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(72) Inventor; and
(71) Applicant : LEE, Randal [US/US]; 1719 Cullen Ave., Austin, TX 78757 (US).

(74) Agents: MOORE, Stanley, R. et al.; Winstead PC, P.O. Box 131851, Dallas, TX 75313 (US).

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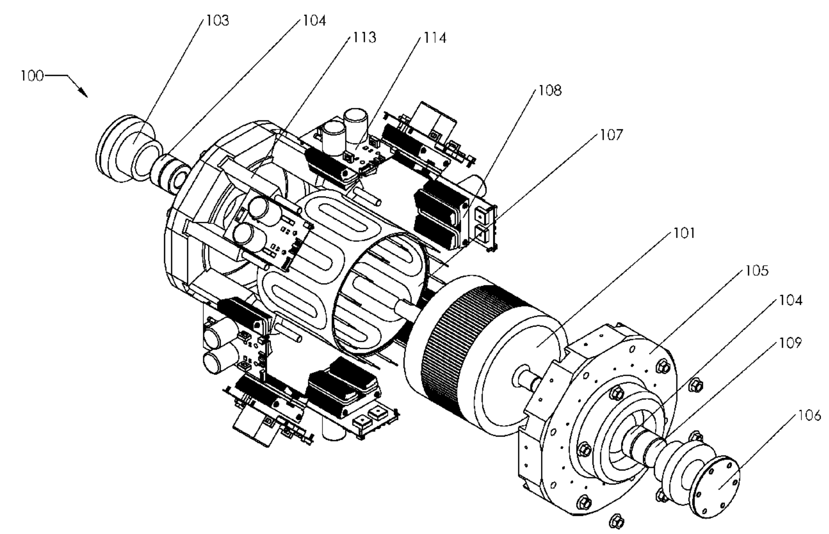

FIG. 3

(57) Abstract: An electric converter is provided which uses independently controlled field coils to impress a temporary magnetic field on a rotor movable relative to one or more armatures. In some embodiments, the rotor of the programmable electric converter is rotatable with the axis of rotation being on a horizontal or vertical axis. In various embodiments, the electric converter disclosed herein may be adapted for use as a continuous power solution to provide power for a limited period of time in the event of a power outage by absorbing energy and storing it mechanically in the rotor. In some embodiments, the electric converter may be utilized as a generator. In some embodiments, both AC and DC could be simultaneously produced, where AC is generated in one armature coil and DC in another coil.

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SYSTEM AND METHOD FOR A PROGRAMMABLE ELECTRIC CONVERTER

Related Applications

[0001] This disclosure claims priority to U.S. Provisional Application No. 61/617,471 filed March 28, 2012 and entitled "SYSTEM AND METHOD FOR A PROGRAMMABLE ELECTRIC CONVERTER," the disclosure of which is expressly incorporated by reference herein in its entirety. This disclosure also claims priority to U.S. Patent Application No. 13/842,953 filed March 15, 2013 and entitled "SYSTEM AND METHOD FOR A PROGRAMMABLE ELECTRIC CONVERTER," the disclosure of which is expressly incorporated by reference herein in its entirety.

Technical Field

[0002] This invention relates in general to the field of electric converters, and more particularly, but not by way of limitation to a programmable electric converter.

Background

[0003] Electro-magnetic machines have been used as generators or as motors or both simultaneously. The operation of the electro-magnetic machine is determined by the type of energy used to drive the machine and the type of energy which is obtained from the operation of the machine. For example, if electrical energy is delivered to the machine and mechanical energy is removed from the machine, then the machine will operate as a motor. Likewise, if mechanical energy is delivered to the machine and electrical energy is removed from the machine, then the machine will act as a generator. In some cases the machine may act both as a motor and as a generator, such as by delivering electrical energy to the machine and removing both electrical energy and mechanical energy therefrom.

[0004] In general, electro-magnetic machines usually comprise a rotor and stator, with one or both of such components having electrically induced magnetic poles. The magnetic flux lines emanating from the magnetic poles serve either to energize the rotational movement or to induce an electrical current in conductors provided adjacent thereto. Such electro-magnetic devices include generally stationary and C-shaped magnets which are arranged about the circumference of a circle and having a plurality of coils arranged around the circumference of a circle which communicates through the openings in the C-shaped magnets.

[0005] If mechanical energy, such as an external torque force, is applied to the central shaft for rotating the coils through the permanent magnets, then the machine operates as a generator. When operated in a generator mode, the external torque source forces rotation of the shaft (and thus the rotor and the magnets), and the interaction of the magnets and the windings causes a magnetic flux to loop the windings in the slots. As the rotor rotates, the magnetic flux in the stator structure changes, and this changing flux results in generation of voltage in the windings, which results in an output current that can be used to power electrical devices, or be stored for later use. When operated in a motor mode, a voltage from an external source is applied to the stator windings, which causes current flow in the windings and results in a magnetic flux to be set up in the magnetic circuit formed by the teeth and back iron. When current is supplied in an appropriate manner to the windings, the rotor can be made to rotate and thus produce usable torque. The operation of such machines is thus well understood.

[0006] Prior art electro-magnetic machines suffer from a variety of limitations which have limited their usefulness somewhat. For example, the frequency and voltage of a permanent magnet electro-magnetic machine operating as a generator may only be varied by varying the rotor speed, which limits the usefulness of such a generator in circumstances where the rotor rotation speed cannot be independently controlled.

[0007] Commutator-type motors do not operate well on high-frequency AC because the rapid changes of current are opposed by the inductance of the motor field. Although commutator-type universal motors are common in 50 Hz and 60 Hz household appliances, they are often small motors, less than 1 kW. The induction motor was found to work well on frequencies around 50 to 60 Hz but not as well at a frequency of, say, 133 Hz. There is a fixed relationship between the number of magnetic poles in the induction motor field, the frequency of the alternating current, and the rotation speed; so, a given standard speed limits the choice of frequency (and the reverse).

[0008] Generators operated by slow-speed reciprocating engines will produce lower frequencies, for a given number of poles, than those operated by, for example, a high-speed steam turbine. For very slow prime mover speeds, it would be costly to build a generator with enough poles to provide a high AC frequency. As well, synchronizing two generators to the same speed was found to be easier at lower speeds. While belt drives were common as a way to increase speed of slow engines, in very large ratings (thousands of kilowatts) these were expensive, inefficient and unreliable. The steadier rotation speed of high-speed machines allowed for satisfactory operation of commutators in rotary converters. The synchronous speed N in RPM is calculated using the formula: $n=(120*f)/p$ where f is the frequency in Hertz and P is the number of poles.

[0009] It would therefore be desirable to improve the controllability of electro-magnetic machines, generally. Accordingly, there is a need to provide an improved electro-magnetic machine which addresses these and other limitations of the prior art.

SUMMARY OF THE INVENTION

[0010] In accordance with the present invention, a system and method for a programmable electric converter is provided.

[0011] In accordance with one aspect of the present invention, an electric converter is provided which uses independently controlled field coils to impress a temporary magnetic field on a rotor movable relative to one or more armatures.

[0012] The above summary of the invention is not intended to represent each embodiment or every aspect of the present invention. Particular embodiments may include one, some, or none of the listed advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A more complete understanding of the method and apparatus of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

[0014] FIG. 1 illustrates a side cut-away view of one embodiment of a programmable electric converter;

[0015] FIG. 2 illustrates a cut away view perpendicular to the axis of rotation of the programmable electric converter of FIG. 1;

[0016] FIG. 3 illustrates an exploded perspective view of the programmable electric converter of FIG. 1;

[0017] FIG. 4 illustrates a perspective view of a field coil cell of the programmable electric converter of FIG. 1;

[0018] FIG. 5 illustrates another embodiment of the field coil cell of FIG. 4 showing the armature coil integrated into the field coil cell;

[0019] FIG. 6 is a perspective view of an embodiment of a rotor of the programmable electric converter of Fig. 1;

[0020] FIGS. 7-8 are views of different embodiments of the rotor of the programmable electric converter of FIG. 1;

[0021] FIG. 9 illustrates how an armature assembly may be used as a vacuum barrier in an embodiment of the programmable electric converter of FIG. 1;

[0022] FIG. 10 shows a perspective view of endplates and spacers forming a frame of the programmable electric converter of FIG. 1;

[0023] FIG. 11 shows a perspective view of the armature assembly of the programmable electric converter of FIG. 1;

[0024] FIGS. 12 shows a partial exploded view of an embodiment of a multi-disc programmable electric converter;

[0025] FIG. 13 shows an embodiment of a multi-disc programmable electric converter;

[0026] FIG. 14 and 14A are views of an embodiment of a circuit board having an inductor thereon for use in a multi-disc programmable electric converter;

[0027] FIG. 15 is a diagram of an embodiment of a multi-disc programmable electric converter in operation; and

[0028] FIG. 16 is an exploded view of an embodiment of a linear programmable electric converter.

DETAILED DESCRIPTION

[0029] Referring to FIGS. 1-3 collectively, an embodiment of a programmable electric converter 100 is shown. In the embodiment shown, a rotor 101 having extrusions on either side thereof along an axis of rotation with one shaft extending thru a bearing cap 106, the rotor being rotatably secured in place via endplates 105 disposed on either side thereof and having bearing assemblies (103, 104, 106, 109). Around a circumference of the rotor are disposed a plurality of C-core field coil cells 108 for inducing a magnetic field 110 in the rotor 101. An armature 107 is disposed between the rotor 101 and the field coil cells 108.

[0030] In some embodiments, the axis of rotation of the rotor 101 of the programmable electric converter 100 may be on a horizontal or vertical axis. In operation, the programmable electric converter 100 the field coil cells 108 may be independently controllable to impress a temporary magnetic field 110 on a cylindrical rotor 101 rotatable relative to one or more armatures 107. Each armature 107 comprises a plurality of armature coils, where each armature coil has two active legs and two armature leads 111 coupled thereto. One or more of the armature leads 111 may be electrically coupled to configure each armature 107 into one or more phases. In the embodiment shown, the armature 107 comprises a total of eight coils totaling sixteen active legs. However, any number of armature coils may be used in armature 107.

[0031] In the embodiment shown, the C-shaped independently controlled field coil cells 108 each have two pole faces and the field coil cells 108 are disposed around the circumference of the rotor 101. As can be seen, each field coil cell 108 is aligned with an armature 107 such that each pole face is aligned with an active leg of the armature coils of armature 107. In operation, a current applied to the field coil cells 108 may impart a plurality of temporary magnetic fields 110 (only one is shown in FIG. 2), each temporary magnetic field having a north and south pole, to the rotor 101. The direction of the current applied to the field coil cells 108 will determine the direction of the magnetic field impressed on the rotor 101. In a first mode of operation, electric potential may be generated by motion of the rotor 101 relative to the armature 107, wherein the plurality of temporary magnetic fields 110 in the rotor 101 produces a DC potential in the armature coils of armature 107. Current will flow through an armature coil in a first direction when a north pole of the temporary magnetic field 110 is applied to one of the active legs of an armature coil and a south pole of the temporary magnetic field 110 is applied to the other of the active legs of the armature coil simultaneously. The direction of the current flow may be switched by switching the direction of the magnetic fields applied to each of the active legs of the armature coils. As the strength of the temporary magnetic field 110 decays below the desired output voltage, the field coil cells 108 may be pulsed again, imparting another plurality of temporary magnetic fields 110. The magnetic impression(s) of magnetic fields 110 onto the rotor 101 are temporary and the dwell time of the impression will depend on, among other things, the magnetic properties of the rotor 101.

