present invention;

1 Fig. 24 is a detail view of a radial conductor used
2 with the conductor layers according to an eighth
3 embodiment of the present invention; and

4 Fig. 25 is a partially exploded view of the stator
5 shown in Fig. 1 with the separate conductor layer shown
6 in Fig. 12.

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8 DESCRIPTION OF A PREFERRED EMBODIMENT

9 The present invention includes a stator formed by
10 stacking a plurality of printed circuit boards (PCBs)
11 containing a plurality of electrical circuits formed of a
12 conductive material and supported by a nonconductive
13 dielectric material. Overall, the invention is flat,
14 relatively thin, and has a circular, square, or other
15 shape suitable for the function of the device.

16 As a non-limiting example, Fig. 1 shows a three-
17 dimensional view of one preferred embodiment of the
18 invention comprised of six PCB layers arranged in a three
19 phase electrical current configuration. The three phases
20 are denoted herein as A, B and C. In Fig. 1, the axial
21 scale has been exaggerated for clarity and the
22 nonconductive material normally present for electrical
23 insulation and mechanical support has been removed. Fig.
24 1 illustrates one of many possible arrangements whereby a
25 phase A circuit, a phase B circuit, and phase C circuit
26 intermesh and bypass one another. In Fig. 2, the phase C
27 circuit has been removed to so that some of the details
28 are more easily seen. Fig. 2 illustrates one of many

1 possible arrangements whereby a phase A circuit
2 intermeshes and bypasses a phase B circuit. As best seen
3 in Fig. 3 which has both phase B and C circuits removed,
4 phase A circuit is comprised of layers of conductive
5 material. Each layer of conductive material is comprised
6 of a plurality of radial conductors, typified by a radial
7 conductor 2, and a variety of non-radial conductors, as
8 represented by non-radial conductors 3, 4, and 5. The
9 radial conductors and non-radial conductors are connected
10 together in series on the same conductor layer and are
11 also connected in series with conductors on other
12 conductor layers by a plurality of interlayer conductors,
13 as represented by interlayer conductor 6. The interlayer
14 conductors may also connect corresponding radial
15 conductors on different layers of the conductive material
16 in parallel. Phase A circuit, with numerous radial and
17 non-radial conductors connected together on the same
18 layer in series, or in series and in parallel, and
19 interconnected between layers in series and in parallel,
20 or in series, or in parallel, intermeshes and bypasses
21 any other phase circuits contained within the same layers
22 of conductive material. Phase circuits A, B, and C are
23 illustrated in Figs. 1-3 as being comprised of six layers
24 of conductive material, but other embodiments of the
25 invention may have a lower or a higher number of layers
26 of conductive material.

27 As seen in Figs. 1-3, and as described in detail
28 below, the dimensions, spatial arrangements, and

1 interconnections of each conductor within the phase A, B
2 and C circuits are optimized based upon the function and
3 desired performance of a device which would incorporate
4 the invention. The dimensions, spatial arrangements, and
5 interconnections of one conductor on one layer of
6 conductive material can be varied independent of any
7 other conductor in the same layer of conductive material.
8 The dimensions, spatial arrangements, and
9 interconnections of one conductor on one layer of
10 conductive material can be varied independent of the
11 dimensions, spatial arrangements, and interconnections of
12 any other conductor on any other layer of conductive
13 material. As one example, Fig. 3 shows radial conductor
14 2 having a width that is smaller than the width of non-
15 radial conductor 3 even though they are connected to each
16 other on the same layer of conductive material. By
17 selectively manipulating the dimensions, spatial
18 arrangements, and interconnections of each and every
19 conductor within the phase A, B and C circuits, the
20 device can be optimized for a number of factors,
21 including but not limited to, electrical resistance,
22 electromagnetic inductance, eddy and loop current
23 generation, heat dissipation, and manufacturing cost.
24 Preferred embodiments of the invention will now be
25 described in detail to further illustrate the scope of
26 the new invention.

27 A preferred embodiment of the invention is shown in
28 Fig. 4. A conductor optimized energy device 10

1 configured to function as a motor or a generator is
2 comprised of two housings 11 and 12, a drive shaft 13, a
3 shaft key 13a, two rotors 14a and 14b, a conductor
4 optimized stator 15, two bearings 16a and 16b, two
5 axially-magnetized permanent magnets 17a and 17b, a wavy
6 washer 18, and three hall sensors 19. Device 10 is also
7 comprised of a stator phase connector 20, a stator sensor
8 connector 21, an electronic control board 22, a control
9 phase connector 23, a control sensor connector 24, a
10 control heat sink 25, and control cover 26. Electronic
11 control board 22 provides an electronic sensing and
12 control means for appropriately delivering an electric
13 current to conductor optimized stator 15. Electronic
14 control board 22 is connected to a dc power source such
15 as a battery or a dc power supply (not shown).
16 Electronic control board 22 is also known in the art as a
17 motor drive and utilizes the conventional types of
18 components normally present such as integrated circuit
19 chips, power transistors, regulators, diodes, resistors
20 and capacitors.

