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(54) Title: WIND DRIVEN POWER GENERATION SYSTEM

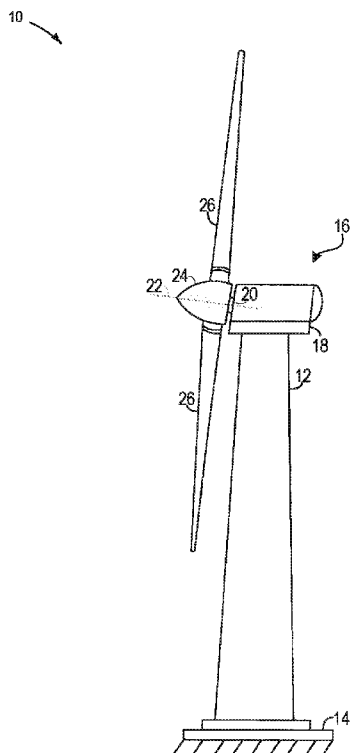


FIG. 1

(57) Abstract: A wind driven power generation system includes a transmission assembly, a transmission, and/or a gearbox. The gearbox includes a first gear-train and a rotating conduit, which is configured to receive lubrication fluid from downstream of the rotating conduit and deliver lubrication fluid upstream of the rotating conduit. Components downstream of the rotating conduit rotate at a different speed than upstream components. The transmission includes a second gear-train enclosed by an outer housing. The outer housing includes a torque reacting joint coupling a first section of the transmission to a second section of the outer housing. The transmission assembly includes a transmission (comprising an input carrier and a gear-train rotatably coupling the input carrier to a transmission output) and a removable input bearing cartridge. The removable input bearing cartridge is coupled to a periphery of the input carrier, exterior to the gear-train, in axial alignment with the input carrier.



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WIND DRIVEN POWER GENERATION SYSTEM

BACKGROUND

[0001] Embodiments of the invention relate to devices for generating electrical power using wind as a motive force.

[0002] The wind turbine industry has been experiencing unprecedented growth in recent years due to the demand for clean, renewable energy. Small and efficient design has been a central objective of the wind turbine industry, to reduce the cost of the wind turbine and in some cases increase the turbine's efficiency. However, small and efficiently designed wind turbines may be difficult to achieve for a multitude of reasons.

[0003] Wind turbines typically include a transmission, such as a gearbox, to transfer and adjust power from turbine blades to a generator. Specifically, the transmission adjusts the speed and the torque from the rotor blades, allowing energy to be efficiently generated in the generator of the wind turbine. However, not only does the transmission transfer the wind generated input to an electric machine for power generation, but it also reacts the wind-generated input torque by an equal and opposite reaction torque. This reaction torque is generally proportional to the size and power output of the turbine. Thus, as the size and power output is increased, the reaction torque is also increased. As such, as the power generated by wind turbines continues to rise, so does the reaction torque that is provided by the transmission, thus frustrating the goal of maintaining a small and efficient wind turbine design.

[0004] In the past, attempts have been made to increase the size of various coupling hardware, such as bolts, in the transmission housing to compensate for the increased reaction torque carried by the transmission. Likewise, the overall size of the transmission housing may

also be increased to compensate for the increased reaction torque. However, in some transmission designs, such as differential planetary gearboxes, the size of the coupling hardware may be restricted due to location, size, etc., of other components included in the transmission. Further, requirements related to locating, packaging, and servicing the transmission in the wind turbine, and properly installing and mounting the transmission to the wind driven blades and the electric power generation units, may also limit the ability to increase the coupling elements of the transmission housing and/or the size of the transmission housing.

[0005] Additionally, standardization of various components included in wind turbines has been slow to catch on, due to the rapid growth. Many smaller manufacturers order small production runs of components, such as transmissions, designed to meet individual specifications, necessitating a unique manufacturing process. Some transmission manufacturers have made attempts to include an integrated bearing, receiving the majority of the loads from the rotor blades and the rotor head, into the transmission, decreasing the transmissions modularity. The integrated bearing may be positioned at various locations within the transmission, preventing easy installation. Consequently, removal and repair of the bearing may be difficult and laborious. The decreased modularity, as well as the difficult installation and removal process, may considerably increase the cost of the transmission.

[0006] Lubrication systems are used in many wind turbines to circulate oil through the gearbox. The lubrication system may decrease the friction between moving components as well as providing cooling for components within the gearbox, thereby decreasing the losses within the gearbox and increasing the lifespan of the wind turbine.

[0007] Many previous lubrication systems have made attempts to externally route oil lines through the outer housing of the gearbox to provide lubrication fluid to various rotating

components in the gearbox, such as bearing and gear meshes in an upwind portion of the gearbox. However, due to the large size of the components included in the gearbox and the small diameters of the oil lines, the oil lines may become damaged, and in some cases, ruptured during installation and/or repair of up-tower components. Therefore, the cost of installation and repair may be increased. Additionally, degradation or possible failure of the gearbox may occur when ruptured oil lines are not discovered. Furthermore, externally directing oil lines into various internal components within the gearbox may be difficult, due to the gearbox's compact design. Therefore, proper lubrication of the gearbox may not be achieved when using external oil lines, thereby decreasing the lifespan of the gearbox.

BRIEF DESCRIPTION OF THE INVENTION

[0008] An embodiment of the present invention relates to a wind driven power generation system, e.g., for inclusion in a wind turbine having one or more wind driven rotor blades. The system comprises a transmission assembly, which includes a transmission and a removable input bearing cartridge. The transmission comprises an input carrier and a gear-train rotatably coupling the input carrier to a transmission output. The input carrier is configured to transfer a rotational input from the rotor blades to the gear-train. The removable input bearing cartridge is coupled to a periphery of the input carrier, exterior to the gear-train, and is in axial alignment with the input carrier. In this way, the removable input bearing cartridge may be installed subsequent to assembly of the transmission, thereby increasing the modularity of the transmission and allowing the transmission to be used in a multitude of wind turbine designs. Also, the installation and removal process is simplified, decreasing the cost of installation as well as repair.

[0009] In another embodiment, the wind driven power generation system comprises a transmission having a gear-train and an outer housing enclosing the gear-train. The outer housing includes a torque reacting joint coupling a first section of the transmission to a second section of the outer housing. The torque reacting joint includes mating indents between the first and second sections. In this way, by carrying the reaction torque substantially via the mating indents, it is possible that coupling hardware size, as well as transmission housing size, can be reduced. Further, by carrying the reaction torque substantially via the mating indents, the mating surfaces of the first and second sections of the outer housing are more free to flex and/or deform, thus more evenly distributing the reaction load and improving radial alignment of the gear-train in the gearbox.

[0010] In another embodiment, the wind driven power generation system comprises a gearbox having a gear-train (including an input and an output) and a rotating conduit internally traversing the gear-train. The rotating conduit is configured to receive lubrication fluid from one or more components downstream of the rotating conduit, and to deliver lubrication fluid to one or more components upstream of the rotating conduit. Additionally, the components upstream of the rotating conduit may rotate at a different speed than components downstream of the rotating conduit. In this way, increased lubrication may be provided to the gearbox while simplifying installation and repair procedures, thereby increasing the longevity of the wind turbine and driving down the cost of the wind turbine.

[0011] This brief description is provided to introduce a selection of concepts in a simplified form that are further described below. This brief description is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit

the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF FIGURES

[0012] The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

[0013] FIG. 1 shows an illustration of a wind driven power generation system, e.g., wind turbine;

[0014] FIG. 2 illustrates a schematic depiction of a nacelle included in the system shown in FIG. 1;

[0015] FIG. 3 shows a cut away view of a transmission included in a wind turbine, according to an embodiment of the present invention;

[0016] FIGS. 4A and 4B show a detailed view of a torque reacting joint, according to an embodiment of the present invention;

[0017] FIG. 5A and 5B shows an exploded view of the torque reacting joint illustrated in FIG. 4A and 4B, including a housing mating surface and a gear-train mating surface;

[0018] FIGS. 6A and 6B show a detailed view of a gear-train mating surface included in the torque reacting joint, shown in FIG. 5B;

[0019] FIGS. 7A and 7B shows a detailed view of the housing mating surface, shown in FIG. 5A;

[0020] FIGS. 8-9 show various detailed views of the torque reacting joint illustrated in FIGS. 4A and 4B;

[0021] FIGS. 10 and 11 illustrate various isometric view of the transmission, shown in FIG. 3;

[0022] FIG. 12 illustrates a schematic depiction of a nacelle, according to an embodiment of the present invention, which may be included in a power-generating wind turbine as shown in FIG. 1;

[0023] FIG. 13A shows a cut-away view of a gearbox and associated lubrication system included in a wind turbine, according to an embodiment of the present invention;

[0024] FIG. 13B illustrates an expanded view of a rear lubrication manifold included in the gearbox shown in FIG. 13A;

[0025] FIGS. 13C and 13D shows various views of a tube-in-tube assembly included in the gearbox shown in FIG. 13A;

[0026] FIG. 13E illustrates an expanded upwind lubrication manifold included in the gearbox shown in FIG. 13A;

[0027] FIG. 14 illustrates a cut away side view of a transmission assembly, according to an embodiment of the present invention;

[0028] FIG. 15 shows an isometric view of the transmission assembly shown in FIG. 14;

[0029] FIG. 16 illustrates a detailed view of an input bearing cartridge and an input carrier included in the transmission assembly, shown in FIG. 14;

[0030] FIG. 17 illustrates an isometric view of the input bearing cartridge and the input carrier shown in FIG. 16;

[0031] FIG. 18 shows an exploded view of the bearing cartridge and the input carrier shown in FIG. 16; and

[0032] FIG. 19 shows a method which may be used to assemble a transmission assembly.

DETAILED DESCRIPTION

[0033] Various embodiments of the present invention relate to a wind driven power generation system, e.g., for inclusion in a wind turbine having one or more wind driven rotor or turbine blades. In one embodiment, the wind driven power generation system comprises a transmission having a torque reacting joint configured to react torque generated by the wind interacting with the turbine blades. The torque reacting joint may be configured to react a substantial amount of the wind-generated torque while maintaining a compact and efficient design using mating indents in a housing of the transmission. In another embodiment, the wind driven power generation system comprises a gearbox having a gear-train (including an input and an output) and a rotating conduit internally traversing the gear-train. The conduit is part of a lubrication system for the wind driven power generation system. The lubrication system may internally direct oil to various components included in a gearbox of the wind turbine, thereby increasing the lubrication provided to the components, and decreasing the likelihood of rupturing an external lubrication line during installation and repair. In another embodiment, the wind driven power generation system comprises a transmission assembly with a removable input bearing cartridge, for increasing the modularity of the transmission and simplifying the installation and removal of the transmission.

[0034] FIGS. 1 and 2 describe an example wind turbine operating environment in which the various embodiments of the wind driven power generation system may be used/implemented, although they may be used in other applications or in wind turbines other than those shown in FIGS. 1 and 2.