[0032] During operation, the magnetic field 110 impressed on an area of the rotor 101 is temporary and can be reinforced or re-written as needed. The ability to selectively control the strength and direction of the magnetic fields 110 on the rotor 101, allowing control of which armature coils are activated at which times, allows the number of poles on the rotor 101 to be changed dynamically from one (homopolar) to any desired number. In some embodiments it may be preferable that the number of poles on the rotor 101 be equal to the number of armature coils of armature 107. Thus, a universal converter may be achieved, which can operate as an AC, DC, or homopolar machine at a wide range of voltages and frequencies by, for example, dynamic and selective gating of the field coil cells 108. The programmability of the programmable electric converter 100 allows a single machine to be configured for use in a plurality of different environments, for example, 480V at 60Hz, 400V at 50Hz, and/or other environments based on the criteria of the specified use. Further, the ability to dynamically change the number of poles means that when the programmable electric converter 100 is operated as a motor, torque can be controlled independent of the voltage or speed.

[0033] In some embodiments, the poles and field currents can be slewed radially around the rotor 101 allowing tolerance in the event of a failure of one or more of the field coil cells 108. For example, in the event of a failure of one of the field coil cells 108, the poles can be remapped on the rotor 101 in such a way as to skip the bad field coil cell 108. In some embodiments, the failed field coil cell 108 may be replaced with a new field coil cell 108 without having to completely power down the programmable electric converter 100.

[0034] Referring to FIG. 4-5, embodiments of C-core-type field coil cells 108 are shown. While field coil cells 108 are shown as C-core field coil cells, any number of different field coil cell configurations may be utilized. In the embodiment shown, the field coil cells 108 may be formed of a laminated steel construction, wherein each C-core field coil cell 108 has two windings therearound 112, one in series with the other, and wound in such a way that each winding 112 produces flux in the same direction in the C-core. Each winding 112 may be coupled to a separate power supply (not shown), such as a DC power source, and may have an insulated gate bipolar transistor (IGBT) 118 disposed between the power source and the windings 112 to allow bi-directional control of the current flow through the windings 112. Using bi-directional IGBTs 118 to independently control each field coil cell 108, the programmable electric converter 100 can simultaneously impress onto the rotor 101 a plurality of different temporary magnetic fields, including magnetic fields of different directions. As previously discussed, aligning each north pole with one active leg of an armature coil and each south pole with the other active leg within the same armature coil creates a complimentary electric potential in each armature coil in the armature 107. Furthermore, the ability to selectively control the temporary magnetic fields impressed on the rotor 101 affords flexibility in operation that is not dependent on the position of the rotor 101. Additionally, armature 107 output frequency regulation may be possible by controlling the gating frequency of the ICBTs 118 in the field coil cell 108. Armature coil output voltage control may be achieved thru closed loop current control of the currents in the field coil cells 108. A potential benefit of the distributed multi-field coil design is that thermal losses are distributed among a plurality of C-cores and associated IGBTs making it easier to reject heat. In some embodiments, in addition to the primary energizing coil(s), multiple parallel windings may be included on the field coil laminations, such as a separate motoring winding circuit, a separate magnetic bearing winding, and/or a separate damping circuit.

[0035] In some embodiments, the rotor 101 may be disposed within a vacuum and the field coil cells 108 may be disposed outside of the vacuum. In some embodiments, the field coil cells 108 may be force air cooled and the windings 112 may be low-turn, high-current windings providing low impendence and high responsiveness. In some embodiments, the power source may include a capacitor 119 to provide a high discharge. In some embodiments, each field coil cell 108 or groups of field coil cells 108 may be coupled to one or more circuit boards 114 for mounting the IGBTs 118 and drivers thereon. In some embodiments, individual armature coils 115 may be assembled as part of the field coil cell 108 for improved serviceability of a failed armature coil 115. In some embodiments the laminations of the C-cores may be made of METGLAS, or amorphous metal alloy, or other materials having low magnetic losses.

[0036] Referring now to FIGS. 6-8, various embodiments of rotor 101 adapted for use in the programmable electric converter 100 of Fig. 1 are shown. In various embodiments, the rotor 101 may be steel and the geometry and material properties of an outer surface of the rotor may be varied depending on design criteria. In some embodiments, efficiencies may be achieved through a reduction in the amount of magnetizable material disposed on the rotor 101. As shown in Fig. 6, in some embodiments, a rotor 101 having a composite design may be utilized comprising a plurality of rings (116a-c) disposed on an outer surface thereof. In some embodiments, one or more magnetically permeable rings 116b may be positioned under the active length of the armature coils and interposed between non-magnetic rings 116a and 116c. In some embodiments, non-magnetic rings 116a and 116c may be protrusions of rotor 101 and/or separate rings secured thereto. In various embodiments, the magnetically permeable ring 116b may be slotted and/or the ring 116b may be constructed of laminations to reduce losses.

[0037] As shown in Fig. 7, in some embodiments, the rotor 101 may be a generally solid cylinder of monolithic steel design having protrusions on a top and bottom thereof along the axis of rotation. The material of the rotor 101 may be chosen based on its physical properties, including, among others, the density of the material and its magnetic field persistence. In some embodiments, various surfaces of the rotor may be manipulated to vary the physical and magnetic properties of the rotor 101. For example, portions of the top and bottom side walls may be removed to reduce the weight of the rotor 101 without reducing the surface area of the outer circumference of the rotor 101. In addition, in some embodiments, the rotor 101 may have a void of a certain depth disposed inside the outer circumference of the rotor 101 to form a magnetic break between the outer surface of the rotor 101 and the internal volume of the rotor 101. As shown in FIG. 8, in some embodiments, slots 101a may be formed in the outer surface of the rotor 101 to isolate the plurality of magnetic fields being created around the rotor 101. In some embodiments, the slots 101a may extend the full height of the outer circumference and in some embodiments the slots 101a may extend less than the full height of the rotor 101. In some embodiments, the number of slots 101a may be equal to or a multiple of the number of field cell coils disposed around the rotor 101. For example, in the embodiment shown in FIG. 2, rotor 101 has four protrusions or teeth within the length of an armature coil. In some embodiments, the rotor 101 may include an integrated air pump for evacuating air from within the optional vacuum barrier. In various embodiments, the radius, height, weight, surface geometry, and other properties of the rotor may be manipulated depending on the desired inputs and outputs of the programmable electric converter 101. In some embodiments, the rotor 101 may be of a composite design having magnetizable pads disposed on or near fingers of the rotor 101.

[0038] In some embodiments, the outer circumference of the rotor 101 may be beveled or chamfered to allow the creation of forces in multiple directions, such as, magnetic thrust bearing forces, and creating differential radial velocities from one end of the armature active length as compared to the other. In some embodiments, one or more bearing assemblies may be a ball bearing 104 (shown in FIG. 1) adapted to receive a radial load and/or one or more bearing assemblies may include both a ball bearing and a pivot bearing 109 (shown in FIG. 1) for receiving a thrust load. In such embodiments, the pivot bearing may be capable of high speed and high thrust and may bring the ball bearings into a smaller diameter, thereby lowering the radial velocities.

[0039] Turning now to FIG. 9, a cut-away view of an embodiment of a programmable electric converter 100 having an optional vacuum barrier 102 applied to the inner diameter of the armature assembly 107 with the associated O-rings 117 used to contain the vacuum around the rotor. In some embodiments, such as, for example, high speed applications, wind drag may have a deleterious effect and creating a vacuum around the rotor may reduce the wind drag. In general, the vacuum barrier 102 may be formed of a non-magnetic material adapted to minimize interference between the field coil cells and the rotor. For non-vacuum systems, clearances between the rotor and the field coil cells may be minimized to reduce drag.

[0040] Referring now to FIG. 10, endplates 105 of the programmable electric converter 100 are shown. Endplates 105 may be adapted to be disposed along the top and bottom surfaces of the rotor, separated by a pattern of spacers 113 around a circumference thereof. The endplates 105 may include a shoulder along an internal surface thereof against which the field coil cells will abut when disposed around the rotor 101 as shown in FIG. 1. The surface on one or both sides of the spacers 113 may be adapted to match the surface of the field coil cells to provide structural support to the field coil cells. In some embodiments, the spacers 113 may be arranged, such as by tapering the sides thereof, to facilitate the transfer of high radial magnetic forces created by the interaction of the energized field coil cells and the rotor to the endplates 105. The spacers 113 and endplates 105 may be formed of a non-magnetic material, such as Aluminum, to, for example, provide shielding, and may have integrated heat sink features formed therein to remove heat from the field coil cells and/or switches (IGBTs).

[0041] Referring now to FIG. 11, an embodiment of an armature 107 used in the embodiment of the programmable electrical converter 100 of FIG. 1 is shown. In various embodiments, the armature 107 may be disposed outside of a vacuum barrier, if applicable. In the embodiment shown, the armature 107 comprises eight armature coils 115, wherein each armature coil has two active legs and two armature leads 111 for a total of sixteen active legs and sixteen armature leads 111. In some embodiments, the armature 107 may be comprised of one or more phases by, for example, coupling two or more armature leads 111 together. In various embodiments, the number of groups of armature leads 111 coupled together can range from two up to a maximum of two times the number of armature coils 115. Any number of internal busing structures can be employed to group together the common armature leads 111 of one or more armature coils 115. For example, one or more switches (not shown) may be disposed between the armature leads 111. These switches may be a combination of series, parallel, or anti-parallel switching elements. Armature assembly 107 may be optimized for forced convection cooling, using, for example, slot wound or bobbin wound armature coils or Z-form coils.

[0042] In various embodiments, the programmable electric converter disclosed herein may be adapted for use as a continuous power solution to provide power for a limited period of time in the event of a power outage and/or as a surge protector (by absorbing the energy and storing it mechanically in the rotor). In such embodiments, the shaft may be coupled to an engine-generator set (gen-set) with a magnetic clutch coupling, which provides a clean slip (i.e., just heat). The inertial energy stored in the spinning rotor may be used to generate the ride-through power to critical loads while also using some of the stored energy for inertial gen-set start prior to transition to an alternative power source, such as a diesel generator. In other embodiments, the ability of the programmable electric converter to receive a variable shaft input and provide a regulated frequency and voltage output may allow its use as a generator in a wind turbine. In some embodiments, the programmable electric converter may be utilized to provide a traction drive with regenerative energy capture on braking and dynamic rotor damping. In such an embodiment, one or more programmable electric converters may be disposed at each wheel of a vehicle. In some embodiments, the programmable electric converter may be utilized as a stepper motor with accurate positional control. In some embodiments, two programmable electric converters (or a single programmable electric converter having two armatures) may be shaft coupled for converting between different frequencies of power, such as, for example, by inputting into one armature from a 50Hz power supply to motor the rotor and simultaneously generating an output at 60 Hz from the other armature.

[0043] In some embodiments, both AC and DC could be simultaneously produced, where AC is generated in one armature coil and DC in another armature coil. In some shaft coupled embodiments, AC power can be converted to DC power by operating one converter as an AC motor while operating the other as a DC generator. In some shaft coupled embodiments, DC power can be converted to AC power by operating one converter as a DC motor while operating the other as an AC generator. In some embodiments, the programmable electric converter can operate as a DC to DC converter using input shaft torque and DC power of the field coil cells to generate DC power at a higher voltage.