21 Stator phase connector 20 interfaces with control
22 phase connector 23 and stator sensor connector 21
23 interfaces with control sensor connector 24 to connect
24 electronic control board 22 to conductor optimized stator
25 15. Also shown are bolts 27 and nuts 28 that fasten
26 housing 11, housing 12, and control cover 26 together. A
27 control mounting bolt 29 fastens electronic control board
28 22 and control heat sink 25 to housing 11.

1 Still referring to Fig. 4, magnets 17a and 17b are
2 magnetized axially and have poles N and S that alternate
3 around the ring. Magnets 17a and 17b are shown and
4 described as ring magnets but may also be made of
5 individual segments. Magnets 17a and 17b are preferably
6 comprised of at least one rare earth metal such as an
7 alloy of neodymium, iron, and boron. When assembled
8 within device 10 as shown in Fig. 5, magnets 17a and 17b
9 are attached to rotors 14a and 14b. The rotors 14a and
10 14b are fixedly secured to drive shaft 13 on opposite
11 sides of the stator 15 with the magnets 17a and 17b
12 positioned so that a N pole on magnet 17a faces a S pole
13 on magnet 17b. Magnets 17a and 17b produce a magnetic
14 flux between them that is perpendicular to the surface of
15 the conductor optimized stator 15. Magnets 17a and 17b
16 are shown and described as having four magnetic poles
17 however device 10 may be configured with magnets
18 comprised of other numbers of poles such as two, six,
19 eight, sixteen, or any other even number that may be
20 feasible to manufacture.

21 In Fig. 5, housings 11 and 12, comprised of a rigid
22 material such as a molded plastic, or an alloy comprised
23 of aluminum or magnesium, support bearings 16a and 16b.
24 The drive shaft 13 is supported by the two bearings 16a
25 and 16b and drive shaft 13 protrudes through an opening
26 in housing 12. Rotors 14a and 14b with attached magnets
27 17a and 17b are attached to shaft 13. Rotors 14a and 14b
28 are made of a magnetically permeable material such as

1 steel in order to provide a flux return for magnets 17a
2 and 17b. Magnets 17a and 17b produce a concentrated
3 magnetic flux between them. Housings 11 and 12 hold
4 conductor optimized stator 15 in position between rotors
5 14a and 14b and across air gaps 31a and 31b from magnets
6 17a and 17b. The portion of conductor optimized stator
7 15 that is within the concentrated magnetic flux between
8 magnets 17a and 17b defines a working section 30. The
9 rotation by an external means of magnets 17a and 17b will
10 induce an electrical current within the conductive
11 material of working section 30 that when properly
12 gathered and delivered allows device 10 to behave as a
13 generator or alternator. Conversely, the proper
14 application of an electrical current to the conductive
15 material of the working section 30 will produce Lorentz
16 forces between the flowing current and the magnetic
17 field. The resultant force is a torque that rotates
18 magnets 17a and 17b that are fixedly attached to rotors
19 14a and 14b that are fixedly attached to drive shaft 13.
20 Drive shaft 13 is available to do work and so device 10
21 can behave as a motor or actuator.

22 In accordance with a preferred embodiment of the
23 present invention, the novel features of conductor
24 optimized rotary energy device 10 will now be described.
25 Conductor optimized stator 15 of device 10 is comprised
26 of stacked PCB layers of a conductive material supported
27 by multiple layers of a nonconductive material. Figs. 6-
28 11 each illustrate a conductor pattern for a layer of

1 conductive material within conductor optimized stator 15.
2 Fig. 6 shows a layer of the conductive material within
3 conductor optimized stator 15 having a "working" PCB
4 pattern 32. Each layer of conductive material is
5 supported by a layer of nonconductive material that
6 separates it from other layers of conductive material.
7 Each layer of conductive material within conductor
8 optimized stator 15 may have an identical or a different
9 PCB pattern. The patterns for each layer represent
10 electrical conductors comprised of an electrically
11 conductive material, such as copper, electrically
12 insulated and mechanically supported by a nonconductive
13 material, such as fiberglass. The conductor patterns of
14 each layer may be produced by various methods including,
15 but not limited to, etching, stamping, spraying, cutting,
16 or machining. A preferred method is to chemically etch
17 conductor patterns, such as conductor pattern 32, into
18 each side of a plurality of two-sided circuit boards 39,
19 comprised of one sheet of fiberglass sandwiched between
20 two sheets of copper. As a non-limiting example, Figs.
21 13A-13C diagrammatically show how conductor optimized
22 stator 15 may be manufactured. In Fig. 13A, three two-
23 sided circuit boards 39 are stacked together with two
24 fiberglass sheets 40 between them. In Fig. 13B, the
25 stacked circuit boards 39 and fiberglass sheets 40 are
26 laminated together using heat and pressure to form a
27 multiple board arrangement for conductor optimized stator
28 15. A center hole 41 is made for shaft 13 to pass

1 through. A plurality of holes 42 are drilled and, as
2 shown in Fig. 13C, holes 42 may be plated with a
3 conductive material such as copper to form a plurality of
4 plated holes typified in Fig. 13C by plated hole 43.