[0035] A power generating wind turbine 10 is shown in FIG. 1. The turbine includes a tower 12 extending substantially vertically out of a base 14. The tower may be constructed from a plurality of stacked components. However, it can be appreciated that alternate configurations of the tower are possible, such as a lattice tower. A nacelle 16 and nacelle bedplate 18 are positioned atop the tower. A drive unit (not shown) may be included in the nacelle bedplate, allowing the nacelle to rotate about a horizontal plane. The nacelle may be positioned, by the drive unit, directly into the wind, increasing the power output of the wind turbine. Further in some examples, a pitch unit controls the vertical pitch of the blades. The nacelle houses a power generation system having a transmission and a generator, shown in FIG. 2 discussed in greater detail herein. Further, various power electronics and control electronics may be housed in nacelle 16.

[0036] As used herein, the wind turbine is positioned with the rotor pointed into the wind, and thus upwind refers to a longitudinal direction pointing from the generator toward the rotor blades and downwind refers to the opposite direction. Furthermore, upwind and downwind components may be used to define the relative position of components included in the wind turbine.

[0037] Continuing with FIG. 1, a main shaft 20 extends out of the nacelle. The main shaft may be coupled to a transmission by an input carrier (not shown) sharing a common central axis 22 with the main shaft. Furthermore, the main shaft 20 may be coupled to a rotor head 24. A plurality of rotor blades 26 may be radially position around the rotor head 24. A wind force (not shown, but generally corresponding to the arrow of element number “10” in FIG. 1) may act on the rotor blades, rotating the blades and therefore the rotor head about the central axis. Thus, the

rotor head may be wind driven. The rotor head may also be configured to reduce drag on the wind turbine, thereby reducing the axial load (e.g., thrust load) on bearings in the wind turbine.

[0038] FIG. 2 shows a detailed illustration of the nacelle 16 housing a transmission 212 included in a power generation system 210 of the wind turbine 10. The power generation system 210 is configured to efficiently convert rotational energy from wind driven rotor blades to electrical energy. The power generation system may include the transmission 212 configured to increase the rotational speed of the main shaft 20 and a generator 214 configured to convert mechanical energy from the transmission into electrical energy. A pitch control system 218 may also be included in the nacelle. The transmission 212 may include an input and an output. The input is configured to transfer rotation from the main shaft to a gear-train (not shown in this figure) and the output is configured to transfer rotation from the transmission to the generator 214, e.g., via an output shaft 216. The transmission is configured to adjust the speed and/or torque of the rotational input from the wind actuated rotor head, allowing the generator to more efficiently utilize the rotational energy from the transmission to extract electrical power from the power generation system. For instance, the transmission may increase the rotational speed of the input, while reducing torque.

[0039] A number of suitable transmissions having an input and an output, which may be axially aligned, can be utilized. Specifically, in this example, a differential planetary transmission is used. Various types of generators may be coupled to the transmission to produce power in the wind turbine, such as an induction type, wound type, synchronous type, secondary resistance control wound induction type (rotor current control or RCC type), secondary excitation control wound induction type (static Scherbius or D.F. type), permanent magnet type,

induction multiple type, etc. Additionally, the generator may be coupled to an electrical transmission system, which may be routed through the tower to the base of the wind turbine.

[0040] It can be appreciated that additional up-tower components may be included in the nacelle 16, such as electrical transmission components including but not limited to a transformer, a generator cooling system such as an open or closed loop heat exchanger, a transmission lubrication system, etc.

[0041] FIG. 3 shows a cut-away side view of a transmission 300, which is included in a wind driver power generation system according to an embodiment of the present invention. The transmission 300 includes a torque reacting joint 324. FIGS. 3-10 show various embodiments of the torque reacting joint.

[0042] In some examples, transmission 300 may be similar to transmission 212. However, in other examples, the transmission 300 may be another suitable transmission. The transmission 300 may be configured to increase the speed of the rotational input from the rotor blades, reducing the torque. The transmission 300 may include an outer housing 302 and a gear-train 304. In some examples, the outer housing may at least partially enclose a gear-train and/or a portion of the transmission. Additionally, the gear-train may include an input carrier 306 and an output shaft 308, forming a transmission input and output, respectively. The input carrier may receive rotational input from the rotor blades and the output shaft may transfer rotational output to a generator. It can be appreciated that in other examples, alternate inputs and outputs may be utilized.

[0043] As noted above, the transmission may be a differential planetary transmission including two power paths. The first power path includes an attachment between the input carrier 306 and a plurality of upwind planet gears 310. The input carrier may be directly coupled

to a pinion of each respective planet gear. Each planet gear may include one or more bearings 312 or bearing sets, allowing the planet gears to rotate. A first ring gear 314 may be in engagement with the upwind planet gears, facilitating proper rotation of the planet gears. The second power path may include an attachment between the input carrier and a second ring gear 316. In turn, the ring gear may drive one or more downwind planet gears 318. Both the upwind and the downwind planet gears may drive a sun gear 320 forming an output of the transmission. Thus, the gear-train includes two power paths which drive a sun gear forming or coupled to an output, such as an output shaft. In some examples, the output may include a parallel stage shaft rotatably coupled to the output shaft. In other examples, alternate suitable transmissions may be used. Additional gears may also be included in the gear-train 304.

[0044] Furthermore, additional components may also be included in the transmission, such as a pitch tube 322. The pitch tube may transverse the transmission as well as house various conduits used to control the position of components in the wind turbine, such as the angle of the rotor blades. Additionally, a lubrication system (not shown) may be used to lubricate various components included in the transmission. Further still, a cooling system (not shown), such as an open or closed loop cooling system, may be included in the transmission.

[0045] Continuing with FIG. 3, the transmission 300 may receive rotational input from rotor blades and transfer the rotational input through the gear-train, as discussed above. A torque reacting joint 324, included in the transmission, may be configured to react the torque in the gear-train through generation of an equal and opposite reaction torque. The torque reacting joint may be compactly and efficiently designed, increasing the torque density, and enhancing the space saving features of the wind turbine.

[0046] In this example, the torque from the downwind planet gears 318 may be transferred to the torque reacting joint 324 through a carrier attachment 325. The torque reacting joint 324 may be included in the outer housing 302 of the transmission, which may be fixedly coupled to a stationary component included in the nacelle, such as the bedplate 18, illustrated in FIG. 1, thereby reacting the torque in the gear-train. A suitable component, such as a housing flange 326, may couple the outer housing of the transmission to the bedplate. Various detailed views of the housing flange are further illustrated in FIGS. 4A, 4B, 5A, 5B, 10, and 11, discussed in greater detail herein. It can be appreciated that the torque reacting joint may be coupled to alternate or additional components in the transmission or wind turbine, such as the first ring gear 314, the transmission output including a parallel stage shaft (not shown), and/or a generator (not shown).

[0047] Due to installation requirements, an outer radius 328 of the torque reacting joint, as illustrated in FIG. 3, may be restricted. In particular, the outer radius of the torque reacting joint may not exceed the inner radius 330 of the housing flange 326, preventing interference of the inner torque reacting joint with the housing flange, allowing various tools, such as a drill or reamer head, to be inserted into the housing flange 326 during assembly, disassembly, and/or repair. Therefore, the installation process may be simplified when a compact and efficiently designed torque reacting joint is utilized, decreasing the cost of the wind turbine. Various detailed views of an example torque reacting joint are shown in FIGS. 4A-5B.

[0048] Specifically, FIG. 4A illustrates a more detailed view of the torque reacting joint 324 included in an outer housing 302. The torque reacting joint 324 may facilitate torque transfer from a carrier attachment 404 to a gear-train housing 406. In this example, carrier attachment 404 may be similar to carrier attachment 325. Further, in this example, the carrier attachment is

coupled to one or more planet carriers, the planet carrier fixing rotation of the one or more planet gears, discussed in greater detail herein with regard to FIGS. 5A and 5B. In this example, the torque reacting joint is radially aligned in that the gear-train and the torque reacting joint have a common center axis 407, allowing for proper load distribution through the torque reacting joint with the gear-train housing positioned upwind of the carrier attachment. However, in other examples, the gear-train housing may be positioned downwind of the carrier attachment. Further, in this example, the gear-train housing encloses a substantial majority of the gear-train, reducing the likelihood of unwanted particulates entering the gear-train, as well as reducing leakage of lubrication fluid from the gear-train.

[0049] Continuing with FIG. 4A, the torque reacting joint may include mating indents 408 between the first and the second sections of the transmission (the carrier attachment and the gear-train housing, in this example), which may be circumferentially formed (meaning that the mating indents extend around the circumference of the torque reacting joint). The mating indents may include a contacted surface area. Various configurations of the mating indents 408 may be used, such as interference keys, splines, etc. Thus, in some examples, the indents in the torque reacting joint may be in the shape of splines. Further, in some examples, the indents may form an interference fit. As should be appreciated, the term “mating indent” refers to a structure that defines a recess in a first part (e.g., the first section of the transmission), which accommodates a correspondingly shaped protuberance in a second part (e.g., the second section of the transmission).

[0050] In this example, the mating indents 408 may include alternating projected and recessed portions, 410 and 412 respectively, allowing an increased amount of torque to be transferred between the first and the second sections of the transmission via the torque reacting

joint, while maintaining a compact and efficient design, thereby increasing the torque density. In other examples, the mating indents may have alternate geometries. An exploded side view of the torque reacting joint is shown in FIG. 4B, illustrating the two section of the transmission coupled through the torque reacting joint.

[0051] Another exploded view of the torque reacting joint 324 is shown in FIG. 5A and 5B, illustrating a more detailed view of the gear-train housing 406 and the carrier attachment 404, which may be coupled to form the torque reacting joint. Specifically FIGS. 5A and 5B illustrate a gear-train mating surface 502 and a housing mating surface 504. The aforementioned surfaces may be mated to form the mating indents of the torque reacting joint. The housing mating surface may further include alternating projected and recessed portions, 506 and 508 respectively, as shown in FIG. 5A. Additionally, the gear-train mating surface may further include alternating projected and recessed portions, 510 and 512 respectively, as shown in FIG. 5B.

[0052] FIG. 5A illustrates the housing mating surface 504, which may also include a plurality of cavities 514 extending into the gear-train housing 406. In this example, each projected and recessed portion may include a cavity positioned proximate to the geometric center of each respective projected portion and recessed portion. However, in other examples, the number and/or position of the cavities may be adjusted depending on various factors, such as design requirements. Further in this example, the cavities 514 extend axially, through the gear-train housing 406, parallel to the common central axis 407 (e.g., central axis of rotation) of the transmission, and may be sized to accept fasteners, such as coupling hardware (e.g., bolts, screws, rivets, or the like), discussed in more detail herein.

[0053] As illustrated in FIG. 5B, the gear-train mating surface 502 may also include a plurality of cavities 518, extending through the carrier attachment 404. In this example, each projected and recessed portion, 510 and 512 respectively, may include a cavity positioned proximate to the geometric center of each respective projected and recessed portion. However, in other examples the number and/or position of the cavities may be adjusted. The cavities extend axially, through the carrier attachment 404, parallel to the common central axis 407 of the transmission, and may be sized to accept fasteners, such as coupling hardware.