[0044] In some embodiments, the programmable electric converter may be utilized to provide electro-magnetic propulsion in magnetic levitation applications to provide precise acceleration profiles and capture regenerative braking energy. In some embodiments, the programmable electric converter may be utilized to propel objects by using a repetitive pulse output to power a coil gun or rail gun. In some embodiments, a plurality of programmable electric converters as disclosed herein may be distributed throughout an electrical grid to provide step-up and step-down transformation, as needed. In some embodiments, the programmable electric converter may be utilized as a motor allowing motor torque to be varied without changing the voltage by adding or removing coils, the tradeoff being efficiency vs. speed (i.e., dynamic torque control via programming). When configured as a motor, the programmable electric converter can change direction faster and more smoothly than conventional electric motors because the various components are independently controlled and therefore can each be assigned different functions. For example, some components of the programmable electric converter could be using electricity to move in a first direction, some components could be generating electricity, and some components could be using that same electricity to move in a second direction, with the proportion of work being done by each component being varied in real time

[0045] Referring now to FIGS. 12-15, an embodiment of a multi-disc programmable electric converter 200 is shown comprised of a rotor 202 and a plurality of stationary circuit boards 201. As shown in FIG. 13, the rotor 202 is comprised of a shaft and a plurality of discs secured therealong, each disc of the rotor 202 having magnetizable areas 202a disposed thereon. In various embodiments, each circuit board 201 is comprised of a layer of material acting as a back-iron, an armature having armature coils (not shown), and a plurality of field coils 201a (shown in FIGS. 14 and 14A) that can be selectively energized and interposed between the back-iron and armature coils. In the embodiment of the multi-disc programmable electric converter shown in FIG. 12, circuit boards 201 are interleaved between each disc of rotor 202 to provide a matrix of field coils 201a that can be energized to impress a magnetic field onto the magnetizable areas 202a of the rotor 202. As shown in FIG. 15, in a first mode of operation, after the field coils 201a have been selectively energized to impart magnetic forces onto the magnetizable areas 202a, the field coils 201a can then be selectively energized to impart magnetic force on the magnetizable areas 202a to cause the rotor 202 to rotate along an axis of rotation. In a second mode of operation, an input torque applied to the rotor 202 causing the magnetizable areas of 202a to move relative to the field coils 201a to generate electricity.

[0046] In some embodiments, the plurality of discs of rotor 202 may comprise a plurality of discrete magnetizable dots, one or more larger magnetizable areas, and/or a plurality of discrete non-magnetizable areas, such as holes, within a larger magnetizable area. In a first mode of operation in embodiments where non-magnetizable areas or holes are disposed within larger magnetizable areas on one or more of the discs of rotor 202, energizing the field coils 201a would create magnetic forces that would impart movement in the rotor 202 as the field coils 201a either attract and/or repel magnetized areas disposed on the discs of the rotor 202. In a second mode of operation, torque applied to the rotor 202 causing movement of the magnetized and non-magnetized areas of the discs of rotor 202 between the poles of the field coils 201a would generate electricity. In some embodiments, the field coils 201a disposed between the discs of rotor 202 could be very small and, for example, disposed on an integrated circuit. In various embodiments, circuit boards 201 could be stacked along the same axis as the discs of rotor 202 to provide high-density energy conversion, operating at low voltages on the micro level, but able to deliver high current and voltage on the system level.

[0047] In some embodiments, the efficiency of a multi-disc programmable electric converter 200 may be related to the proportion of the mass of the rotor 202 to the overall mass of the programmable electric converter 200. By maximizing the active area where field coils 201a and magnetizable areas 202a come into contact, the material costs may be reduced and cost effectiveness may be increased. It is well known that electromagnetic fields drop off with the square of the distance. Therefore, in some embodiments, the relatively large area and close proximity of the contact that may be provided by the multi-disc programmable electric converter 200 may reduce radiant energy loss. In various embodiments, to avoid magnetic coupling of adjacent field coils 201a, the field coils 201a may be operated at low voltages and/or be spaced apart one from another. In various embodiments, the operating voltage may be used to selectively control the speed and responsiveness of a multi-disc programmable electric converter 202 due to the time required to generate or take down an impressed magnetic field. Lower voltage operation may allow higher frequency field modulation and allow closer spacing of the field coils 201a. In some embodiments, magnetic coupling between closely spaced field coils

201a may be reduced by activating alternating rows of electromagnetic coils 201a on a time slicing schedule. In some embodiments, an inductor layout could be made to descend into a multilayer board such that the flux lines on both sides of the inductor board could be used to interact with the magnetizable areas 202a, thereby reducing magnetic radiant losses. In some embodiments, a printed circuit board could hold an inductor driver and have connectors that would hook up to a microcontroller or FPGA.

[0048] Referring now to FIG. 16, an embodiment of a linear programmable electric converter 300 is shown comprising a rod 301 and a rotor 302 having a plurality of magnetizable areas 300a disposed along an outer surface thereof. In various embodiments, the rod 301 comprises a layer of material acting as a back-iron, an armature having armature coils (not shown) disposed on an internal surface of the rod 301, and a plurality of field coils 300b interposed between the back-iron and the armature. In this embodiment, the linear programmable electric converter 300 is acting as a solenoid, with the rotor 302 oscillating linearly back and forth within the rod 301. In such an embodiment, the armature coils may be utilized to either exert a magnetic force on the magnetizable areas 300a to drive the shaft 302 or generate current from the motion of the magnetizable areas 300a relative to the armature coils. In the embodiment shown, the shaft 302 is hollow with magnetizable areas (not shown) disposed on an inner surface thereof and the rod 301 includes an inner rod with armature and field coils (not shown) disposed on an outer surface thereof. In some embodiments, there may be a fixed magnet or spring at each end to provide restorative force to reset the linear programmable electric converter 300 for the next cycle. One of the mechanical applications for this type of linear programmable electric converter 300 may include use as a shock absorber in a car where the up and down motions could be used to generate electricity and/or smooth out the ride. In some embodiments, the linear programmable electric converter 300 may comprise, generally, a programmable coil configuration in an electromechanical transducer. The dispersal of coils enables an assembly of driver/pickup coils to be independently actuated, and the mechanical substrate may link the actions of the parts, allowing them to be multiplied into a single electromechanical system with a dynamically alterable function. In the embodiment shown, the rotor 302 is sized for oscillating back and forth within the rod 301; whereas in other embodiments, the rotor 302 may be sized for oscillation adjacent to an external surface of the rod 301 and/or the rotor 302 may be stationary and the rod 301 is movable relative to the rotor 302.

[0049] In some embodiments, the armature and field coils and the magnetizable areas may be embedded into a flexible material and electrical pulses may be used to control the folding of that material and/or movement of the material could be sensed as electrical pulses to indicate position and orientation of the material. In some embodiments, the programmable electric converter may be adapted to be disposed in a running shoe that could generate electricity to power, for example, blinking safety LEDs or a wireless performance monitor. In other embodiments, a sheet of programmable electric converters in a flexible material could “flap” in the wind to generate power. In various embodiments, the programmable electric converter could be operated as an electromechanical transducer, wherein the switch/coil/dot unit assembly may be preferable to the piezoelectric effect in that the properties can vary in time and space, with a subdivision and specialization of function within the same system.

[0050] Although various embodiments of the method and apparatus of the present invention have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the invention is not limited to the embodiments disclosed, but is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A programmable electric device, comprising:

an armature having a first side and a second side, the armature comprising a plurality of armature coils, each armature coil having two active legs and two armature leads coupled thereto;

a rotor disposed adjacent to the first side of the armature and movable relative thereto, the rotor comprising a magnetizable material operable to have one or more temporary magnetic fields impressed therein, each of the one or more temporary magnetic fields comprising a north pole and a south pole;

a plurality of field coil cells disposed adjacent to the second side of the armature and proximate to the rotor such that the armature is interposed therebetween, the plurality of field coil cells operable to receive electrical power and be energized to generate magnetic fields therein and thereby impress the one or more temporary magnetic fields onto the rotor;

control circuitry coupled to the plurality of field coil cells to control the energization of the plurality of field coil cells, the control circuitry operable to selectively energize the plurality of field coil cells to dynamically control the one or more temporary magnetic fields impressed on the rotor;

wherein movement of the rotor relative to the armature causes the one or more temporary magnetic fields to generate an electric potential in one or more of the plurality of armature coils; and

wherein an electric current flowing in the plurality of armature coils creates a magnetic field to impart magnetic force on the one or more temporary magnetic fields to move the rotor relative to the armature.

2. The programmable electric device of claim 1, wherein:

the control circuitry is operable to vary a magnitude of the magnetic force exerted on the rotor by selectively energizing the plurality of field coil cells to dynamically control the one or more temporary magnetic fields impressed on the rotor.

3. The programmable electric device of claim 1, wherein:

the armature and the rotor are operable as an AC motor when AC power is supplied to the armature leads to produce a rotating magnetic field in the armature and DC power is supplied to the plurality of field coil cells to impress the one or more temporary magnetic fields onto the rotor, the rotating magnetic field exerting the magnetic force on the one or more temporary magnetic fields to cause the rotor to move relative to the armature.

4. The programmable electric device of claim 1, wherein:

the armature and the rotor are operable as a DC motor when DC power is supplied to the armature leads and sequentially pulsed to produce a rotating magnetic field in the armature and DC power is supplied to the plurality of field coil cells to impress the one or more temporary magnetic fields onto the rotor, the rotating magnetic field exerting the magnetic force on the one or more temporary magnetic fields to cause the rotor to move relative to the armature.

5. The programmable electric device of claim 1, wherein:

the armature and the rotor are operable as a DC generator when an input force is applied to the rotor causing the rotor to move relative to the armature and a DC power source is coupled to the plurality of field coil cells to impress the one or more temporary magnetic fields onto the rotor, the motion of the rotor relative to the armature producing a DC potential in the plurality of armature coils.

6. The programmable electric device of claim 5, wherein:

the DC potential is controlled by an amplitude of the electric current applied to the field coil cells and a frequency and time of a duty cycle of the field coil cells and a speed of the movement of the rotor relative to the armature.

7. The programmable electric device of claim 5, wherein:

the one or more temporary magnetic fields persist for a period of time such that the DC potential is produced in a first direction and subsequently in a second direction such that an AC potential is produced at the armature leads of the armature coils.

8. The programmable electric device of claim 5, wherein:

the DC generator is operable as a DC-to-DC power converter.

9. The programmable electric device of claim 1, wherein:

the armature and the rotor are operable as an AC generator when an input force is applied to the rotor causing the rotor to move relative to the armature and a DC power source is coupled to the plurality of field coil cells to impress the one or more temporary magnetic fields onto the rotor, the DC power supplied to the field coil cells being bi-directional such that a polarity of the one or more temporary magnetic fields impressed onto the rotor by the DC power in a first direction can be switch by applying the DC power in a second direction; and

the motion of the rotor relative to the armature and the switching of the polarity of the one or more temporary magnetic fields impressed onto the rotor produces an AC potential in the plurality of armature coils.

10. The programmable electric device of claim 8, wherein:

the AC potential is controlled by an amplitude of the current applied to the field coil cells and a frequency and time of a duty cycle of the field coil cells and a speed of the movement of the rotor relative to the armature.

11. The programmable electric device of claim 1 and further comprising:

a second armature having one or more armature coils adjacent to the rotor such that movement of the rotor relative to the second armature causes the one or more temporary magnetic fields to generate an electric potential in one or more of the armature coils of the second armature.

12. The programmable electric device of claim 11, wherein:

the pole faces of the plurality of field coil cells are disposed adjacent to the second armature.

13. The programmable electric device of claim 1, wherein:

the motion of the rotor relative to the armature is linear.

14. The programmable electric device of claim 1, wherein:

the movement of the rotor relative to the armature is caused by torque forces.