5 It is preferred to use circuit boards that have
6 copper sheets that are thicker than the copper sheets
7 used in most commonly produced circuit boards. Copper
8 sheet thicknesses ranging from 0.004 inches to 0.007
9 inches are preferred but other thickness of copper sheet
10 may be used. As previously shown in Fig. 1, copper sheet
11 thickness in the preferred range produce conductors that
12 are ribbon-shaped when viewed without the supporting
13 fiberglass. Referring again to Fig. 6, holes are drilled
14 in precise locations through the multiple circuit boards
15 of conductor optimized stator 15 and then the inner walls
16 of the holes are plated with a conductive material such
17 as copper. The plated holes, also known as vias, provide
18 a plurality of interlayer conductors, typified by vias
19 201 and 301 that electrically connect the conductors on
20 different layers of conductor optimized stator 15.
21 Although plated holes are shown and described in the
22 current embodiment, it should be understood that other
23 interlayer conductor means are possible, including but
24 not limited to, holes filled with conductive material,
25 metal pins, crimp points, spot welds, or wire. As
26 previously stated, the various conductors on the
27 different layers of conductor optimized stator 15,
28 connected together in series and in parallel by the vias,

1 comprise the optimized conductor circuits of the
2 invention. Present day circuit board manufacturing
3 techniques are able to provide quantities of conductor
4 optimized stators 15 with relatively small variances for
5 conductor dimensions, spatial arrangement, stator
6 thickness, and stator flatness, as well as a one hundred
7 percent assurance of continuity for the conductor
8 circuits.

9 In the currently described preferred embodiment
10 shown in Figs. 4-11, there are three optimized conductor
11 circuits, one for each electrical power phase of a three
12 phase power circuit, in conductor optimized stator 15.
13 As previously described, Fig. 6 shows a layer of
14 conductive material within conductor optimized stator 15
15 comprised of a working PCB pattern 32. Fig. 7
16 illustrates a layer of conductive material within
17 conductor optimized stator 15 comprised of a "connecting"
18 PCB pattern 33. PCB pattern 32 of Fig. 6 and PCB pattern
19 33 of Fig. 7 are comprised of conductors connected
20 together in order to electrically complete a portion of
21 the phase A circuit. PCB patterns 32 and 33 are also
22 comprised of conductors associated with phase B and C
23 circuits. Similarly, a working PCB pattern 34 shown in
24 Fig. 8 and a connecting PCB pattern 35 shown in Fig. 9
25 are comprised of conductors connected together in order
26 to electrically complete a portion of the phase B
27 circuit. PCB patterns 34 and 35 are also comprised of
28 conductors associated with the phase A and C circuits.

1 Also, a working PCB pattern 36 shown in Fig. 10 and a
2 connecting PCB pattern 37 shown in Fig. 11 are comprised
3 of conductors connected together in order to electrically
4 complete the phase C circuit. PCB patterns 36 and 37 are
5 also comprised of conductors associated with the phase A
6 and B circuits.

7 The pattern of radial conductors in PCB patterns 32,
8 33, 34, 35, 36 and 37 are identical in all layers.

9 Fig. 12 shows a PCB layer of conductive material
10 having a PCB pattern 38 of radial conductors identical to
11 the patterns of radial conductors in the other PCB
12 layers. PCB pattern 38 further includes a plurality of
13 conductors 44 that connect a plurality of sensor
14 terminals 45 to a plurality of sensor mounting pads 46.
15 Sensor mounting pads 46 provide for the surface mounting
16 of a means to detect the position of the magnetic poles N
17 and S of magnets 17a and 17b, such as an array of Hall
18 sensors. One Hall sensor 19 is shown mounted to one
19 sensor mounting pad 46. Sensor mounting pad 46A provides
20 for the surface mounting of a temperature sensing means
21 such as a thermistor. Sensor terminals 45 provide a
22 connection means to an external electronic control means
23 such as a motor drive. PCB pattern 38 is also comprised
24 of conductors associated with the phase A, B and C
25 circuits. Fig. 25 shows PCB pattern 38 on top of the
26 stacked PCB patterns 32, 33, 34, 35, 36 and 37 previously
27 shown in Fig. 1. PCB pattern 38 is preferably a top or a
28 bottom layer in order to facilitate the surface mounting

1 of sensors and connectors, such as Hall sensors 19 to
2 sensor mounting pads 46, stator phase connector 20 to
3 phase terminals 53, and stator sensor connector 21 to
4 sensor terminals 45. Radial conductors I PCB pattern 38
5 are electrically connected with via conductors to phase
6 circuits A, B and C of PCB patterns 32, 33, 34, 35, 36
7 and 37.