[0054] To facilitate torque transfer from the gear-train to the torque reacting joint 324, the carrier attachment 404 may be coupled to various components in the gear-train, as previously discussed. Therefore, in this example, as illustrated in FIG. 5B, the carrier attachment 404 may include a plurality of planet attachments 526, arranged around the central axis of rotation of the gear-train. The planet attachments 526 may be configured to fix the rotation of one or more planet gears included in the gear-train, shown in FIG. 3. One or more bearings or bearing sets may be coupled to the planet attachments, providing axial and/or radial support to the planet gears included in the gear-train as well as fixing the rotation of the planet gears. Suitable bearing types that may be used include cylindrical roller bearings, tapered roller bearings, or a combination thereof. In this example, the planet attachments are cylindrical. However, it can be appreciated that in other examples, the geometry and/or size of the planet attachments may be adjusted depending on various design specifications. Further, in other examples, the planet attachments may be configured to fix additional or alternate components included in the gear-train, such as a ring gear.

[0055] Returning to FIG. 5B, the carrier attachment 404 may include a central cavity 528. When the carrier attachment is assembled in the transmission the transmission's output (e.g., sun

gear) may extend through the central cavity. The transmission output may include a central rotating shaft and/or a sun gear.

[0056] To facilitate torque transfer from the torque reacting joint 324 to the nacelle (e.g., bedplate) the transmission (e.g., the outer housing 302) may additionally include, in some examples, a housing flange 326, as previously discussed. The housing flange 326 includes a plurality of axially aligned flange cavities 530 extending through the entire housing flange. Suitable coupling hardware, such as bolts, screws, rivets, and the like, may be used to couple the flange to the stationary component, such as the bedplate. In this way, reaction torque from the outer housing may be transferred to the nacelle. Thus, the gear-train housing and the carrier attachment may be fixed components. In other examples, the housing flange 326 may be coupled to alternate suitable fixed components in the nacelle. Further still, in other examples, another suitable attachment mechanism, such as two or more torque arms, may be used to fixedly couple the outer housing 302 to a stationary component in the nacelle.

[0057] Detailed views of both of the mating surfaces, discussed above, are shown in FIG. 6A-7B, further illustrating the geometries of each mating surfaces (the housing mating surface and the gear-train mating surface in this example). Specifically, FIGS. 6A and 6B show a detailed view of the gear-train mating surface 502, shown in FIG. 5B, and FIGS. 7A-7B show a detailed view of the housing mating surface 504, shown in FIG. 5A. Therefore, similar parts are labeled accordingly.

[0058] As illustrated in FIGS. 6A-6B, the projected and recessed portions, 510 and 512 respectively, may be planar and axially offset. However, in other examples, the projected and/or recessed portions may be curved in a convex or concave manner. In this example, the gear-train

mating surface is milled. However, in other examples, the gear-train mating surface may be cast, welded, etc.

[0059] Continuing with FIGS. 6A and 6B, the gear-train mating surface may further include, in some examples, a plurality of banks 602. Each bank may have three segments: two substantially straight segments, 604 and 606, and a curved segment 608. In some examples, the banks may be angled (e.g., tapered), discussed in more detail herein with regard to FIG. 8. The straight segments, 604 and 606, may be radially aligned with the central axis of rotation of the gear-train. Alternatively, in other examples, the straight segments may be parallel. Furthermore, the curved segment may be curved in suitable fashion, such as a parabolic curve, U-shaped curve, non-symmetric curve, etc. The radially alignment of the banks as well as the curved segment allows the mating indents to properly mate during operation of the wind turbine.

[0060] FIGS. 7A and 7B show a detailed view of the housing mating surface 504 included in the outer housing 302. To facilitate mating, the housing mating surface 504 may have a similar geometry to the gear-train mating surface 502. In this example, the projected and recessed portions (506 and 508 respectively), included in the housing mating surface, may be planar and axially offset. However, in other examples, the projected and/or recessed portions may be curved in a convex or concave manner. Further, in this example, the housing mating surface is milled. However, in other examples, the housing mating surface may be cast, welded, etc.

[0061] Continuing with FIGS. 7A and 7B, each of the projected portions 506, included in the housing mating surface 504, may include four banks (702, 704, 706, and 708). In this example, three of the banks (702, 704, and 706) are formed with an angle. The bank 708 may be axially aligned with the common central axis 407, illustrated in FIGS. 4A-5B. Returning to

FIGS. 7A and 7B, in this example, the banks 702 and 706 are radially aligned. However, in other examples, the banks 702 and 706 may be parallel.

[0062] FIG. 8 illustrates a detailed view of the carrier attachment mated with the gear-train housing, forming the torque reacting joint having mating indents. The mating indents may be formed with an angle 802. In this example, the angle is oblique. However, it can be appreciated that in other examples, the angle may be radially aligned (e.g., perpendicular) with the central axis of rotation of the gear-train. The angle 802 may be defined as the angle of intersection between an axially aligned plane 804 and a plane 806 parallel to one of the banks (602, 706, 708, and 710). The angle 802 may be adjusted to allow other components to carry a portion of the torque as axial force, discussed in more detail herein. Various parameters may be taken into account when determining the angle such as the surface area of at least a portion of the mating surfaces, the component's size (e.g., diameter), and the material grade of the components and the mating surfaces. In some examples, the angle 802 may be between 6° and 30° , that is, $6^\circ \leq (\text{angle } 802) \leq 30^\circ$.

[0063] The cavities included in both the housing mating surface and the gear-train mating surface, 504 and 502 respectively, discussed above, may be correspondingly positioned to allow fasteners 910 to be inserted axially through each cavity, when the torque reacting joint is formed through mating of the mating surfaces. Exemplary illustrations of the torque reacting joint including the fasteners are shown in FIGS. 9 and 11. Suitable fasteners that may be used include bolts, screws, and rivets. In some examples, the fasteners may be $\frac{3}{4}$ inch (M20) bolts. However, it can be appreciated that in other examples the size of the fasteners may be adjusted or the fasteners may not be included in the torque reacting joint.

[0064] Due to manufacturing tolerances, such as machining tolerances, a portion of the mating surfaces (e.g., housing mating surface and the gear-train mating surface) may not be in contact. Therefore, in some examples, the fasteners may be flexible, allowing the contacted surface area to be increased. Specifically, in this example, the fasteners may be configured to flex to a greater degree than the mating indents. The size, geometry, and/or material composition of the torque reacting joint as well as the fasteners may be adjusted to create the desired flexibility in the mating indents and the fasteners. Thus, during operation of the gear-train, the fasteners may deform, allowing the mated surface of the torque reacting joint to evenly distribute the loads transferred through the torque reacting joint 324 via increased contacted surface area. In this way, the stress on various portions of the mating indents may be decreased, thereby increasing the lifespan of the torque reacting joint. In some examples, the fasteners may be used for tension loading only. However, in other examples, the fasteners may provide support for both the tension and the shear loading.

[0065] FIGS. 10 and 11 show various isometric views of the assembled transmission and generator. Similar parts are labeled accordingly.

[0066] In one example, the wind driven power generation system, discussed above, may include the mating indents 408 having a first mating surface (e.g., the housing mating surface 504) and a second mating surface (e.g., the gear-train mating surface 502) having a contacted surface area. Further, in this example, the first and second mating surfaces may have axially offset and radially aligned projected and recessed planar surfaces (e.g., 510, 512, 506, and 508), obliquely angled banks (e.g., 608, 702, 704, 706) joining the projected and recessed planar surfaces, and centrally positioned cavities (e.g., 514 and 518). The centrally positioned cavities may extend through each of the first and second mating surfaces. Additionally, the cavities may

be configured to accept fasteners that may be configured to flex to a greater degree than the contacted surface area of the mating indents.

[0067] As indicated above, FIGS. 1 and 2 describe an example wind turbine operating environment in which the torque reacting joint of the wind driven power system may be used. However, the torque reacting joint is not limited for use in wind turbines, and may also be used in other power transmission applications.

[0068] FIGS. 12-13E show additional embodiments of the present invention, directed to a wind driven power generation system comprising a gearbox having a gear-train (including an input and an output) and a rotating conduit internally traversing the gear-train. The conduit is part of a lubrication system of the wind driven power generation system. The lubrication system may internally direct oil to various components included in a gearbox of the wind turbine, thereby increasing the lubrication provided to the components, and decreasing the likelihood of rupturing an external lubrication line during installation and repair. The disclosed lubrication system is described with regard to a wind turbine. However, it can be appreciated that the lubrication system may be applied to other suitable gearboxes outside of the wind energy sector, such as gearboxes used in the mining industry. Before describing the lubrication system in detail, an operating environment in which the lubrication system may be used is described with regard to FIG. 12. (FIGS. 1 and 2 are also applicable.)

[0069] A more detailed illustration of an embodiment of a nacelle 16 is shown in FIG. 12. The nacelle 16 houses a power generation system 1210, allowing wind force to be converted into electrical energy. The power-generating system may include a gearbox 1212 having an input and an output. The input may be coupled to, and may receive rotational input from, the rotor head 24. An input bearing 1213, such as a roller bearing, may be provided within the nacelle,

allowing a rotational input to be transferred to various components within the gearbox. The input may include a torque coupling, included in an input carrier, discussed in more detail herein with regard to FIG. 13. The gearbox may be configured to adjust the speed of a rotational input from the rotor head. Furthermore, the output of the gearbox may be coupled to a generator 214 and configured to convert mechanical energy from the output into electrical energy. A suitable output device, such as an output shaft 216, may couple the output of the gearbox to the generator.

[0070] The generator 214 may be coupled to an electrical transmission system (not shown), which may be routed through the tower to the base of the wind turbine. Various types of generators may be used in the wind turbine, such as an induction type, wound type, synchronous type, secondary resistance control wound induction type (rotor current control or RCC type), secondary excitation control wound induction type (static Scherbius or D.F. type), permanent magnet type, induction multiple type, etc.

[0071] Moreover, a pitch control system 218 may be included in the nacelle. The pitch control system may include a controller 1220. In this example, the controller may be coupled to a rear portion of the gearbox. However, in other examples, the controller may be located in another suitable location, such as the bedplate of the nacelle. The controller may include a processing unit 1222, memory 1224 such as random access memory (RAM) and read only memory (ROM), and/or other suitable components.

[0072] Continuing with FIG. 12, stationary electrical wires 1228 may electrically couple the controller 1220 to a slip ring 1226, included in the pitch control system 218. The slip ring may be configured to transfer electricity from a stationary state into a rotating state. In this way, the slip ring may act as an interface between the stationary electrical wires 1228 and the rotating electrical wires 1230. The rotating electrical wires may be enclosed by a pitch tube 1232 or

other suitable rotating conduits that internally traverse the gearbox. Therefore various gears included in the gearbox may be arranged around the pitch tube. Furthermore, the pitch tube and/or rotating electrical wires may rotate at the same speed as the rotor head. Additionally, the pitch tube may also contain a lubrication channel internally traversing the gearbox, included in a lubrication system, as discussed in more detail herein with regard to FIGS. 13A-13E. In other examples, it can be appreciated that additional or alternate pitch control lines, such as hydraulic lines, may be directed through the pitch tube.

