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(54) Title: SHROUDED WIND TURBINE WITH RIM GENERATOR AND HALBACH ARRAY

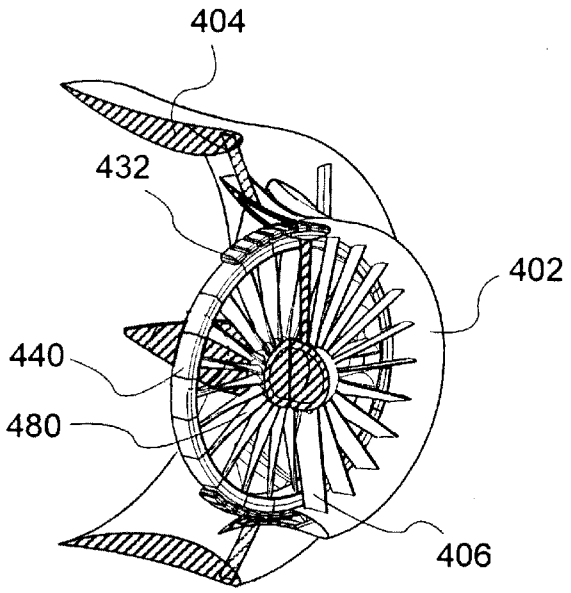


FIG. 9

(57) Abstract: A wind turbine comprises a turbine shroud and optionally an ejector shroud. The wind turbine encloses a permanent magnet ring generator. A static ring of phase windings is located in the turbine shroud, and wind airflow causes a rotor having permanent magnets thereon to rotate, creating an electric current in the static ring. The permanent magnets are arranged to form a Halbach cylinder with the magnetic field being exterior to the rotor.

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SHROUDED WIND TURBINE WITH RIM GENERATOR AND HALBACH ARRAY

BACKGROUND

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 61/222,142, filed July 1, 2009. This application is also a continuation-in-part from U.S. Patent Application Serial No. 12/054,050, filed March 24, 2008, which claimed priority from U.S. Provisional Patent Application Serial No. 60/919,588, filed March 23, 2007. This application is also a continuation-in-part from U.S. Patent Application Serial No. 12/629,714, filed December 2, 2009, which claimed priority from U.S. Provisional Patent Application Serial No. 61/119,078, filed December 2, 2008. The disclosures of these applications are hereby fully incorporated by reference in their entirety.

[0002] The present disclosure relates to rim generators for use with a shrouded wind turbine. In particular, a ring generator based on a rotor/stator assembly is modified to serve as a permanent magnet generator. The magnets included in the ring generator are arranged in a Halbach array in order to enhance power generation by the shrouded wind turbine. Methods of making and using such systems are also disclosed.

[0003] Conventional wind turbines used for power generation generally have two to five open blades arranged like a propeller, the blades being mounted to a horizontal shaft attached to a gear box which drives a power generator. Such turbines are generally known as horizontal axis wind turbines, or HAWTs. Although HAWTs have achieved widespread usage, their efficiency is not optimized. In particular, they will not exceed the Betz limit of 59.3% efficiency in capturing the potential energy of the wind passing through it. These turbines typically require a supporting tower ranging from 60 to 90 meters in height. The blades generally rotate at a rotational speed of about 10 to 22 rpm. A gear box is commonly used to step up the speed to drive the generator, although some designs may directly drive an annular electric generator. Some turbines operate at a constant speed. However, more energy can be collected by using a variable speed turbine and a solid state power converter to interface the turbine with the generator.

[0004] It would be desirable to collect additional energy from the wind turbine.

BRIEF DESCRIPTION

[0005] The present disclosure relates to shrouded wind turbines comprising a ring generator. The permanent magnets in the ring generator are arranged in a Halbach array to maximize the power generation capability of the wind turbine.

[0006] Disclosed in embodiments is a wind turbine comprising: a turbine shroud and an impeller. The turbine shroud encloses or surrounds the impeller. The turbine shroud also includes a static ring that has at least one phase winding. The impeller comprises a rotor. The rotor has a central ring, an outer ring, a plurality of rotor blades extending between the central ring and the outer ring, and a plurality of permanent magnets on the outer ring. The static ring of the turbine shroud and the outer ring of the rotor are aligned with each other. The plurality of permanents magnets are arranged on the outer ring to form a Halbach cylinder that produces a magnetic field exterior to the rotor.

[0007] The turbine shroud may further comprise a ring of mixing lobes formed on a trailing edge. A trailing edge of the turbine shroud may have a circular crenellated shape.

[0008] The permanent magnets may comprise a rare earth element. In particular embodiments, the permanent magnets are $Nd_2Fe_{14}B$ magnets. The plurality of permanent magnets may more specifically be located along a rear end of the outer ring.

[0009] In embodiments, the static ring has three phase windings connected in series.

[0010] The wind turbine may further comprise an ejector shroud, an inlet end of the ejector shroud surrounding an outlet end of the turbine shroud. The wind turbine may also further comprise a stator defining an inlet end of the wind turbine, the stator comprising a plurality of stator vanes.

[0011] Disclosed in other embodiments is a wind turbine comprising: a turbine shroud, an impeller, and an ejector shroud. The turbine shroud encloses or surrounds the impeller. The turbine shroud also includes a static ring that has at least one phase winding. The impeller comprises a rotor. The rotor has a central ring, an outer ring, a plurality of rotor blades extending between the central ring and the outer ring, and a plurality of permanent magnets on the outer ring. The static ring of the turbine shroud and the outer ring of the rotor are aligned with each other. The plurality of permanents magnets are arranged on the outer ring to form a

Halbach cylinder that produces a magnetic field exterior to the rotor. An inlet end of the ejector shroud surrounds an outlet end of the turbine shroud.

[0012] In particular embodiments, the turbine shroud further comprises a ring of mixing lobes formed on a trailing edge, and the ejector shroud has an airfoil shape (i.e. the ejector shroud does not have mixing lobes).

[0013] Also disclosed is a wind turbine comprising: a turbine shroud enclosing an impeller; wherein the turbine shroud encloses a static ring that has at least one phase winding and has a ring of mixing lobes formed on a trailing edge; wherein the impeller comprises a stator and a rotor, the stator being upstream of the rotor and the rotor having a central ring, an outer ring, a plurality of rotor blades extending between the central ring and the outer ring, and a plurality of permanent magnets on the outer ring; wherein the static ring and the outer ring are aligned with each other; and wherein the plurality of permanents magnets are arranged on the outer ring to form a Halbach cylinder that produces a magnetic field exterior to the rotor; and an ejector shroud having an airfoil shape, an inlet end of the ejector shroud surrounding an outlet end of the turbine shroud.

[0014] These and other non-limiting features or characteristics of the present disclosure will be further described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The following is a brief description of the drawings, which are presented for the purposes of illustrating the disclosure set forth herein and not for the purposes of limiting the same.

[0016] **FIG. 1** is an exploded view of a first exemplary embodiment or version of a MEWT of the present disclosure.

[0017] **FIG. 2** is a front perspective view of **FIG. 1** attached to a support tower.

[0018] **FIG. 3** is a front perspective view of a second exemplary embodiment of a MEWT, shown with a shrouded three bladed impeller.

[0019] **FIG. 4** is a rear view of the MEWT of **FIG. 3**.

[0020] **FIG. 5** is a front perspective view of another exemplary embodiment of a MEWT according to the present disclosure.

[0021] **FIG. 6** is a side cross-sectional view of the MEWT of **FIG. 5** taken through the turbine axis.

[0022] **FIG. 7** is a smaller view of **FIG. 6**.

[0023] **FIG. 7A** and **FIG. 7B** are magnified views of the mixing lobes of the MEWT of **FIG. 7**.

[0024] **FIG. 8** is a cutaway view of another exemplary embodiment of a MEWT showing the static ring portion of a ring generator.

[0025] **FIG. 9** is a cutaway view of another exemplary embodiment of a MEWT showing the rotor portion of a ring generator.

[0026] **FIG. 10** is a closeup view of the static ring portion of a ring generator having three phase windings.

[0027] **FIG. 11** is the front view of an exemplary static ring.

[0028] **FIG. 12** is the side view of an exemplary static ring.

[0029] **FIG. 13** is the front view of an exemplary rotor.

[0030] **FIG. 14** is the side view of an exemplary rotor.

[0031] **FIG. 15** is a closeup view showing the rotor and the static ring of a ring generator in relation to each other.

DETAILED DESCRIPTION

[0032] A more complete understanding of the components, processes, and apparatuses disclosed herein can be obtained by reference to the accompanying figures. These figures are merely schematic representations based on convenience and the ease of demonstrating the present development and are, therefore, not intended to indicate the relative size and dimensions of the devices or components thereof and/or to define or limit the scope of the exemplary embodiments.

[0033] Although specific terms are used in the following description for the sake of clarity, these terms are intended to refer only to the particular structure of the embodiments selected for illustration in the drawings and are not intended to define or limit the scope of the disclosure. In the drawings and the following description below, it is to be understood that like numeric designations refer to components of like function.