8 Referring now to Fig. 6A, PCB pattern 32 is
9 comprised of a plurality of concentric ring-shaped
10 sections differentiated by the function of the conductors
11 that they contain. Fig. 6A illustrates the various
12 functional ring-shaped sections of the PCB pattern 32
13 with some of the detail of the PCB pattern 32 removed for
14 clarity. The following description of the functional
15 ring-shaped sections of PCB pattern 32 shall apply to
16 each PCB pattern on each layer of conductive material
17 within conductor optimized stator 15. Also shown in Fig.
18 6A is magnet 17b with magnetic poles N and S. Magnet 17b
19 is positioned behind conductor optimized stator 15 as
20 drawn in Fig. 6A and magnet 17a, not shown, is in the
21 same location but positioned above conductor optimized
22 stator 15. PCB pattern 32 has a working conductor section
23 30 that is defined by the magnetic poles N and S of
24 magnet 17a. In other words, the working conductor
25 section 30 is the portion of conductor optimized stator
26 15 that is intersected by the magnetic flux between
27 magnets 17a and 17b. As shown in Fig. 6A, there is a
28 plurality of phase sectors of the working conductor

1 section 30 that are designated A, B, and C. The total
2 number of phase sectors is equal to the number of
3 magnetic poles multiplied by the number of electrical
4 phases being utilized. In the currently described
5 embodiment, device 10 utilizes a three phase
6 configuration and four magnetic poles and therefore
7 working conductor section 30 has a total of twelve phase
8 sectors. Device 10 may also be configured for use with
9 other multi phase configurations that would change the
10 number of phase sectors. As a nonlimiting example,
11 another embodiment of device 10 utilizing a five phase
12 configuration and four magnetic poles will have a working
13 conductor section 30 divided into twenty phase sectors.
14 As illustrated in Fig. 6A, the arrangement of the phase
15 sectors A, B, and C is sequential around the working
16 conductor section 30 and the combined area of three phase
17 sectors is equal to the area of one magnetic pole.

18 Still referring to Fig. 6A, other sections of PCB
19 pattern 32 will be described. Radially inward of working
20 conductor section 30 is an inner via section 47.
21 Radially inward of inner via section is an inner non-
22 radial conductor section 48. Radially inward of inner
23 non-radial conductor section 48 is a shaft hole 49.
24 Radially outward of the working conductor section 30 is
25 an outer via section 50. Radially outward of outer via
26 section 50 is an outer non-radial conductor section 51.
27 Radially outward of outer non-radial conductor section 51
28 is a heat sink section 52. Heat sink section 52 contacts

1 housings 11 and 12 to provide a means to transfer heat
2 from conductor optimized stator 15 to the housings 11 and
3 12. One area of heat sink section 52 is designated as a
4 terminal section 53 which provides a connection means to
5 an external electrical system such as a motor drive, a
6 rectifier, or a converter.

7 PCB pattern 32 of conductor optimized stator 15 is
8 shown having six concentric ring-shaped sections but
9 other embodiments of the invention with a lower or a
10 higher number of concentric ring-shaped sections are
11 possible.

12 The terminal section 53 includes terminals 53A, 53B,
13 53C, 53D, 53E and 53F, two terminals for each phase of
14 the electrical power circuit. Each of the stacked layers
15 have these terminals connected together with via
16 connectors as shown in Fig. 1. Working conductor layer
17 32 is connected to terminals 53A, 53B. Working conductor
18 layer 34 is connected to terminals 53C and 53D. Working
19 conductor layer 36 is connected to terminals 53E and 53F.

20 As seen in Figs. 6-11, the size and shape of a first
21 conductor in a first section of PCB pattern 32 is usually
22 different than the size and shape of a second conductor
23 in a second section of PCB pattern 32. Also, the size,
24 shape and location of a conductor in a first section of a
25 first pattern on a first layer of conductor optimized
26 stator 15 may either be the same or different than a
27 conductor in a corresponding first section of a second
28 pattern of a second layer of conductor optimized stator

1 15. This is in contrast to the conductors in
2 conventional motors and generators that are wound with a
3 fixed diameter wire which dictates that the conductors
4 are of a constant size and shape throughout the motor or
5 generator.

6 The configuration of the conductive material in each
7 section of the PCB pattern 32 depends upon what
8 functional role each section plays for conductor
9 optimized stator 15. As previously shown and described,
10 phase sectors A, B, and C are within the flux field
11 between magnets 17a and 17b. Referring now to Fig. 14, a
12 portion of PCB pattern 32 is illustrated with portions of
13 working conductor section 30, inner via section 47, inner
14 non-radial conductor section 48, shaft hole 49, outer via
15 section 50, and outer non-radial conductor section 51.
16 As an example of how a conductor is optimized in
17 different sections of the PCB pattern 32, a radial
18 conductor 101 and some associated non-radial conductors
19 will be described in detail. In the currently described
20 embodiment, radial conductor 101 is comprised of a
21 working conductor 101a that has a width 54 that is
22 constant within working conductor section 30 and width 54
23 is symmetrical along a radius 55. Radial conductor 101
24 is also comprised of an inner pad 101b within inner via
25 section 47 that has a width 56 and an outer pad 101c
26 within outer via section 50 that has a width 57. Width
27 54 is less than or equal to width 56. Width 54 is less
28 than width 57. Since width 54 lies in a plane normal to