15. A method for utilizing temporary magnetic fields in a programmable electric device operable in multiple modes of operation, the method comprising:

providing a rotor having a magnetizable material on a surface thereof;

providing an armature and a plurality of field coil cells disposed in close proximity to the rotor, the armature having a plurality of armature coils interposed between the rotor and the plurality of field coil cells, each armature coil having two active legs and two armature leads coupled thereto;

coupling the plurality of field coil cells to control circuitry;

impressing one or more temporary magnetic fields onto the rotor by selectively energizing the plurality of field coil cells to generate magnetic fields therein, the temporary magnetic fields comprising a north pole and a south pole;

moving the rotor relative to the armature in a first mode of operation to cause the one or more temporary magnetic fields to generate an electric potential in at least one of the plurality of armature coils; and

applying electric power to the at least one of plurality of armature coils to generate magnetic fields therein in a second mode of operation and impart magnetic force on the one or more temporary magnetic fields to move the rotor relative to the armature.

16. The method of claim 15 and further comprising:

varying a magnitude of the magnetic force exerted on the rotor in the first mode of operation by using the control circuitry to selectively energize the plurality of field coil cells to dynamically control the one or more temporary magnetic fields impressed on the rotor.

17. The method of claim 15 and further comprising:

wherein the electrical power supplied to the at least one of the plurality of armature coils in the second mode of operation is either AC power or pulsed DC power to produce a rotating magnetic field in the armature; and

controlling a magnitude of the magnetic force imparted on the rotor by using the control circuitry to selectively energize the plurality of field coil cells to dynamically control the one or more temporary magnetic fields impressed onto the rotor.

18. The method of claim 15 and further comprising:

varying the electric potential generated in the first mode of operation without changing a speed of the movement of the rotor relative to the armature by using the control circuitry to vary a frequency or an amplitude of the energizing the plurality of field coil cells.

19. The method of claim 15 and further comprising:

providing a second armature having one or more armature coils therein adjacent to the rotor such that movement of the rotor relative to the second armature causes the one or more temporary magnetic fields to generate an electric potential in one or more of the armature coils of the second armature.

20. The method of claim 15, wherein:

the motion of the rotor relative to the armature is linear.

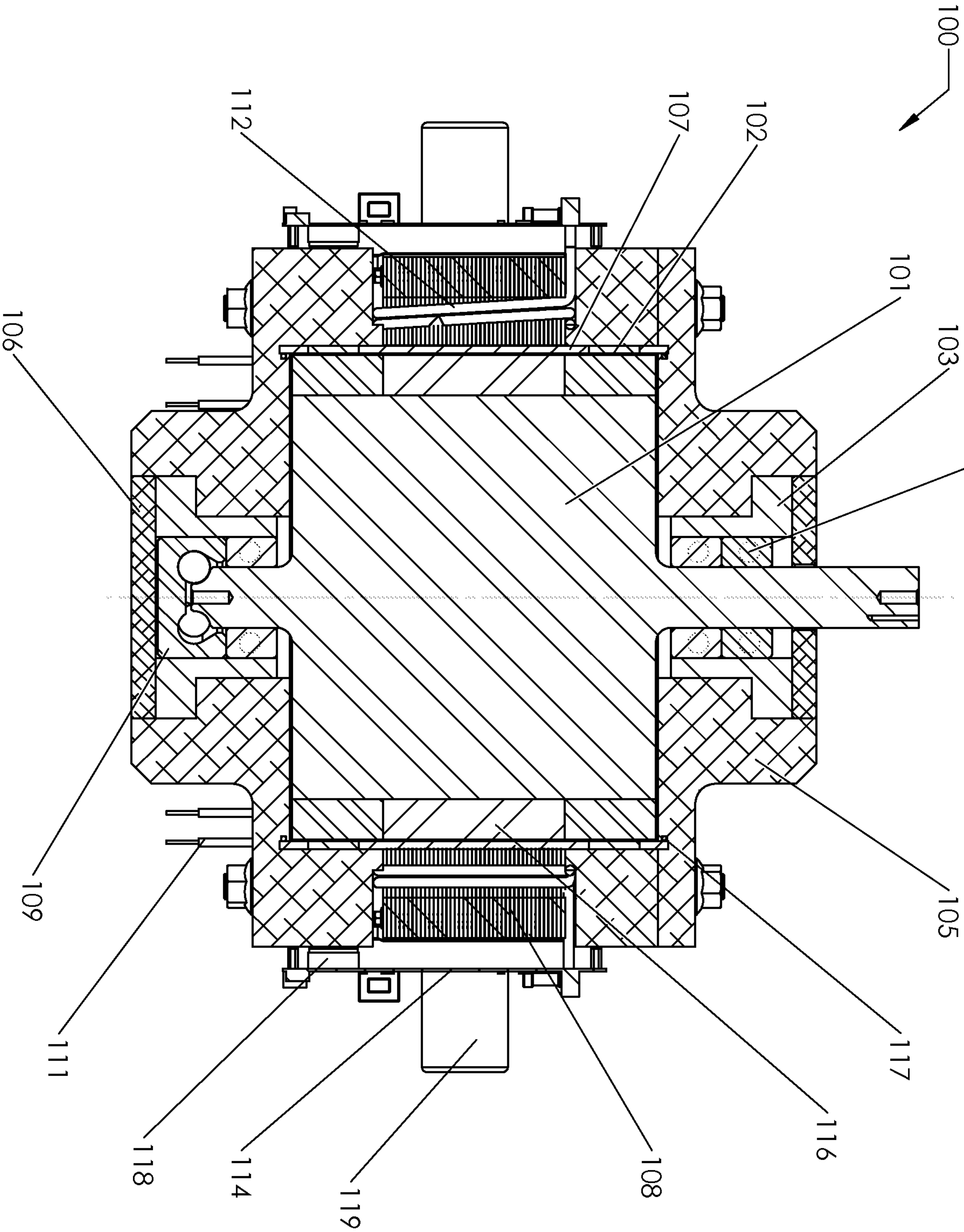
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FIG. 1