[0034] The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (for example, it includes at least the degree of error associated with the measurement of the particular quantity). When used in the context of a range, the modifier "about" should also be considered as disclosing the range defined by the absolute values of the two endpoints. For example, the range "from about 2 to about 4" also discloses the range "from 2 to 4."

[0035] A Mixer-Ejector Power System (MEPS) provides a unique and improved means of generating power from wind currents. A MEPS includes:

- a primary shroud containing a turbine or bladed impeller, similar to a propeller, which extracts power from the primary stream; and
- a single or multiple-stage mixer-ejector to ingest flow with each such mixer/ejector stage including a mixing duct for both bringing in secondary flow and providing flow mixing-length for the ejector stage. The inlet contours of the mixing duct or shroud are designed to minimize flow losses while providing the pressure forces necessary for good ejector performance.

[0036] The resulting mixer/ejectors enhance the operational characteristics of the power system by: (a) increasing the amount of flow through the system, (b) reducing the exit or back pressure on the turbine blades, and (c) reducing the noise propagating from the system.

[0037] The MEPS may include:

- camber to the duct profiles to enhance the amount of flow into and through the system;
- acoustical treatment in the primary and mixing ducts for noise abatement flow guide vanes in the primary duct for control of flow swirl and/or mixer-lobes tailored to diminish flow swirl effects;
- turbine-like blade aerodynamics designs based on the new theoretical power limits to develop families of short, structurally robust configurations which may have multiple and/or counter-rotating rows of blades;
- exit diffusers or nozzles on the mixing duct to further improve performance of the overall system;
- inlet and outlet areas that are non-circular in cross section to accommodate installation limitations;
- a swivel joint on its lower outer surface for mounting on a vertical stand/pylon allowing for turning the system into the wind;
- vertical aerodynamic stabilizer vanes mounted on the exterior of the ducts with tabs or vanes to keep the system pointed into the wind; or
- mixer lobes on a single stage of a multi-stage ejector system.

[0038] Referring to the drawings in detail, the figures illustrate alternate embodiments of Applicants' axial flow Wind Turbine with Mixers and Ejectors ("MEWT").

[0039] Referring to **FIG. 1** and **FIG. 2**, the MEWT **100** is an axial flow turbine with:

a) an aerodynamically contoured turbine shroud **102**;

b) an aerodynamically contoured center body **103** within and attached to the turbine shroud **102**;

c) a turbine stage **104**, surrounding the center body **103**, comprising a stator ring **106** having stator vanes **108a** and a rotor **110** having rotor blades **112a**. Rotor **110** is downstream and "in-line" with the stator vanes, i.e., the leading edges of the impeller blades are substantially aligned with trailing edges of the stator vanes, in which:

i) the stator vanes **108a** are mounted on the center body **103**;

ii) the rotor blades **112a** are attached and held together by inner and outer rings or hoops mounted on the center body **103**;

d) a mixer indicated generally at **118** having a ring of mixer lobes **120a** on a terminus region (i.e., end portion) of the turbine shroud **102**, wherein the mixer lobes **120a** extend downstream beyond the rotor blades **112a**; and,

e) an ejector indicated generally at **122** comprising an ejector shroud **128**, surrounding the ring of mixer lobes **120a** on the turbine shroud, wherein the mixer lobes (e.g., **120a**) extend downstream and into an inlet **129** of the ejector shroud **128**.

[0040] The center body **103** of MEWT **100**, as shown in **FIG. 2**, is desirably connected to the turbine shroud **102** through the stator ring **106**, or other means. This construction serves to eliminate the damaging, annoying and long distance propagating low-frequency sound produced by traditional wind turbines as the wake from the turbine blades strike the support tower. The aerodynamic profiles of the turbine shroud **102** and ejector shroud **128** are aerodynamically cambered to increase flow through the turbine rotor.

[0041] Applicants have calculated, for optimum efficiency, the area ratio of the ejector pump **122**, as defined by the ejector shroud **128** exit area over the turbine shroud **102** exit area, will be in the range of 1.5-3.0. The number of mixer lobes **120a** would be between 6 and 14. Each lobe will have inner and outer trailing edge angles between 5 and 65 degrees. These angles are measured from a tangent line

that is drawn at the exit of the mixing lobe down to a line that is parallel to the center axis of the turbine, as will be explained further herein. The primary lobe exit location will be at, or near, the entrance location or inlet **129** of the ejector shroud **128**. The height-to-width ratio of the lobe channels will be between 0.5 and 4.5. The mixer penetration will be between 50% and 80%. The center body **103** plug trailing edge angles will be thirty degrees or less. The length to diameter (L/D) of the overall MEWT **100** will be between 0.5 and 1.25.

[0042] First-principles-based theoretical analysis of the preferred MEWT **100**, performed by Applicants, indicate the MEWT can produce three or more times the power of its un-shrouded counterparts for the same frontal area; and, the MEWT **100** can increase the productivity of wind farms by a factor of two or more. Based on this theoretical analysis, it is believed the MEWT embodiment **100** will generate three times the existing power of the same size conventional open blade wind turbine.

[0043] A satisfactory embodiment **100** of the MEWT comprises: an axial flow turbine (e.g., stator vanes and impeller blades) surrounded by an aerodynamically contoured turbine shroud **102** incorporating mixing devices in its terminus region (i.e., end portion); and a separate ejector shroud **128** overlapping, but aft, of turbine shroud **102**, which itself may incorporate mixer lobes in its terminus region. The ring **118** of mixer lobes **120a** combined with the ejector shroud **128** can be thought of as a mixer/ejector pump. This mixer/ejector pump provides the means for consistently exceeding the Betz limit for operational efficiency of the wind turbine. The stator vanes' exit-angle incidence may be mechanically varied in situ (i.e., the vanes are pivoted) to accommodate variations in the fluid stream velocity so as to assure minimum residual swirl in the flow exiting the rotor.

[0044] Described differently, the MEWT **100** comprises a turbine stage **104** with a stator ring **106** and a rotor **110** mounted on center body **103**, surrounded by turbine shroud **102** with embedded mixer lobes **120a** having trailing edges inserted slightly in the entrance plane of ejector shroud **128**. The turbine stage **104** and ejector shroud **128** are structurally connected to the turbine shroud **102**, which is the principal load carrying member.

[0045] These figures depict a rotor/stator assembly for generating power. The term "impeller" is used herein to refer generally to any assembly in which blades are attached to a shaft and able to rotate, allowing for the generation of power or energy from wind rotating the blades. Exemplary impellers include a propeller or a

rotor/stator assembly. Any type of impeller may be enclosed within the turbine shroud **102** in the wind turbine of the present disclosure.

[0046] In some embodiments, the length of the turbine shroud **102** is equal or less than the turbine shroud's outer maximum diameter. Also, the length of the ejector shroud **128** is equal or less than the ejector shroud's outer maximum diameter. The exterior surface of the center body **103** is aerodynamically contoured to minimize the effects of flow separation downstream of the MEWT **100**. It may be configured to be longer or shorter than the turbine shroud **102** or the ejector shroud **128**, or their combined lengths.

[0047] The turbine shroud's entrance area and exit area will be equal to or greater than that of the annulus occupied by the turbine stage **104**, but need not be circular in shape so as to allow better control of the flow source and impact of its wake. The internal flow path cross-sectional area formed by the annulus between the center body **103** and the interior surface of the turbine shroud **102** is aerodynamically shaped to have a minimum area at the plane of the turbine and to otherwise vary smoothly from their respective entrance planes to their exit planes. The turbine and ejector shrouds' external surfaces are aerodynamically shaped to assist guiding the flow into the turbine shroud inlet, eliminating flow separation from their surfaces, and delivering smooth flow into the ejector entrance **129**. The ejector **128** entrance area, which may alternatively be noncircular in shape, is greater than the mixer **118** exit plane area; and the ejector's exit area may also be noncircular in shape if desired.

[0048] Optional features of the preferred embodiment **100** can include: a power take-off, in the form of a wheel-like structure, which is mechanically linked at an outer rim of the impeller to a power generator; a vertical support shaft with a rotatable coupling for rotatably supporting the MEWT, the shaft being located forward of the center-of-pressure location on the MEWT for self-aligning the MEWT; and a self-moving vertical stabilizer fin or "wing-tab" affixed to upper and lower surfaces of the ejector shroud to stabilize alignment directions with different wind streams.

[0049] The MEWT **100**, when used near residences can have sound absorbing material affixed to the inner surface of its shrouds **102**, **128** to absorb and thus eliminate the relatively high frequency sound waves produced by the interaction of the stator **106** wakes with the rotor **110**. The MEWT **100** can also contain blade containment structures for added safety. The MEWT should be considered to be a horizontal axis wind turbine as well.