1 the magnetic flux, increasing width 54 will result in an
2 increase in eddy currents in working conductor 101a.
3 Eddy currents produce forces that oppose the rotation of
4 magnets 17a and 17b, robbing device 10 of power when
5 device 10 is performing as either a generator or a motor.
6 The speed of the rotation of magnets 17a and 17b is one
7 factor used to determine width 54. A faster speed of
8 rotation produces more eddy currents and so an embodiment
9 of device 10 configured to rotate at a high speed will
10 have a value of width 54 that is less than a value of
11 width 54 in an embodiment of device 10 that is configured
12 to rotate at a low speed. Electrical resistance is
13 another factor that is used to determine a value of width
14 54. Electrical resistance robs device 10 of power when
15 device 10 is performing as either a generator or a motor.
16 Electrical resistance produces heat as electrical current
17 flows through the conductive material of optimized stator
18 15 and electrical resistance increases as the temperature
19 of the conductive material increases. Electrical
20 resistance increases as width 54 is decreased. So in
21 order to reduce the losses attributed to electrical
22 resistance, a maximum value of width 54 can be selected.
23 However, depending upon the operating speed of device 10,
24 a maximum value of width 54 may result in substantial
25 losses due to eddy currents. Therefore, a value of width
26 54 of working conductor 101a is selected that balances
27 eddy current losses with electrical resistance losses.

1 Referring to Figs. 6 and 14, pad 101b is within
2 inner via section 47. Inner via 201 electrically
3 connects inner pad 101b of radial conductor 101 to
4 corresponding radial conductors on other layers of
5 conductive material within conductor optimized stator 15.
6 Inner pad 101b is continuous with an inner non-radial
7 conductor 58 that has a width 59. Width 59 of inner non-
8 radial conductor 58 is preferably greater than or equal
9 to width 56 of inner pad 101b of radial conductor 101.
10 Outer pad 101c has outer via 301 that connects pad 101c
11 of radial conductor 101 to corresponding radial
12 conductors on other layers of conductive material within
13 conductor optimized stator 15. Outer pad 101c is
14 continuous with an outer non-radial conductor 62 that has
15 a width 61. Width 61 is preferably greater than or equal
16 to width 57. In Fig. 14, inner pad 101b is shown to be
17 continuous with an inner non-radial conductor 63 and
18 outer pad 101c is shown to be continuous with an outer
19 non-radial conductor 62. However, in the currently
20 described embodiment, inner pad 101b of radial conductor
21 101 is only connected to an inner non-radial conductor 63
22 in PCB pattern 32, shown in Fig. 6 and inner non-radial
23 conductor 65 in PCB pattern 33, shown in Fig. 7. The
24 outer pad 101c is only connected to an outer non-radial
25 conductor 62 in PCB pattern 32, shown in Fig. 6. Radial
26 conductor 101 of PCB patterns 34, 35, 36, and 37, shown
27 in Figs. 8, 9, 10, and 11 respectively, are not shown to
28 be connected to an inner non-radial conductor or an outer

1 non-radial conductor. It should be understood that
2 radial conductor 101 may be selectively connected to
3 inner non-radial conductor 63 or to an outer non-radial
4 conductor 62 on any layer of conductive material within
5 conductor optimized stator 15.

6 Referring again to Fig. 14, inner pad 101b and outer
7 pad 101c of radial conductor 101, inner non-radial
8 conductor 63, and outer non-radial conductor 62 are not
9 subjected to the concentrated magnetic field of magnets
10 17a and 17b. Therefore, eddy currents are not a factor
11 and widths 56, 57, 59, and 61 are made as large as
12 possible within their respective sections of conductor
13 optimized stator 15 in order to reduce the electrical
14 resistance of the total circuit.

15 Another method of reducing the total electrical
16 resistance of a conductor circuit within conductor
17 optimized stator 15 is to connect corresponding
18 conductors that are on different layers of conductive
19 material in parallel. As a nonlimiting example, Fig. 15
20 illustrates six layers of radial conductor 101
21 electrically connected in parallel by vias 201 and 301.
22 The total electrical resistance of a number of parallel
23 conductors, each with an electrical resistance value, is
24 equal to one divided by the sum of the reciprocals of
25 resistance value of each conductor. When the conductors
26 each have the same resistance value, such as each of the
27 six layers of radial conductor 101 shown in Fig. 15, the
28 formula can be simplified to be the total resistance

1 equal to the resistance value of one conductor divided by
2 the number of conductors in parallel. For example, if
3 radial conductor 101 of the first layer has a resistance
4 value of 0.006 ohms, and the radial conductor 101 in each
5 of the other five layers has the same resistance value,
6 then the total electrical resistance value of all six
7 layers of radial conductor 101 is equal to 0.006 ohms
8 divided by six conductors or 0.001 ohms. Fig. 15 shows
9 the parallel connection of one set of radial conductors
10 across six layers. Fig. 3 shows the parallel connection
11 of the radial conductors in each sector for the phase A
12 circuit across six layers.