[0073] The rotating electrical wires 230 may be coupled to one or more pitch control mechanisms 234 located within the rotor head. The pitch control mechanisms may be configured to adjust the pitch of one or more rotor blades. In this way, the rotor blades may be adjusted to optimize the power output of the wind turbine.

[0074] FIG. 13A illustrates a schematic depiction of a differential planetary gearbox 1310 having a central axis of rotation 1311, as part of an embodiment of the wind driven power generation system. The differential planetary gearbox 1310 may be utilized in a power-generating wind turbine, such as shown in FIGS. 1, 2, and 12. However, it can be appreciated that alternate gearboxes may be used in the power-generating wind turbine illustrated in FIGS. 1, 2, and 12, such as a simple planetary gearbox, compound planetary gearbox, etc. Additionally, various gearboxes currently in production may be used, such as the GE Wind Energy 2.5xl, Fuhrlander FL2500, and/or Unison U88 and U93. The differential planetary gearbox 1310 may include a lubrication system 1336 configured to internally deliver oil to various components within the gearbox. In this way, oil may be effectively delivered to the gearbox, increasing lubrication and/or cooling in the gearbox, and avoiding potential degradation of the lubrication lines due to human error during installation, repair, etc. The lubrication system and its various

benefits are discussed in more detail herein. It can be appreciated that other suitable lubrication fluids may be used, such as synthetic oils, silicon based lubricants, or a combination thereof.

[0075] The gearbox 1310 may include a gear-train 1312 at least partially enclosed by a housing 1313. The gear-train may include a torque coupling 1314 which may be included in an input carrier 1315. As discussed above, the wind driven rotor head may be coupled to the torque coupling through suitable attachment mechanisms, such as bolts, screws, etc. An input bearing 1316, or bearing set, configured to facilitate rotation of the input carrier, may be positioned on an exterior surface 1318 of the input carrier. In some examples, the input bearing may be a suitable bearing, such as a tapered roller bearing, allowing the bearing to accept the majority of the thrust, axial, and bending loads, thereby eliminating the gearbox as a structural member of the power-generating wind turbine. It can be appreciated that other types of bearings may be utilized such as a double row tapered roller bearing, a non-tapered roller bearing, etc.

[0076] An upwind set of planet gears 1320 may be coupled to the input carrier 1315 through planet pinions 1321. Herein, the input carrier may drive the upwind set of planet gears in an orbital rotation. It can be appreciated that a set may include one or more components. The upwind set of planet gears may include corresponding upwind planet bearings 1322 (or bearing set). In this example, a fixed upwind ring gear 1324 may be coupled to the upwind planet gears through meshing engagement, directing the rotation of the upwind set of planet gears. However, in other examples, the upwind ring gear 1324 may not be included in the gear-train. Additionally, the upwind set of planet gears 1320 may be in meshing engagement with a sun gear 1326.

[0077] The input carrier 1315 may also be fixedly coupled to a downwind ring gear 1328. The downwind ring gear may be in meshing engagement with a downwind set of planet gears

1330. The downwind set of planet gears 1330 may also be in meshing engagement with the sun gear 1326. In some examples, the downwind set of planet gears 1330 and the upwind set of planet gears 1320 may be rotatably coupled. However, in other examples, the downwind set of planet gears and the upwind set of planet gears may not be rotatably coupled. Further, in some examples, at least a portion of the aforementioned meshing engagements in the gear-train may be helical. Each downwind planet gear may include a corresponding downwind planet bearing (not shown), facilitating rotation of the downwind set of planet gears.

[0078] Accordingly, the gearbox may include two power paths. A first power path may pass through the upwind set of planet gears 1320 and a second power path may pass through the downwind ring gear 1328. The upwind set of planet gears may drive the sun gear 1326 and the downwind ring gear may drive the downwind set of planet gears 1330, which in turn may drive the sun gear. Therefore, both of the power paths pass through and recombine at the sun gear 1326. By designing a gearbox with two power paths, the weight as well as the size gearbox may be reduced, allowing for a compact and efficient design.

[0079] Furthermore, the sun gear may be coupled to an output shaft 1332, which may be included in an output of the gearbox or gear-train. A rear bearing 1334 (or bearing set) may be coupled to the output shaft, facilitating rotation of the output shaft. In some examples, the output shaft may lead to a parallel stage shaft (not shown), which may be included in the output of the gearbox. However, in other examples, the output shaft may lead to another suitable component included in the output of the gearbox.

[0080] The gearbox may further include a lubrication system 1336 configured to deliver oil to various components included in the gearbox. The lubrication system may include a rear lubrication manifold 1338, which may be stationary, located in a rear portion of the gearbox.

[0081] Additionally, the rear lubrication manifold may be fluidly coupled to a pump 1345. The pump may be configured to increase the pressure of the oil in the lubrication system, and direct pressurized oil downstream into the rear lubrication manifold. In this example, the pump 1345 is an electrical pump. However, it can be appreciated that other suitable pumps may be utilized. Furthermore, the pump may be coupled to additional components included in the lubrication system. The additional components may include a suitable collection apparatus, such as a sump 1346. The sump may collect oil from the gear-train and direct it back to the rear lubrication manifold through a return line 1347. In this way, oil may be circulated through the lubrication system. In this example, the sump and the return line are external to the gearbox. However, it can be appreciated that in other examples the sump and/or the return line may be internal components in the gearbox, preventing the line from being damaged or ruptured during installation or repair.

[0082] Additional components may be included in the lubrication system, including a closed loop cooling system (not shown) configured to remove heat from the oil. Additionally or alternatively, a filtering system (not shown) may be used to remove unwanted contaminants from the lubrication system. The filtering system may include one or more filters having similar or varying degrees of filtration. In this way, the wear on the gear-train may be decreased by removing unwanted particulates from the lubrication system, thereby increasing the lifespan of the wind turbine.

[0083] FIG. 13B illustrates an enlarged view of the rear lubrication manifold. The rear lubrication manifold 1338 may be configured to deliver oil to the rear bearing 1334 and/or other suitable components included in the gear-train. The rear lubrication manifold 1338 may include a feed line 1340, which may be stationary. In this example, the feed line is radially positioned.

However, in other examples, the position of the feed line 1340 may be adjusted depending on various design requirements. The feed line may be fluidly coupled to a first and a second downwind bearing lubrication line, 1341 and 1342 respectively. The first and the second downwind bearing lubrication lines may extend towards the rear bearings, thereby providing the rear bearing with oil. In this example, the diameter of the first and second downwind lubrication lines (1341 and 1342) may be smaller than the feed line 1340. However, it can be appreciated that in other examples the size, geometry, etc., of the first downwind lubrication line, second downwind lubrication line, and/or feed line may be altered. Further, in other examples, additional lubrication lines may be included in the rear lubrication manifold.

[0084] Continuing with FIG. 13B, a hydraulic union 1348, which may be stationary, is fluidly coupled to the rear lubrication manifold. The hydraulic union may be configured to transfer oil from the rear lubrication manifold to a rotating lubrication channel 1349, surrounding the pitch tube. In this example, the hydraulic union 1348 may extend around the periphery of the outer tube 1350. However, in other examples, the hydraulic union 1348 may only extend around a portion of the rotating conduit. The rotating lubrication channel may rotate at the same speed as the rotor head 24, illustrated in FIGS. 1, 2, and 12. Continuing with FIG. 13B, the rear lubrication manifold and the rotating lubrication channel may rotate at different speeds. Rotating at different speeds includes one non-moving component and one rotating component, for example. Therefore, oil may be directed downstream into the rotating lubrication channel from a stationary component. The rotating lubrication channel may direct oil in an axial (e.g. upwind) direction to various components in the gearbox.

[0085] FIGS. 13C and 13D illustrate a detailed view of the rotating lubrication channel 1349. An outer tube 1350, or other suitable rotating conduit, may surround at least a portion of

the pitch tube 1232, thereby forming a tube-in-tube assembly 1351. In this example, the annulus of the tube-in-tube assembly is the lubrication channel. It can be appreciated that in other examples other configurations are possible, such as a configuration in which the pitch tube surrounds the lubrication channel and a configuration in which the tubes are not concentric. Furthermore, the shape of the tubes may be cylindrical or may have another suitable geometry.

[0086] In this example, the pitch tube 1232 and the outer tube 1350 rotate at the same speed and are joined through a suitable coupling apparatus, such as a slip coupling (not shown). However, in other examples, the pitch tube 1232 and the outer tube may rotate at different speeds. The pitch tube may form an inner channel 1352 housing various electrical wires, as discussed above, separated from the oil in the lubrication channel. Therefore, oil may be directed down the lubrication channel in an axial (e.g., upwind) direction to various gearbox components without interfering with the pitch control system.

[0087] Returning to FIG. 13A, various distribution manifolds may be fluidly coupled to the lubrication channel 1349, configured to deliver oil to various components included in the gearbox 1310. The distribution manifolds may include an intermediate lubrication manifold 1360 as well as an upwind distribution manifold 1370. The intermediate lubrication manifold may include various lubrication lines configured to deliver oil to the gear mesh between the downwind set of planet gears 1330 and the sun gear 1326. The lubrication lines, included in the intermediate lubrication manifold, may extend in a radial direction away from the lubrication channel 1349.

[0088] FIG. 13E illustrates a detailed view of the upwind distribution manifold 1370 as well as various lubrication lines configured to deliver oil to various components in the gear-train 1312, downstream of the pitch tube 1232, included in the upwind distribution manifold. The

upwind distribution manifold may rotate at the same speed as the tube-in-tube assembly. The lubrication lines may include bearing lubrication lines 1372 facilitating delivery of oil to the input bearing 1316 and/or the upwind planet bearings 1322. In some examples, the bearing lubrication lines 1372 may be routed through the input carrier 1315 via internal plumbing. However, in other examples, the bearing lubrication lines may be routed around the input carrier. In particular, the bearing lubrication lines may include a main conduit 1374 extending radially away from the pitch tube. A first branch conduit 1376 may extend towards the input bearing and a second branch conduit 1378 may extend toward the upwind planet bearing. The first branch conduit 1376 may be coupled to an input bearing port 1380. The input bearing port may direct oil into the center of the bearing between two sets of rollers. The second branch conduit 1378 may be coupled to an upwind planet bearing port 1382. The input bearing port 1380 and/or the upwind planet bearing port 1382 may include nozzles, orifices, or other suitable devices configured to direct oil into various components.

[0089] Additionally, gear lubrication lines 1384 may be included in the upwind distribution manifold 1370, configured to deliver oil to the gear mesh between upwind set planet gears 1320 and the sun gear 1326. The gear lubrication lines may include a main conduit 1386, first extending radially away from the pitch tube, and then axially downwind. Three gear ports, 1388, 1389, and 1390 respectively, may extend radially away from the main conduit 1386. A fourth gear port 1392 may also be included in the upwind lubrication manifold. It can be appreciated that in other examples the geometry, size, and/or positioning of the upwind distribution manifold, bearing lubrication lines, etc., may be altered based on various parameters, such as the lubrication requirements, type of gearbox in use, etc. Also, the aforementioned ports may

include nozzles, orifices, or other suitable devices configured to direct oil into various gearbox components.