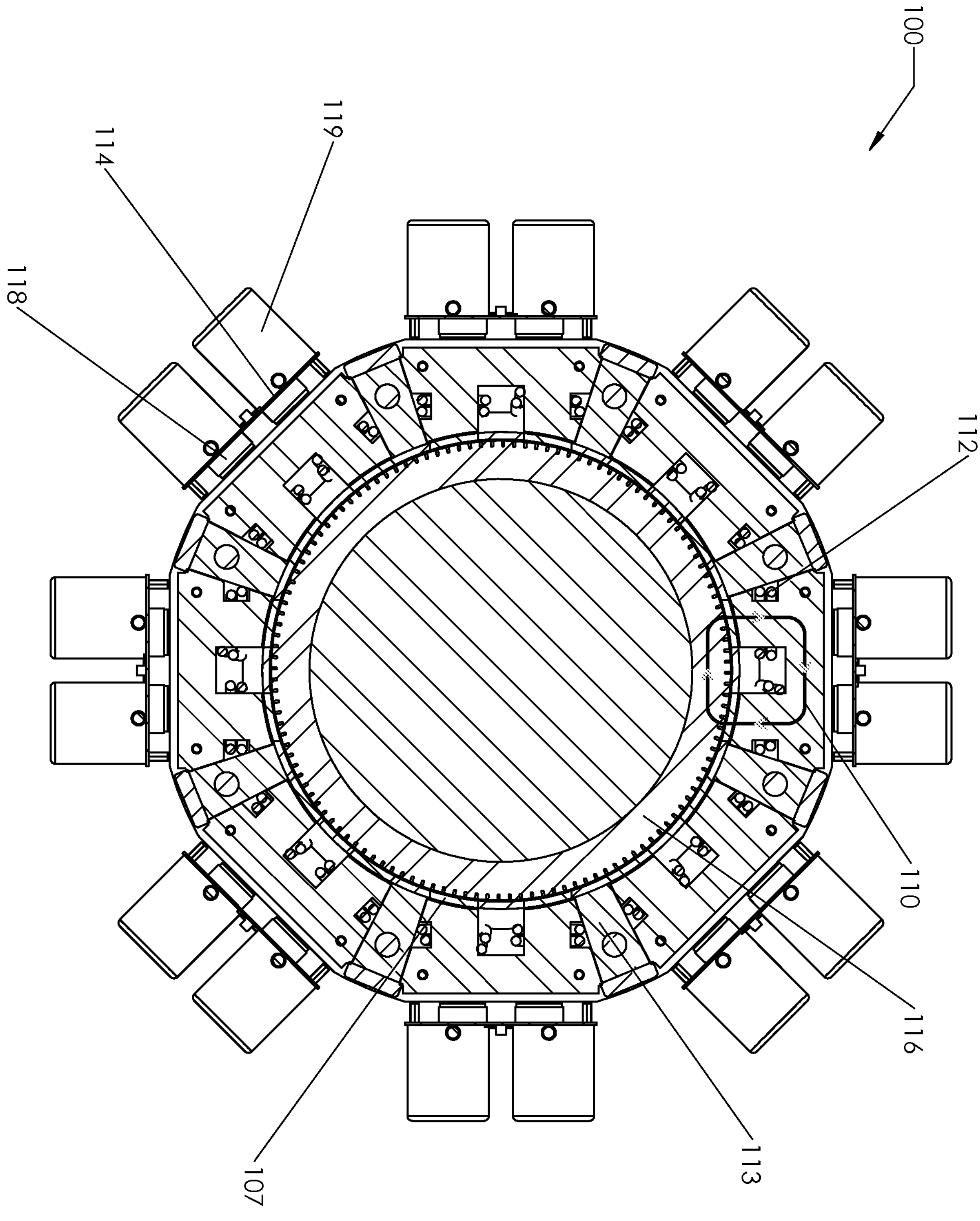


FIG. 2

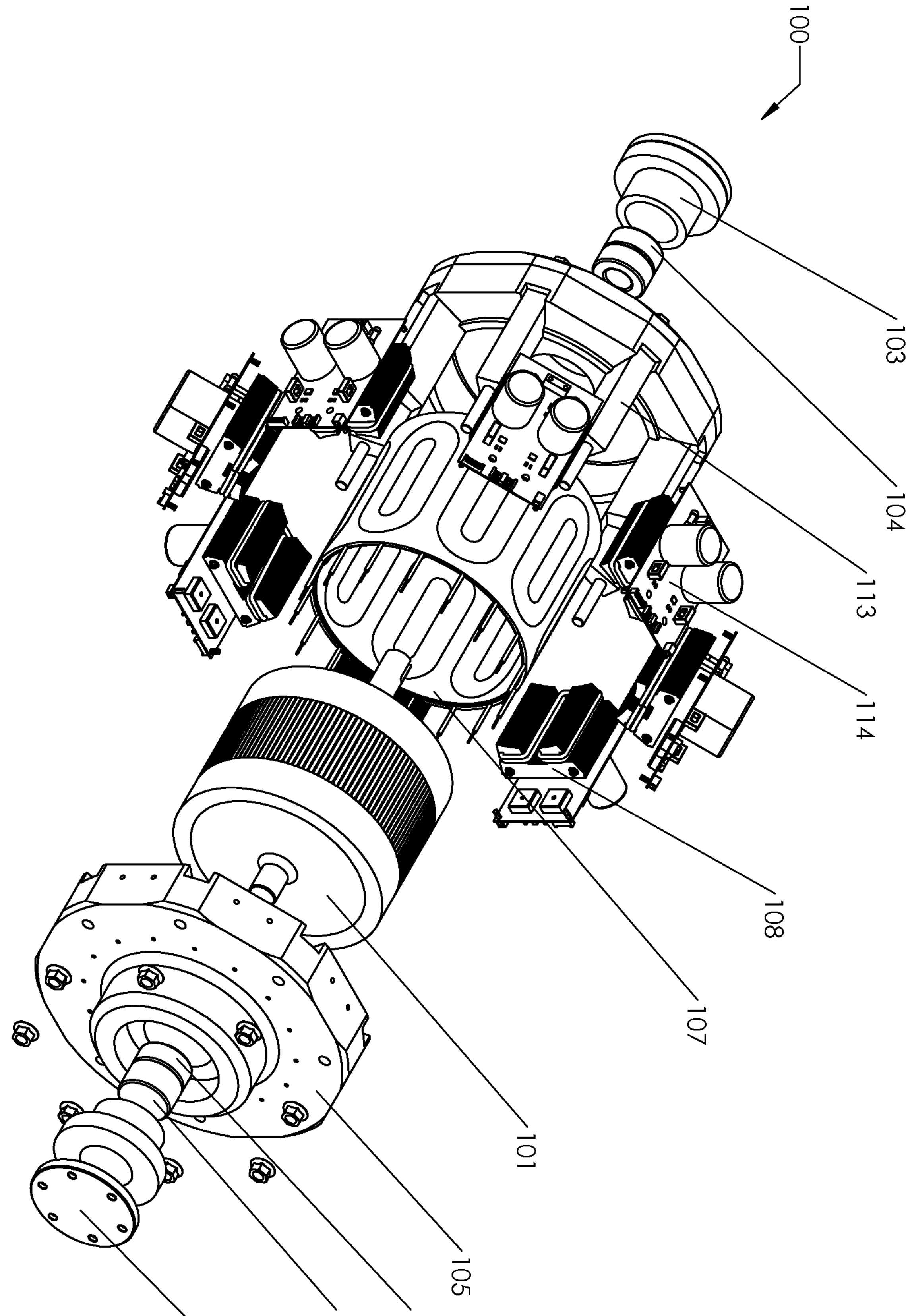


FIG. 3

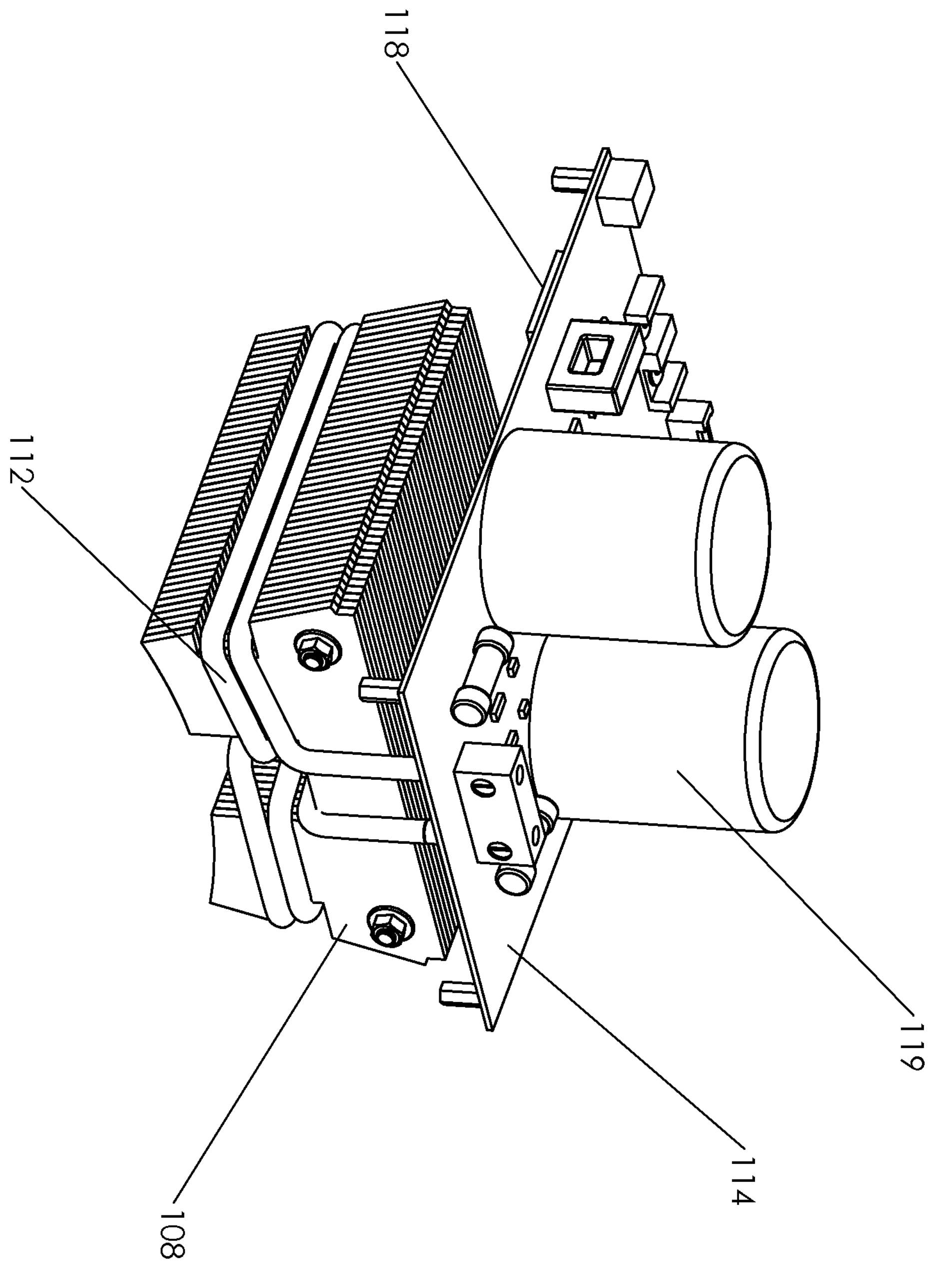


FIG. 4