13 As an example of how conductor optimized stator 15
14 functions, the path of an electric current as it flows
15 through one circuit of the present embodiment when device
16 10 is driven as a motor will be described. Referring now
17 to Fig. 16, working conductor section 30 of working PCB
18 pattern 32 is comprised of radial conductors 101 to 172.
19 In the currently illustrated preferred embodiment, each
20 phase sector contains six radial conductors that carry an
21 electric current through a phase sector in the same
22 radial direction. Radial conductors 101 to 106 are
23 within a positive phase sector A, radial conductors 107
24 to 112 are within a positive phase sector B, and working
25 conductors 113 to 118 are within a positive phase sector
26 C. Radial conductors 119 to 124 are within a negative
27 phase sector A, radial conductors 125 to 130 are within a
28 negative phase sector B, and radial conductors 131 to 136

1 are within a negative phase sector C. Radial conductors
2 137 to 142 are within a positive phase sector A, radial
3 conductors 143 to 148 are within a positive phase sector
4 B, and radial conductors 149 to 154 are within a positive
5 phase sector C. Radial conductors 155 to 160 are within
6 a negative phase sector A, radial conductors 161 to 166
7 are within a negative phase sector B, and radial
8 conductors 167 to 172 are within a negative phase sector
9 C. It should be understood that other embodiments with a
10 lower or a higher number of radial conductors in each
11 phase sector may be produced depending upon the desired
12 output requirements of device 10.

13 The radial conductors of each phase sector are
14 connected in series to provide a number of electrical
15 current passes through the working section 30. Fig. 16
16 shows the previously described working PCB pattern 32
17 with the phase A circuit highlighted and Fig. 17 shows
18 the connecting electrical conductor PCB pattern 33, also
19 with the phase A circuit highlighted.

20 In Fig. 16, an electric current is delivered to an
21 A+ terminal 53b from a control means. The control means
22 such as electronic control board 22 previously described,
23 utilizes a sensing means to determine the polarization of
24 the magnetic flux produced by permanent magnets 17A and
25 17b passing through each phase sector of phase circuits
26 A, B and C. The sensing means is preferably an array
27 Hall sensors surface mounted on conductor optimized
28 stator 15. The control means uses a plurality power

1 transistors or MOSFETS that switch the electric current
2 to phase circuits A, B and C at the proper time and
3 duration to produce and maintain the rotary motion of the
4 device based upon the input of the Hall sensor array.
5 The control means is external to device 10 and the
6 electrical connections between the control means and the
7 conductor optimized stator 15 may be carried by a
8 separate conductor such as a bundle of wires or a ribbon
9 cable.

10 From the A+ terminal 53B the electric current moves
11 through an outer non-radial conductor 62. The current is
12 led into and through a radial conductor 101 and then into
13 an inner non-radial conductor 63. The inner non-radial
14 conductor 63 leads the current into and through radial
15 conductor 124. From this point the current leaves
16 working PCB pattern 32. The current travels through an
17 outer via 324 to connecting PCB pattern 33 in Fig. 17.
18 From outer via 324, the current travels through an outer
19 non-radial conductor 64 to reach radial conductor 102.
20 The current travels through working conductor 102 to an
21 inner non-radial conductor 65, into radial conductor 123,
22 then to outer non-radial conductor 66 and into radial
23 conductor 103. Each time that the electrical current
24 travels through a radial conductor, the current passes
25 through the working conductor section 30. The electrical
26 current continues the current passes through radial
27 conductors 122, 104, 121, 105, 120, 106, and 119. From
28 radial conductor 119 the current returns through an outer

1 via 319 to working PCB pattern 32 shown in Fig. 16. From
2 outer via 319, the current travels through an outer non-
3 radial conductor 67 and into radial conductor 137. From
4 radial conductor 137, the electrical current travels
5 through an inner non-radial conductor 68 to radial
6 conductor 160. The current must travel through an outer
7 via 360 to connecting PCB pattern 33, again referring to
8 Fig. 17, where the current is then able to flow through
9 an outer non-radial conductor 69 to radial conductor 138.
10 The electric current flows from radial conductor 138 into
11 inner non-radial conductor 70 and then flows into radial
12 conductor 159. The current continues the current passes
13 through radial conductors 139, 158, 140, 157, 141, 156,
14 142 and 155. From radial conductor 155, the current is
15 led through an outer via 355 to the working PCB pattern
16 32 as shown in Fig. 16. From outer via 355 the current
17 travels through outer non-radial conductor 71 to an A-
18 terminal 53A. From the A- terminal 53A the current is
19 delivered back to the control means. In similar fashion,
20 working pattern 34 is connected to terminals 53C and 53D
21 and electric current flows through the phase B circuit,
22 included in working PCB pattern 34 and connecting PCB
23 pattern 35, as shown in Figs. 8 and 9. Also, working
24 pattern 36 is connected to terminals 53E and 53F and
25 electric current flows through the phase C circuit,
26 included in working PCB pattern 36 and connecting PCB
27 pattern 37, as shown in Figs. 10 and 11. As previously
28 shown and described in Fig. 15, outer via 301 and inner

1 via 201 connect radial conductors 101 on each layer of
2 conductive material included in the PCB patterns 32, 33,
3 34, 35, 36, and 37 in parallel. Similarly, radial
4 conductors 102 to 172 shown in Figs. 16 and 17 are
5 connected in parallel to the corresponding radial
6 conductors on each layer of conductor material within
7 conductor optimized stator 15 by outer vias 302 to 372
8 and by inner vias 202 to 272.