[0090] The various examples of the disclosed lubrication system allow external lubrication lines to be eliminated in the upwind portion of the gearbox, if desired. Therefore, degradation and possible rupture of the oil lines during installation or maintenance, due to human error, may be reduced. In this way, the longevity of the gearbox may be increased.

[0091] Other aspects of the present invention relate to a wind driven power generation system, e.g., for inclusion in a wind turbine having one or more wind driven rotor blades, embodiments of which are shown in FIGS. 14-19. The system comprises a transmission assembly 2310, which includes a transmission 2316 and a removable input bearing cartridge 2312. The transmission 2316 comprises an input carrier 2314 and a gear-train 2318 rotatably coupling the input carrier to a transmission output 2320. The input carrier 2314 is configured to transfer a rotational input from the rotor blades 26 to the gear-train 2318. The removable input bearing cartridge 2312 is coupled to a periphery of the input carrier, exterior to the gear-train, and is in axial alignment with the input carrier. In this way, the removable input bearing cartridge may be installed subsequent to assembly of the transmission, thereby increasing the modularity of the transmission and allowing the transmission to be used in a multitude of wind turbine designs. Also, the installation and removal process is simplified, decreasing the cost of installation as well as repair.

[0092] The input bearing cartridge 2312 is removable, meaning it may be installed and removed from the transmission subsequent to assembly of the transmission. Further, the removable input bearing cartridge may include a suitable bearing such as a tapered roller bearing, allowing the bearing to accept the majority of the radial and axial loads, from the rotor

head and rotor blades. Therefore, the transmission of loads from the rotor blades and rotor head into the gear-train is substantially decreased or eliminated, allowing the transmission assembly to be used in a greater number of wind turbines, thereby increasing the transmission assembly's modularity. It can be appreciated that other types of bearings may be utilized, such as a double row tapered roller bearing, standard roller bearing, etc. Furthermore, due to the location and configuration of the input bearing cartridge, up-tower repair of both the removable bearing cartridge and the transmission can be performed, decreasing repair cost. Various detailed illustrations of various embodiments of the bearing cartridge are shown in FIGS. 14-18, discussed in greater detail herein. The illustrations in FIGS. 14-18 are drawn approximately to scale.

[0093] A number of suitable transmissions having an input and an output may be utilized. Specifically, in this example a differential planetary gearbox is utilized. However, other suitable transmissions may be utilized, such as gearboxes with axially aligned input and output axes of rotation, or gearboxes having parallel output shafts.

[0094] FIG. 14 shows a cut away side view of the transmission assembly 2310. The transmission assembly 2310 shown in FIG. 14 may be similar to the transmission assembly 212 shown in FIG. 2. The transmission assembly 2310 includes the removable input bearing cartridge 2312, discussed in more detail herein with regard to FIGS. 16-18. The removable input bearing cartridge 2312 is coupled to the periphery of the input carrier 2314. The removable input bearing cartridge may be in axial alignment with the input carrier 2314. The input carrier 2314 is included in a transmission 2316, which further comprises a gear-train 2318 rotatably coupling the input carrier 2314 to the transmission output 2320. The input carrier is upwind of the transmission output 2320. In this example, the transmission is a planetary gearbox having a

central axis of rotation 2321. However, it can be appreciated that an alternate suitable transmission may be utilized.

[0095] The planetary gearbox may include a ring gear 2322, a plurality of planet gears, and a sun gear 2324. In this example, the input carrier 2314 is coupled to the ring gear 2322 and a first set of planet gears 2326, thereby driving the gear-train. However, it can be appreciated that alternate configurations are possible. The first set of planet gears 2326 may be in meshing engagement with the sun gear 2324. The ring gear 2322 may be in meshing engagement with a second set of planet gears 2327. Further, the second set of planet gears 2327 may be in meshing engagement with the sun gear. The sun gear may be coupled to a central rotating shaft 2328 rotating about the central rotating axis 2321. Additionally, the central rotating shaft may be coupled to the output 2320. Each of the meshing gear engagements, including between the ring gear and the planet gears, as well as between the planet gears and the sun gear, may be a helical meshing engagement.

[0096] Also, a pitch control tube 2330 is shown directed through the center of the generator and the transmission (e.g., through the rotor, transmission output, and transmission input), along the central rotating axis 2321. In this way, the pitch control tube traverses from the transmission input through the generator and is inside the center of the planetary transmission. The pitch control tube may include various conduits (not shown), such as electric wires and/or hydraulic lines, and is configured to adjust the orientation (e.g., pitch) of the rotor blades. The conduits may be coupled to a suitable controller (not shown) located in the rotor hub, nacelle or at a down-tower location. A torque tube 2334 may also be included in the gear-train. The torque tube may be configured to transfer torque from the input carrier to various components included in the gear-train.

[0097] Further, it can be appreciated that alternate types of bearings may be included in the transmission (e.g., gearbox). For example, one or more planet bearings may be included in the gear-train for allowing the planet gears to orbitally rotate about the sun gear. Additionally, a bearing (not shown) may be included near the output to receive loads, thereby supporting the gear-train and/or generator. In this example, the input bearing serves as the primary support for the input carrier.

[0098] The design of the transmission assembly, in particular the design of the input bearing cartridge positioned exterior to the gear-train, simplifies the manufacturing, installation, removal, and repair process when compared to bearing used in prior art transmission designs which integrate the bearing into the gear-train. In this way, the cost of the transmission assembly and therefore of the wind turbine is decreased.

[0099] Lubrication may be provided to various components in the transmission assembly, such as the input bearing cartridge, decreasing the friction between the components during operation as well as dissipating the thermal energy produced in rotation. A suitable lubricating fluid such as high viscosity oil may be utilized.

[00100] FIG. 15 shows an isometric view of the transmission assembly 2310 including a transmission housing 2410 surrounding at least a portion of the transmission.

[00101] Various detailed views of the input carrier 2314 and the bearing cartridge 2312 are shown in FIGS. 16-18. FIG. 16 shows a cut away view of an assembled bearing cartridge and input carrier. FIG. 18 shows an exploded view of the bearing cartridge and input carrier. FIG. 17 shows an isometric view of an assembled bearing cartridge and input carrier.

[00102] As shown in FIG. 18, the bearing cartridge 2312 may include two bearing rows, an upwind bearing row 2534 and a downwind bearing row 2536. Each of the bearing rows may

include an inner and an outer race, 2540 and 2538 respectively, at least partially enclosing a plurality of rollers 2542. In other examples, the bearing rows may include the outer race and the rollers. In this example, the rollers are cylindrical. However, in other examples the rollers may be spherical or conical. Each roller may have an axis of rotation 2544, as shown in FIG. 16, about which the rollers rotate during operation of the wind turbine. A spacer 2545 may be interposed between the upwind bearing row 2534 and the downwind bearing row 2536, allowing the loads on the bearing rows to be properly distributed.

[00103] The inner race 2540 may be coupled to an exterior surface 2546 of the input carrier. The outer race 2538 may be coupled to a portion of the transmission housing. In this way, the input bearing cartridge 2312 may allow the input carrier 2314 to rotate about a central rotating axis. A lubrication fluid, such as oil, may at least partially surround the rollers, decreasing the wear on the rollers and the inner and outer race. Additionally, a suitable bearing spacer may be interposed between the upwind bearing row and the downwind bearing row.

[00104] A bearing housing 2547, shown in FIGS. 16 and 18, may be included in the input bearing cartridge. The bearing housing 2547 is coupled to and at least partially surrounds the outer races. The bearing may be configured to couple to a stationary transmission housing (not shown) attached to the nacelle through a suitable coupling apparatus. In this way, the bearing housing and the outer races act as a stator. In other examples, the outer race may include the bearing housing. The bearing housing 2547 may include holes configured to receive various attachment mechanisms such as bolts, shoulder bolts, etc. The bolt holes may be positioned such that various components, for example the bearing cap discussed in greater detail herein, may be coupled to the bearing housing.

[00105] In some examples, the bearing housing may contain at least a portion of a lubrication system 2548. The lubrication system may include one or more supply passage(s) 2549 and/or one or more drain passage(s) (not shown). The supply passage(s) and/or drain passage(s) may extend through various components included in the bearing cartridge, such as spacers, to provide various rotating components in the bearing with lubrication fluid. It can be appreciated that a pump may be fluidly coupled to the supply passage(s) and/or the drain passage(s) to provide pressurized lubrication fluid.

[00106] Furthermore, the bearing rows 2534, 2536 may be tapered. A taper angle of the bearing cartridge may be the angle 2550 defined by the intersection of the axis of rotation 2544 of one or more of the rollers 2542 included in a bearing row and a line 2551 substantially parallel to the central axis of rotation 2321 of the transmission (e.g., input carrier). A taper angle 2550, defined by the intersection of an axis of rotation 2544 of a roller included in the upwind row and line 2551, is illustrated in FIG. 16. It can be appreciated that the downwind row may also have a taper angle, which may be substantially equivalent to the taper angle 2550 or may be another suitable angle.

[00107] As shown in FIG. 16, a stator shim 2554 may be coupled to the outer race of the first and second bearing rows using suitable coupling hardware 2552, such as bolts. An extended section 2556 of the stator shim may be configured to clamp the outer race of the upwind row as well as the bearing housing. The contacted surfaces of the stator shim and the outer race mate to form a static oil seal, preventing oil from leaking out of the input bearing cartridge. A rotor shim 2558 is coupled to the input carrier and the upwind bearing row 2534. The rotor shim may be positioned to maintain a desired end play for the input carrier. An additional coupling apparatus

(not shown) may be attached to the rotor shim and the input carrier for clamping the rotor shim to the input carrier.

[00108] The input bearing cartridge 2312 is configured to axially and radially support the input carrier 2314. Support may include receiving at least a portion of the loads generated by or transferred to a component. Due to the configuration of the transmission assembly loads from the rotor head, main shaft, and/or the transmission, shown in FIGS. 1 and 2, may be transferred to the input carrier. Additionally, the input bearing cartridge allows the input carrier to rotate. Consequently, during operation of the wind turbine, the input carrier may receive rotational input from the main shaft 20, shown in FIGS. 1 and 2, and initiate rotation of the gear-train, thereby initiating electrical power generation in the wind turbine. The input bearing cartridge may receive the majority of the loads generated by the wind (i.e., loads from the rotor head) through the input carrier. Consequently, the wind loads from the rotor blades and rotor head are not translated to the gear-train included in the transmission, decreasing the wear on the gear-train. Thus, the gear-train may be used in numerous wind turbines having different designs.

[00109] The input carrier 2314 may include a coupling interface 2562, as shown in FIG. 17, configured to couple the input carrier to the main shaft. The coupling interface may be configured to couple to the main shaft by suitable coupling hardware (not shown), such as bolts extending through bored holes 2564. Additionally, a bearing cap 2566, shown in FIG. 17, may be coupled to the bearing housing 2547 using hardware 2568. The bearing cap prevents unwanted particulates from entering the input bearing cartridge and acts as a seal for lubrication. In some examples, the coupling interface may be upwind of the input bearing cartridge. In other examples, the coupling interface may be positioned at another suitable location.