[0050] **FIG. 3** and **FIG. 4** show a second exemplary embodiment of a shrouded wind turbine **200**. The turbine **200** uses a propeller-type impeller **142** instead of the rotor/stator assembly used in **FIG. 1** and **FIG. 2**. In addition, the mixing lobes can be more clearly seen in this embodiment. The turbine shroud **210** has two different sets of mixing lobes. Referring to **FIG. 3** and **FIG. 4**, the turbine shroud **210** has a set of high energy mixing lobes **212** that extend inwards toward the central axis of the turbine. In this embodiment, the turbine shroud is shown as having 10 high energy mixing lobes. The turbine shroud also has a set of low energy mixing lobes **214** that extend outwards away from the central axis. Again, the turbine shroud **210** is shown with 10 low energy mixing lobes. The high energy mixing lobes alternate with the low energy mixing lobes around the trailing edge of the turbine shroud **210**. The impeller **142**, turbine shroud **210**, and ejector shroud **230** are coaxial with each other, i.e. they share a common central axis.

[0051] From the rear, as seen in **FIG. 4**, the trailing edge of the turbine shroud may be considered as having a circular crenellated shape.

[0052] The trailing edge **250** can be considered as including several inner circumferentially spaced arcuate portions **252** which each have the same radius of curvature. Those inner arcuate portions are preferably evenly spaced apart from each other. In those spaces between portions **252** are several outer arcuate portions **254**, which each have the same radius of curvature. The radius of curvature for the inner arcuate portions is different from the radius of curvature for the outer arcuate portions **254,** but the inner arcuate portions and outer arcuate portions should share generally the same center (i.e. along the central axis). The inner portions **252** and the outer arcuate portions **254** are then connected to each other by radially extending portions **256**. This results in a circular crenellated shape. The term “crenellated” or "castellated" are not used herein as requiring the inner arcuate portions, outer arcuate portions, and radially extending portions to be straight lines, but rather to refer to the general up-and-down or in-and-out shape of the trailing edge **250**. This crenellated structure forms two sets of mixing lobes, high energy mixing lobes **212** and low energy mixing lobes **214**.

[0053] The entrance area **232** of the ejector shroud **230** is larger than the exit area **234** of the ejector shroud. It will be understood that the entrance area refers to the entire mouth of the ejector shroud and not the annular area of the ejector shroud between the ejector shroud **230** and the turbine shroud **210**. However, as seen

further herein, the entrance area of the ejector shroud may also be smaller than the exit area **234** of the ejector shroud. As expected, the entrance area **232** of the ejector shroud **230** is larger than the exit area **218** of the turbine shroud **210**, in order to accommodate the mixing lobes and to create an annular area **238** between the turbine shroud and the ejector shroud through which high energy air can enter the ejector.

[0054] As shown here, mixing lobes are present on the turbine shroud. If desired, mixing lobes may also be formed on a trailing edge of the ejector shroud.

[0055] The mixer-ejector design concepts described herein can significantly enhance fluid dynamic performance. These mixer-ejector systems provide numerous advantages over conventional systems, such as: shorter ejector lengths; increased mass flow into and through the system; lower sensitivity to inlet flow blockage and/or misalignment with the principal flow direction; reduced aerodynamic noise; added thrust; and increased suction pressure at the primary exit.

[0056] **FIGS. 5-7** illustrate another exemplary embodiment of a MEWT. The MEWT **300** in **FIG. 5** has a stator **308a** and rotor **310** configuration for power extraction. A turbine shroud **302** surrounds the rotor **310** and is supported by or connected to the blades or spokes of the stator **308a**. The turbine shroud **302** has the cross-sectional shape of an airfoil with the suction side (i.e. low pressure side) on the interior of the shroud. An ejector shroud **328** is coaxial with the turbine shroud **302** and is supported by connector members **305** extending between the two shrouds. An annular area is thus formed between the two shrouds. The rear or downstream end of the turbine shroud **302** is shaped to form two different sets of mixing lobes **318**, **320**. High energy mixing lobes **318** extend inwardly towards the central axis of the mixer shroud **302**; and low energy mixing lobes **320** extend outwardly away from the central axis.

[0057] Free stream air indicated generally by arrow **306** passing through the stator **308a** has its energy extracted by the rotor **310**. High energy air indicated by arrow **329** bypasses the shroud **302** and stator **308a** and flows over the turbine shroud **302** and directed inwardly by the high energy mixing lobes **318**. The low energy mixing lobes **320** cause the low energy air exiting downstream from the rotor **310** to be mixed with the high energy air **329**.

[0058] Referring to **FIG. 6**, the center nacelle **303** and the trailing edges of the low energy mixing lobes **320** and the trailing edge of the high energy mixing lobes **318**

are shown in the axial cross-sectional view of the turbine of **FIG. 5**. The ejector shroud **328** is used to direct inwardly or draw in the high energy air **329**. Optionally, nacelle **303** may be formed with a central axial passage therethrough to reduce the mass of the nacelle and to provide additional high energy turbine bypass flow.

[0059] In **FIG. 7A**, a tangent line **352** is drawn along the interior trailing edge indicated generally at **357** of the high energy mixing lobe **318**. A rear plane **351** of the turbine shroud **302** is present. A line **350** is formed normal to the rear plane **351** and tangent to the point where a low energy mixing lobe **320** and a high energy mixing lobe **318** meet. An angle $\emptyset_2$ is formed by the intersection of tangent line **352** and line **350**. This angle $\emptyset_2$ is between 5 and 65 degrees. Put another way, a high energy mixing lobe **318** forms an angle $\emptyset_2$ between 5 and 65 degrees relative to the turbine shroud **302**.

[0060] In **FIG. 7B**, a tangent line **354** is drawn along the interior trailing edge indicated generally at **355** of the low energy mixing lobe **320**. An angle $\emptyset$ is formed by the intersection of tangent line **354** and line **350**. This angle $\emptyset$ is between 5 and 65 degrees. Put another way, a low energy mixing lobe **320** forms an angle $\emptyset$ between 5 and 65 degrees relative to the turbine shroud **302**.

[0061] The leading edge of the turbine shroud may be considered the front of the wind turbine, and the trailing edge of the ejector shroud may be considered the rear of the wind turbine. A first component of the wind turbine located closer to the front of the turbine may be considered "upstream" of a second component located closer to the rear of the turbine. Put another way, the second component is "downstream" of the first component.

[0062] The shrouded wind turbine of the present disclosure uses a ring generator to capture energy from wind. Essentially, moving magnets are used to generate current in a stationary phase winding. The magnets of the present disclosure are permanent magnets arranged to form a Halbach array. A Halbach array is an arrangement of permanent magnets that increases the magnetic field on one side of the array and cancels the magnetic field on the opposite side of the array to near zero. The Halbach array of magnets can be arranged into a cylindrical form, with the increased magnetic field on the interior or the exterior of the cylinder. This form of a Halbach array is also referred to as a Halbach cylinder. The Halbach cylinder of the present disclosure is arranged so that the magnetic field is on the exterior of the cylinder, as will be further explained herein.

[0063] Referring now to **FIGs. 8-15**, a shrouded wind turbine **400** is shown that uses a ring generator. The turbine **400** comprises a mixer shroud **402** and an ejector shroud **404**. The mixer shroud **402** encloses a rotor/stator assembly **406**. Stator vanes **408** run between the mixer shroud **402** and a nacelle or center body **403**. Attachment struts **410** join or connect the mixer shroud **402** with the ejector shroud **404**.

[0064] **FIG. 8** shows a static ring **430** that is mounted on or within the mixer shroud **402**. The static ring is made up of one or more phase windings **432**.

[0065] In **FIG. 9**, part of the static ring is removed to expose permanent magnet arrays **440** which are mounted on the rotor **420**. As the rotor rotates, a constant rotating magnetic field is produced by the magnet arrays **440**. This magnetic field induces an alternating current (AC) voltage in the phase windings **432** to produce electrical energy which can be captured. One advantage of the permanent ring generator is that it does not need an initial injection of power in order to begin producing electricity.

[0066] It should be noted that in the field of electric motors, the word "stator" is used to refer to the stationary portion of a rotor/stator system. The phrase "static ring" is used here to reduce any confusion between the stationary portion **430** of the power generation system in the wind turbine and the stationary vane **408** that direct air against the rotor **420**.

[0067] **FIG. 9A** is an enlarged view of some permanent magnets **445**. On each magnet is an arrow showing the orientation of the magnetic field. The magnets are arranged in a Halbach array, so that the magnetic field exterior or outside of the rotor (indicated by reference numeral **447**) is enhanced, while the magnetic field interior to or inside of the rotor (indicated by reference numeral **449**) is decreased to near zero.

[0068] **FIG. 10** is an enlarged view of the static ring showing the phase windings **432**. Each phase winding is comprised of a series of coils. In particular embodiments such as that depicted here, the stator has three phase windings **432**, **434**, **436** connected in series for producing three-phase electric power. Each winding contains 40 wound coils in series spaced by nine degrees, so that the combination of three phase windings covers the 360° circumference of the stator. **FIG. 11** and **FIG. 12** show the assembled stator **430** from the front and side, respectively.