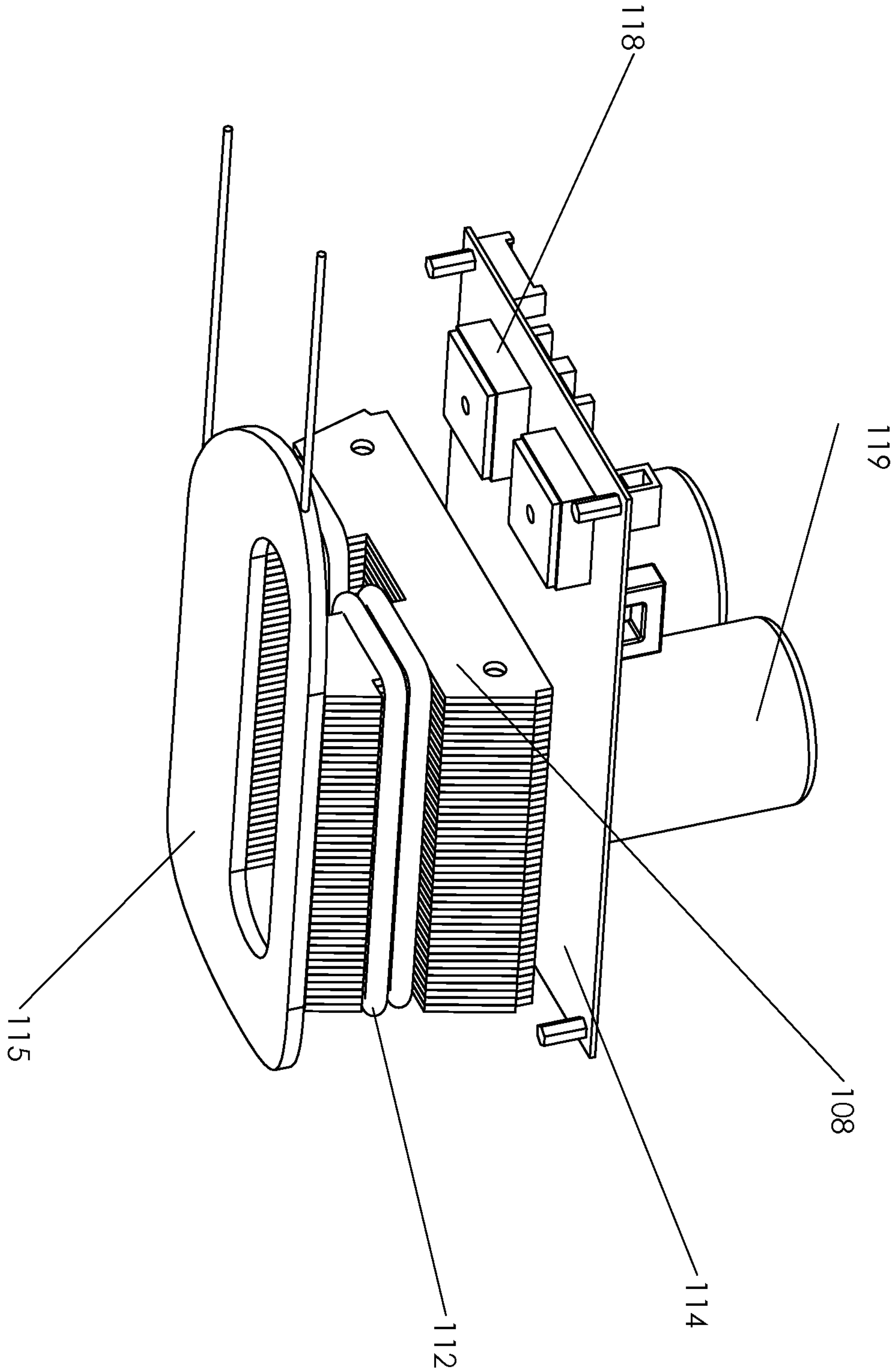


FIG. 5

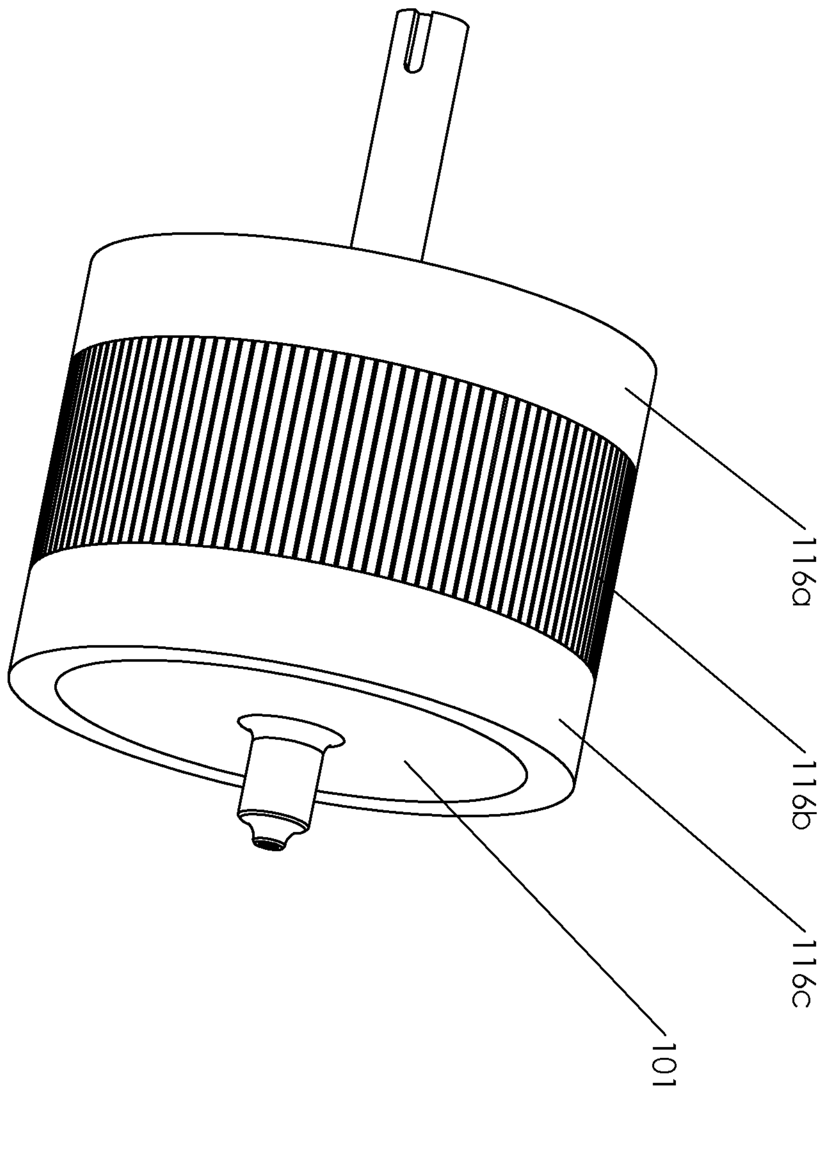


FIG. 6

FIG. 7

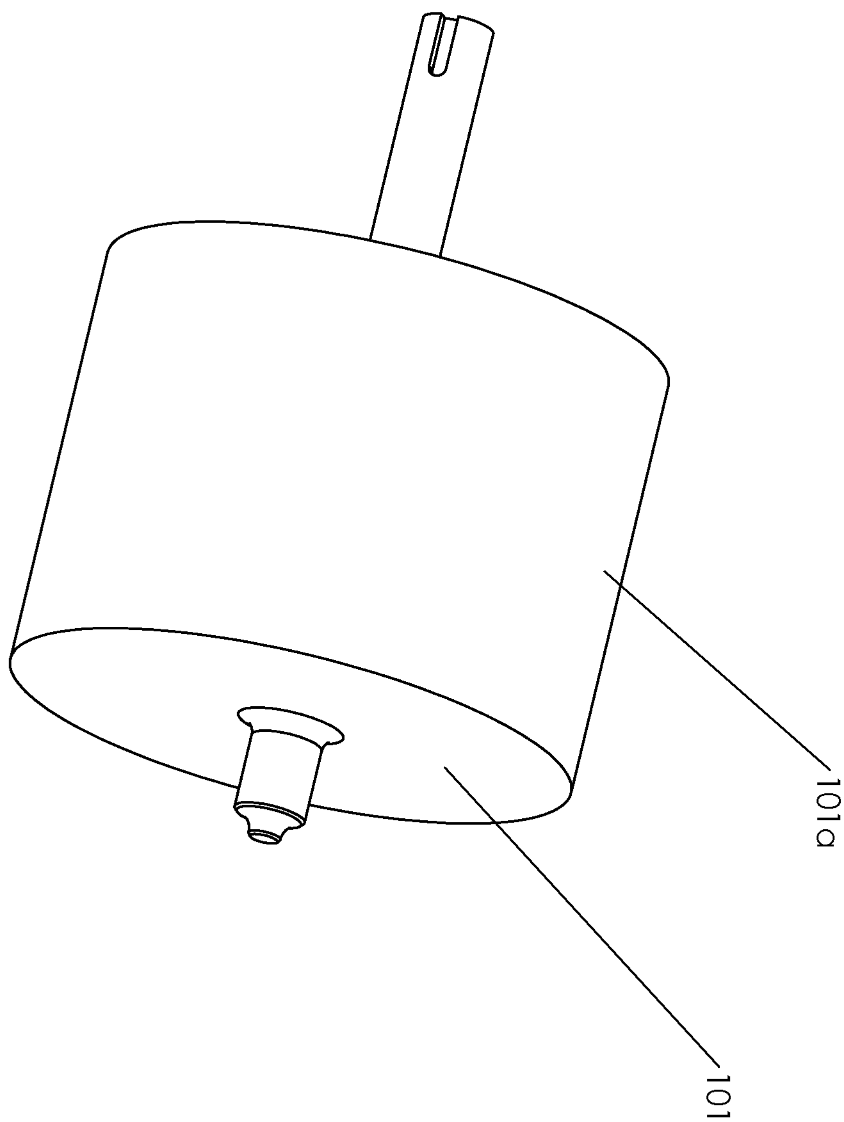
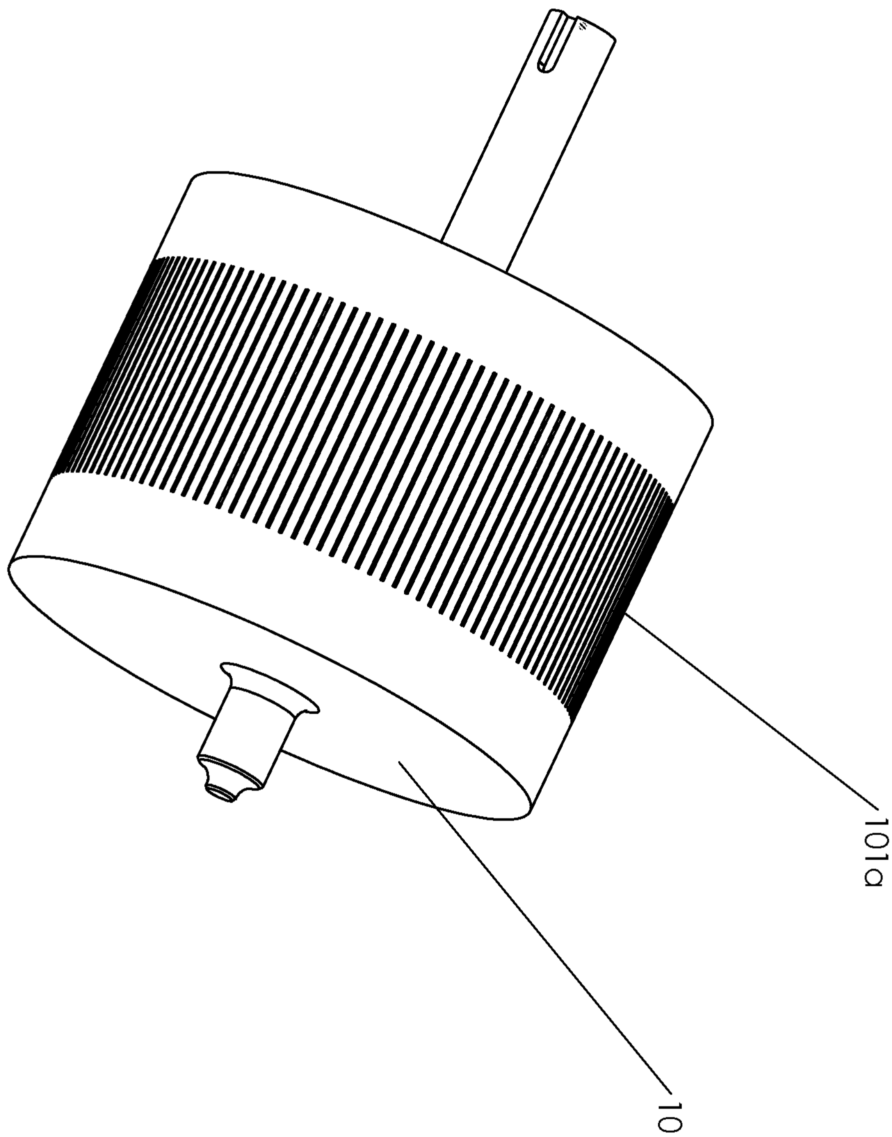


