(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 October 2010 (21.10.2010)

PCT

(10) International Publication Number
WO 2010/120487 A1

(51) International Patent Classification:
F03D 1/04 (2006.01)

(21) International Application Number:
PCT/US2010/029079

(22) International Filing Date:
29 March 2010 (29.03.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/425,358 16 April 2009 (16.04.2009) US
12/629,714 2 December 2009 (02.12.2009) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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(54) Title: WIND TURBINE

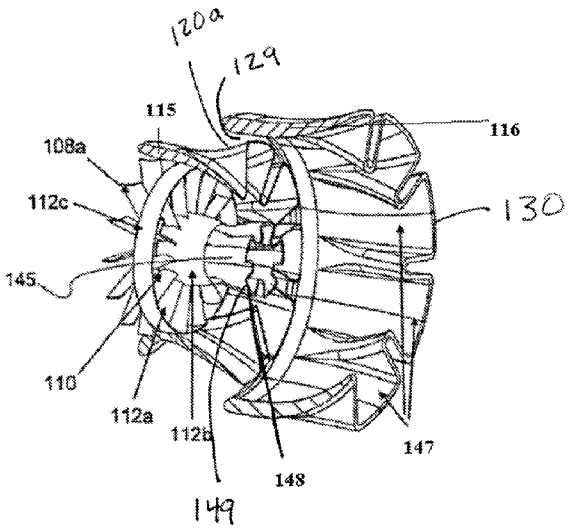


FIG. 5

(57) Abstract: A wind turbine comprises an impeller and a turbine shroud disposed about the impeller. The impeller surrounds a center body having a central passageway through which air can flow through the center body to bypass the impeller. The impeller comprises a central ring and a plurality of impeller blades extending therefrom. When air passes through the impeller blades, some of its energy is used to turn the blades. The reduced-energy air is then mixed with the air flowing through the central passageway. This mixing allows the operating efficiency of the turbines to routinely exceed the Betz limit.

WO 2010/120487 A1

Published:

— *with international search report (Art. 21(3))*

WIND TURBINE

BACKGROUND

[0001] This application is a continuation-in-part of U.S. Patent Application Serial No. 12/054,050, filed March 24, 2008, which claimed priority to U.S. Provisional Patent Application Serial No. 60/919,588, filed March 23, 2007. This application is also a continuation-in-part of U.S. Patent Application Serial No. 12/425,358, filed April 16, 2009, which is a continuation-in-part of U.S. Patent Application Serial No. 12/053,695, filed March 24, 2008, which claimed priority to U.S. Provisional Patent Application Serial No. 60/919,588, filed March 23, 2007. U.S. Patent Application Serial No. 12/425,358 also claimed priority to U.S. Provisional Patent Application Serial No. 61/124,397, filed April 16, 2008. This application is also a continuation-in-part of U.S. Patent Application Serial No. 12/629,714, filed December 2, 2009, which claimed priority to U.S. Provisional Patent Application Serial No. 61/119,078, filed December 2, 2008. The disclosure of these applications is fully incorporated by reference herein.

[0002] This present disclosure relates to wind turbines, such as axial flow wind turbines. In particular, the wind turbines include a rotor or impeller that surrounds a center body having an open central passageway (i.e. central aperture). The central passageway allows air to flow through the center body and bypass the rotor or impeller. This air is later mixed with other air streams to improve the efficiency of the wind turbine / power generator.

[0003] In this regard, wind turbines usually contain a propeller-like device, termed the "rotor" or “impeller”, which is faced into a moving air stream. As the air hits the impeller, the air produces a force on the impeller in such a manner as to cause the impeller to rotate about its center. The impeller is connected to either an electricity generator or mechanical device through linkages such as gears, belts, chains or other means. Such turbines are used for generating electricity and powering batteries. They are also used to drive rotating pumps and/or moving machine parts. It is common to find wind turbines in large electricity generating "wind farms" containing multiple such turbines in a geometric pattern designed to allow maximum power extraction with minimal impact of each such turbine on one another and/or the surrounding environment.

[0004] The ability of an impeller to convert fluid power to rotating power, when placed in a stream of very large width compared to its diameter, is limited by the well documented theoretical value of 59.3% of the oncoming stream's power, known as the "Betz" limit as documented by A. Betz in 1926. This productivity limit applies especially to the traditional multi-bladed axial wind/water turbine presented in **FIG. 1A**, labeled Prior Art.

[0005] Existing wind turbines share a litany of troublesome limitations. These limitations include poor performance at low wind speed, which is relevant because many of the "good-wind" sites have been taken up and the industry has had to begin focusing on technologies for "small wind" sites. Also, safety concerns exist due to poor containment for damaged propellers and shielding of rotating parts. In addition, an irritating pulsating noise caused by the turbine can travel far from the source, disturbing others located long distances away. Moreover, significant bird strikes and kills occur, so that wildlife concerns are implicated. Furthermore, high first and recurring costs occur due to expensive internal gearing and expensive turbine blade replacements caused by high wind and wind gusts. Additionally, existing turbines have poor and/or unacceptable esthetics for urban and suburban settings. Finally, poor mixing of the air that passes through the impeller blades with higher energy air that does not pass through the impeller blades leads to inefficiencies.

[0006] Attempts have been made to try to increase wind turbine performance potential beyond the "Betz" limit. Shrouds or ducts surrounding the impeller have been used. See, e.g., U.S. Pat. No. 7,218,011 to Hiel et al. (see **FIG. 1B**); U.S. Pat. No. 4,204,799 to de Geus (see **FIG. 1C**); U.S. Pat. No. 4,075,500 to Oman et al. (see **FIG. 1D**); and U.S. Pat. No. 6,887,031 to Tocher. Properly designed shrouds cause the oncoming flow to speed up as it is concentrated into the center of the duct. In general, for a properly designed impeller, this increased flow speed causes more force on the impeller and subsequently higher levels of power extraction. Often though, the impeller blades break apart due to the shear and tensile forces involved with higher winds.

[0007] Values two times the Betz limit allegedly have been recorded but not sustained. See Igar, O., Shrouds for Aerogenerators, AIAA Journal, October 1976, pp. 1481-83; Igar & Ozer, Research and Development for Shrouded Wind Turbines, Energy Cons. & Management, Vol. 21, pp. 13-48, 1981; and see the AIAA Technical Note, entitled "Ducted Wind/Water Turbines and Propellers Revisited", authored by

Applicants ("Applicants' AIAA Technical Note"), and accepted for publication. Copies can be found in Applicants' Information Disclosure Statement. Such claims however have not been sustained in practice and existing test results have not confirmed the feasibility of such gains in real wind turbine application.

[0008] To achieve such increased power and efficiency, it is necessary to closely coordinate the aerodynamic designs of the shroud and impeller with the sometimes highly variable incoming fluid stream velocity levels. Such aerodynamic design considerations also play a significant role on the subsequent impact of flow turbines on their surroundings, and the productivity level of wind farm designs.

[0009] In an attempt to advance the state of the art, ducted (also known as shrouded) concepts have long been pursued. These have consistently provided tantalizing evidence that they may offer significant benefits over those of traditional unducted design. However, as yet, none have been successful enough to have significantly entered the marketplace. This is apparently due to several major weaknesses of current designs including: (a) they generally employ propeller based aerodynamic concepts versus turbine aerodynamic concepts, (b) they do not employ concepts for noise and flow improvements, and (c) they lack a first principles based ducted wind/water turbine design methodology equivalent to the "Betz/Schmitz Theory" that has been used extensively for unducted configurations.

[0010] Ejectors are known and documented fluid jet pumps that draw flow into a system and thereby increase the flow rate through that system. Mixer/ejectors are short compact versions of such jet pumps that are relatively insensitive to incoming flow conditions and have been used extensively in high speed jet propulsion applications involving flow velocities near or above the speed of sound. See, for example, U.S. Pat. No. 5,761,900 by Dr. Walter M. Presz, Jr, which also uses a mixer downstream to increase thrust while reducing noise from the discharge. Dr. Presz is a co-inventor in the present application.

[0011] Gas turbine technology has yet to be applied successfully to axial flow wind turbines. There are multiple reasons for this shortcoming. Existing wind turbines use non-shrouded turbine blades to extract the wind energy. As a result, a significant amount of the flow approaching the wind turbine blades flows around and not through the blades. Also, the air velocity decreases significantly as it approaches existing wind turbines. Both of these effects result in low flow through, turbine velocities. These low velocities minimize the potential benefits of gas turbine

technology such as stator/impeller concepts. Previous shrouded wind turbine approaches have keyed on exit diffusers to increase turbine blade velocities. Diffusers, which typically include a pipe-like structure with openings along the axial length to allow slow, diffusive mixing of water inside the pipe with that outside the pipe, generally require long lengths for good performance. Diffusers also tend to be very sensitive to oncoming flow variations. Such long, flow sensitive diffusers are not practical in wind turbine installations. Short diffusers stall thus reducing the energy conversion of the system. Also, the downstream diffusion needed may not be possible with the turbine energy extraction desired at the accelerated velocities. These effects have hampered previous attempts at more efficient wind turbines using gas turbine technology.

[0012] Accordingly, it is an object of the present disclosure to provide an axial flow wind turbine that employs advanced fluid dynamic mixer/ejector pump principles to consistently deliver levels of power well above the Betz limit.

[0013] It is another object to provide an improved axial flow wind turbine that employs unique flow mixing (for wind turbines) of low energy air and high energy air and control devices to increase productivity of and minimize the impact of its attendant flow field on the surrounding environment located in its near vicinity, such as found in wind farms.

[0014] It is another object to provide an improved axial flow wind turbine that pumps in more flow through the impeller and then rapidly mixes the low energy turbine exit flow with high energy bypass wind flow before exiting the system.

[0015] It is a more specific object, commensurate with the above-listed objects, to provide an axial flow wind turbine which is relatively quiet and safer to use in populated areas.

BRIEF DESCRIPTION

[0016] A mixer/ejector wind turbine system (referred to herein as the "MEWT") for generating power is disclosed that combines fluid dynamic ejector concepts, advanced flow mixing and control devices, and an adjustable power turbine.

[0017] Disclosed in some embodiments is a wind turbine comprising a center body, an impeller, and a turbine shroud. The center body comprises a central passageway. The impeller is disposed about the center body and comprises a plurality of impeller blades. The turbine shroud is disposed about the impeller. The

central passageway permits air to flow from one end of the turbine shroud to the other end without passing through the impeller.

[0018] The turbine shroud may be in the shape of a ring airfoil. Alternatively, the turbine shroud has a plurality of mixer lobes disposed around an exhaust end. Each mixer lobe on the turbine shroud has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

[0019] The center body may also further comprise a plurality of mixer lobes disposed around an outlet end. Each mixer lobe on the center body has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

[0020] The wind turbine may further comprise an ejector shroud downstream from and coaxial with the mixer shroud. A mixer shroud outlet extends into an ejector shroud inlet.

[0021] The ejector shroud may be in the shape of a ring airfoil. Alternatively, the ejector shroud has a ring of mixer lobes around an ejector shroud outlet. Each mixer lobe on the ejector shroud has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

[0022] The impeller can be a rotor/stator assembly, the rotor/stator assembly including a rotor and a stator. The stator has at least one phase winding. 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. In some embodiments, the plurality of permanent magnets is located along a rear end of the outer ring. Alternatively, the wind turbine may further comprise a power generator located in the center body and connected to the impeller.

[0023] The wind turbine may further comprise a wing-tab or directional vane for aligning the wind turbine with the direction of airflow. The turbine shroud may have a non-circular frontal cross-section. An inlet area of the turbine shroud can be greater than an exit area of the turbine shroud.

[0024] Disclosed in other embodiments is a wind turbine comprising a center body, a rotor assembly, and a stator assembly. The center body comprises a central passageway. The rotor assembly rotates around the center body. The turbine shroud surrounds the rotor assembly. The stator assembly is upstream of the rotor

assembly and connects the turbine shroud with the center body. The central passageway comprises a plurality of mixer lobes disposed around an outlet end thereof.

[0025] First-principles-based theoretical analysis of the preferred MEWT indicates that the MEWT can produce three or more times the power of its un-shrouded counterparts for the same frontal area, and increase the productivity of wind farms by a factor of two or more.

[0026] Other objects and advantages of the current disclosure will become more readily apparent when the following written description is read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] 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.

[0028] **FIGS. 1A**, **1B**, **1C** and **1D**, labeled "Prior Art", illustrate examples of conventional and prior turbines.

[0029] **FIG. 2** is an exploded view of the components of an exemplary wind turbine of the present disclosure.

[0030] **FIG. 3** is a front perspective view of an exemplary wind turbine attached to a support tower.

[0031] **FIG. 4** is a front perspective view of a further exemplary embodiment of a wind turbine of the present disclosure.

[0032] **FIG. 5** is a rear cross-sectional perspective view of an additional exemplary embodiment of a wind turbine of the present disclosure.

[0033] **FIG. 6** is a front view of an exemplary wind turbine having wing-tabs or directional vanes for wind alignment.

[0034] **FIG. 7A** is a front perspective view of another exemplary embodiment of a wind turbine having a turbine shroud and an ejector shroud. The turbine shroud includes mixer lobes, while the ejector shroud has a ring airfoil shape.

[0035] **FIG. 7B** is a partial front cross-sectional view of the turbine of **FIG. 7A** with the ejector shroud removed, showing the mixer lobes on the turbine shroud.

[0036] **FIG. 7C** is a partial rear cross-sectional view of the turbine of **FIG. 7A** with the ejector shroud removed, showing the mixer lobes on the turbine shroud. The central passageway does not include mixer lobes.

[0037] **FIG. 7D** is a full cross-sectional view of the turbine of **FIG. 7A**.

[0038] **FIG. 8A** is a full rear cross-sectional view of a further exemplary embodiment of a wind turbine having a turbine shroud and an ejector shroud. The turbine shroud includes mixer lobes, while the ejector shroud has a ring airfoil shape. The central passageway also includes mixer lobes.