[0069] Referring now to **FIG. 13** and **FIG. 14**, the rotor **450** contains a central ring **460** and an outer ring **470**. Rotor blades **480** extend between the central ring **460** and the outer ring **470**, connecting them together. Referring back to **FIG. 9**, the center body **403** extends through the central ring **460** to support the rotor **450** and fix its location relative to the mixer shroud **402**.

[0070] A plurality of permanent magnet arrays **440** is located on the outer ring **470**. The magnets are generally evenly distributed around the circumference of the rotor and along the outer ring **470**. As seen in **FIG. 14**, in embodiments the magnet arrays are located along a rear end **472** of the outer ring. The magnet arrays are arranged to form a Halbach cylinder, i.e. with the magnetic field exterior to the outer ring. The magnets **440** are separated by potting material **442** which secures the magnets to the rotor **450**. It should be noted that while the overall magnetic field created by the Halbach cylinder is on the exterior of the rotor, the magnetic field itself is generated by a combination of flux lines that alternate in direction, resulting in a magnetic field that can induce AC voltage in the phase windings. Electrical current is generated in the phase windings due to the alternating magnetic field. Because the strength of the generated current is proportional to the magnitude of the magnetic field, the arrangement of the magnets into a Halbach array increases the amount of electrical current generated per rotation of the rotor.

[0071] **FIG. 15** is an enlarged view showing the rotor **450** and static ring **430** and their relationship to each other. The rotor and static ring are aligned with each other. Put another way, if a radial line is drawn from the central axis of the wind turbine, the rotor and the static ring will be on the same radial line.

[0072] Permanent magnets are made from magnetized materials which create their own persistent magnetic field. Exemplary magnetic materials are ferromagnetic and ferromagnetic materials including iron, nickel, cobalt, rare earth metals, and lodestone. Permanent magnets are distinguished from electromagnets which are made up of a wire coil through which an electric current passes to create a magnetic effect.

[0073] In some embodiments, the permanent magnets comprise a rare earth metal selected from the group consisting of lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. The rare earth metal magnets

may comprise neodymium-iron-boron material such as $Nd_2Fe_{14}B$ or a samarium-cobalt material such as $SmCo_5$ or $SmCo_7$.

[0074] The present disclosure has been described with reference to exemplary embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the present disclosure be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A wind turbine comprising:

a turbine shroud enclosing an impeller;

wherein the turbine shroud includes a static ring that has at least one phase winding;

wherein the impeller comprises a rotor, the rotor having a central ring, an outer ring, a plurality of rotor blades extending between the central ring and the outer ring, and a plurality of permanent magnets on the outer ring;

wherein the static ring and the outer ring are aligned with each other; and

wherein the plurality of permanents magnets are arranged on the outer ring to form a Halbach cylinder that produces a magnetic field exterior to the rotor.

2. The wind turbine of claim 1, wherein the turbine shroud further comprises a ring of mixing lobes formed on a trailing edge.

3. The wind turbine of claim 1, wherein a trailing edge of the turbine shroud has a circular crenellated shape.

4. The wind turbine of claim 1, wherein the permanent magnets comprise a rare earth element.

5. The wind turbine of claim 1, wherein the permanent magnets are $Nd_2Fe_{14}B$ magnets.

6. The wind turbine of claim 1, wherein the static ring has three phase windings connected in series.

7. The wind turbine of claim 1, wherein the plurality of permanent magnets are located along a rear end of the outer ring.

8. The wind turbine of claim 1, further comprising an ejector shroud, an inlet end of the ejector shroud surrounding an outlet end of the turbine shroud.

9. The wind turbine of claim 1, further comprising a stator defining an inlet end of the wind turbine, the stator comprising a plurality of stator vanes.

10. A wind turbine comprising:

a turbine shroud enclosing an impeller;

wherein the turbine shroud includes a static ring that has at least one phase winding;

wherein the impeller comprises a stator and a rotor, the stator being upstream of the rotor and the rotor having a central ring, an outer ring, a plurality of rotor blades extending between the central ring and the outer ring, and a plurality of permanent magnets on the outer ring;

wherein the static ring and the outer ring are aligned with each other; and

wherein the plurality of permanents magnets are arranged on the outer ring to form a Halbach cylinder that produces a magnetic field exterior to the rotor; and

an ejector shroud, an inlet end of the ejector shroud surrounding an outlet end of the turbine shroud.

11. The wind turbine of claim 10, wherein the turbine shroud further comprises a ring of mixing lobes formed on a trailing edge, and wherein the ejector shroud has an airfoil shape.

12. The wind turbine of claim 10, wherein a trailing edge of the turbine shroud has a circular crenellated shape.

13. The wind turbine of claim 10, wherein the permanent magnets comprise a rare earth element.

14. The wind turbine of claim 10, wherein the permanent magnets are $Nd_2Fe_{14}B$ magnets.

15. The wind turbine of claim 10, wherein the static ring has three phase windings connected in series.

16. The wind turbine of claim 10, wherein the plurality of permanent magnets are located along a rear end of the outer ring.

17. A wind turbine comprising:

a turbine shroud enclosing an impeller;

wherein the turbine shroud encloses a static ring that has at least one phase winding and has a ring of mixing lobes formed on a trailing edge;

wherein the impeller comprises a stator and a rotor, the stator being upstream of the rotor and the rotor having a central ring, an outer ring, a plurality of rotor blades extending between the central ring and the outer ring, and a plurality of permanent magnets on the outer ring;

wherein the static ring and the outer ring are aligned with each other; and

wherein the plurality of permanents magnets are arranged on the outer ring to form a Halbach cylinder that produces a magnetic field exterior to the rotor; and

an ejector shroud having an airfoil shape, an inlet end of the ejector shroud surrounding an outlet end of the turbine shroud.