[00110] Various design features of the input bearing cartridge, such as the taper angle, may be adjusted based upon the design specification of the rotor head, nacelle, etc. Additionally, the bearing settings may also be adjusted to meet specific design requirements. The bearing settings include at least one of the following: the position of the bearing rows, the input bearing cartridge position, the position of one or more shims, and/or the spacer size and/or position. Thus, the transmission may be adapted for use in a multitude of wind turbine designs, decreasing the cost of manufacturing. The design specifications of the rotor head include static and dynamic loading characteristics. For example, the tapered angle may be increased to account for increased thrust load on the bearing.

[00111] FIG. 19 illustrates a method 2800 for manufacturing a transmission assembly. The transmission assembly may include an input carrier, an output shaft, and a plurality of gears included in a gear-train of a transmission. The gear-train is configured to increase the rotational speed of the output shaft. In some examples, the transmission assembly is a planetary gearbox assembly. The disclosed method may be used to manufacture the transmission assembly 2310, shown in FIGS. 14-18, utilizing the components discussed above. Alternatively, the disclosed method may be used to manufacture another suitable transmission assembly.

[00112] First, at 2810, the method includes assembling an input carrier, gears, and an output forming a transmission, with the transmission having a central rotating axis. Assembling the gear-train may include assembling the gears and associated bearings, such as planet gear bearings, into an input carrier, at 2810A. The gears may include a plurality of planet gears, a ring gear, and a sun gear. Optionally, assembling the gear-train may include assembling the torque tube onto the input carrier, at 2810B. In some examples, the gear-train may be assembled in a separate facility or location.

[00113] Optionally, at 2812 the method may include coupling an inner bearing race to the input carrier. In other examples, the inner bearing race may be included in the input bearing cartridge.

[00114] At 2814, the method includes assembling an input bearing cartridge. Assembling the input bearing cartridge may include at 2814A positioning a plurality of rollers within an outer race of a first and/or a second bearing row. It can be appreciated that in some examples the input bearing cartridge may include a single bearing row. Also, at 2814B the method may include attaching a torque tube onto the input carrier. Additionally, at 2814C the method may include positioning a spacer between the first and second bearing rows. Further, in some examples the method may include installing one or more bearing cups, as at 2814D.

[00115] At 2816 the method includes installing the input bearing cartridge on a peripheral or exterior portion of the input carrier. Installing may include coupling. Suitable assembly hardware, such as bolts, may be used to install the input bearing cartridge on the input carrier. In some examples, installing the input bearing cartridge to the input carrier may include coupling a bearing cap to a stator shim and/or coupling a rotor shim to an inner race, at 2816A. In this way a lubrication seal may be formed, impeding lubrication fluid, such as oil, from exiting the input bearing cartridge, sealing the input bearing cartridge. Additionally, installing the input bearing cartridge may include adjusting the bearing cartridge settings at 2816B. The bearing settings may include the positioning of various components included in the input bearing cartridge to allow loads on the bearing to be properly distributed, decreasing the wear on the input bearing cartridge during operation. Further in some examples, installing the input bearing cartridge may include installing one or more bearing cones through suitable coupling hardware.

[00116] In some examples the method may include rotating the transmission assembly with the torque tube, at 2818. The rotation may include 180° of rotation. Next, at 2820, the method may include positioning the transmission assembly within a transmission housing, forming a transmission assembly. The method may further include removing the input bearing cartridge from the transmission assembly and repairing or replacing the input bearing cartridge. This may occur subsequent to on site construction of a wind turbine when maintenance may be needed. Also, the removal of the input bearing cartridge may occur at an up-tower location.

[00117] Even if not explicitly enumerated herein, any of the aforementioned embodiments, features, and elements of the wind driven power generation system may be combined with any of the other embodiments, features, and elements of the wind driven power generation system, within the spirit and scope of the present invention. For example, in one embodiment, a wind turbine (e.g., FIG. 1) includes a transmission assembly (with removable input bearing cartridge), a transmission (with torque reacting joint), and a gearbox (with lubrication system) as described above. The gearbox includes a first gear-train and a rotating conduit, which is configured to receive lubrication fluid from downstream of the rotating conduit and deliver lubrication fluid upstream of the rotating conduit. Components downstream of the rotating conduit rotate at a different speed than upstream components. The transmission includes a second gear-train enclosed by an outer housing. The outer housing includes a torque reacting joint coupling a first section of the transmission to a second section of the outer housing. The transmission assembly includes a transmission (comprising an input carrier and a gear-train rotatably coupling the input carrier to a transmission output) and a removable input bearing cartridge. The removable input bearing cartridge is coupled to a periphery of the input carrier, exterior to the gear-train, in axial alignment with the input carrier.

[00118] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from its scope. While the dimensions and types of materials described herein are intended to define the parameters of the invention, they are by no means limiting and are exemplary embodiments. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Moreover, in the following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. § 112, sixth paragraph, unless and until such claim limitations expressly use the phrase “means for” followed by a statement of function void of further structure.

[00119] This written description uses examples to disclose several embodiments of the invention, including the best mode, and also to enable any person skilled in the art to practice the embodiments of invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ

from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[00120] As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to “one embodiment” of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments “comprising” or “having” an element or a plurality of elements having a particular property may include additional such elements not having that property.

[00121] Since certain changes may be made in the above-described wind driver power generation system, without departing from the spirit and scope of the invention herein involved, it is intended that all of the subject matter of the above description or shown in the accompanying drawings shall be interpreted merely as examples illustrating the inventive concept herein and shall not be construed as limiting the invention.

CLAIMS:

1. A wind driven power generation system comprising:
a nacelle including a bedplate;
a rotor having a plurality of blades configured to be driven by wind; and
a transmission including an input and an output, the transmission input coupled to the rotor, the transmission including a planetary gear-train enclosed by an outer housing, the outer housing including a torque reacting joint coupling a first section of the outer housing to a second section of the outer housing, the torque reacting joint including mating indents between the first and second sections, where the first section is fixedly coupled to a carrier attachment included in the planetary gear-train, and the second section is fixedly mounted to the bedplate.
2. The system of claim 1, further comprising fasteners coupling the first and second sections through the mating indents, the mating indents forming an interference fit, wherein the fasteners are configured to flex to a greater degree than the indents.
3. The system of claim 1, wherein the torque reacting joint reacts torque produced by the rotor blades driven through the bedplate.
4. The system of claim 1, wherein the mating indents are formed in mating surfaces of the first and second sections, and where the mating indents are circumferentially formed around the mating surfaces of the first and second sections.

5. The system of claim 4, wherein the mating surface of the first section is upwind of the mating surface of the second section.
6. The system of claim 4, wherein the mating indents are formed as splines.
7. The system of claim 4, wherein the mating indents include a first mating surface and a second mating surface having a contacted surface area, the first and second mating surfaces having axially offset and radially aligned projected and recessed planar surfaces, obliquely angled banks joining the projected and recessed planar surfaces, and centrally positioned cavities extending through each of the first and second mating surfaces, the cavities configured to accept fasteners, the fasteners configured to flex to a greater degree than the contacted surface area of the mating indents.
8. The system of claim 1, wherein the torque reacting joint reacts torque produced by rotor blades driven by wind and the outer housing is an outer gear-train housing.
9. The system of claim 1, wherein the torque reacting joint forms an interference fit, the transmission further comprising fasteners coupling the first and second sections, and the fasteners are configured to flex to a greater degree than the interference fit of the torque reacting joint.
10. A wind driven power generation system comprising:
one or more rotor blades coupled to a rotor head configured to rotate about a central axis;

a planetary gearbox including a planetary gear-train having an input configured to receive rotational input from the rotor head, and an output configured to direct rotational output to a generator; and

a rotating conduit internally and axially traversing the planetary gearbox, the conduit configured to receive pressurized lubrication fluid from one or more stationary components included in the planetary gearbox and direct the pressurized lubrication fluid, in an upwind direction, to one or more rotating components included in the planetary gearbox .

11. The system of claim 10, wherein the input and the output of the gear-train are at least one of aligned with the central axis and/or axially aligned with one another.

12. The system of claim 10, wherein the gearbox input includes an input carrier configured to transfer rotation input to one or more planet gears included in the gear-train.

13. The system of claim 10, wherein the rotating conduit houses one or more control lines, which include hydraulic lines and/or electrical wires, the rotating conduit coupled to the rotor head and configured to adjust a pitch of one or more rotor blades coupled to the rotor head

14. The system of claim 10, further comprising at least one distribution manifold configured to deliver lubrication fluid from the rotating conduit radially outward to one or more rotating components included in the gear-train.

15. The system of claim 10, further comprising at least one lubrication manifold configured to direct lubrication fluid radially outward from the rotating conduit into at least one moving component in the gearbox.
16. The system of claim 10, further comprising a housing, surrounding at least a portion of the gear-train, configured to impede lubrication fluid from exiting the gear-train.
17. The system of claim 10, wherein the stationary components include a feed line fluidly coupled to a pump, the pump configured to increase the pressure of the lubrication fluid.
18. The system of claim 10, wherein the stationary components are coupled to the rotating conduit through a hydraulic union, the hydraulic union configured to transfer lubrication fluid from the components downstream of the rotating conduit into a lubrication channel within the rotating conduit.
19. The system of claim 10, wherein the rotating conduit comprises a tube-in-tube assembly defining a lubrication channel, and the lubrication channel is configured to direct lubrication fluid to the components upstream of the lubrication channel.
20. The system of claim 19, wherein the tube-in-tube assembly includes a second channel housing electrical wires coupled to a control system.

21. A wind driven power generation system comprising:

a transmission assembly comprising a transmission and a removable input bearing cartridge;

the transmission including an input carrier and a gear-train rotatably coupling the input carrier to a transmission output, the input carrier configured to transfer a rotational input from one or more wind driven rotor blades to the gear-train; and

the removable input bearing cartridge coupled to a periphery of the input carrier, exterior to the gear-train, wherein the removable input bearing cartridge rotatably supports the input carrier.

22. The system of claim 21, wherein the input carrier and the output of the transmission are located on a common central rotating axis.

23. The system of claim 21, wherein the input bearing cartridge is configured to receive radial and/or axial loads from a rotor head coupled to the rotor blades.

24. The system of claim 21, wherein the input carrier is coupled to a plurality of planet gears and a ring gear included in the gear-train, wherein the ring gear is in meshing engagement with plurality of planet gears, and wherein the planet gears include an upwind set of planet gears.

25. The system of claim 21, wherein the input bearing cartridge includes at least one inner race and one outer race surrounding at least one row of rollers.

26. The system of claim 21, further comprising a bearing housing configured to at least partially surround the inner races and outer races.

27. The system of claim 21, wherein the input bearing cartridge includes a rotor shim coupled to the inner race of the bearing cartridge and a stator shim coupled to the outer race of the bearing cartridge.