[0039] **FIG. 8B** is a full front cross-sectional view of the turbine of **FIG. 8A**.

[0040] **FIG. 9A** is a full rear cross-sectional view of an additional exemplary embodiment of a wind turbine having a turbine shroud and an ejector shroud. The turbine shroud, ejector shroud, and central passageway each include mixer lobes.

[0041] **FIG. 9B** is a full front cross-sectional view of the turbine of **FIG. 9A**.

[0042] **FIG. 10** is a front perspective view of yet another exemplary embodiment of a MEWT having a central passageway.

[0043] **FIG. 11** is a side cross-sectional view of the MEWT of **FIG. 10**.

[0044] **FIGS. 12A** and **12B** are magnified views of the mixing lobes of the MEWT of **FIG. 11**.

[0045] **FIGS. 13A** and **13B** are a magnified side view of a wind turbine and illustrate the use of flow blockage doors and a rotatable stator vane to control the flow of fluid through the turbine.

[0046] **FIG. 14** is a cutaway view of another exemplary embodiment of a MEWT having a central passageway showing the stator portion of a ring generator.

[0047] **FIG. 15** is a cutaway view of another exemplary embodiment of a MEWT having a central passageway showing the rotor portion of a ring generator.

[0048] **FIG. 16** is a closeup view showing the rotor and stator of a ring generator in relation to each other.

[0049] **FIG. 17** is the front view of an exemplary rotor.

[0050] **FIG. 18** is the side view of an exemplary rotor.

[0051] **FIG. 19** is the front view of an exemplary stator.

[0052] **FIG. 20** is the side view of an exemplary stator.

[0053] **FIG. 21** is a diagram illustrating the flow of faster air through the central passageway of a center body having mixer lobes.

0054] **FIG. 22** is a diagram illustrating the flow of slower air around the center ody having mixer lobes. The slower air is formed by removing energy from fast air rough the impeller.

0055] **FIG. 23** is a diagram illustrating the meeting of a faster air stream and a ower air stream.

0056] **FIG. 24** is a diagram illustrating a vortex formed by the meeting of a faster r stream and a slower air stream.

0057] **FIG. 25** is a diagram illustrating the resulting series of vortices formed by e mixer lobes on the center body.

0058] **FIG. 26** is a cross-sectional diagram of a center body having mixer lobes.

DETAILED DESCRIPTION

0059] A more complete understanding of the components, processes, and parapparatuses disclosed herein can be obtained by reference to the accompanying jures. These figures are merely schematic representations based on convenience nd the ease of demonstrating the present development and are, therefore, not tended to indicate the relative size and dimensions of the devices or components ereof and/or to define or limit the scope of the exemplary embodiments.

0060] Although specific terms are used in the following description for the sake clarity, these terms are intended to refer only to the particular structure of the nbodiments selected for illustration in the drawings and are not intended to define limit the scope of the disclosure. In the drawings and the following description low, it is to be understood that like numeric designations refer to components of e function.

0061] The modifier "about" used in connection with a quantity is inclusive of the ated value and has the meaning dictated by the context (for example, it includes at ast the degree of error associated with the measurement of the particular quantity). hen used in the context of a range, the modifier "about" should also be considered disclosing the range defined by the absolute values of the two endpoints. For ample, the range "from about 2 to about 4" also disclosed the range "from 2 to 4."

0062] A wind turbine can theoretically capture at most 59.3% of the potential ergy of the wind passing through it, a maximum known as the Betz limit. The nount of energy captured by a wind turbine can also be referred to as the efficiency the turbine. The MEWT may exceed the Betz limit.

[0063] **FIG. 1A-1D** show prior art wind turbines. Such turbines are limited by the Betz limit.

[0064] A Mixer-Ejector Power System (MEPS) provides a unique and improved means of generating power from wind currents. A MEPS includes:

- a primary duct containing a turbine or propeller blade 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 mixing duct inlet contours are designed to minimize flow losses while providing the pressure forces necessary for good ejector performance.

[0065] The resulting mixer/ejectors enhances the operational characteristics of the power system by: (a) increasing the amount of flow through the system, (b) reducing the back pressure on the turbine blade, and (c) reducing the noise propagating from the system.

[0066] 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 current;
- vertical aerodynamic stabilizer vanes or directional vanes mounted on the exterior of the ducts with tabs to keep the system pointed into the wind; or
- mixer lobes on a single stage of a multi-stage ejector system.

[0067] Referring to the drawings in detail, **FIGS. 2-9B** show alternate embodiments of Applicants' axial flow wind turbine with mixers and ejectors ("MEWT").

[0068] In embodiments, the MEWT **100** is an axial flow turbine comprising:

(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** of stator vanes (e.g., **108a**) and an impeller or rotor **110** having impeller or rotor blades (e.g., **112a**) downstream and "in-line" with the stator vanes (i.e., leading edges of the impeller blades are substantially aligned with trailing edges of the stator vanes), in which:

(i) the stator vanes (e.g., **108a**) are mounted on the center body **103**;

(ii) the impeller blades (e.g., **112a**) are attached and held together by inner and outer rings or hoops mounted on the center body **103**;

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

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

[0069] Notably, the turbine **100** includes an open central passageway **145** along the central axis of the turbine **100**. The central passageway **145** extends through the center body **103** and the impeller **110**.

[0070] The center body **103** of the MEWT **100**, as shown in **FIG. 3**, is preferably connected to the turbine shroud **102** through the stator ring **106** (or other means) to eliminate the damaging, annoying and long distance propagating low-frequency sound produced by traditional wind turbines as the turbine's blade wakes strike the support tower. The aerodynamic profiles of the turbine shroud **102** and ejector shroud **128** preferably are aerodynamically cambered to increase flow through the turbine rotor.

[0071] Applicants have calculated, for optimum efficiency in the preferred embodiments **100**, 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 between 1.5 and 3.0. The number of mixer lobes (e.g., **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 center line that is parallel to the axial center of the turbine. 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.

[0072] **FIG. 4** is another embodiment of the wind turbine with the open central passageway **145**. The turbine shroud **115** concentrically surrounds the impeller, of which the impeller blades **112a** are visible. The turbine shroud **115** comprises mixing elements **146** on a downstream edge **150** thereof, or in other words the mixing elements are located around an outlet end or rear end of the turbine shroud. A stator assembly **108** resides in front of the impeller and comprises a plurality of stator vanes **108a**. The turbine shroud **115** is in the shape of an airfoil with the suction side (i.e. low pressure side) on the interior of the shroud. An ejector shroud **116** is coaxial with the turbine shroud **115**. The ejector shroud also comprises mixing elements **147** on a downstream edge **151** thereof, or in other words the mixing elements are located around an outlet end or rear end of the ejector shroud. Here, the mixing elements are depicted as slots.

[0073] **FIG. 5** shows a rear cross-sectional perspective view of another exemplary wind turbine. Stator vanes **108a** are located in front of the impeller **112**. The impeller **112** itself includes impeller blades **112a**, a central ring **112b**, and an outer impeller ring **112c**. The center body **103** includes an open passageway **145**. As shown here, the center body also comprises a plurality of mixing elements, shown here as mixer lobes **148**, on a downstream edge **149** thereof, or in other words the mixing elements are located around an outlet end or rear end of the center body. The central ring **112b** allows the impeller **112** to freely rotate about the center body **103**. A turbine shroud **115** concentrically surrounds the impeller **112** and comprises turbine shroud mixing elements, shown here as mixer lobes **120a**. An ejector shroud **116** coaxially surrounds the turbine shroud **115**. The ejector shroud **116** also

comprises a plurality of mixer lobes **130**. The mixer lobes **120a** of the turbine shroud **115** extend into the inlet **129** of the ejector shroud.

[0074] **FIG. 6** shows an embodiment of a wind turbine having wing-tabs or directional vanes **136** to align the turbine with the direction of wind flow. The turbine here is shown with two wing-tabs; different numbers of wing-tabs are contemplated as well.

[0075] **FIGS. 7A-7D** show various views of another embodiment of a wind turbine. Here, the wind turbine **100** has a turbine shroud **115** and an ejector shroud **116**. A central passageway **145** is present in the center body **103**. Here, the turbine shroud **115** has mixer lobes **120a**, while the ejector shroud **116** has a ring airfoil shape. Put another way, the ejector shroud **116** is cambered.

[0076] **FIGS. 8A-8B** show two views of another embodiment of a wind turbine. This turbine is similar to that shown in **FIGS. 7A-7D**. However, the central passageway also includes mixer lobes **148**.

[0077] **FIGS. 9A-9B** show two views of another embodiment of a wind turbine. Here, the turbine shroud **115**, ejector shroud **116**, and central passageway **145** each have mixer lobes **120a**, **130**, **148** on their outlet end.

[0078] **FIGS. 10-13** illustrate another embodiment of a MEWT. The MEWT **900** in **FIG. 10** has a stator **908a** and a rotor **910** configuration for power extraction. The turbine shroud **902** surrounds the rotor **910** and is supported by or connected to the blades of the stator **908a**. The turbine shroud **902** is in the shape of an airfoil with the suction side (i.e. low pressure side) on the interior of the shroud. An ejector shroud **928** is coaxial with the turbine shroud **902** and is supported by connectors **905** extending between the two shrouds. An annular area is formed between the two shrouds. The rear end of the turbine shroud **902** is shaped to form two different sets of mixing lobes **918**, **920**. High energy mixing lobes **918** extend inward towards the central axis of the mixer shroud **902**, which low energy mixing lobes **920** extend outwards away from the central axis. A central passageway **945** extends through the turbine **900**. As seen in **FIG. 11**, there are no mixing elements on the downstream end of the nacelle or center body **903**.

[0079] Free stream air **906** passing through the stator **908a** has its energy extracted by the rotor **910**. Relatively high energy air **929** (see **FIG. 10**) bypasses the stator **908a** and is brought in behind the turbine shroud **902** by the high energy mixing lobes **918**. Similarly, relatively high energy air **931** flows through the central

passageway **945**. The low energy mixing lobes **920** cause the relatively low energy air downstream from the rotor **910** to be mixed with the high energy air **929, 931**. This mixing effect is discussed in greater detail below.

[0080] The nacelle **903** and the trailing edges of the low energy mixing lobes **920** and the trailing edge of the high energy mixing lobes **918** may be seen in **FIG. 11**. The ejector shroud **928** is used to draw in the high energy air **929**.

[0081] In **FIG. 12A**, a tangent line **952** is drawn along the interior trailing edge **957** of the high energy mixing lobe **918**. A rear plane **951** of the turbine shroud **902** is present. A centerline **950** is formed tangent to the rear plane **951** that intersects the point where a low energy mixing lobe **920** and high energy mixing lobes **918** meet. An angle $Ø_2$ is formed by the intersection of tangent line **952** and centerline **950**. This angle $Ø_2$ is between 5 and 65 degrees. Put another way, a high energy mixing lobe **918** forms an angle $Ø_2$ between 5 and 65 degrees relative to the turbine shroud **902**.

[0082] In **FIG. 12B**, a tangent line **954** is drawn along the interior trailing edge **955** of the low energy mixing lobe **920**. An angle **Ø** is formed by the intersection of tangent line **954** and centerline **950**. This angle **Ø** is between 5 and 65 degrees. Put another way, a low energy mixing lobe **920** forms an angle **Ø** between 5 and 65 degrees relative to the turbine shroud **902**.

[0083] **FIGS. 13A** and **13B** show two different mechanisms which may optionally be included controlling the flow of air into the wind turbine. **FIG. 13A** shows flow blockage doors **140a**, **140b**. The doors can be open (**140b**) or closed (**140a**) to reduce or stop flow through the turbine when damage to a generator or other components due to high wind speed is a possibility. In **FIG. 13B**, the exit angle of the stator vanes **108** can be mechanically varied in situ (i.e. the vanes can be pivoted, or are rotatable) (as indicated by reference numeral **142**) to accommodate variations in the fluid stream velocity so as to assure minimum residual swirl in the flow exiting the rotor.

[0084] **FIG. 14** and **FIG. 15** show another exemplary embodiment of a wind turbine **400** of the present disclosure. 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**. A central passageway **445** runs through the center body **403** and

the rotor/stator assembly **406**. Attachment struts **410** join or connect the mixer shroud **402** with the ejector shroud **404**.

[0085] The rotor/stator assembly **406** operates as a permanent ring generator. With reference to **FIGs. 15-20**, permanent magnets **440** are mounted on a rotor **420**. One or more phase windings **432** are mounted in the stator **430**. As the rotor rotates, a constant rotating magnetic field is produced by the magnets **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 compared to an induction generator is that the induction generator requires power from the electrical grid itself to form a magnetic field. In contrast, the permanent magnet generator does not need power from the grid to produce electricity.

[0086] Each phase winding is comprised of a series of coils. In particular embodiments, the stator has three phase windings 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. 19** and **FIG. 20** show the assembled stator **430** from the front and side, respectively.

[0087] **FIG. 15** is cut away to show the permanent magnets **440**. Referring now to **FIG. 17** and **FIG. 18**, 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. 14**, 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**.

[0088] A plurality of permanent magnets **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. 18**, in embodiments the magnets are located along a rear end **472** of the outer ring. In particular embodiments, there are 80 permanent magnets spaced every 4.5 degrees. The magnet poles are oriented radially on the outer ring, i.e. one pole being closer to the central ring than the other pole. The magnets are arranged so that their poles alternate, for example so that a magnet with its north pole oriented outward is surrounded by two poles with their south pole oriented outward. The magnets **440** are separated by potting material **442** which secures the magnets to the rotor **450**.

[0089] In embodiments, the permanent magnets are rare earth magnets, i.e. are made from alloys of rare earth elements. Rare earth magnets produce very high magnetic fields. In embodiments, the permanent magnets are neodymium magnets, such as $Nd_2Fe_{14}B$.