WO 2011/002979 PCT/US2010/040750

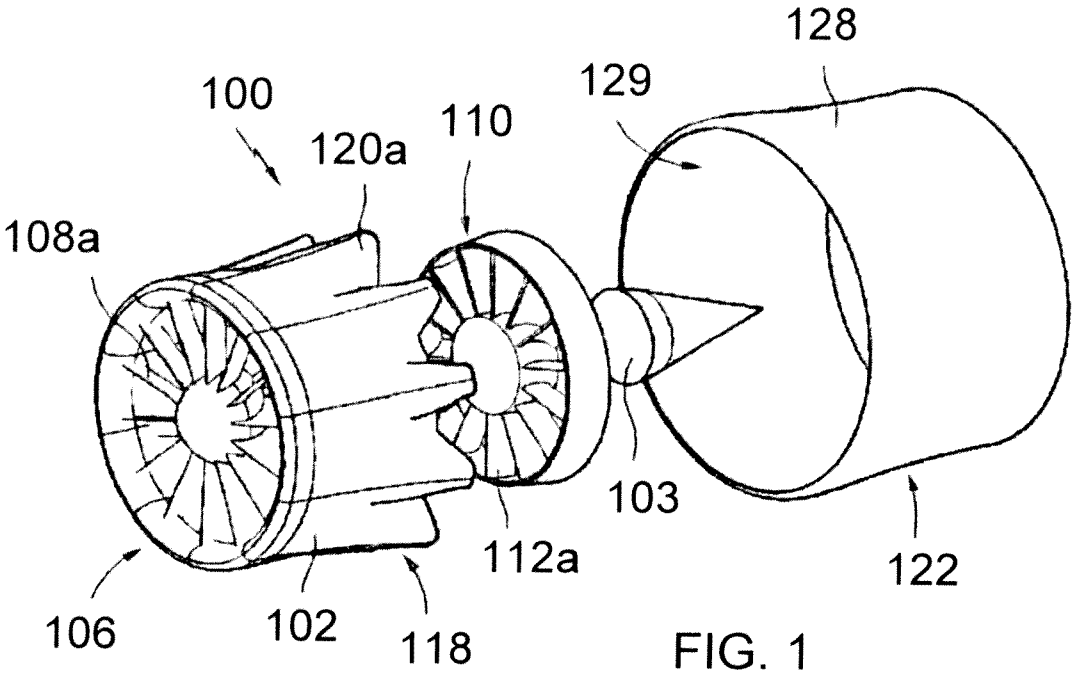


FIG. 1

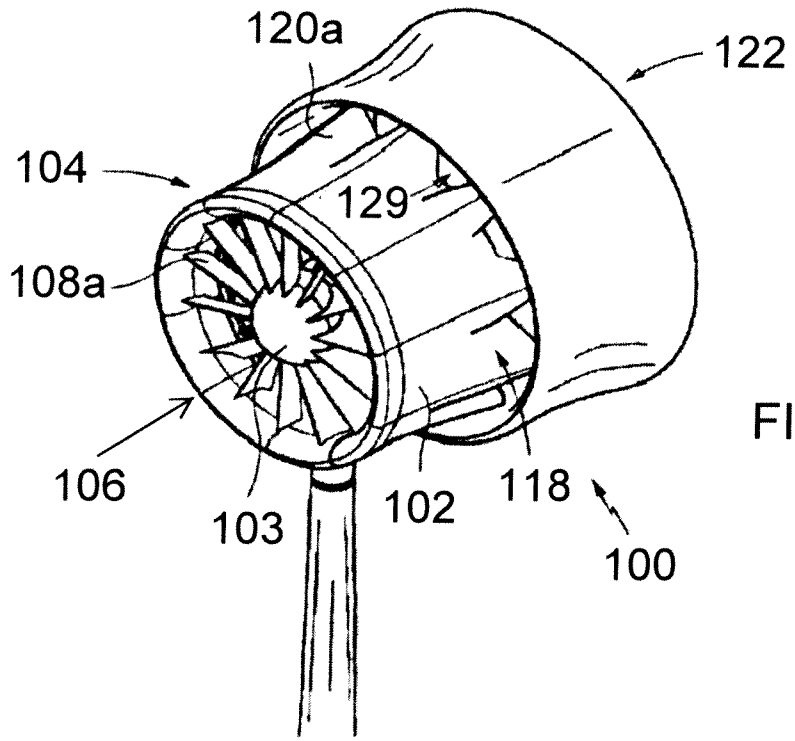


FIG. 2

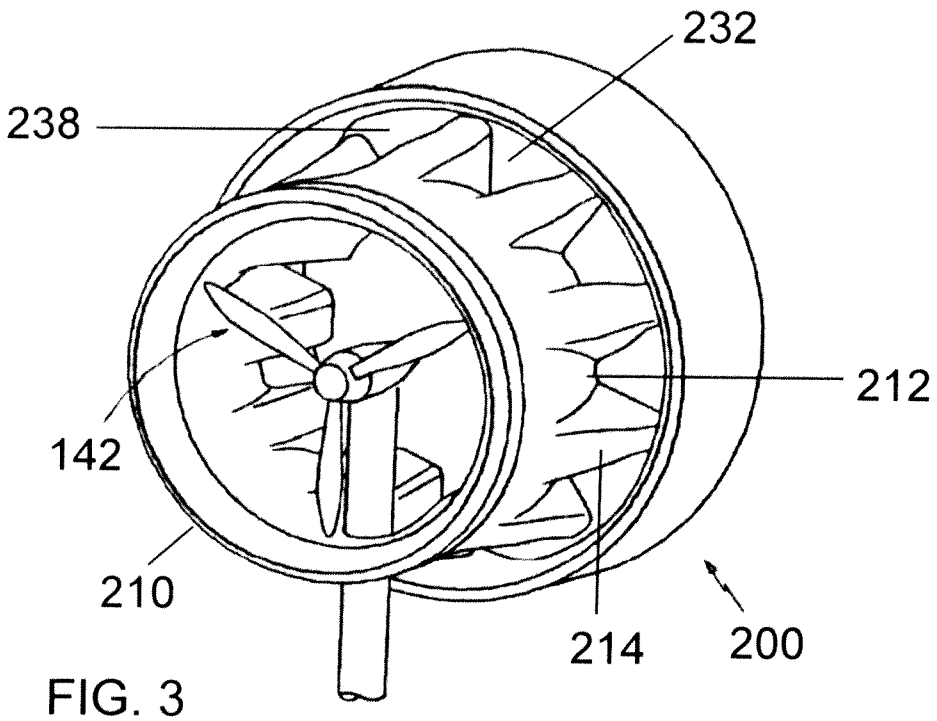


FIG. 3