28. The system of claim 21, wherein the input bearing cartridge axially and radially supports the input carrier.

29. The system of claim 21, wherein the input bearing cartridge is configured to be removed at an up-tower location.

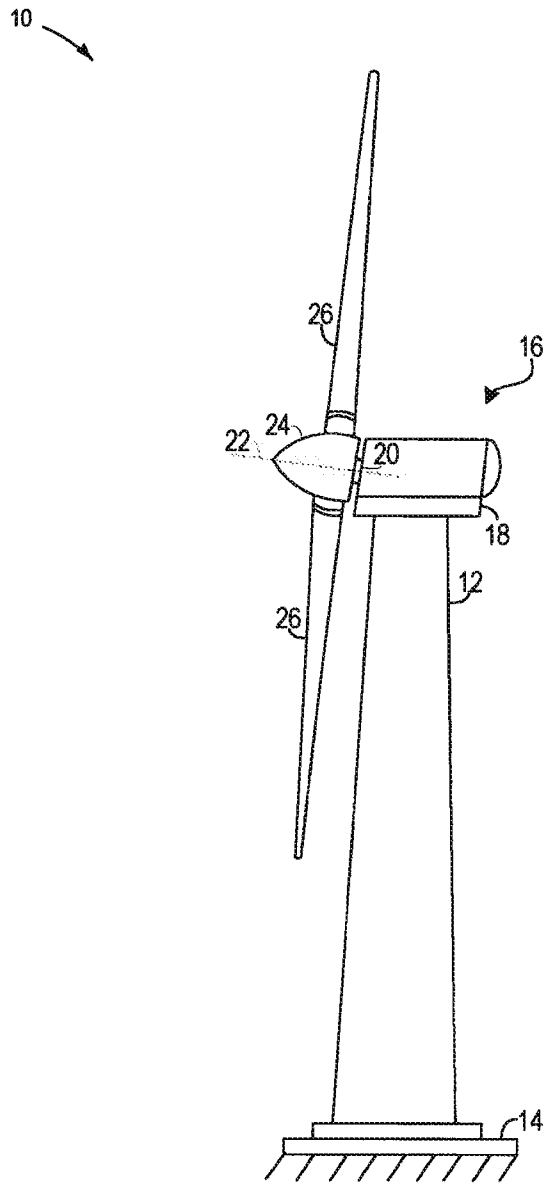


FIG. 1

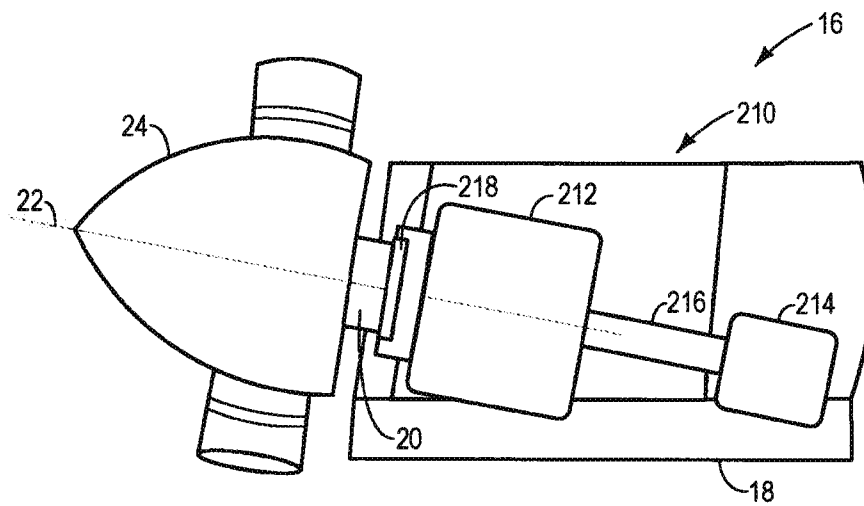


FIG. 2

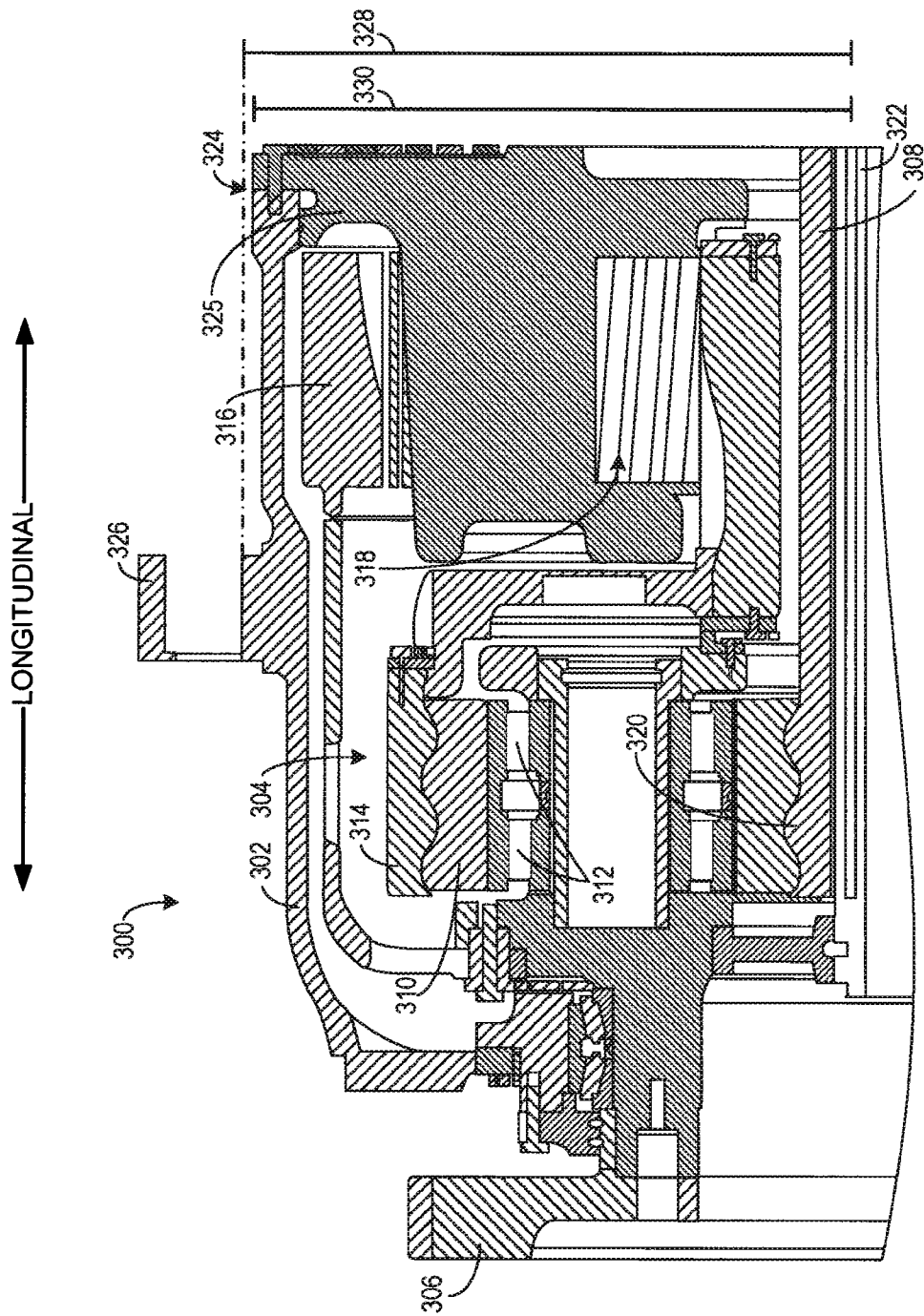


FIG. 3

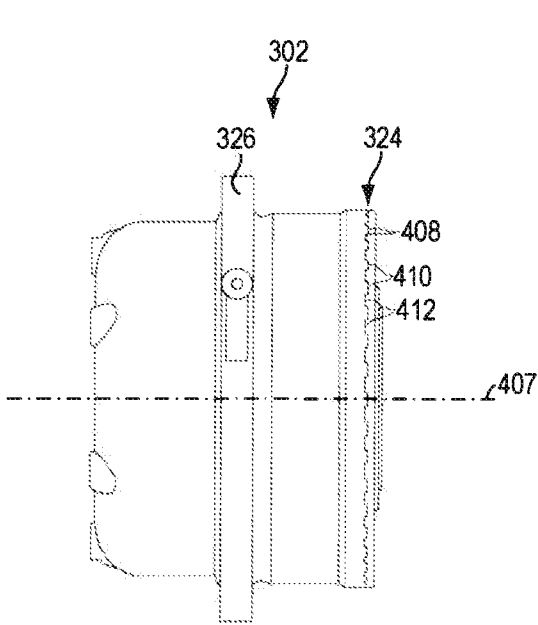


FIG. 4A