[0090] **FIG. 16** is an enlarged view showing the rotor **450** and stator **430** and their relationship to each other.

[0091] One advantage of a mixer-ejector wind turbine as described herein compared to traditional three-bladed horizontal axis wind turbines is that the blades of a typical turbine may be as much as 50 meters long or longer. This results in a large swept area for the blades. However, the area enclosed by the permanent magnets is much smaller. Because the ratio of the area for the blades to the area for the magnets is very high, the ring generator is unable to turn as efficiently as it otherwise could. However, the ratio of the area for the MEWT is about 1:1, which allows for greater efficiency and greater power generation. Another advantage is that the MEWT has a lower "cut-in" speed, i.e. the rotor on the MEWT will start turning and generating energy at lower wind speeds. Normally, due to the intermittent generation of the wind turbine, the turbine is not directly connected to an electrical grid because the fluctuations in electricity production would inject voltage and frequency disturbances into the grid.

[0092] **FIGS. 21-25** illustrate methods by which energy or power is produced, or by which the energy or power of a fluid turbine is increased, or by which additional amounts of energy are extracted from a fluid stream.

[0093] As shown in **FIGs. 21** and **22**, a center body **800** has an outlet or exit end **802**. A plurality of mixer lobes **830** is disposed around this outlet **802**. Only the rear portion of the center body is shown, and the impellers upstream of the center body are not shown. A first fluid stream **810** passes through the central passageway **845**, while a second fluid stream **820** that passes outside the center body has flowed through an impeller, resulting in the extraction of energy or power from the second fluid stream, so that the second fluid stream is a relatively slower stream compared to the first fluid stream. Reference numeral **812** refers to the first fluid stream as it exits the outlet **802** of the center body **800**.

[0094] Referring to the cross-sectional view of **FIG. 26**, each mixer lobe **830** has an outer trailing edge angle **α** and an inner trailing edge angle **β**. The center body **800** has a central axis **804**. The angles **α** and **β** are measured relative to a plane

840 which is parallel to the central axis, perpendicular to the entrance plane **806** of the center body, and along the surface **805** of the center body. The angle is measured from the vertex point **842** at which the center body begins to diverge to form the mixer lobes. The outer trailing edge angle **α** is measured at the outermost point **844** on the trailing edge of the mixer lobe, while the inner trailing edge angle **β** is measured at the innermost point **846** on the trailing edge of the mixer lobe. In some embodiments, outer trailing edge angle **α** and inner trailing edge angle **β** are different, and in others **α** and **β** are equal. In particular embodiments, inner trailing edge angle **β** is greater than or less than outer trailing edge angle **α**. As mentioned previously, each angle can be independently in the range of 5 to 65 degrees.

[0095] As seen in **FIG. 21**, the mixer lobes 830 cause first fluid stream **812** to flare outwards after passing through the turbine. Put another way, the center body **800** directs relatively high energy fluid stream **812** away from central axis **804**.

[0096] As seen in **FIG. 22**, the mixer lobes 830 cause second fluid stream **820** to flow inwards. Put another way, the center body **800** directs relatively low energy fluid stream **820** toward central axis **804**.

[0097] As noted in **FIG. 23**, first fluid stream **812** and second fluid stream **820** thus meet at an angle **ω**. Angle **ω** is typically between 10 and 50 degrees. This design of the mixer shroud takes advantage of axial vorticity to mix the two fluid streams.

[0098] As shown in **FIGS. 24** and **25**, the meeting of the two fluid streams **812**, **820** causes an "active" mixing of the two fluid streams. This differs from "passive" mixing which would generally occur only along the boundaries of two parallel fluid streams. In contrast, the active mixing here results in substantially greater energy transfer between the two fluid streams.

[0099] **FIG. 24** illustrates a vortex **850** formed by the meeting of relatively high energy fluid stream **812** and relatively low energy fluid stream **820** behind one mixer lobe. **FIG. 25** shows the series of vortices formed by the plurality of mixer lobes **830** at the outlet **802** of the center body. The vortices are formed behind the center body **800**. Another advantage of this design is that the series of vortices formed by the active mixing reduce the distance downstream of the turbine in which turbulence occurs. With conventional turbines, the resulting downstream turbulence usually means that a downstream turbine must be placed a distance of 10 times the diameter of the upstream turbine away in order to reduce fatigue failure. In contrast,

the present turbines can be placed much closer together, allowing the capture of additional energy from the fluid.

[0100] Alternatively, the center body **800** can be considered as separating incoming air into a first fast fluid stream **810** and a second fast fluid stream **820**. The first fast fluid stream passes through the central passageway. The second fast fluid stream passes through the impeller and energy is extracted therefrom, resulting in a slow fluid stream **820** flowing along the exterior of the center body, which is relatively slower than the first fast fluid stream. The slow fluid stream **820** is then mixed with the first fast fluid stream **812**.

[0101] The wind turbine of the present disclosure, including the hollow center body, provides unique benefits over existing systems. The wind turbine provides a more effective and efficient wind generating system and significantly increases the maximum power extraction potential. The wind turbine is quieter, cheaper, and more durable. The wind power system operates more effectively in low wind speeds and is more acceptable aesthetically for both urban and suburban settings. The wind turbine reduces bird strikes, the need for expensive internal gearing, and the need for turbine replacements caused by high winds and wind gusts. The design is more compact and structurally robust. The turbine is less sensitive to inlet flow blockage and/or alignment of the turbine axis with the wind direction and uses advanced aerodynamics to automatically align itself with the wind direction. Mixing of high energy air and low energy air inside the turbine is more efficient which reduces turbulence.

[0102] The exemplary embodiment has been described with reference to the preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the exemplary embodiment 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 center body comprising a central passageway;

an impeller disposed about the center body and comprising a plurality of impeller blades; and

a turbine shroud disposed about the impeller.

2. The wind turbine of claim 1, wherein the turbine shroud is in the shape of a ring airfoil.

3. The wind turbine of claim 1, wherein the turbine shroud has a plurality of mixer lobes disposed around an exhaust end.

4. The wind turbine of claim 3, wherein each mixer lobe on the turbine shroud has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

5. The wind turbine of claim 1, wherein the center body further comprises a plurality of mixer lobes disposed around an outlet end.

6. The wind turbine of claim 5, wherein each mixer lobe on the center body has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

7. The wind turbine of claim 1, further comprising an ejector shroud downstream from and coaxial with the mixer shroud, wherein a mixer shroud outlet extends into an ejector shroud inlet.

8. The wind turbine of claim 7, wherein the ejector shroud is in the shape of a ring airfoil.

9. The turbine of claim 7, wherein the ejector shroud has a ring of mixer lobes around an ejector shroud outlet.

10. The wind turbine of claim 9, wherein each mixer lobe on the ejector shroud has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

11. The wind turbine of claim 1, wherein the impeller is a rotor/stator assembly, the rotor/stator assembly including a rotor and a stator;

wherein the stator has at least one phase winding; and

wherein 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.

12. The wind turbine of claim 11, wherein the plurality of permanent magnets are located along a rear end of the outer ring.

13. The wind turbine of claim 1, further comprising a wing-tab for aligning the wind turbine with the direction of airflow.

14. The wind turbine of claim 1, wherein the turbine shroud has a non-circular frontal cross-section.

15. The wind turbine of claim 1, wherein an inlet area of the turbine shroud is greater than an exit area of the turbine shroud.

16. The wind turbine of claim 1, further comprising a power generator located in the center body and connected to the impeller.

17. A wind turbine comprising:

a center body comprising a central passageway;

a rotor assembly which rotates around the center body;

a turbine shroud surrounding the rotor assembly; and

a stator assembly upstream of the rotor assembly and connecting the turbine shroud with the center body;

wherein the central passageway comprises a plurality of mixer lobes disposed around an outlet end thereof.

18. The wind turbine of claim 17, wherein the turbine shroud has a plurality of mixer lobes disposed around an exhaust end, wherein each mixer lobe on the turbine shroud has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

19. The wind turbine of claim 17, further comprising an ejector shroud downstream from and coaxial with the mixer shroud, wherein a mixer shroud outlet extends into an ejector shroud inlet.

20. The wind turbine of claim 19, wherein the ejector shroud has a ring of mixer lobes around an ejector shroud outlet, wherein each mixer lobe on the ejector shroud has an inner trailing edge angle and an outer trailing edge angle, and the inner angle and the outer angle are independently in the range of 5 to 65 degrees.

21. The wind turbine of claim 17, wherein the stator has at least one phase winding; and

wherein 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.

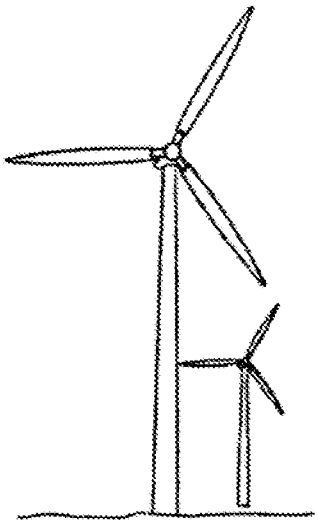


FIG. 1A
PRIOR ART

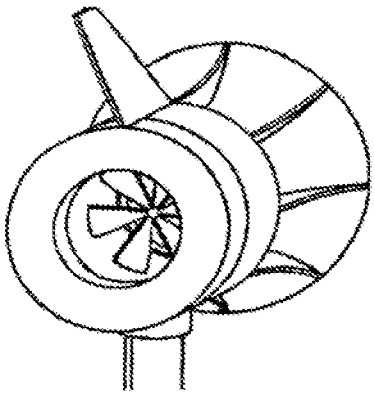


FIG. 1B
PRIOR ART

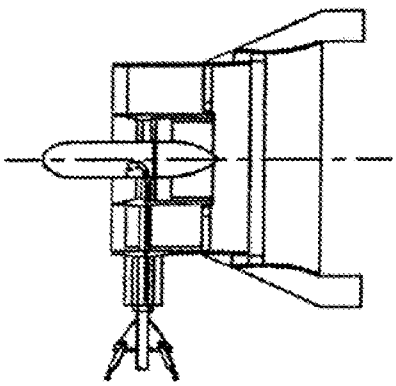


FIG. 1C
PRIOR ART

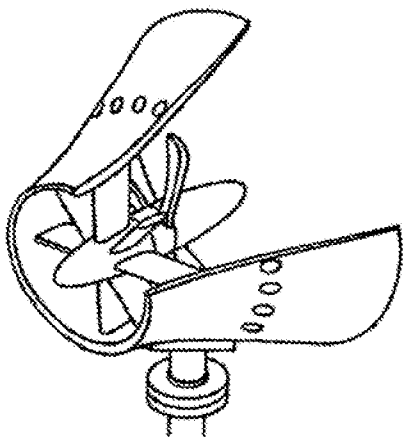


FIG. 1D
PRIOR ART

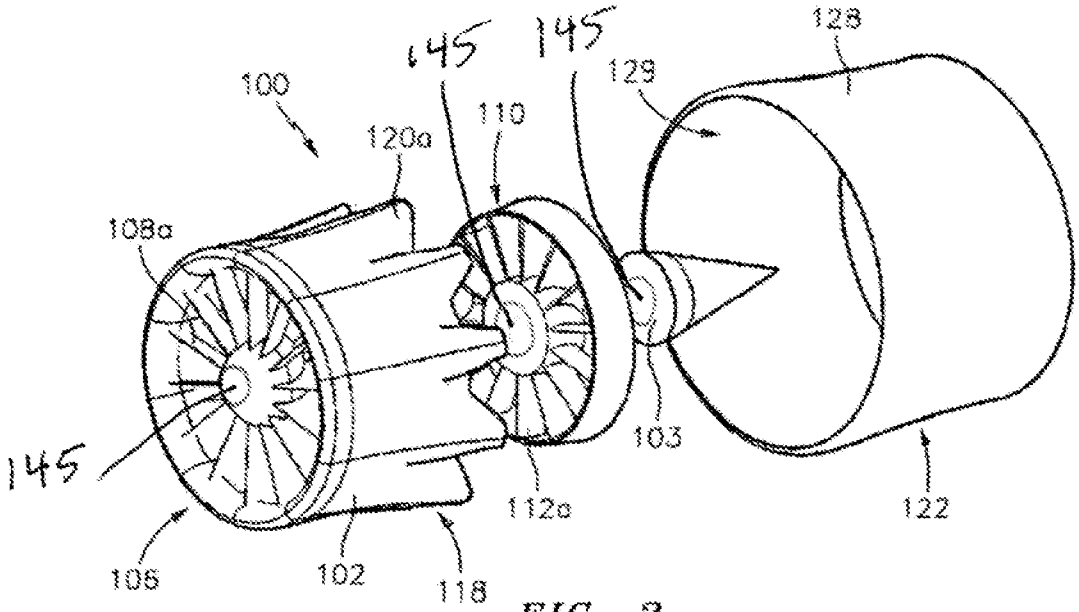

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145
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100
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120a
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112a
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FIG. 2