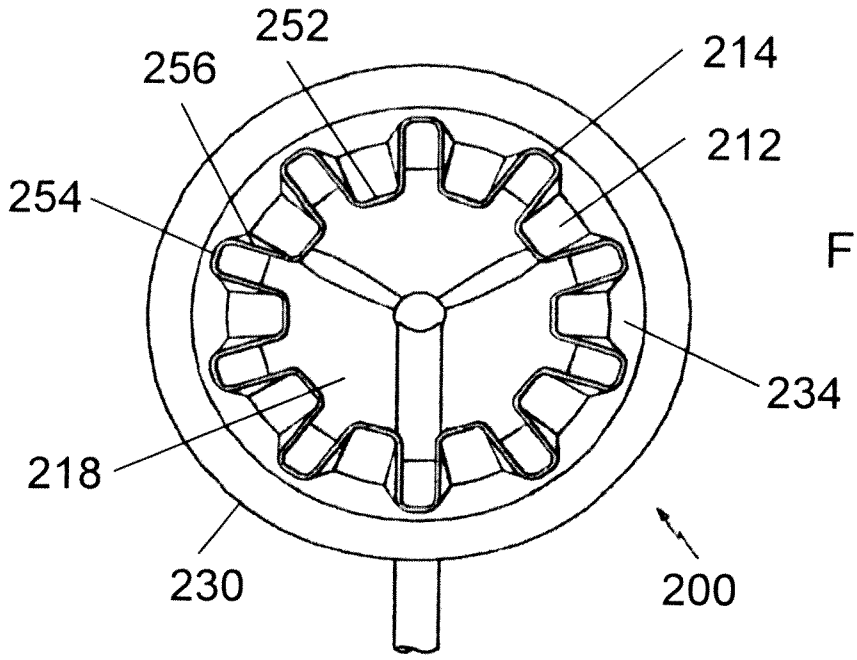


FIG. 4

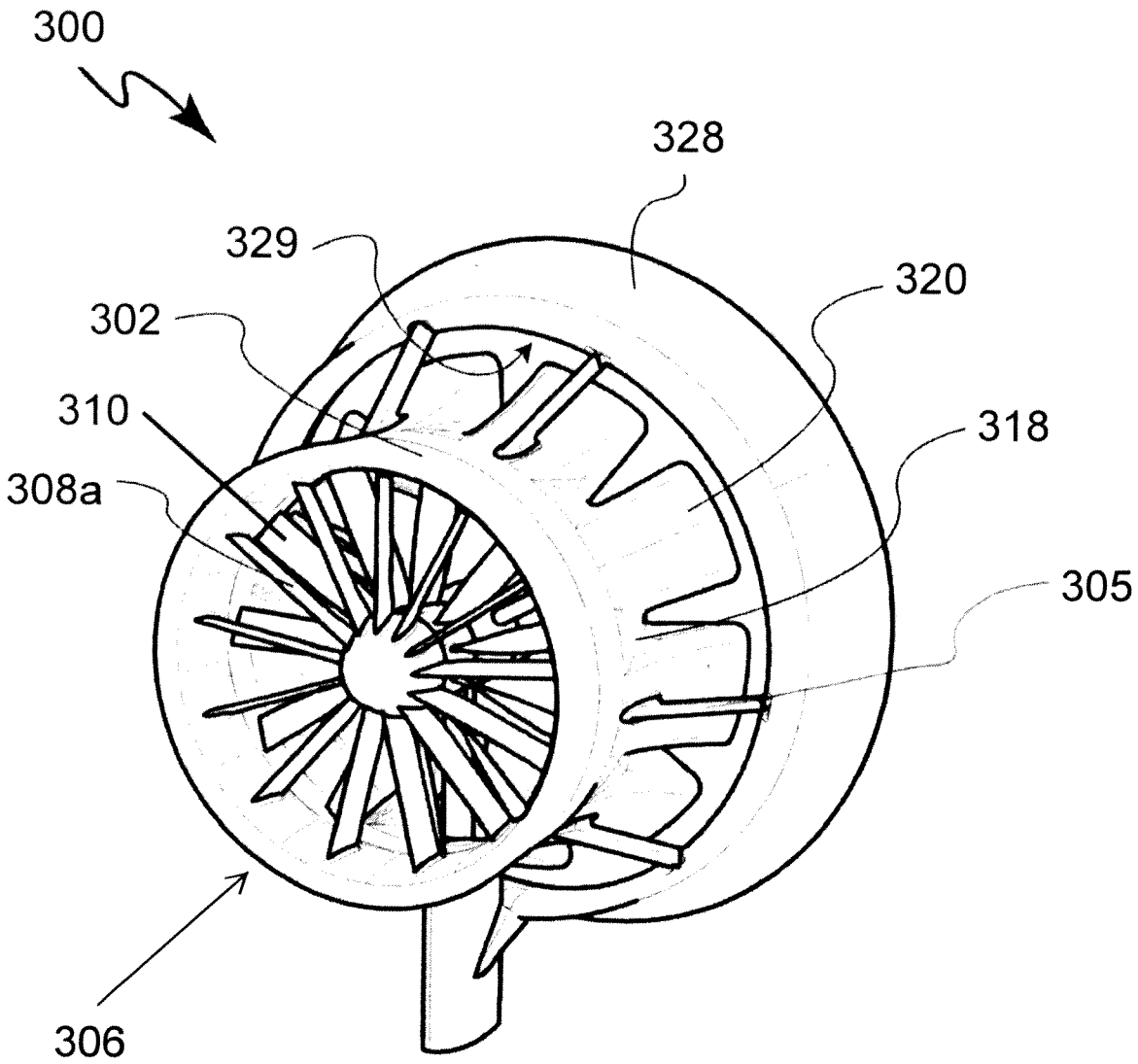


FIG. 5

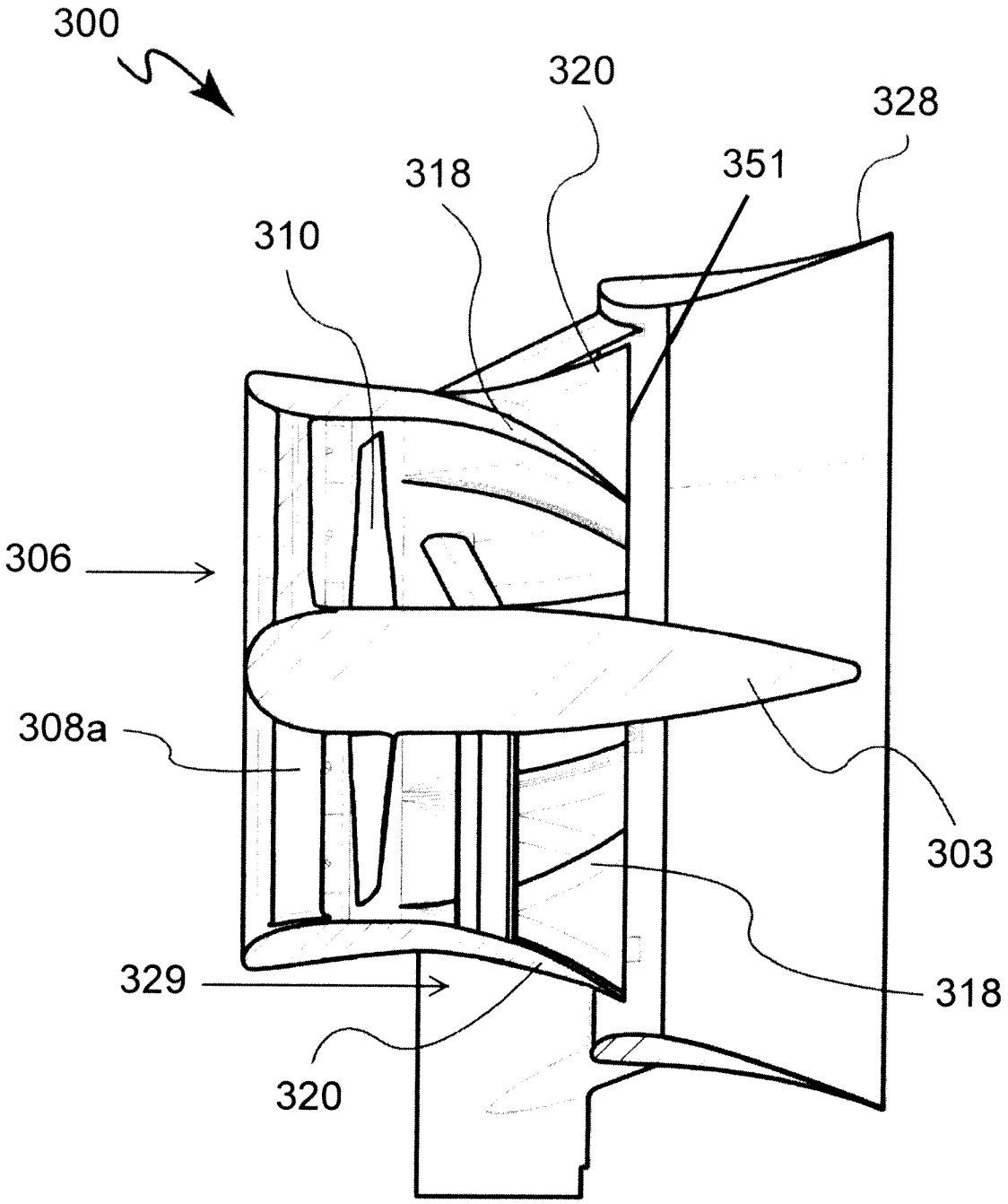


FIG. 6

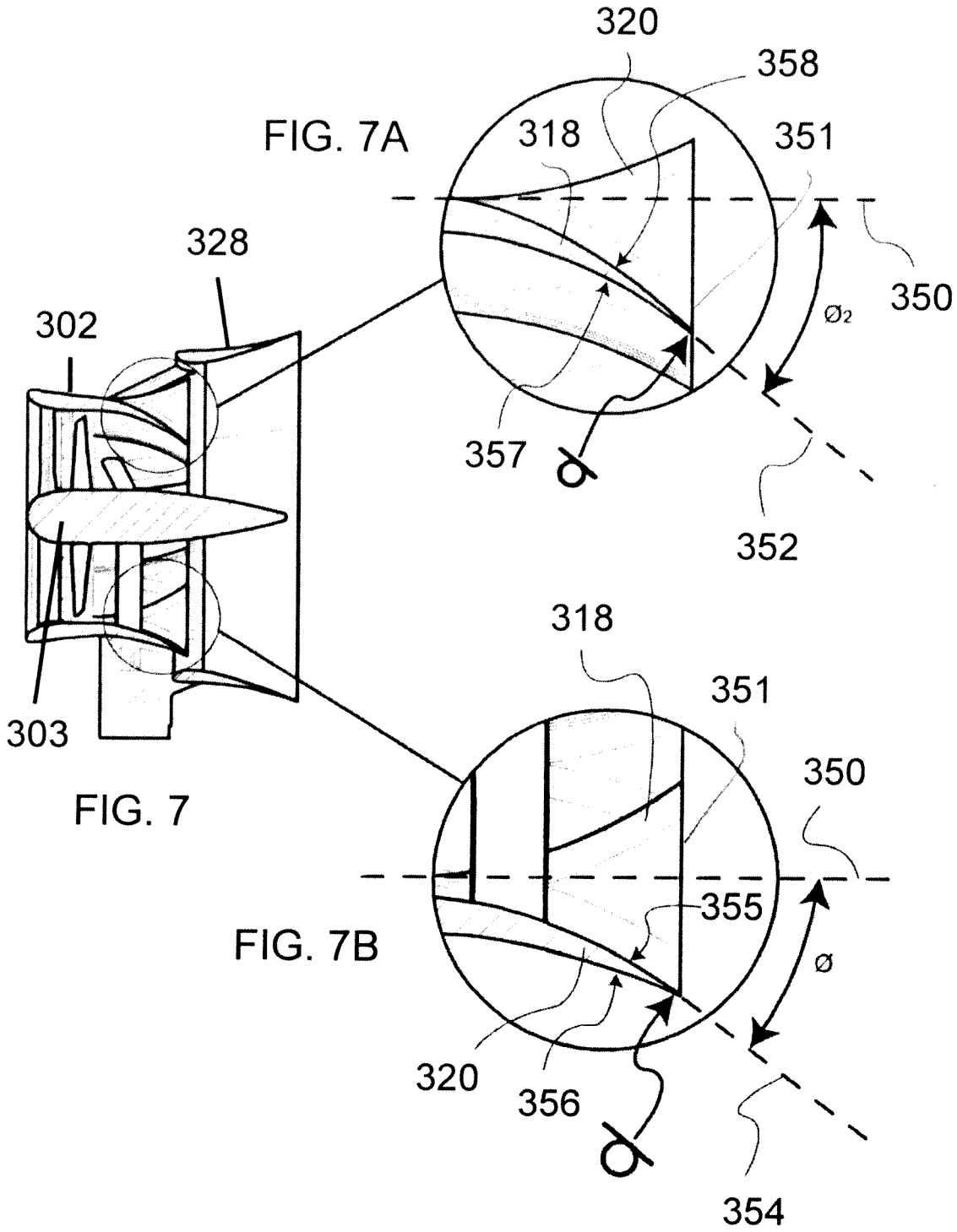


FIG. 7A

FIG. 7

FIG. 7B