9 Another embodiment of the invention is shown in Fig.
10 18. The embodiment includes a PCB pattern 91 used with
11 stator 15. The differences from the previously described
12 embodiment include a means to position magnetic pole
13 sensors, such as Hall sensors 95, within working section
14 30. Pattern 91 comprises sensor pockets 92. Sensor
15 pockets 92 are vacant areas that extend through all
16 layers of conductive and nonconductive material. Sensor
17 pockets 92 are sized and positioned to allow a magnetic
18 pole sensor to be placed within the concentrated magnetic
19 flux between magnets 17a and 17b. The radial conductors
20 near sensor pockets 92 are patterned to provide adequate
21 clearance and maintain connections within the circuits of
22 conductor optimized stator 15.

23 The invention provides for other embodiments that
24 optimize the conductors of conductor optimized stator 15
25 in addition to those mentioned above. As previously
26 shown, Fig. 15 illustrates one configuration of radial
27 conductor 101, that being comprised of a single, straight
28 working conductor 101a symmetrical about a radius 55

1 along with inner via pad 101b, inner via 201, outer via
2 pad 101c, and outer via 301. As non-limiting examples,
3 Figs. 19-24 show other possible means to optimize the
4 conductors of the invention. Fig. 19 shows a radial
5 conductor 101 as described above that comprises three
6 vias 201 in inner pad 101b and three vias 301 in outer
7 pad 101c. Increasing the number vias connecting radial
8 conductor 101 on each layer of conductive material
9 increases the total plated area of each connection which
10 reduces the electrical resistance of the circuit.
11 Although three vias 201 and three vias 301 are shown, it
12 is understood that other numbers of vias are possible.

13 Another embodiment shown in Fig. 20 shows a radial
14 conductor 401 that is comprised of two working conductors
15 401a and 401b. Working conductors 401a and 401b are
16 parallel to radius 55 and are of equal width 402. Radial
17 conductor 401 is shown with two working conductors.
18 However, other numbers of working conductors may be used.
19 The width of each individual working conductor is
20 minimized to help reduce eddy current losses. Having a
21 number of working conductors in parallel, such as working
22 conductors 401a and 401b, reduces the electrical
23 resistance and improves the transfer of heat outward when
24 compared to a single working conductor.

25 Fig. 21 illustrates another possible embodiment of a
26 radial conductor within the invention. Branching
27 conductor 501 is shown as working conductor 501a
28 continuous with inner pad 501b. Radially outward,

1 working conductor 501a branches into working conductors
2 501d and 501e, and further on branches again into working
3 conductors 501f, 501g, and 501h. Branching conductor 501
4 is another method to reduce eddy current losses, reduce
5 resistance, and increase the transfer of heat to the
6 outer edges of conductor optimized stator 15.

7 In Figs. 22 and 23, a plurality of vias 602 in
8 working section 30 cross of a pair of working conductors
9 from one side of radius 55 to the other. In Fig. 22,
10 radial conductor 601 is comprised of working conductors
11 601a, 601b, 601c and 601d. Working conductors 601a and
12 601b are continuous as shown and working conductors 601c
13 and 601d end at vias 602 as shown. An electrical current
14 moving through working conductor 601a is on one side of
15 radius 55 and then is crossed to the other side of radius
16 55 in working conductor 601b. Electric current traveling
17 in 601c is connected to another layer of conductive
18 material by via 602 which is configured as illustrated in
19 Fig. 23. The electric current moves from via 602 into
20 working conductor 601c and then is moved across radius 55
21 to working conductor 601d. On the layer of conductive
22 material illustrated in Fig. 23, working conductors 601a
23 and 601b end at vias 602. An electric current traveling
24 through working conductor 601a is connected to the layer
25 of conductive material shown in Fig. 22 where it is
26 connected to working conductor 601a and then is moved
27 across radius 55 to working conductor 601b. Crossing the
28 working conductors in the manner just described is a

1 method of reducing loop currents that are induced within
2 parallel conductors in an alternating magnetic field.

3 Fig. 24 illustrates another embodiment with radial
4 conductor 701 which is comprised of a midpoint 702 that
5 is a distance 703 from radius 55 and a distance 704 from
6 the center 705 of optimized conductor stator 15.
7 Midpoint 702 can have the same or different values for
8 distance 703 and 704 on different layers of conductive
9 material within conductor optimized stator 15. Bending
10 radial conductor 701 away from radius 55 in the manner
11 just described is a method of reducing cogging.

12 The different configurations of radial conductors
13 illustrated in Figs. 14 and 15 and in Figs. 19-24 are
14 presented as non-limiting examples and it will be
15 understood that many other configurations that will
16 further optimize the conductors are possible.