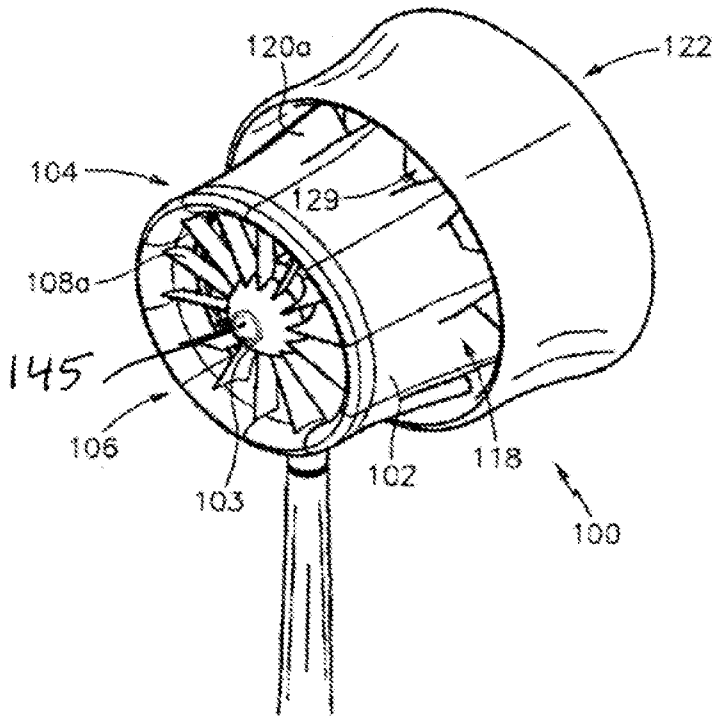

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FIG. 3

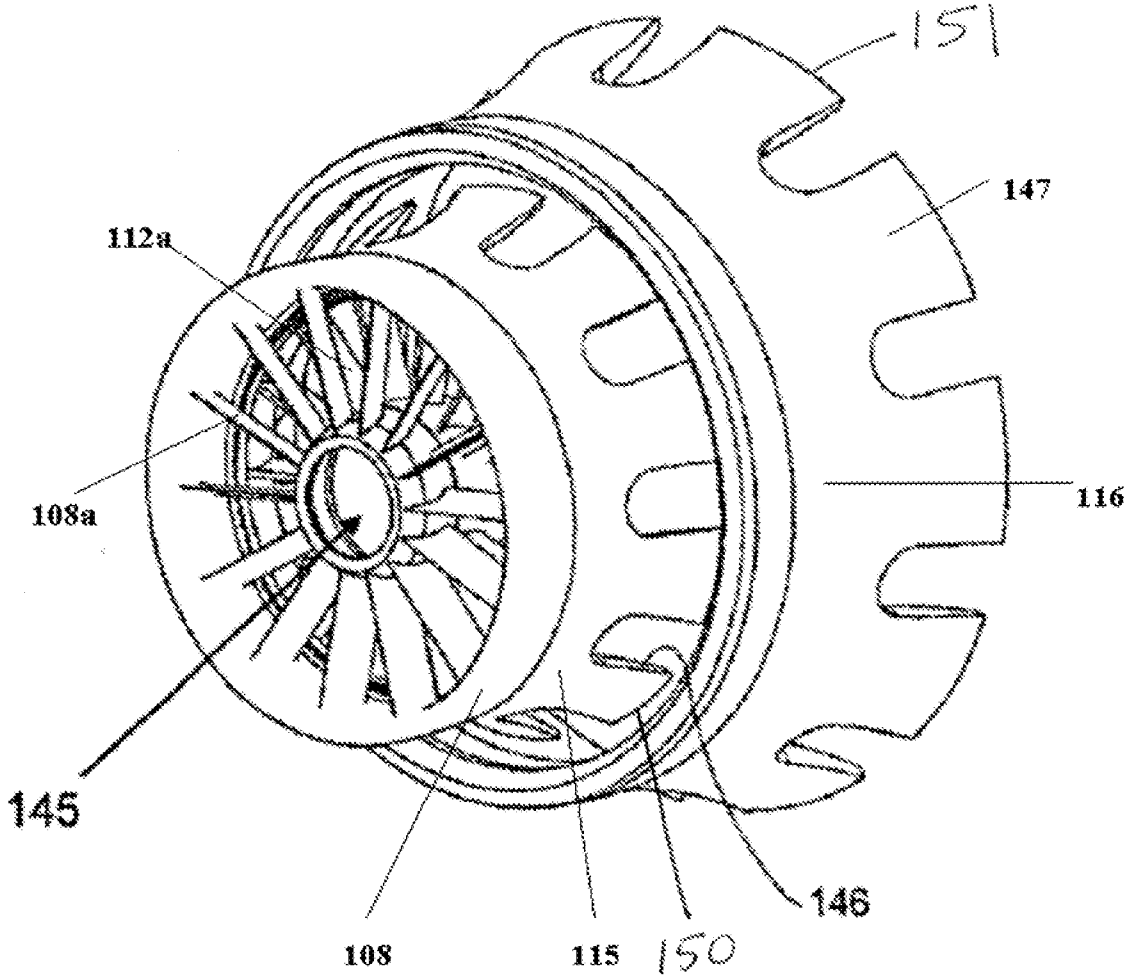


FIG. 4

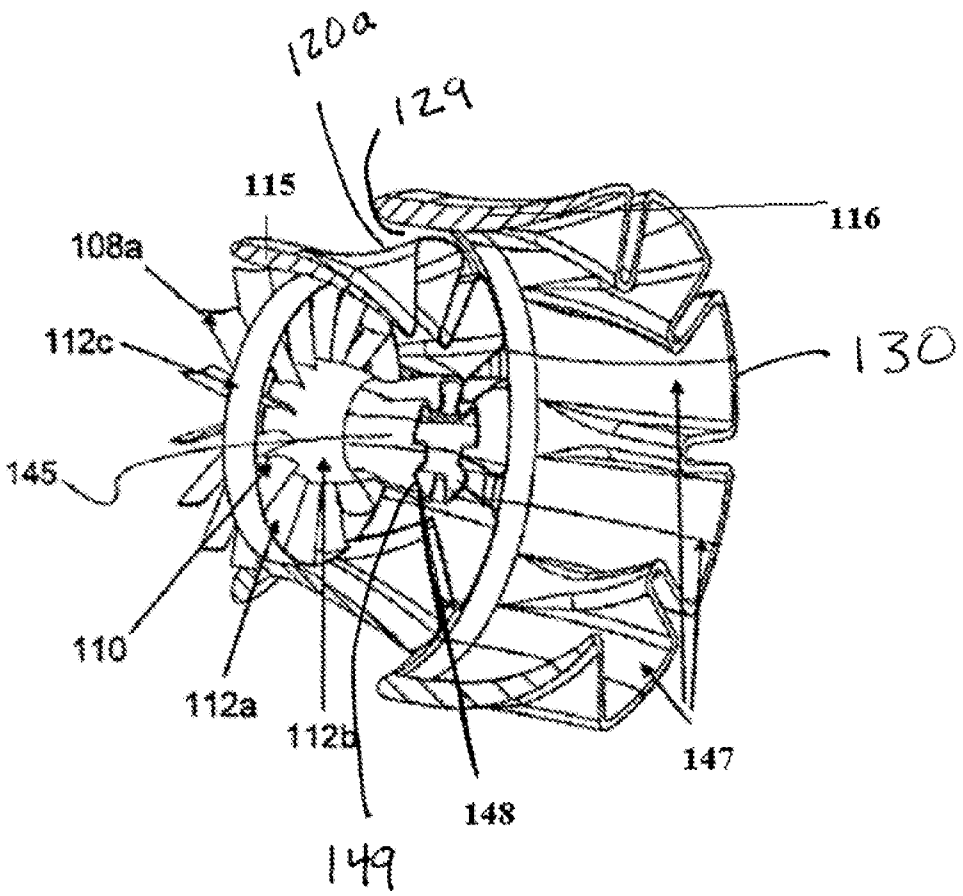


FIG. 5

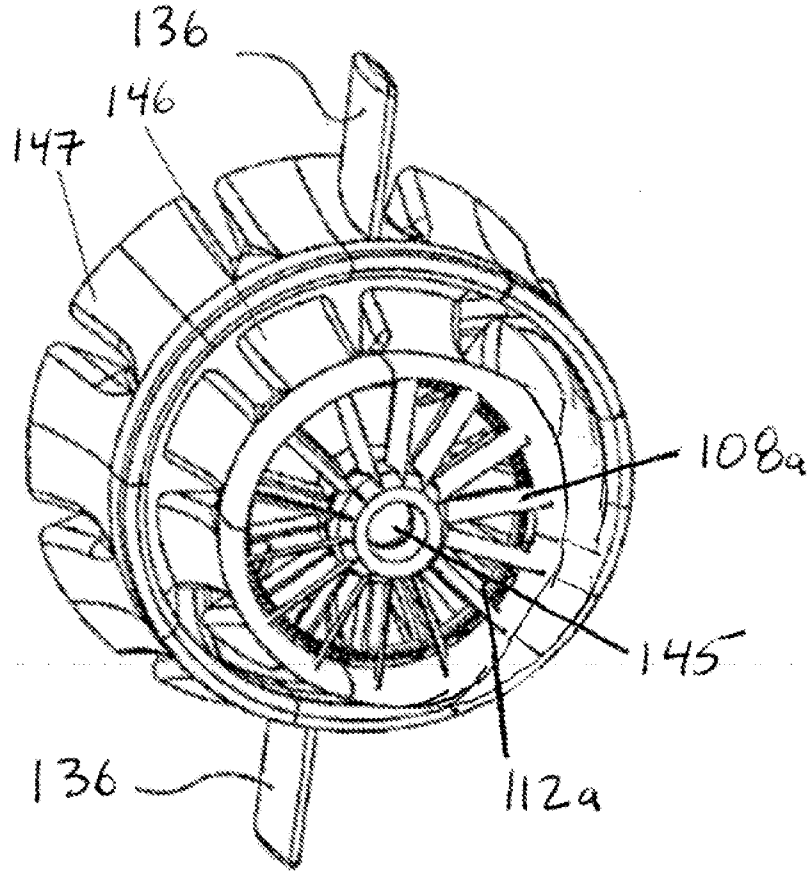


FIG. 6

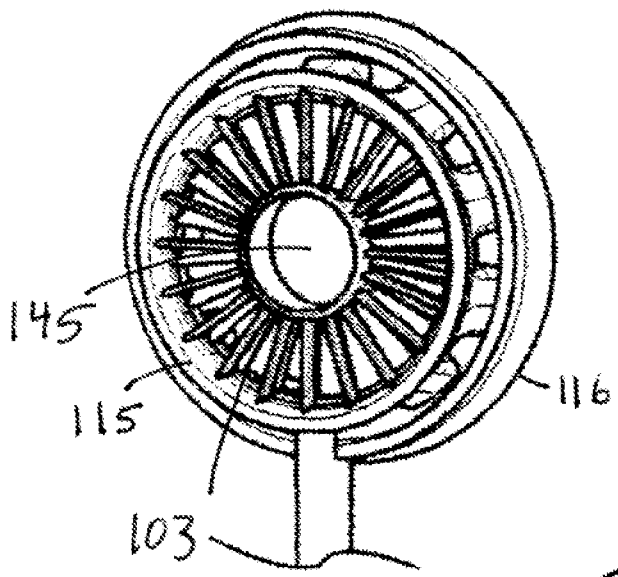


FIG. 7A

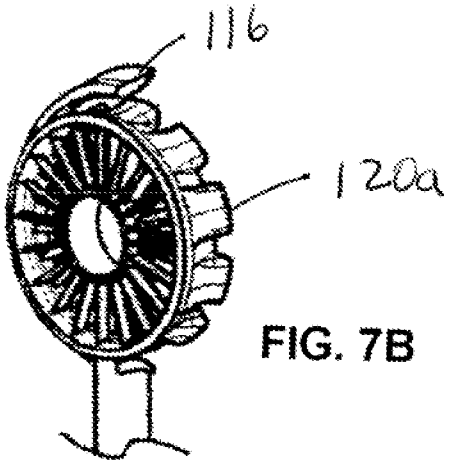


FIG. 7B

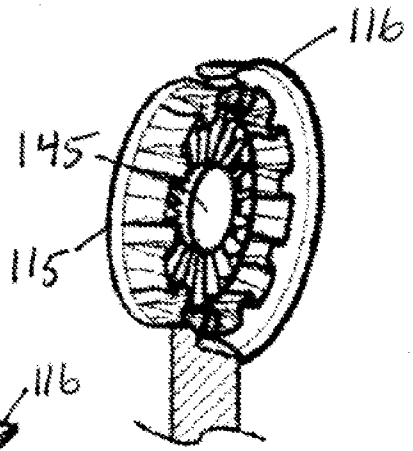