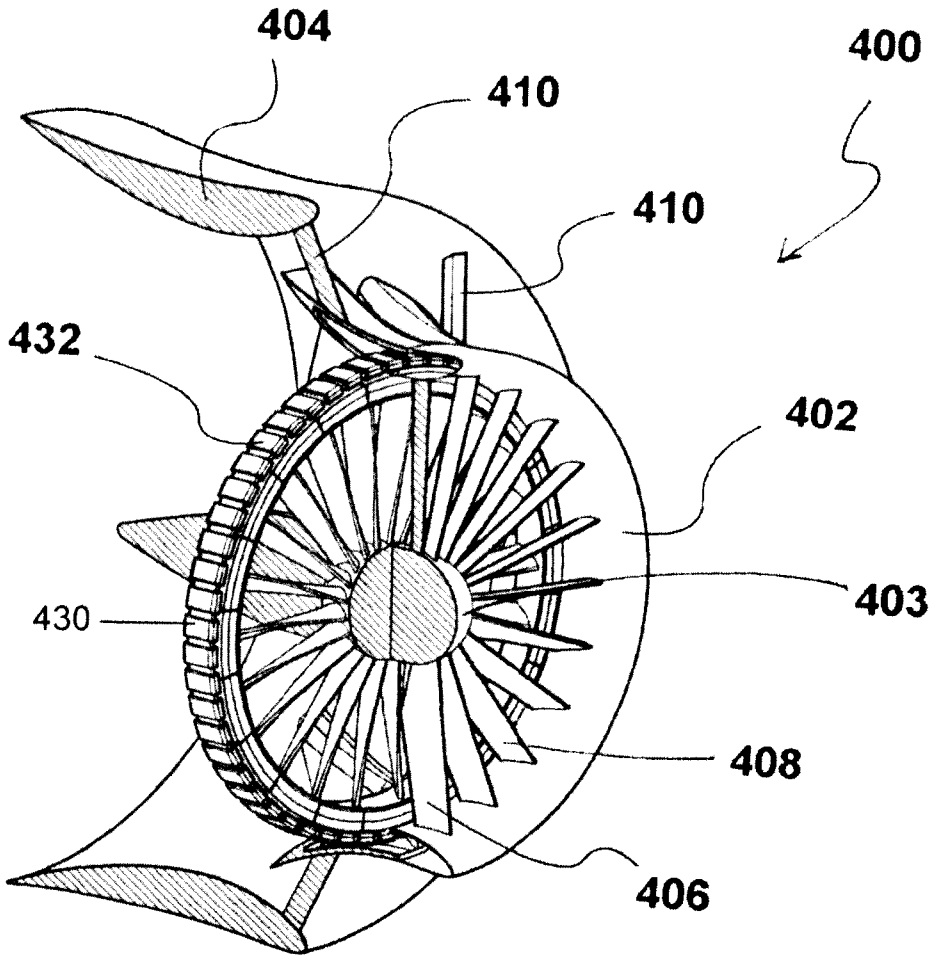


FIG. 8

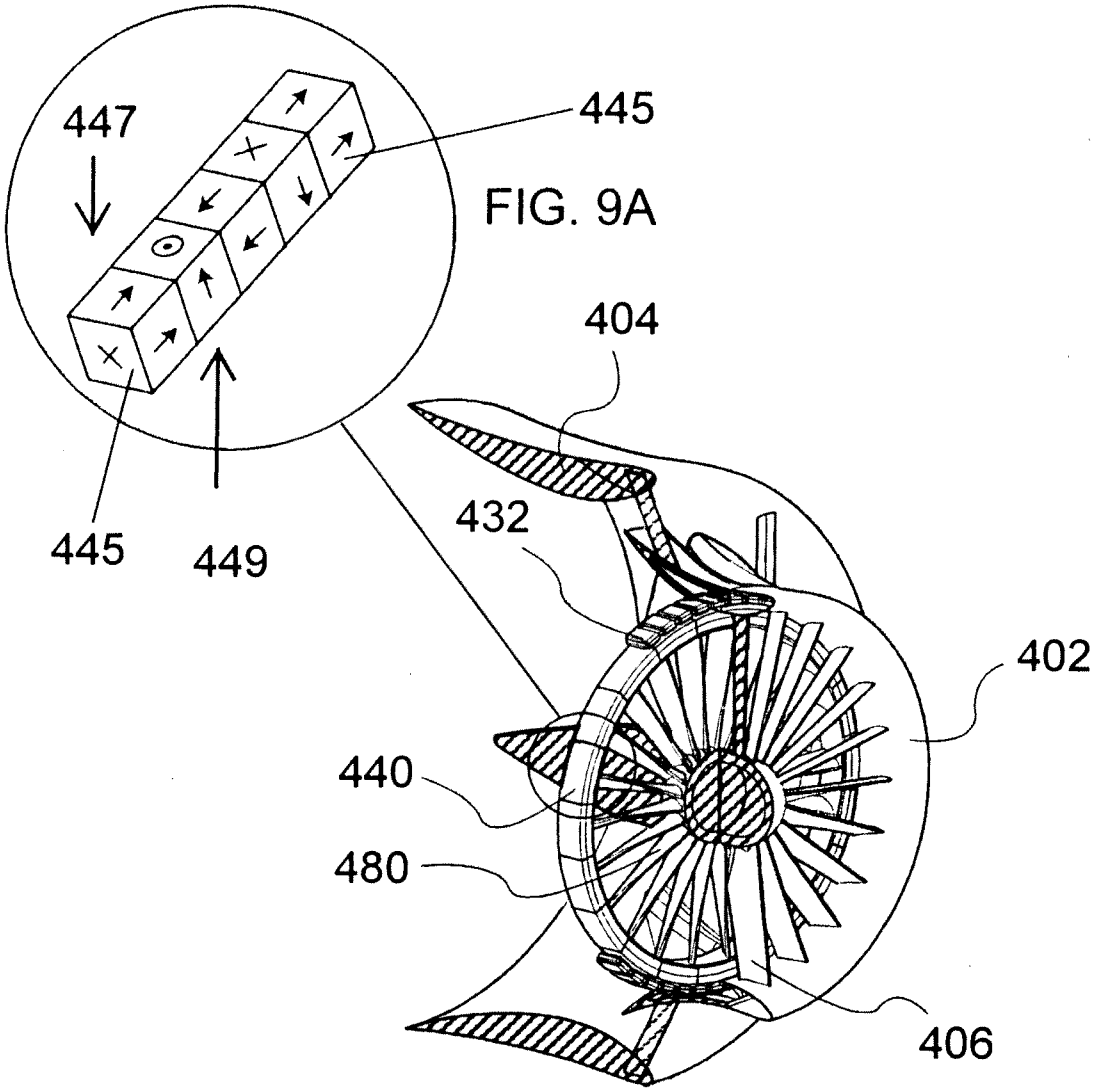


FIG. 9A

FIG. 9

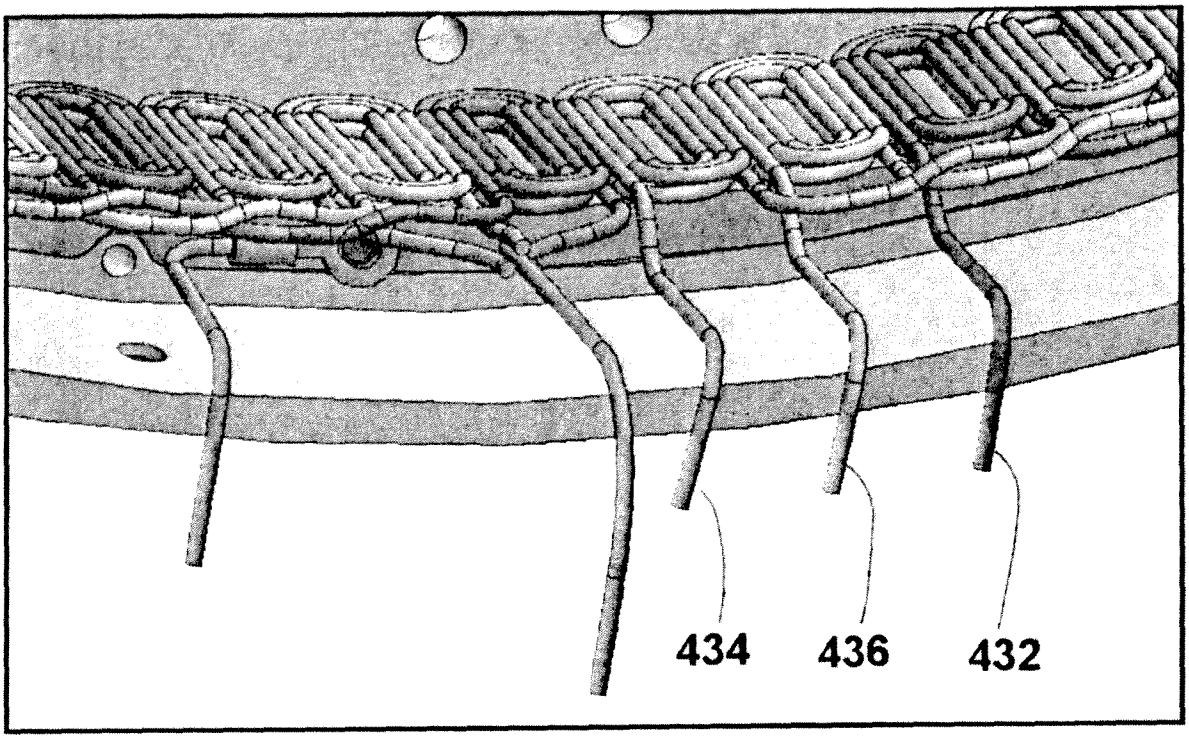


FIG. 10

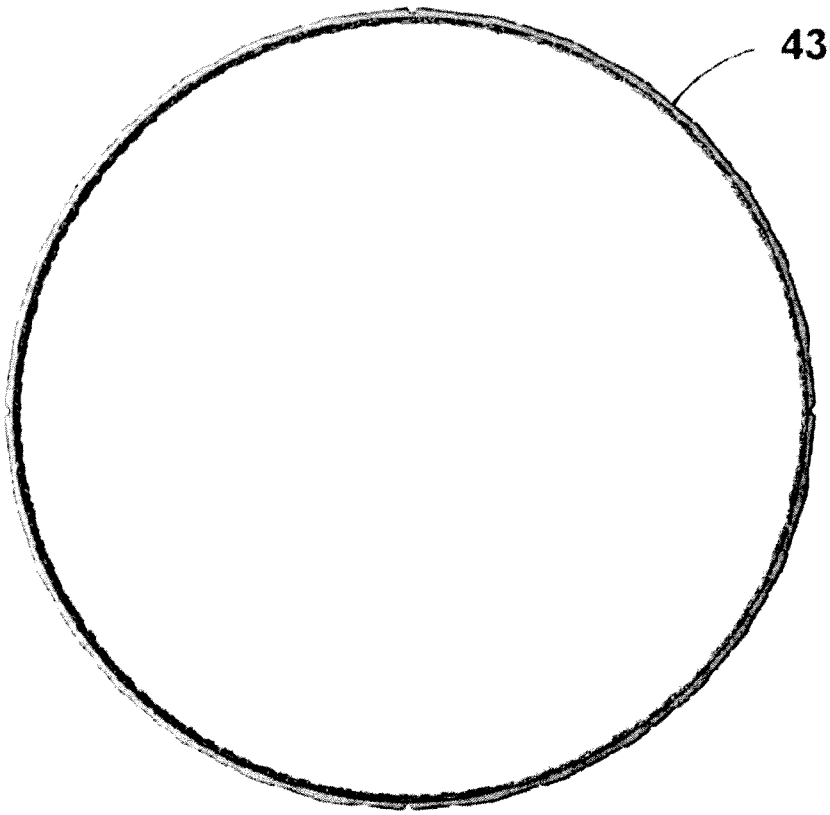


FIG. 11