FIG. 8



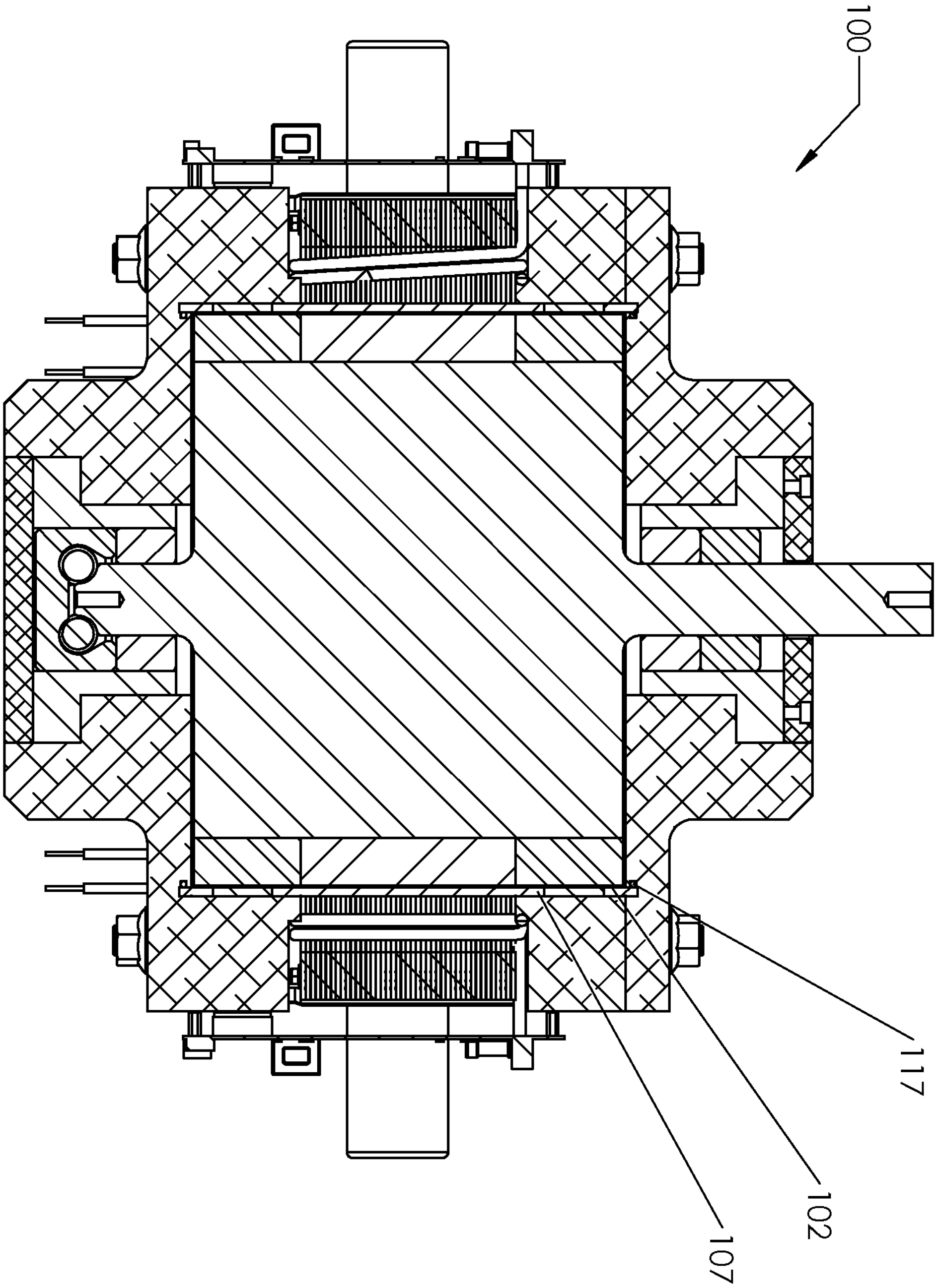


FIG. 9

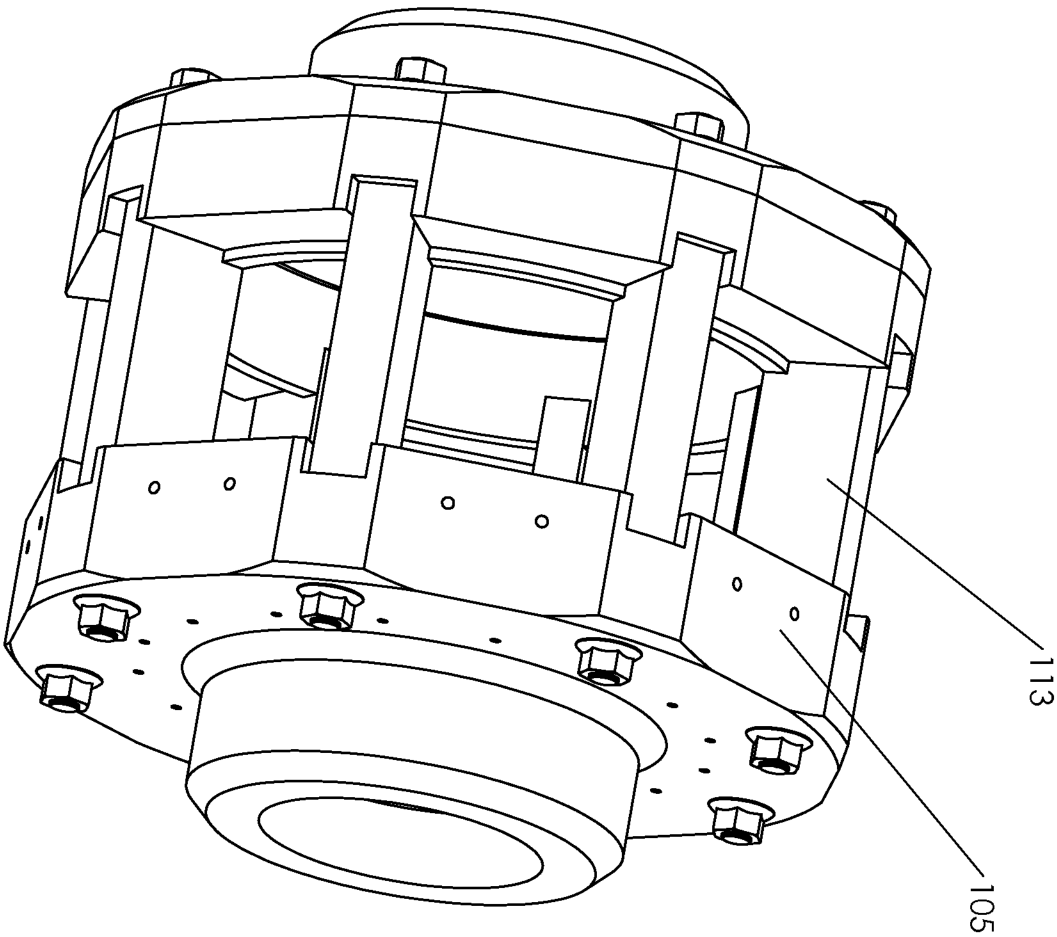


FIG. 10

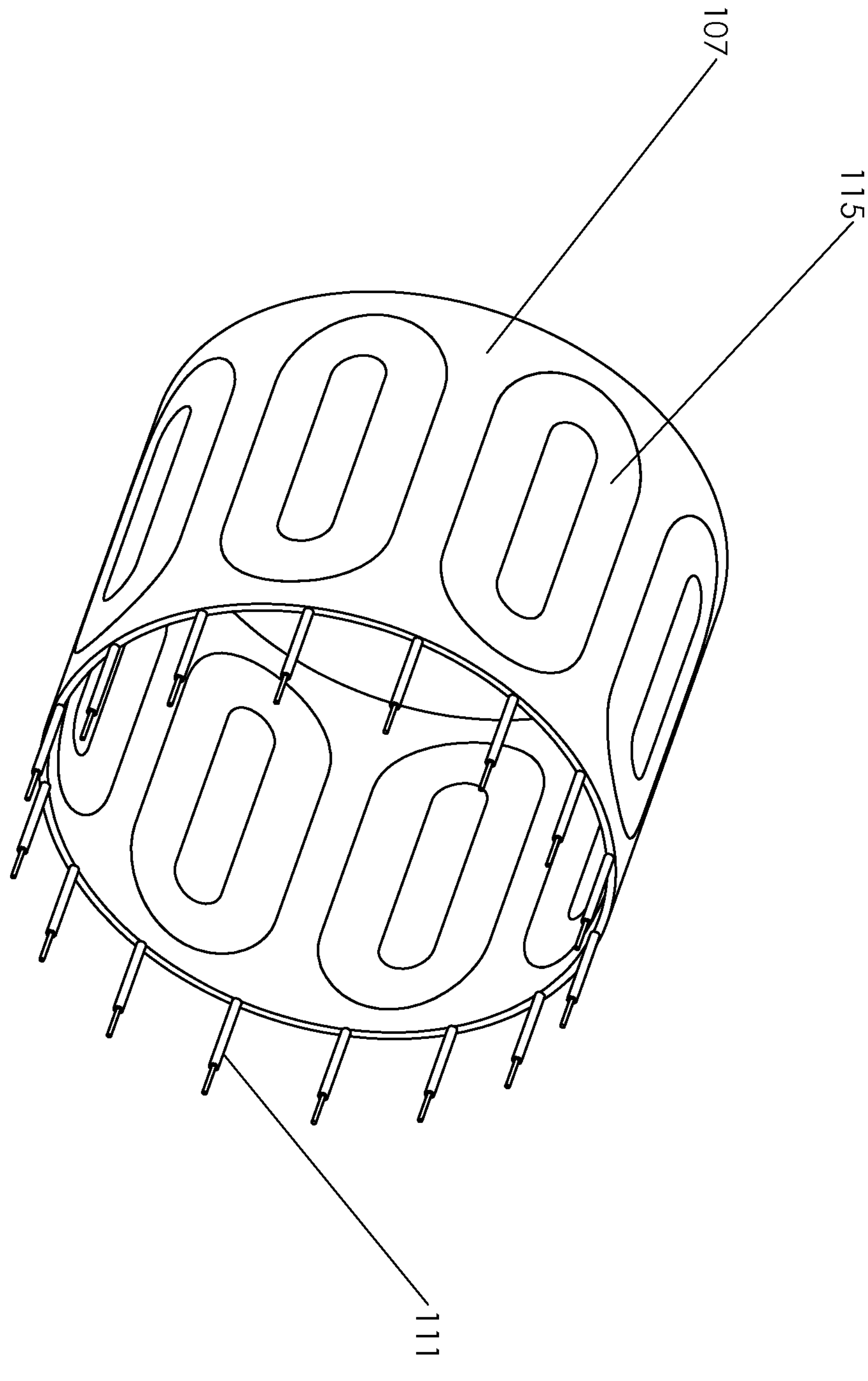


FIG. 11

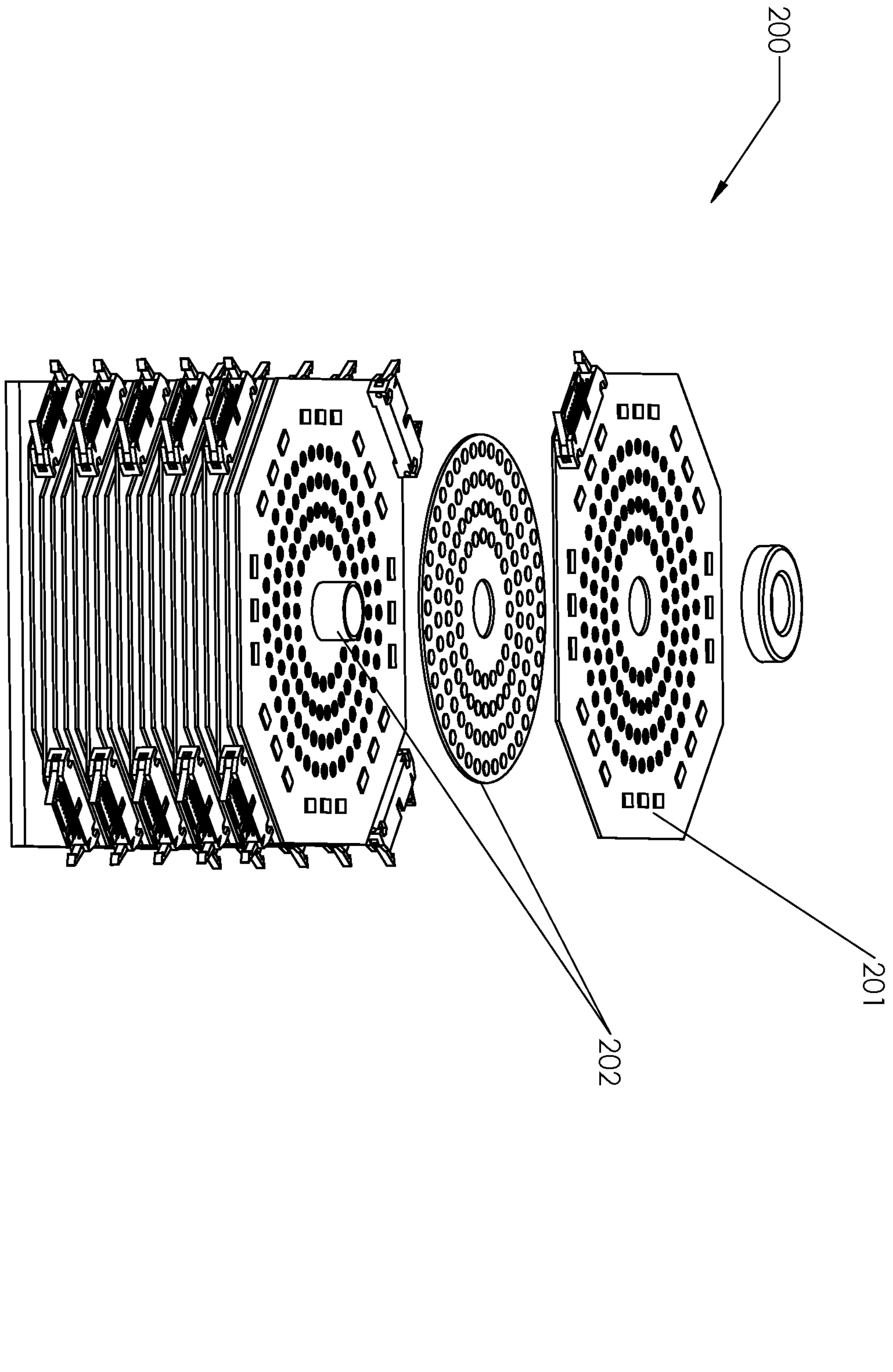


FIG. 12

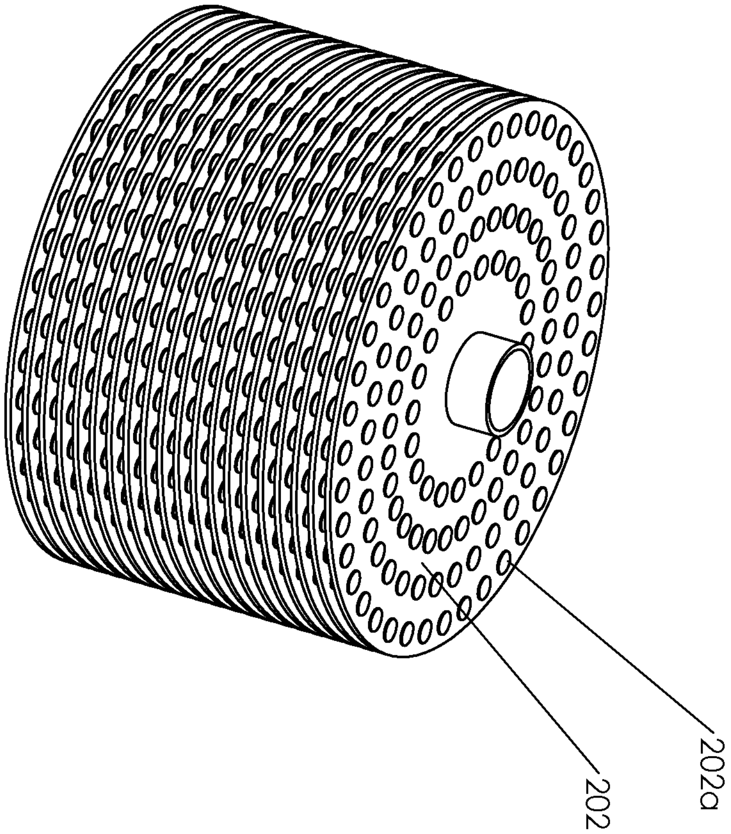


FIG. 13

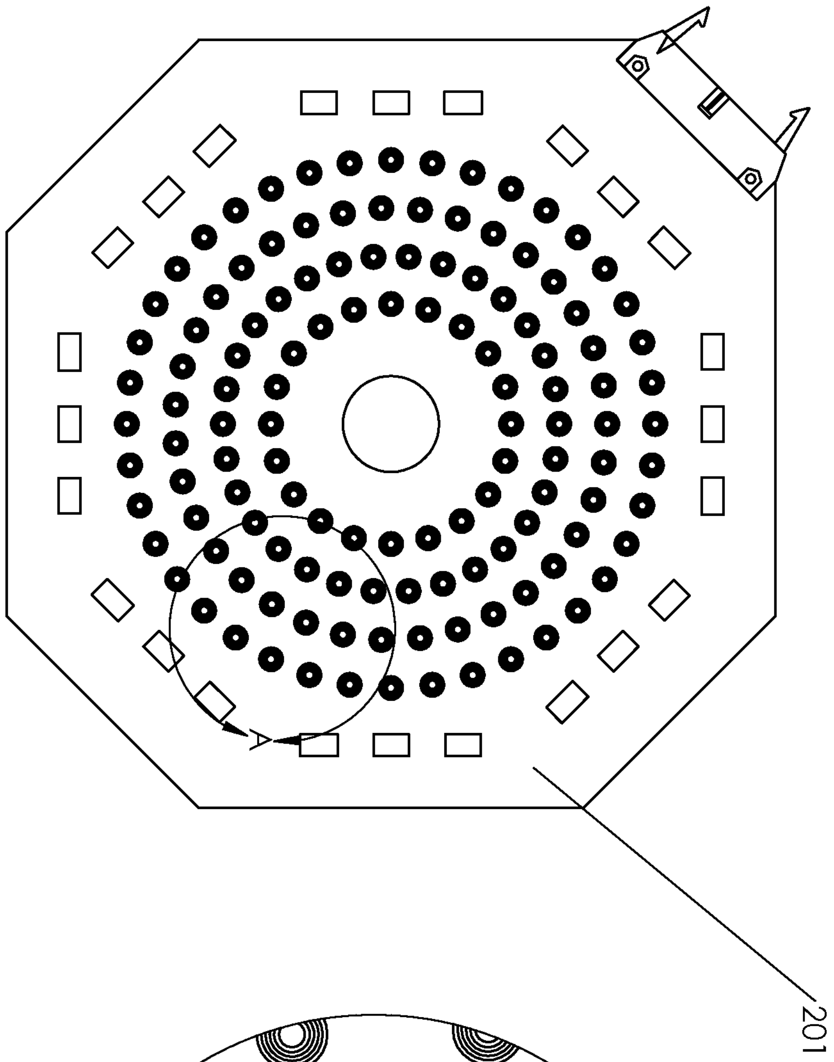


FIG. 14

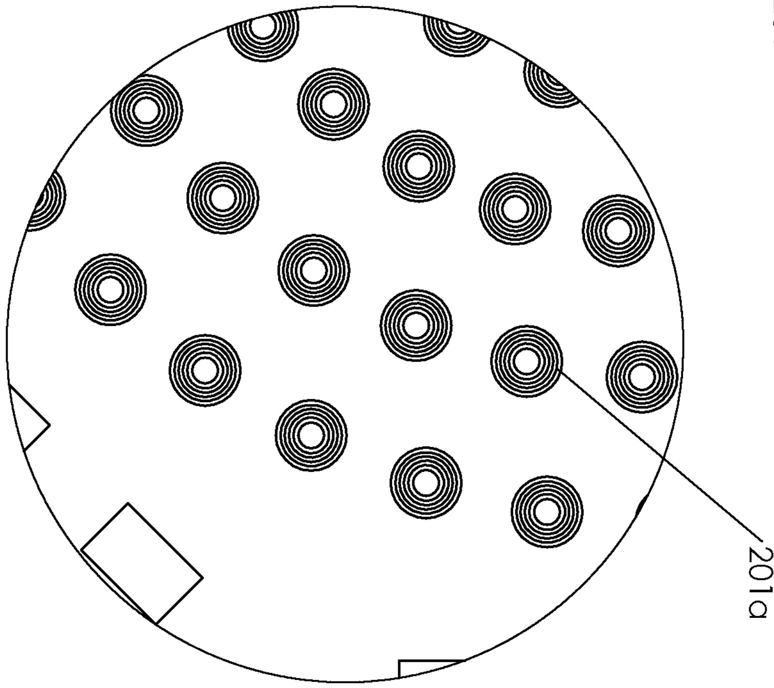


FIG. 14A

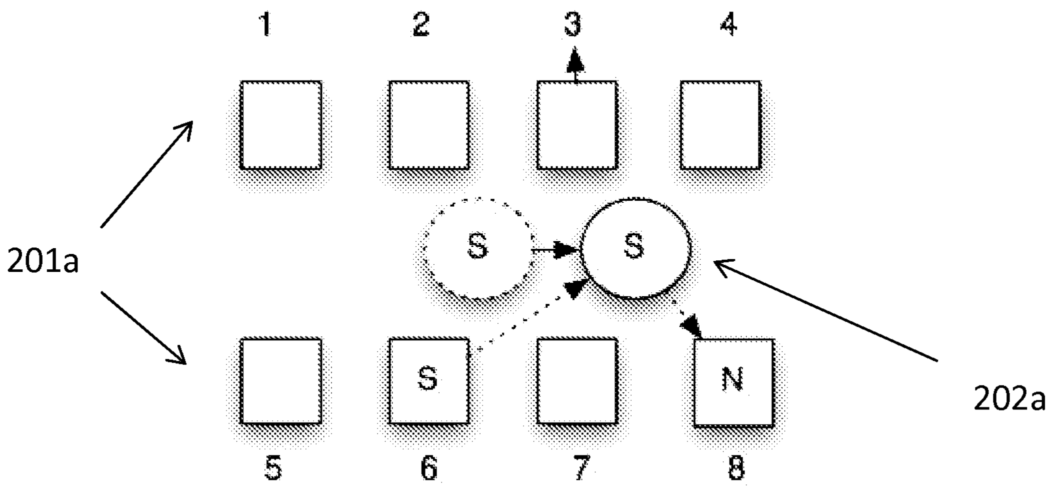


FIG. 15

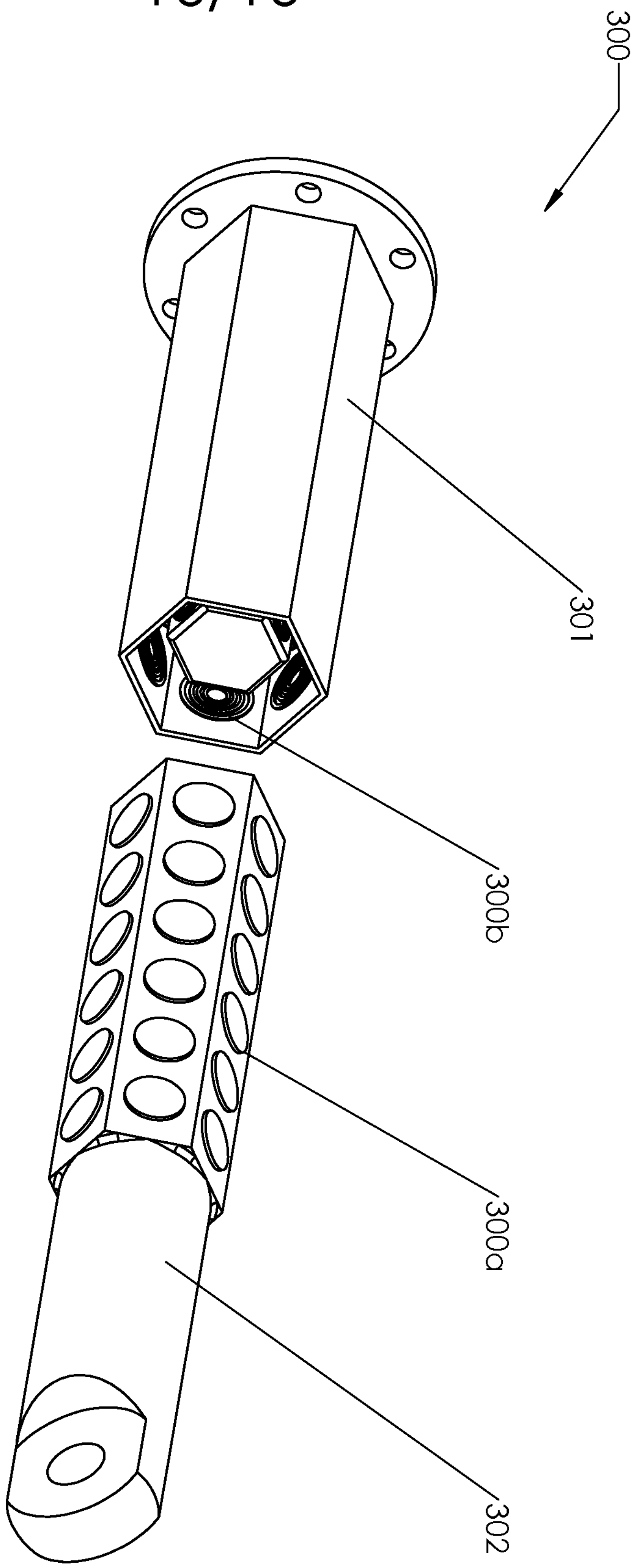


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/034495

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H02K 1/08 (2013.01)
USPC - 310/195
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)
IPC(8) - H02P 9/08, 9/36; H02K 1/00,1/08,11/00,15/02,15/03,15/085,15/095,6/00,16/02,16/04,19/06,21/00,21/10,21/12,55/04 (2013.01)
USPC - 310/179, 180, 181, 184, 185, 195, 254.1; 322/61, 62, 63; 505/166

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC: H02K 1/24, 1/2706, 3/28 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Minesoft Patbase, Google Patents, Google

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,308,318 A (DUNAISKI et al) 07 March 1967 (07.03.1967) entire document	1-20
A	US 6,232,691 B1 (ANDERSON) 15 May 2001 (15.05.2001) entire document	1-20
A	US 6,121,705 A (HOONG) 19 September 2000 (19.09.2000) entire document	1-20
A	US 4,087,711 A (KIRTLEY, JR. et al) 02 May 1978 (02.05.1978) entire document	1-20
A	WO 2009/056879 A1 (POLLOCK et al) 07 May 2009 (07.05.2009) entire document	1-20
A	US 2010/0308674 A1 (KASAOKA et al) 09 December 2010 (09.12.2010) entire document	1-20
A	US 4,467,267 A (HUCKER et al) 21 August 1984 (21.08.1984) entire document	1-20
A	US 2011/0148238 A1 (GOODZEIT et al) 23 June 2011 (23.06.2011) entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 June 2013	05 JUL 2013

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774