FIG. 7C

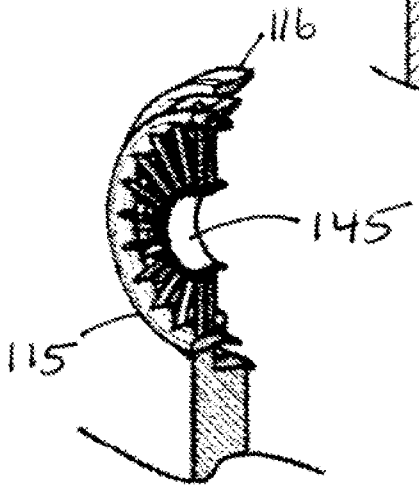


FIG. 7D

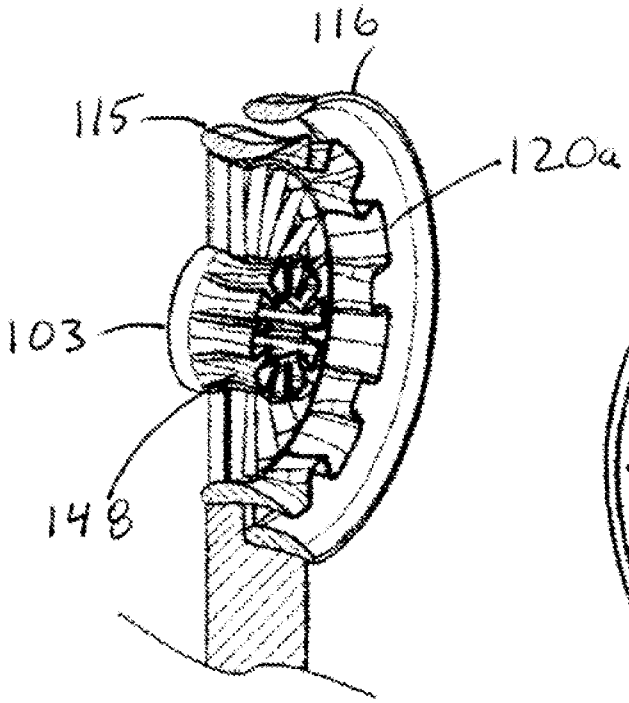


FIG. 8A

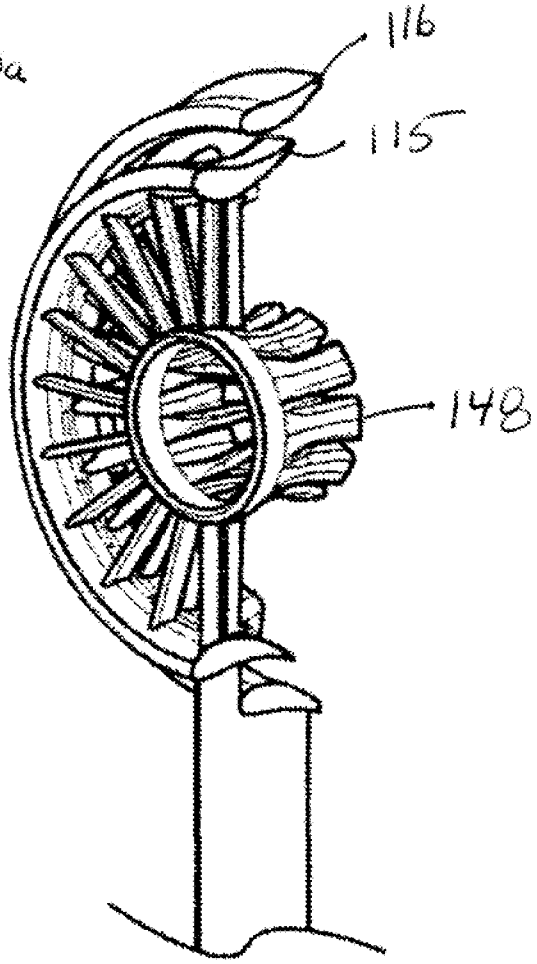


FIG. 8B

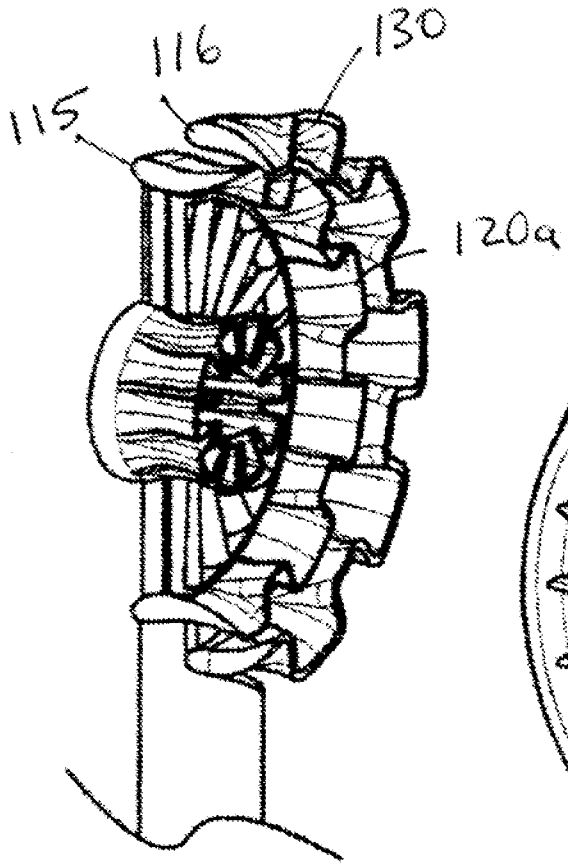


FIG. 9A

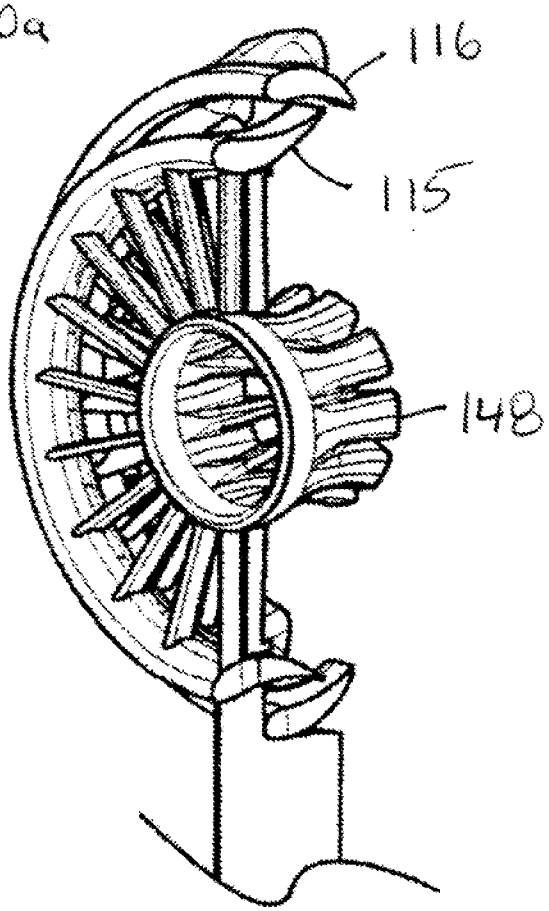


FIG. 9B

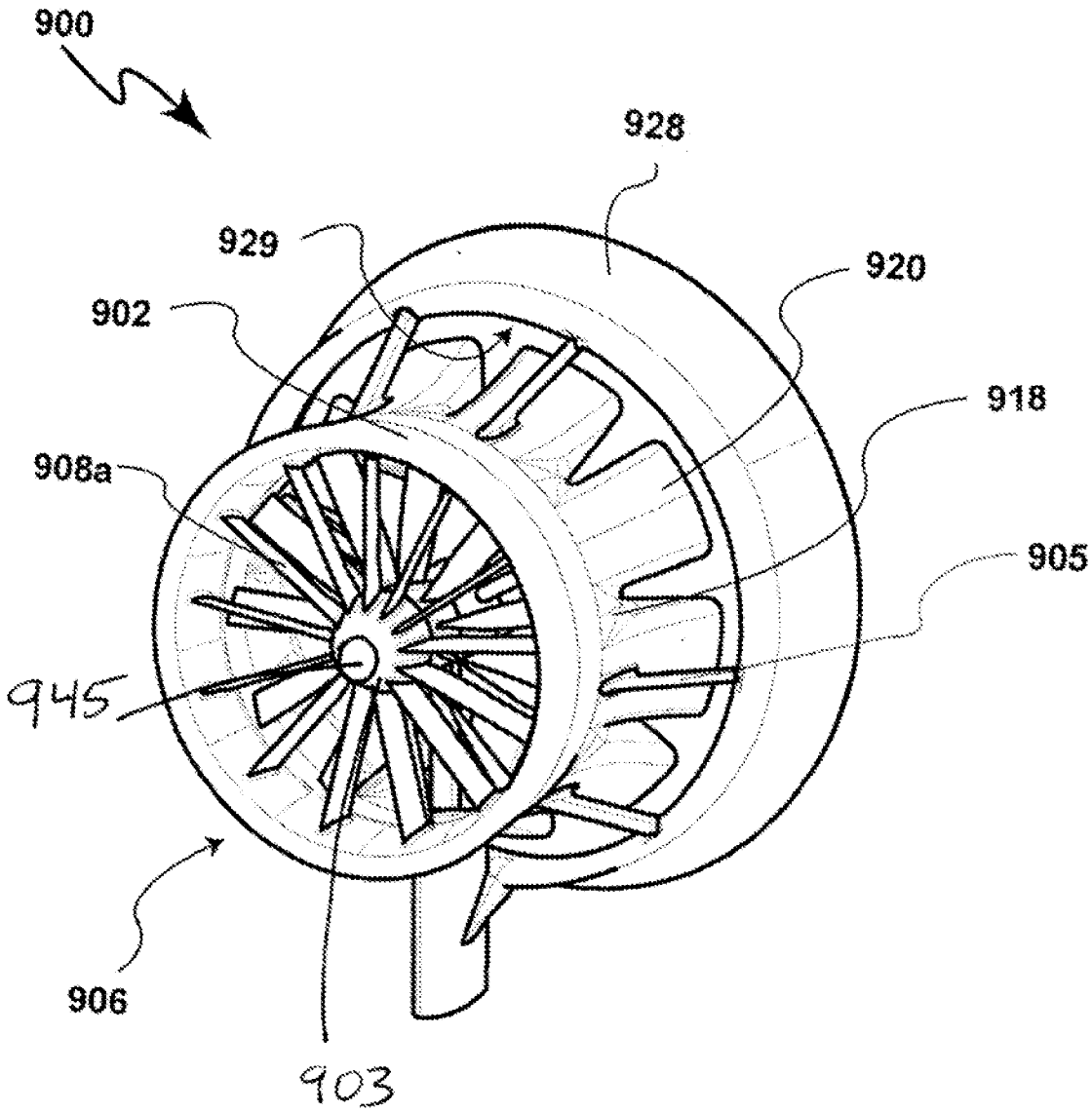


FIG. 10

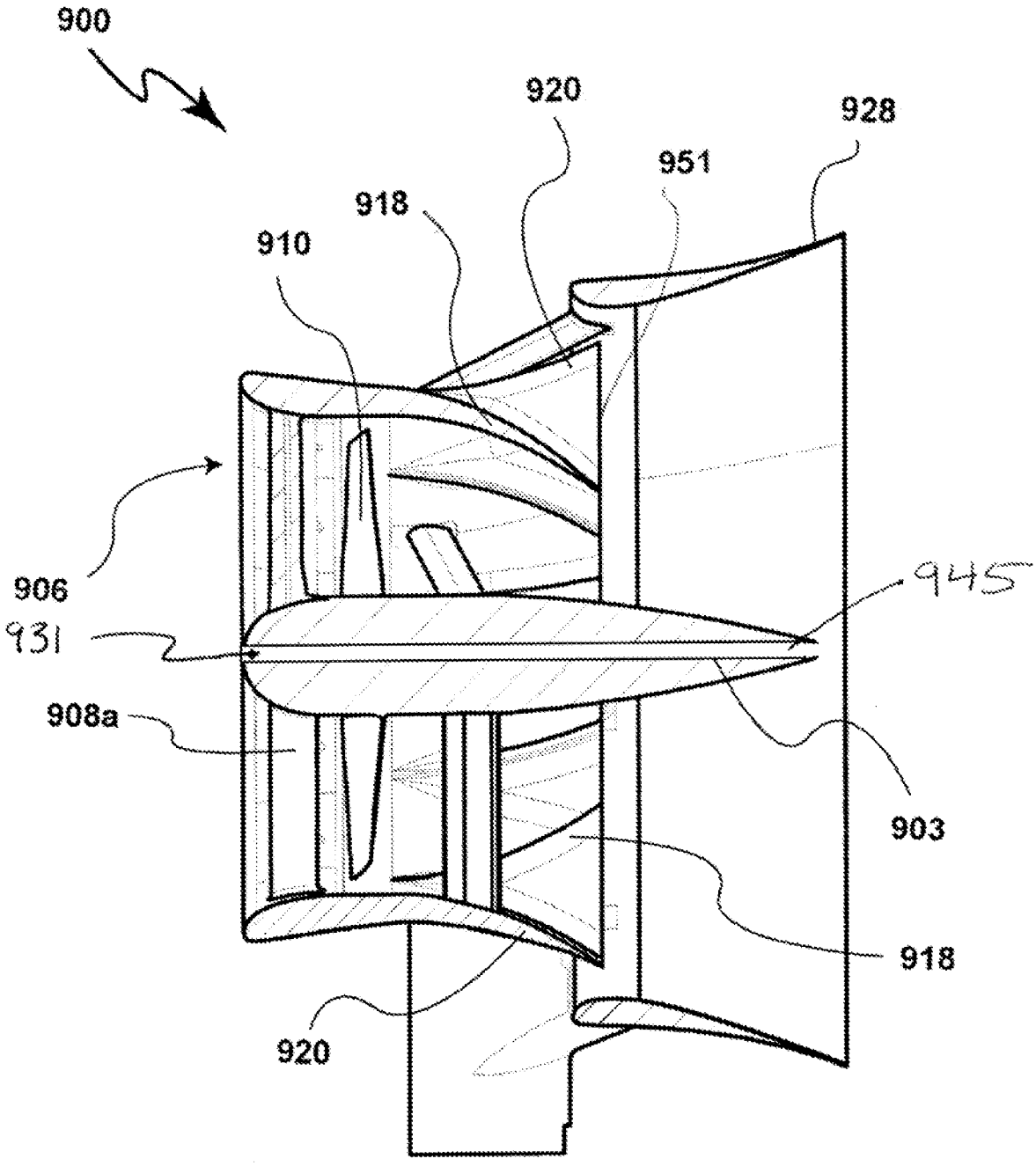
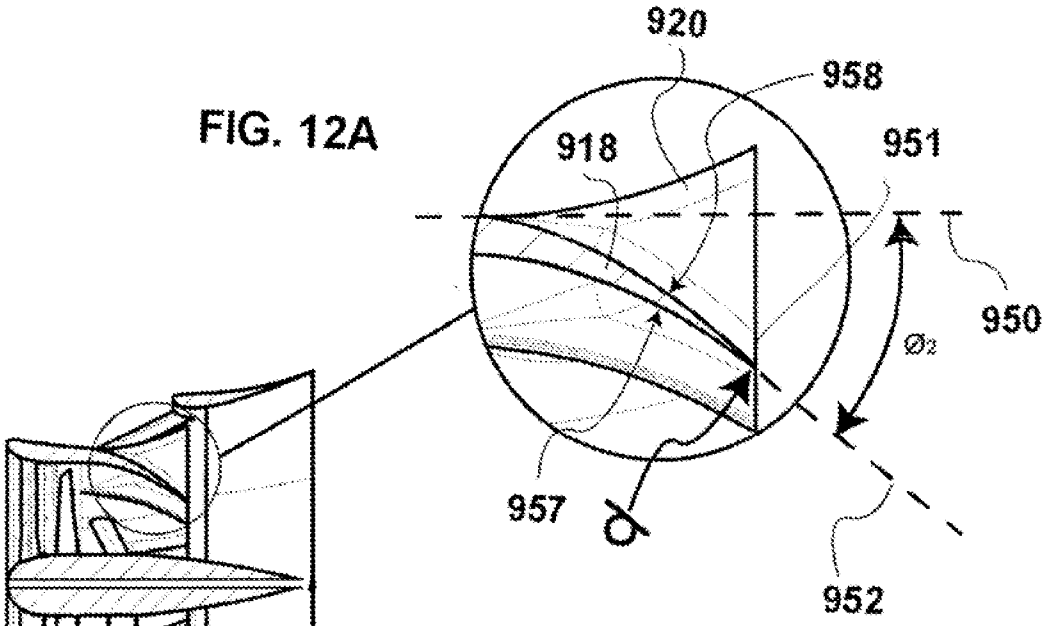