17 While the fundamental novel features of the
18 invention have been shown and described, it should be
19 understood that various substitutions, modifications, and
20 variations may be made by those skilled in the art,
21 without departing from the spirit or scope of the
22 invention. Accordingly, all such modifications or
23 variations are included in the scope of the invention as
24 defined by the following claims:

25

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1 I Claim:

2 1. An axial field rotary energy device having positive
3 and negative polarity, multi-phase electric current
4 terminals comprising:

5 a rotor having a plurality of permanent magnet
6 poles; and

7 a stator having:

8 a plurality of circuit board working
9 conductor layers having at least one working
10 conductor layer for each phase of the electric
11 current, each of said working conductor layers
12 including a pattern of a plurality of radial
13 conductors running between an inner through-
14 hole and an outer through-hole, said inner
15 through-holes being located at an inner
16 diameter of said working conductor layer and
17 said outer through-holes being located at an
18 outer diameter of said working conductor layer;
19 each working layer further having a pair
20 of outer conductors for electrically connecting
21 the positive and negative terminals of one
22 phase of the electric current to selected outer
23 through-holes and a plurality of inner
24 conductors for electrically connecting selected
25 inner through-holes together;

26 a plurality of circuit board connecting
27 conductor layers, at least one of which is
28 associated with each working conductor layer,

1 and each one including a pattern of a plurality
2 of radial conductors running between an inner
3 through-hole and an outer through-hole, said
4 inner through-holes being located at an inner
5 diameter of said connecting conductor layer and
6 said outer through-holes being located at an
7 outer diameter of said connecting conductor
8 layer;

9 each connecting layer further having a
10 plurality of outer conductors for electrically
11 connecting selected outer through-holes
12 together and a plurality of inner connectors
13 for electrically connecting selected inner
14 through-holes together; and

15 a plurality of via conductors, positioned
16 within selected inner and outer through-holes
17 of the working conductor layer and connecting
18 layers, for electrically connecting selected
19 ones of the radial connectors of the connecting
20 conductor layer to selected ones of the radial
21 connectors of the working conductor layer.

22

23 2. The rotary energy device according to claim 1
24 wherein each circuit board working conductor layer has a
25 planar configuration and each circuit board connecting
26 conductor layer has a planar configuration and the stator
27 is formed by stacking the working conductor layers and

1 the connecting conductor layers one upon the other with a
2 substrate layer in between each layer.

3

4 3. The rotary energy device according to claim 2
5 wherein the stator has a central bore therethrough in a
6 direction perpendicular to the planar configuration of
7 the layers and further including a rotatable drive shaft
8 extending through the central bore and further including
9 a first rotor fixedly secured to the drive shaft on one
10 side of the stator and a second rotor fixedly secured to
11 the drive shaft on the opposite side of the stator.

12

13 4. The rotary energy device according to claim 3
14 further including a sensing means mounted to the stator
15 for determining the rotational position of the permanent
16 magnet poles.

17

18 5. The rotary energy device according to claim 3
19 wherein the permanent magnet poles of the first rotor are
20 positioned with respect to the permanent magnet poles of
21 the second rotor so that flux lines pass through the
22 stator in a direction perpendicular to the planar
23 configuration of the working conductor layers.

24

25 6. The rotary energy device according to claim 3
26 wherein each rotor has at least four permanent magnet
27 poles.

28

1 7. The rotary energy device according to claim 1
2 configured for at least a three-phase electric circuit.

3

4 8. The rotary energy device according to claim 1
5 wherein the radial conductors of the working conductor
6 layer and the connecting conductor layer have a
7 preselected width and the outer and inner conductors of
8 the working conductor layer and the outer and inner
9 conductors of the connecting conductor layer have a width
10 wider than the preselected width.

11

12 9. The rotary energy device according to claim 1
13 wherein each working conducting layer and each connecting
14 conductor layer is divided into sectors with each sector
15 associated with a positive or negative polarity of each
16 phase of the electric current and with radial conductors
17 running through each sector.

18

19 10. The rotary energy device according to claim 9
20 wherein the inner conductors of each working conductor
21 layer together with the inner and outer conductors of
22 each connecting conductor layer connect the radial
23 connectors in each sector associated with a phase of the
24 electric current together in series through the via
25 conductors.

26

27 11. The rotary energy device according to claim 10
28 wherein the device is configured for at least three-phase

1 electric current and wherein the rotor includes at least
2 four permanent magnet poles and wherein each working
3 conductor layer and each connecting layer is divided into
4 at least twelve sectors and further wherein the working
5 conductor layer includes at least one outer conductor for
6 connecting a sector associated with the negative polarity
7 of a phase to a sector associated with a positive
8 polarity of this phase.

9

10 12. The rotary energy device according to claim 10
11 wherein the radial conductors of each working conductor
12 layer and each connecting conductor layer are arranged in
13 an identical pattern and wherein corresponding radial
14 conductors in each layer are electrically connected in
15 parallel with the via conductors.

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