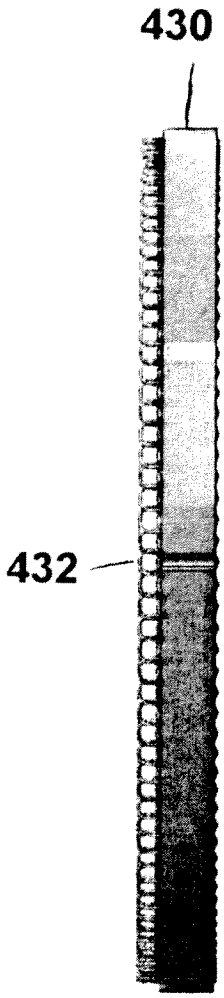


FIG. 12

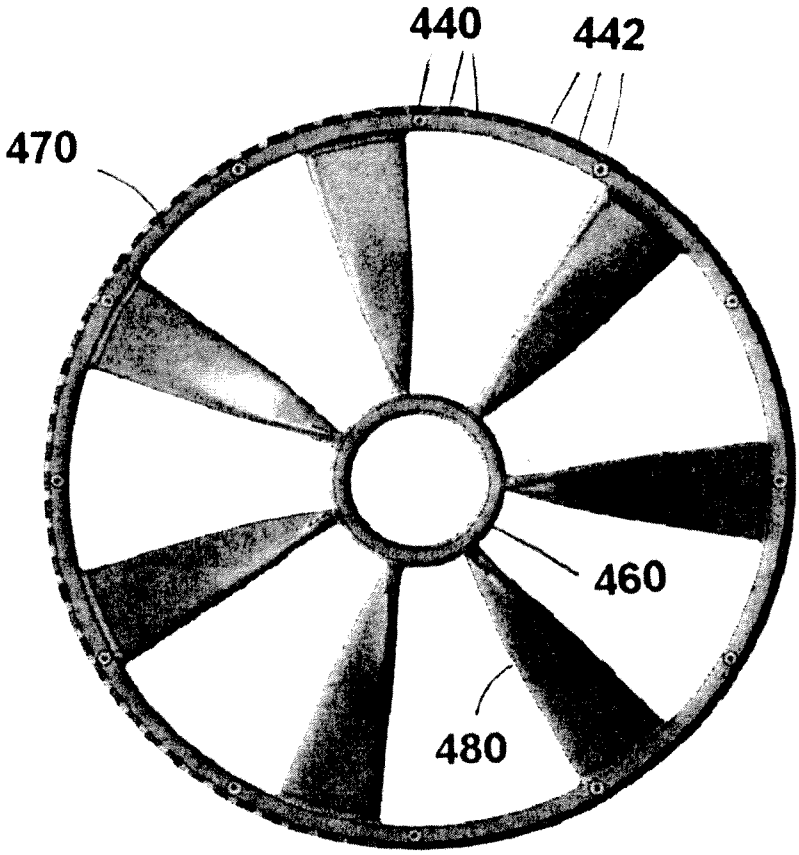


FIG. 13

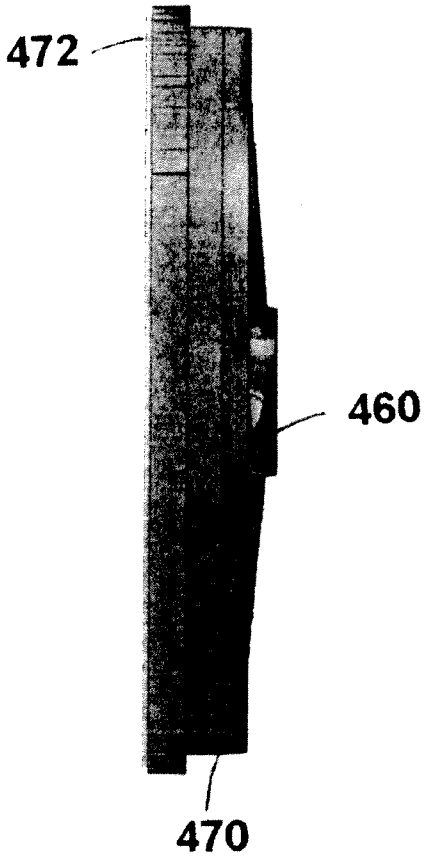


FIG. 14

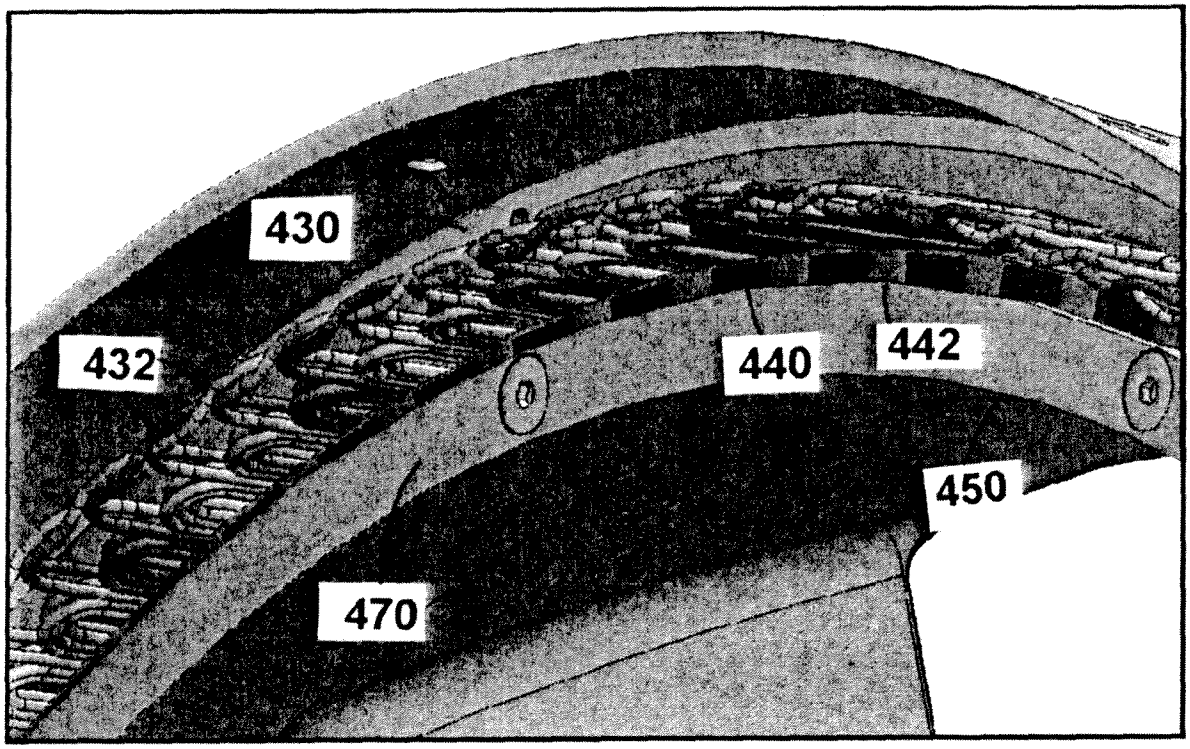


FIG. 15