FIG. 11

FIG. 12A



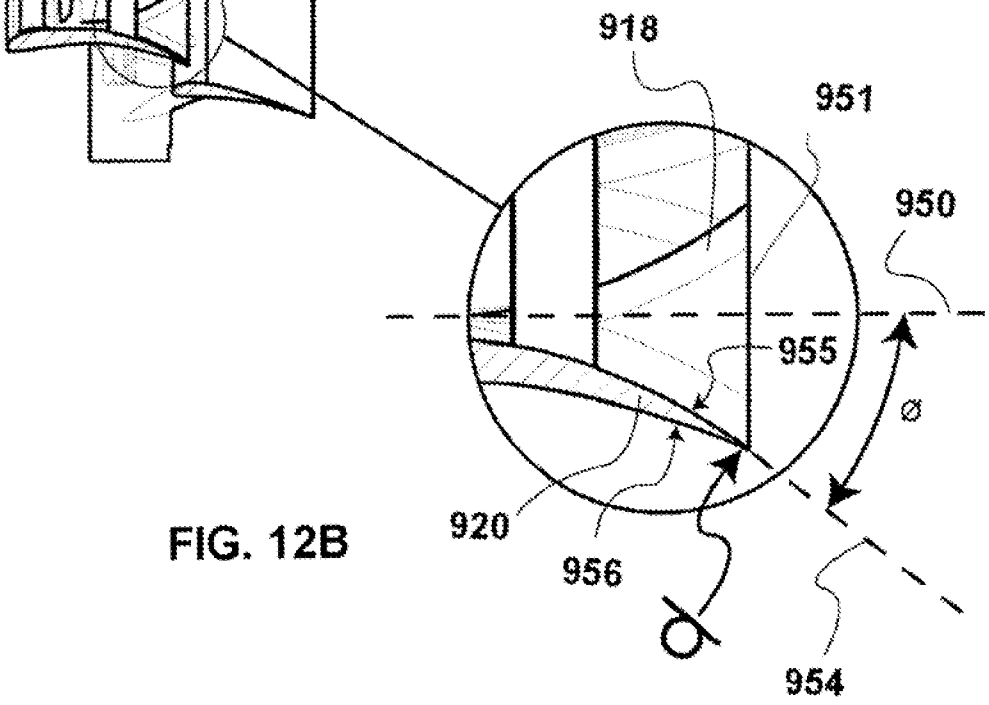


FIG. 12B

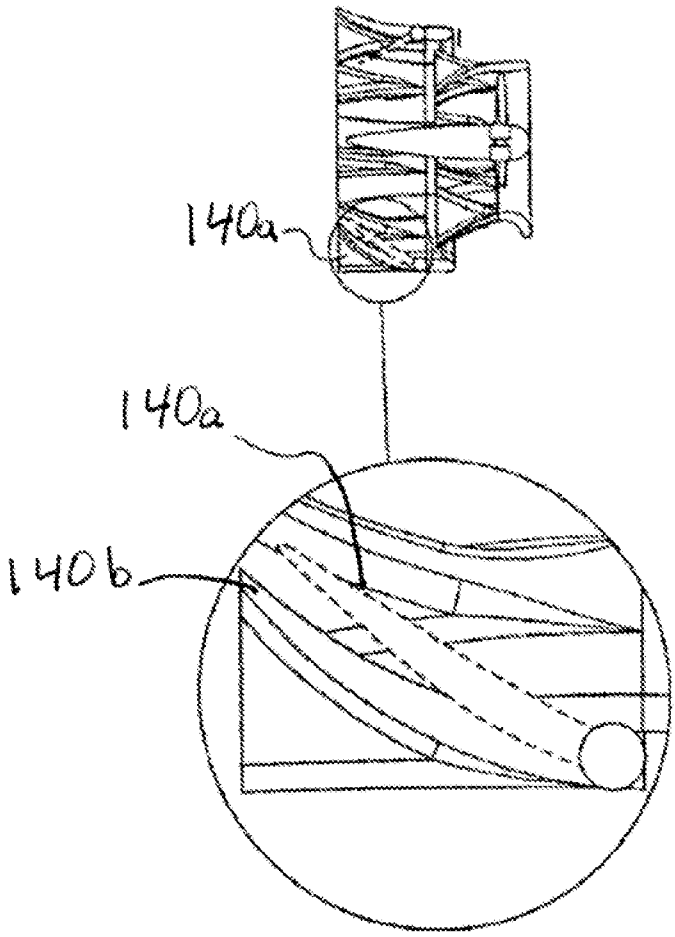


FIG. 13A

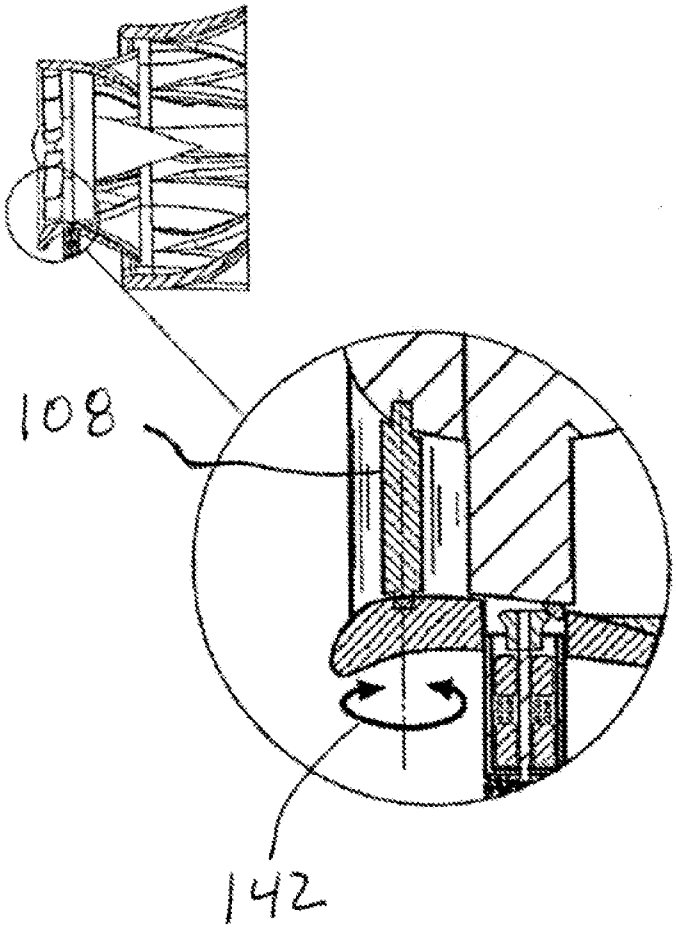


FIG. 13B

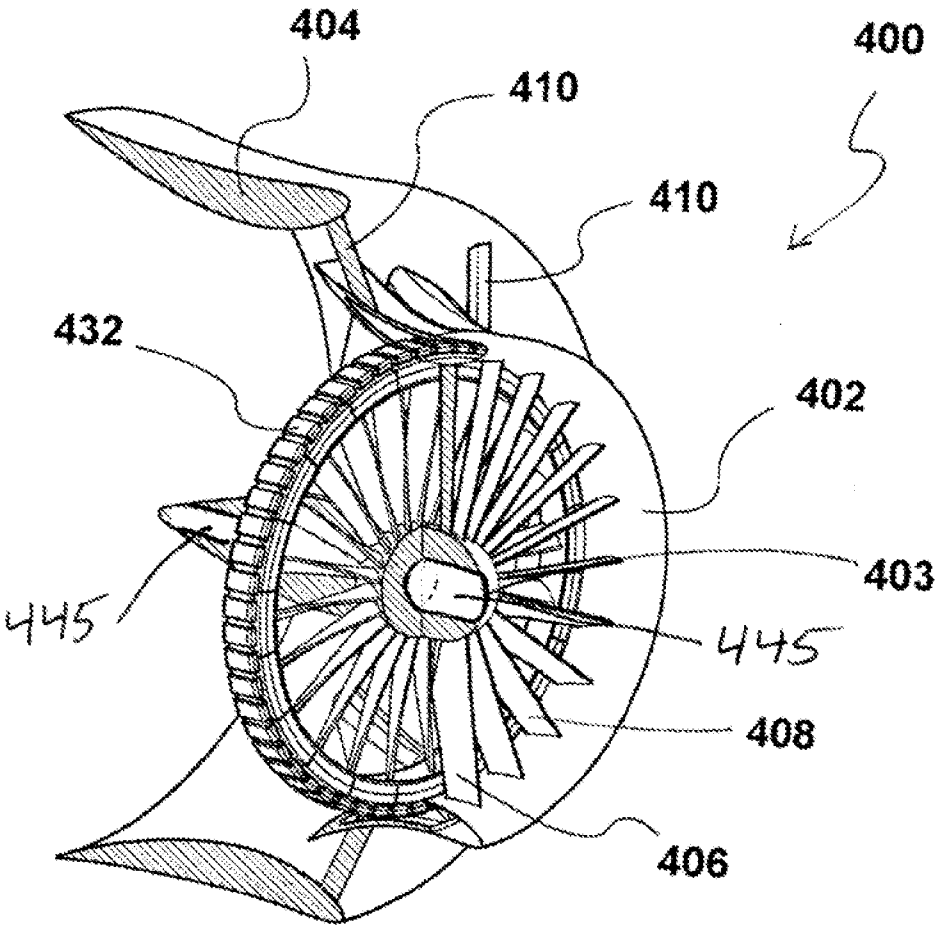


FIG. 14

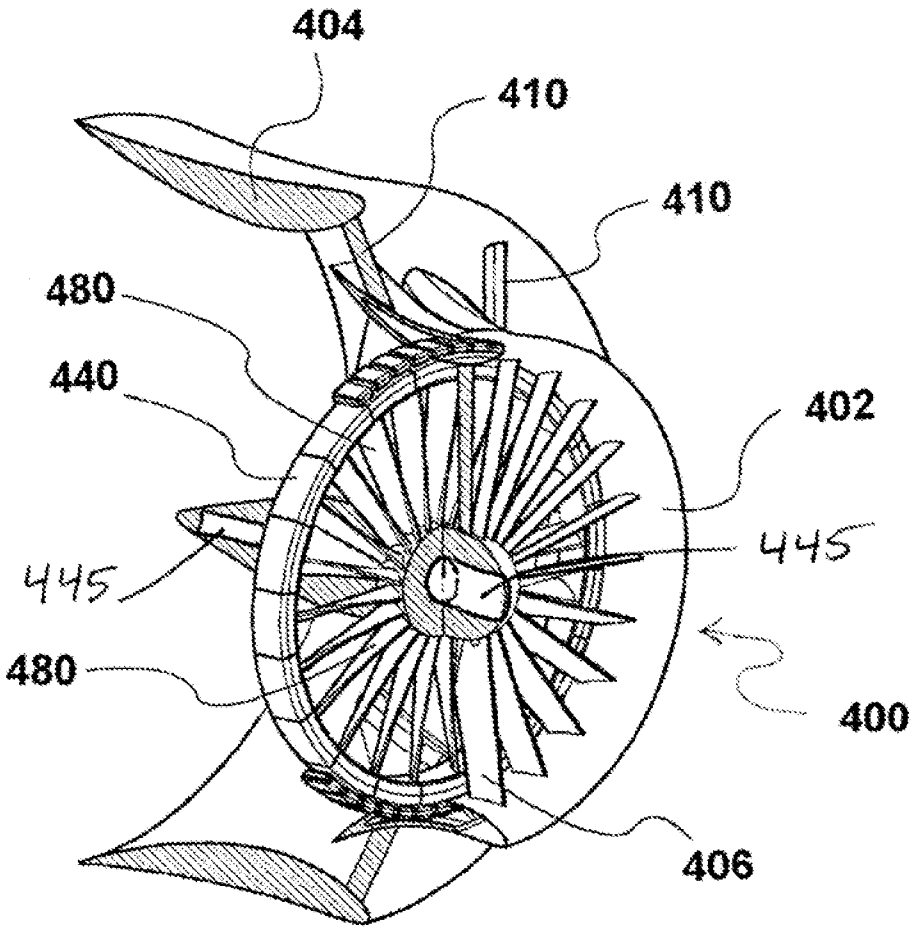


FIG. 15

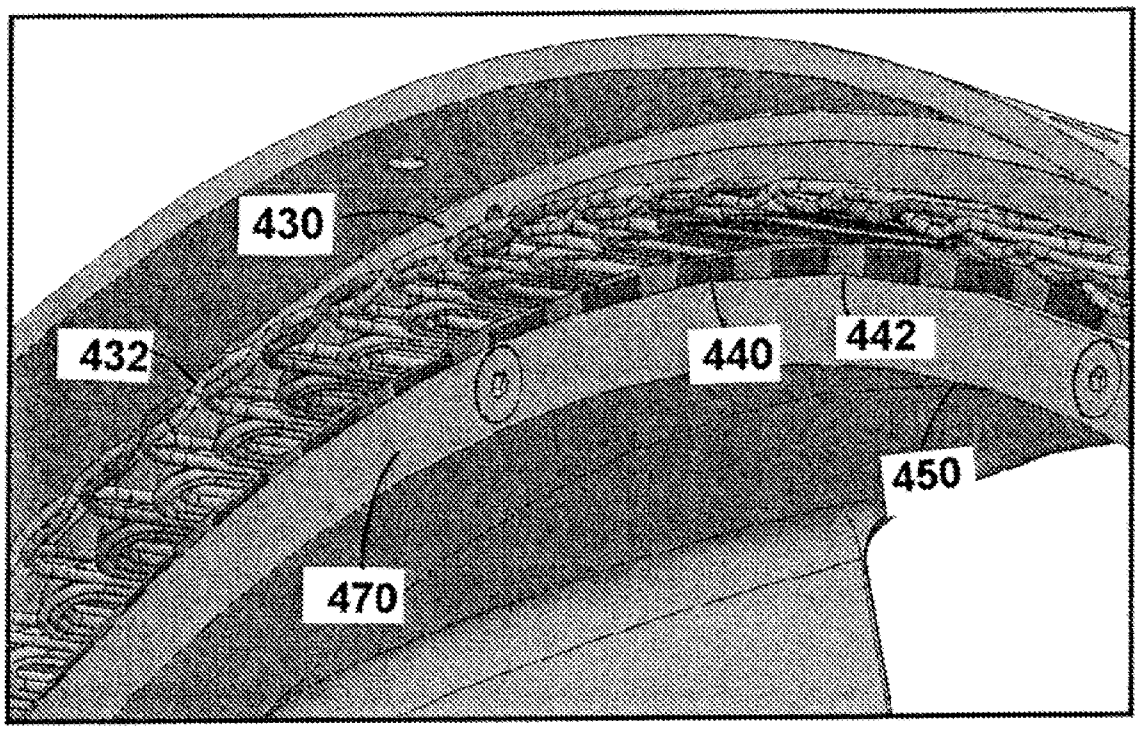


FIG. 16

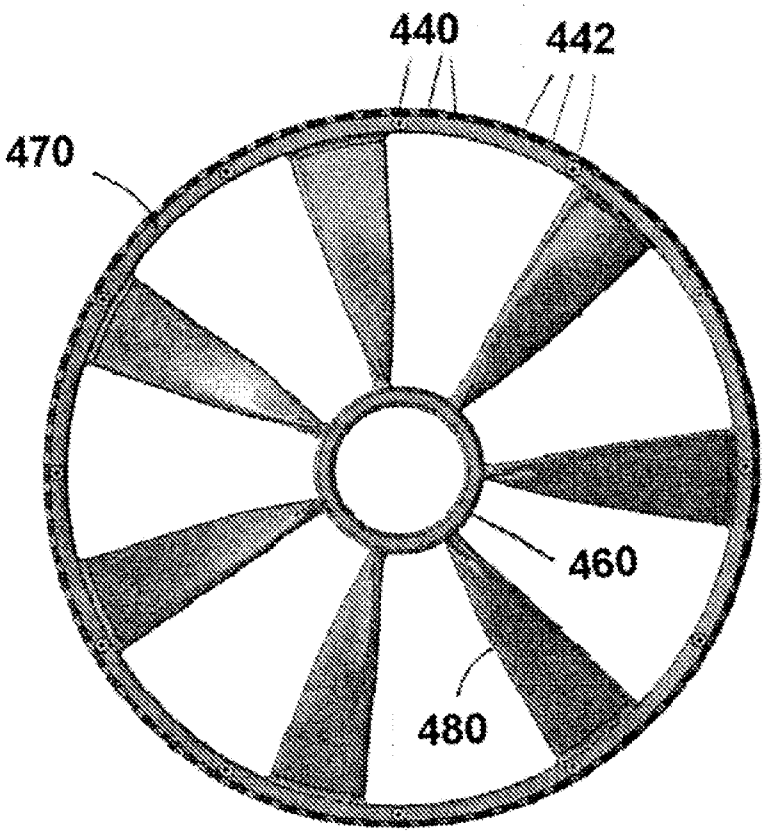


FIG. 17

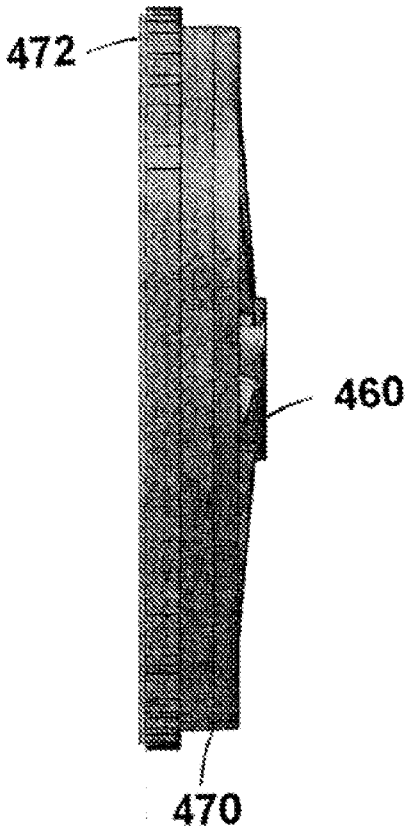


FIG. 18

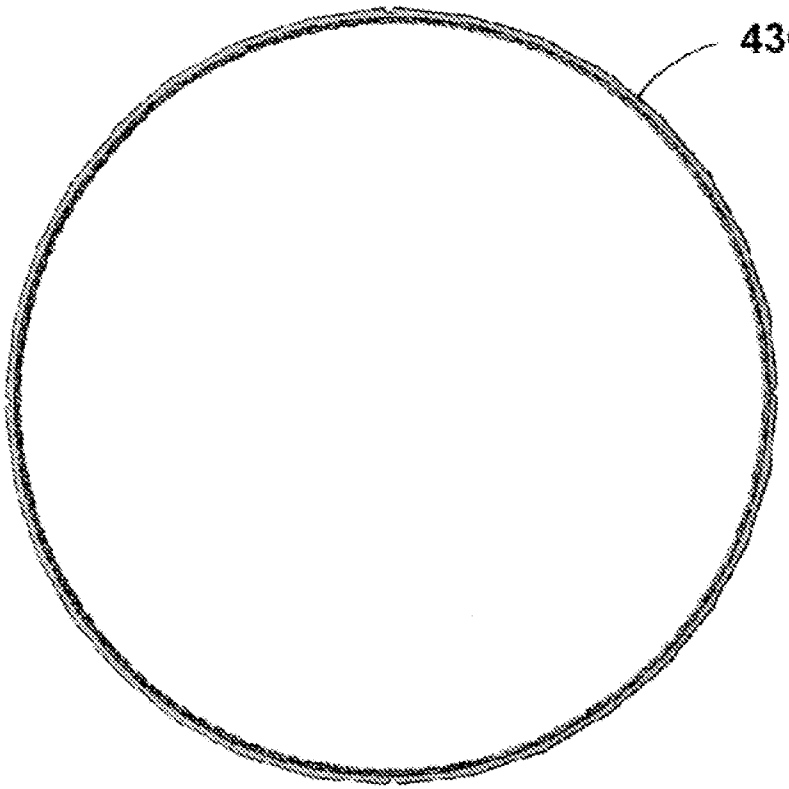


FIG. 19

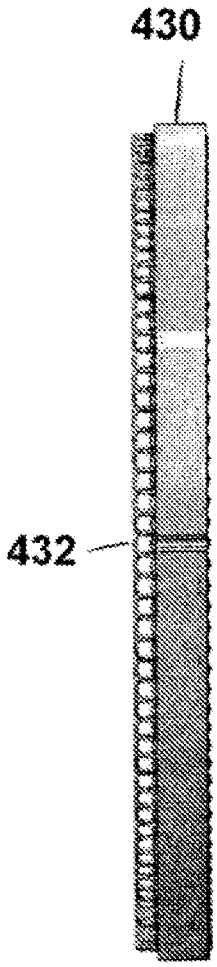


FIG. 20

FIG. 21

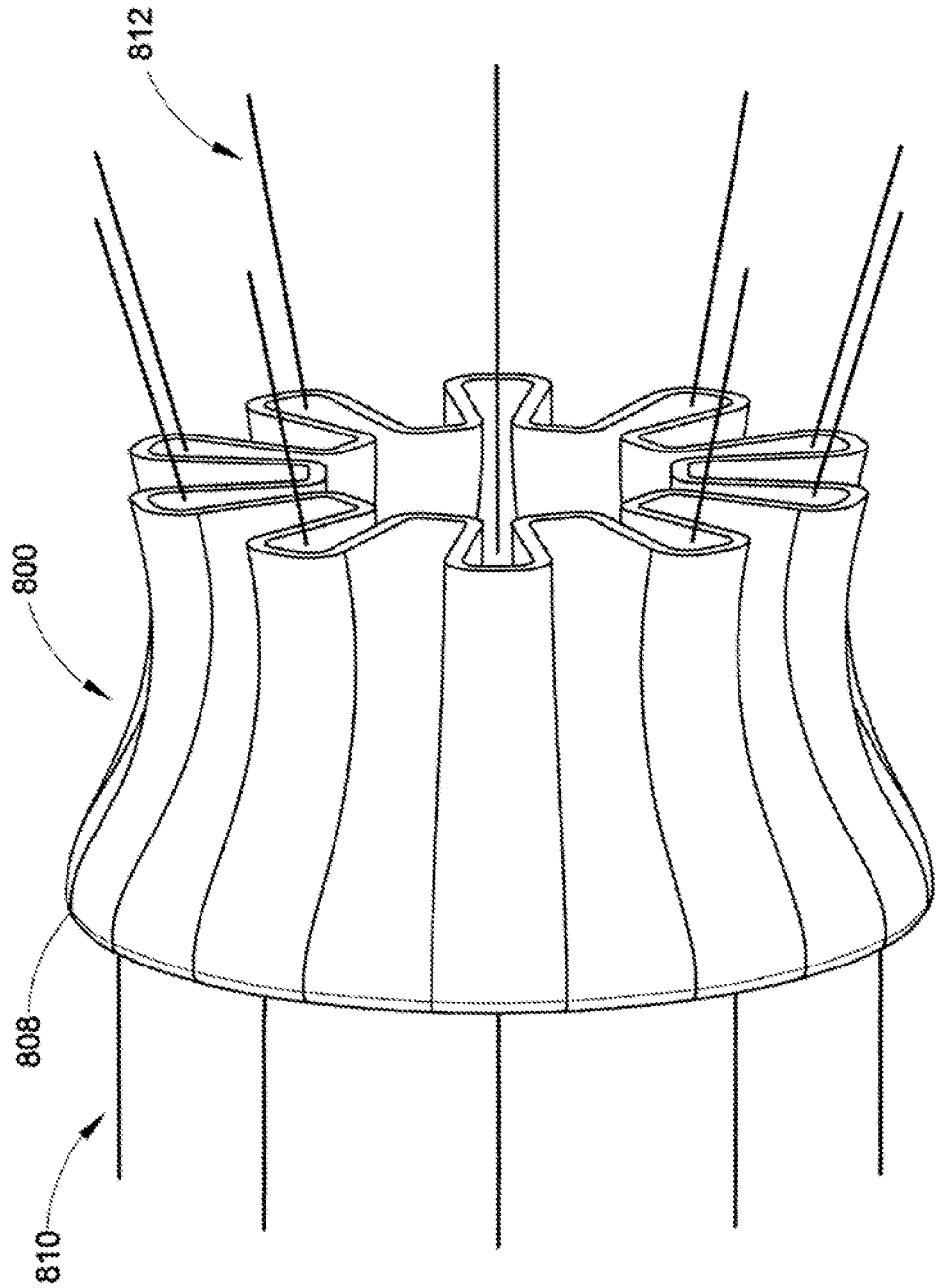
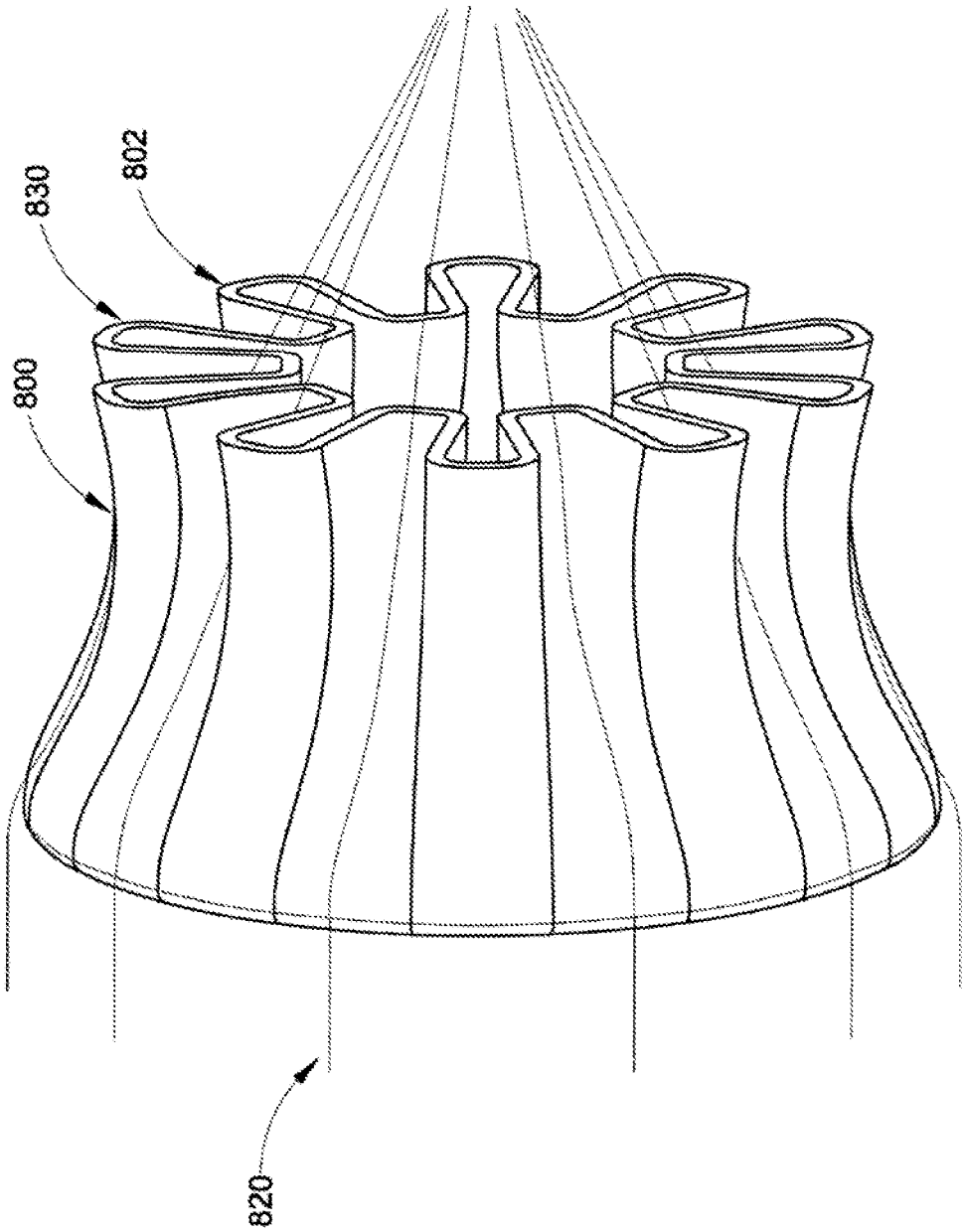


FIG. 22



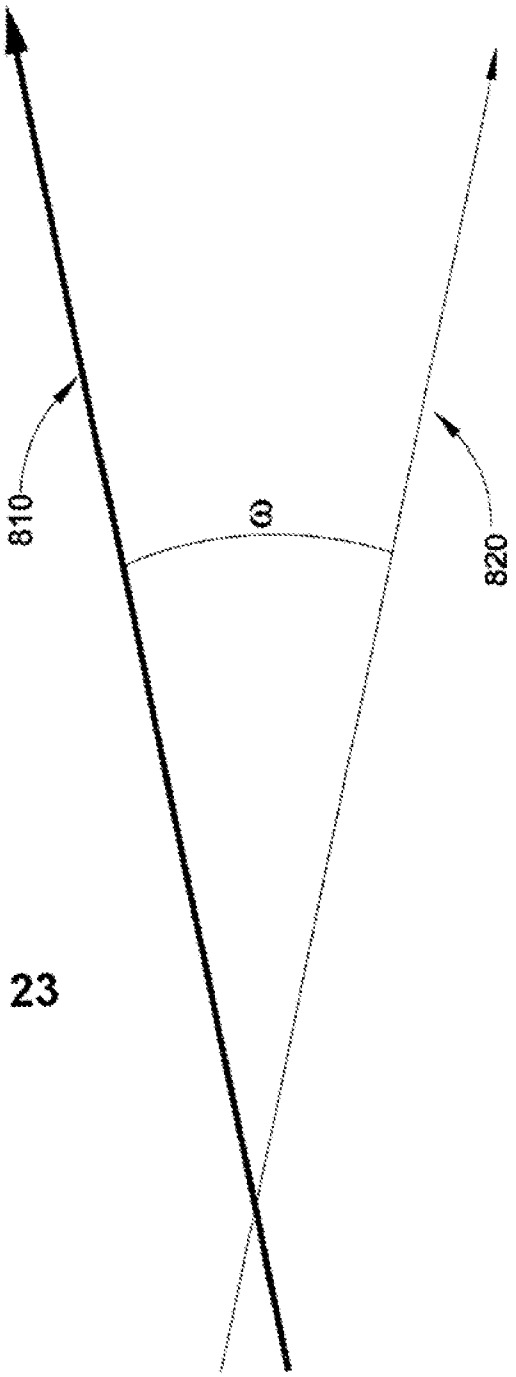


FIG. 23

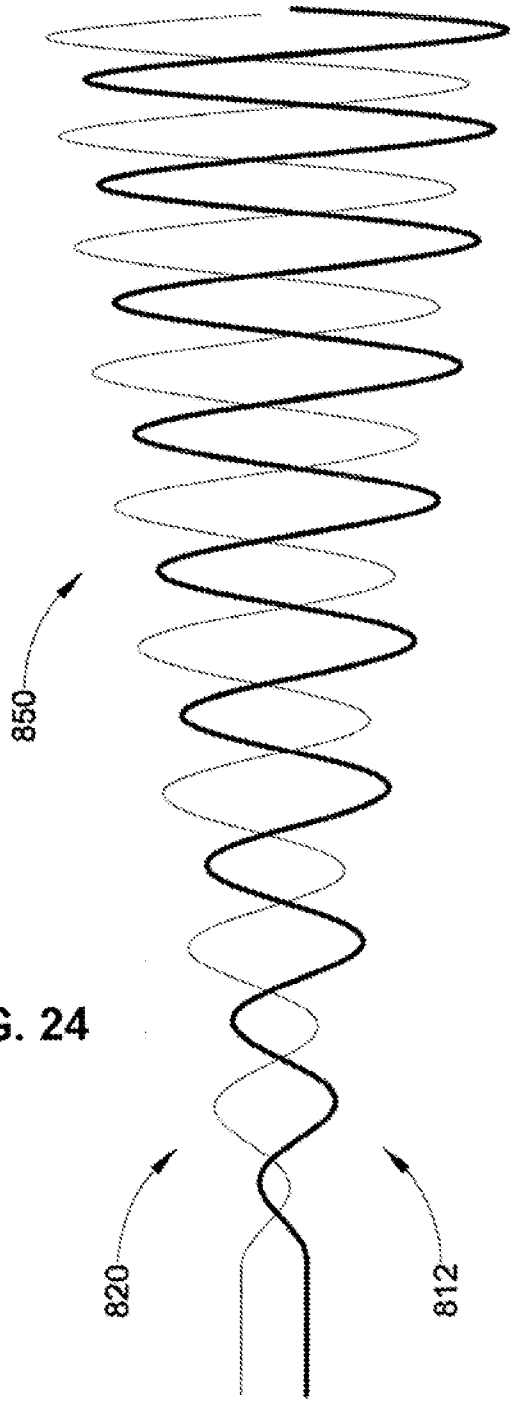
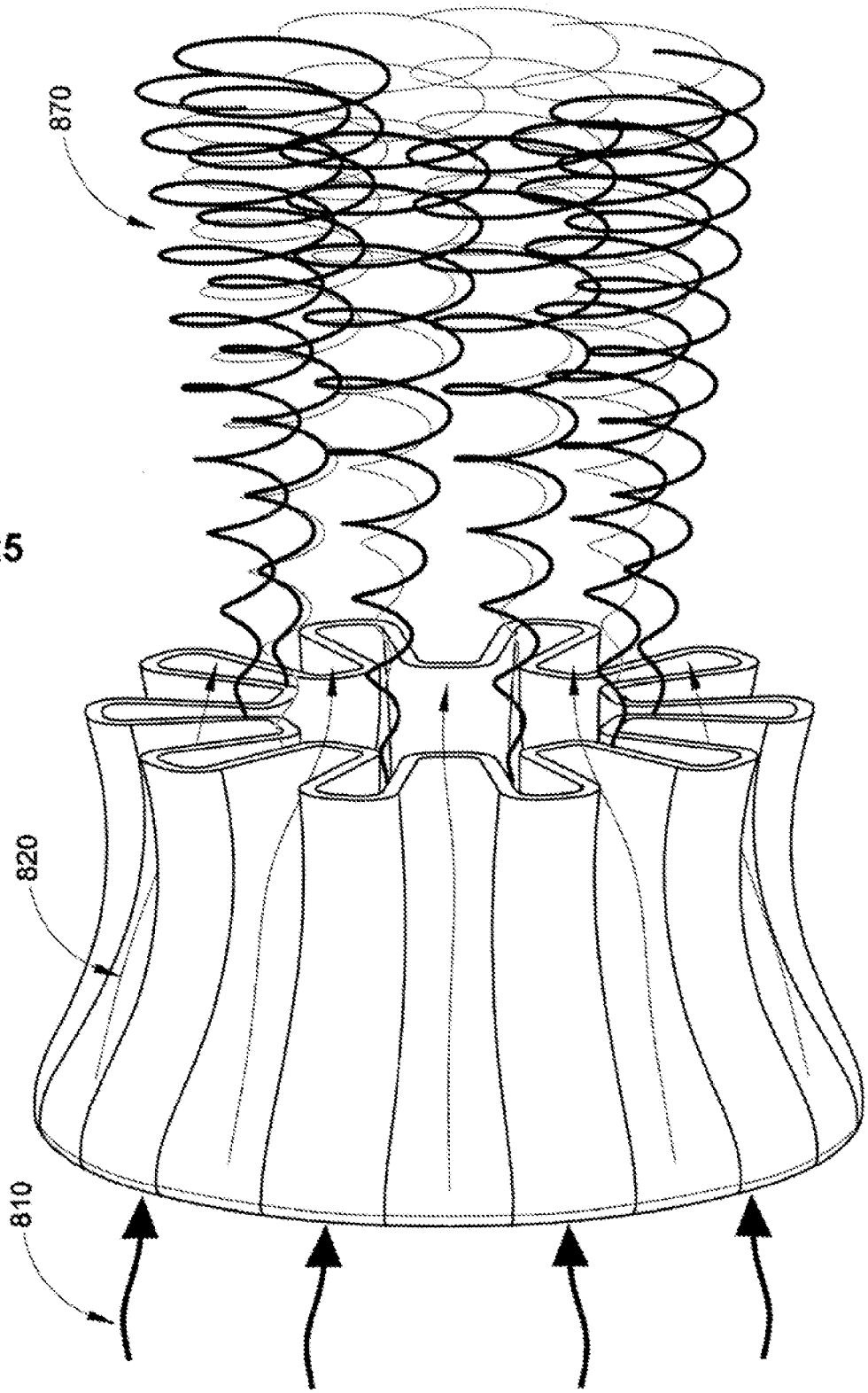


FIG. 24

FIG. 25



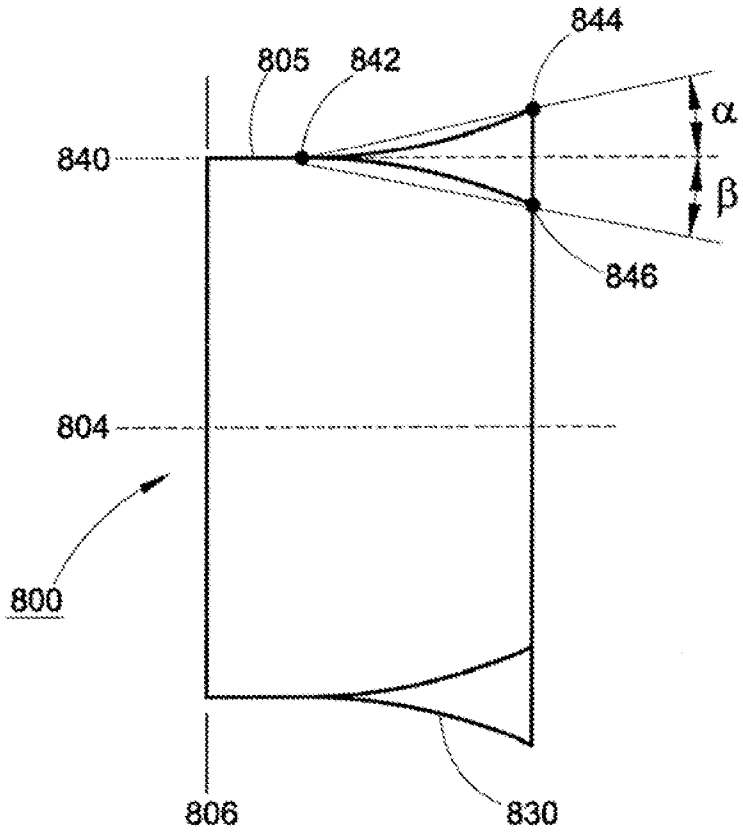


FIG. 26

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/029079

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F03D 1/04 (2010.01)
USPC - 415/220
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) - F03D 1/00, 1/04 (2010.01)
USPC - 290/55; 415/4.3, 4.5, 220

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/0232957 A1 (PRESZ et al) 25 September 2008 (25.09.2008) entire document	1-21
Y	US 4,140,433 A (ECKEL) 20 February 1979 (20.02.1979) entire document	1-21
Y	US 4,548,034 A (MAGUIRE) 22 October 1985 (22.10.1985) entire document	5, 6, 17-21
Y	US 4,781,522 A (WOLFRAM) 01 November 1988 (01.11.1998) entire document	11, 12
A	US 3,579,993 A (TANNER et al) 25 May 1971 (25.05.1971) entire document	1-21
A	US 5,761,900 A (PRESZ JR) 09 June 1998 (09.06.1998) entire document	1-21
A	US 6,276,127 B1 (ALBERTI) 21 August 2001 (21.08.2001) entire document	1-21

☐ 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
28 April 2010	21 MAY 2010
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)