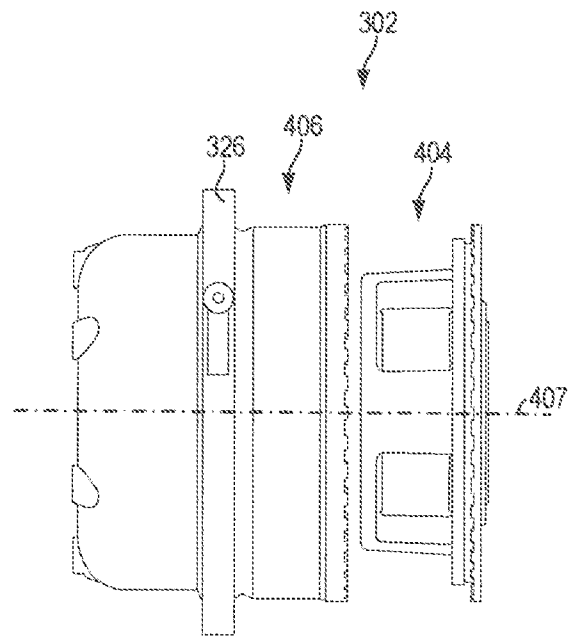


FIG. 4B

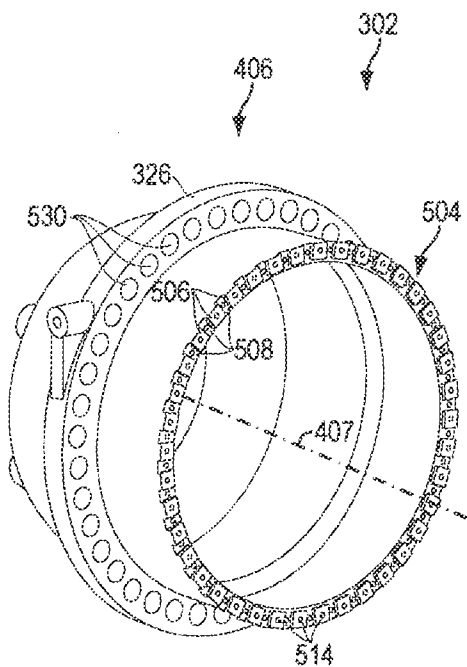


FIG. 5A

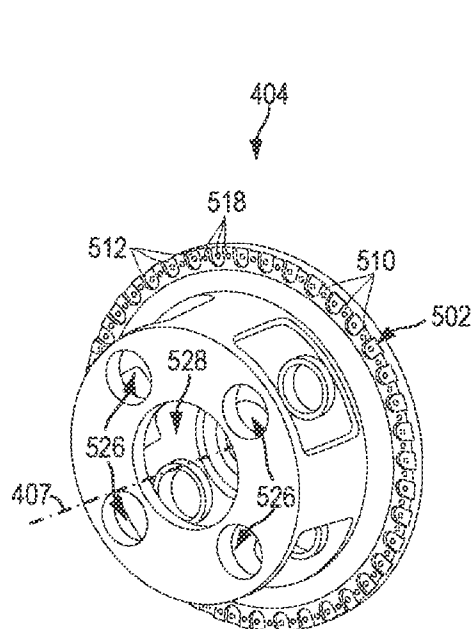


FIG. 5B

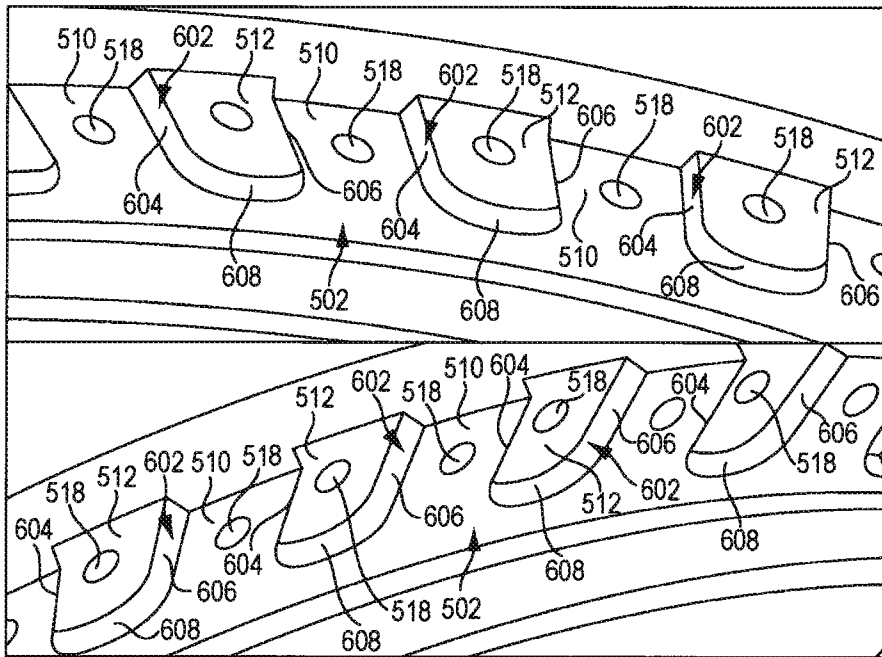


FIG. 6A

FIG. 6B

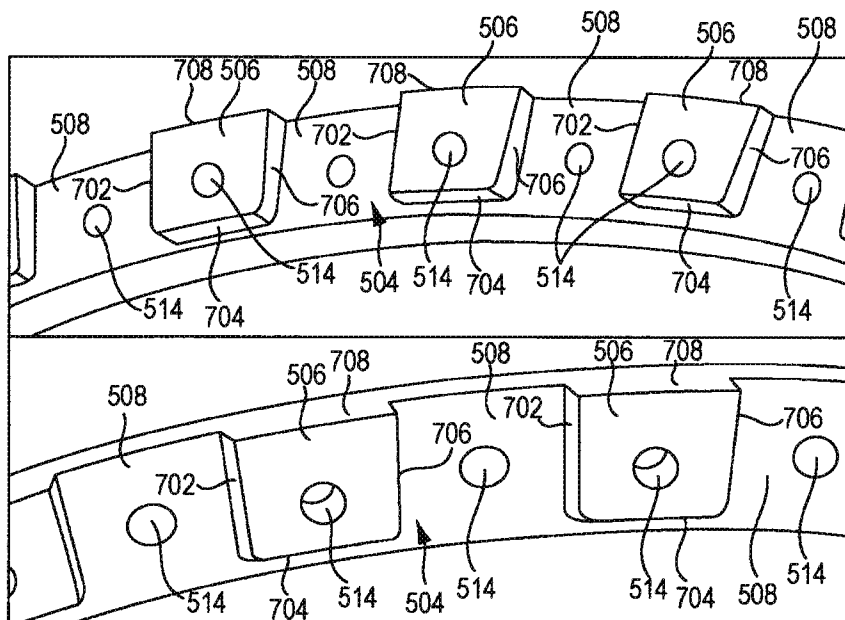


FIG. 7A

FIG. 7B

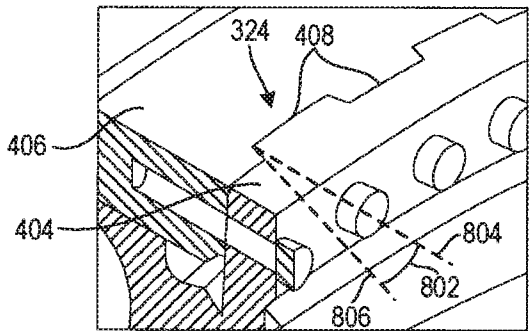


FIG. 8

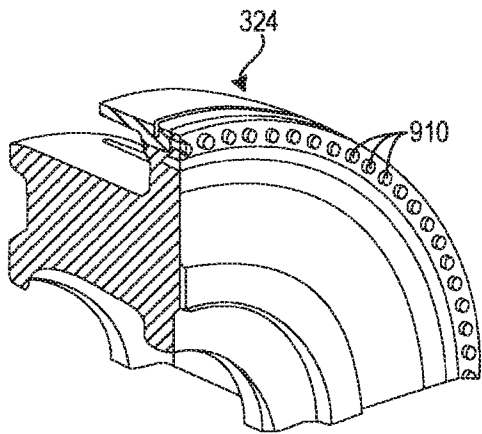
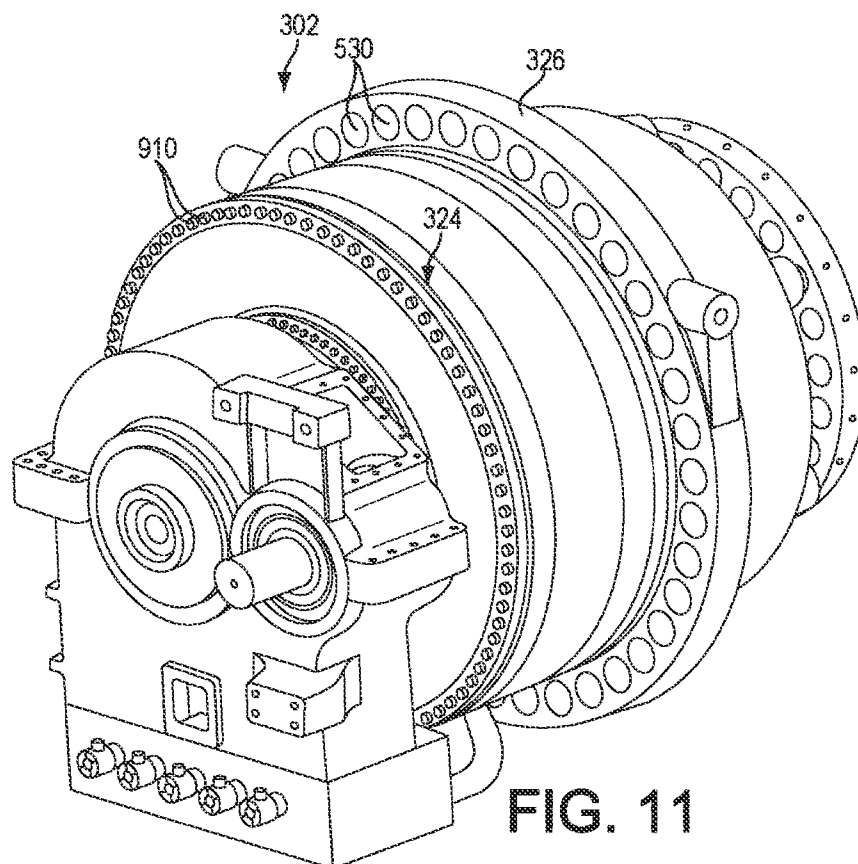
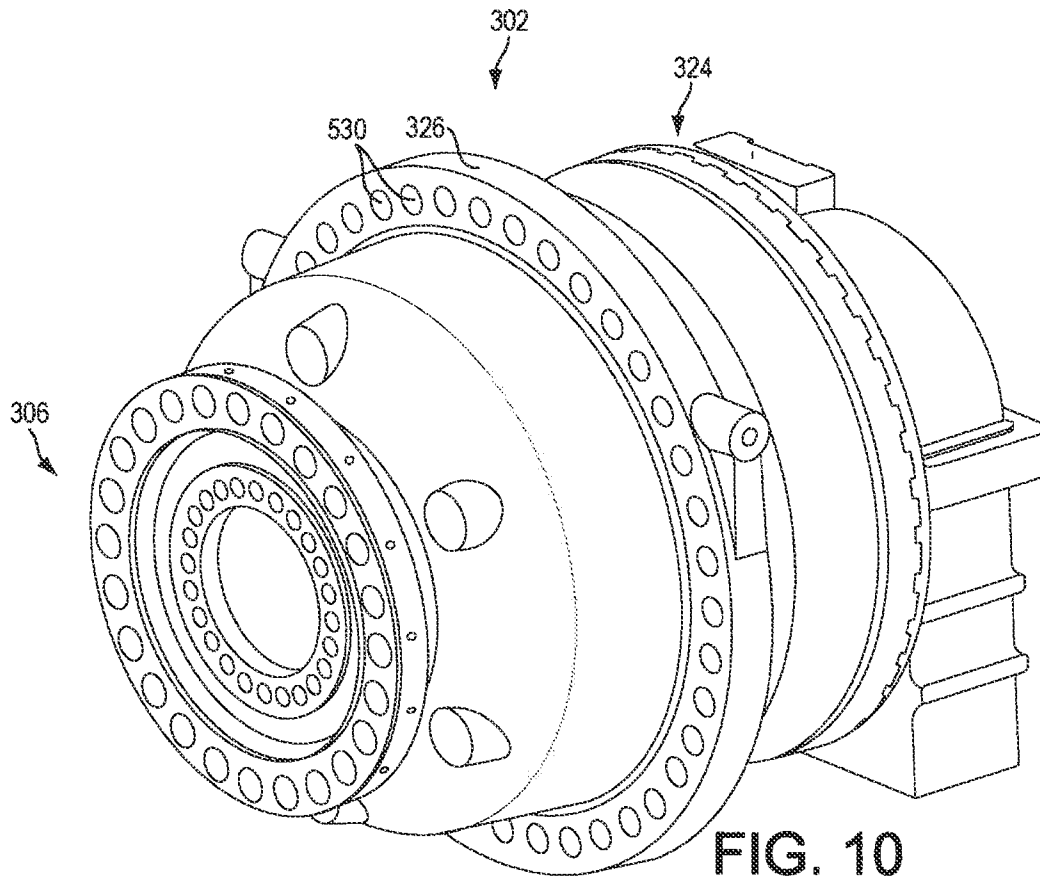


FIG. 9



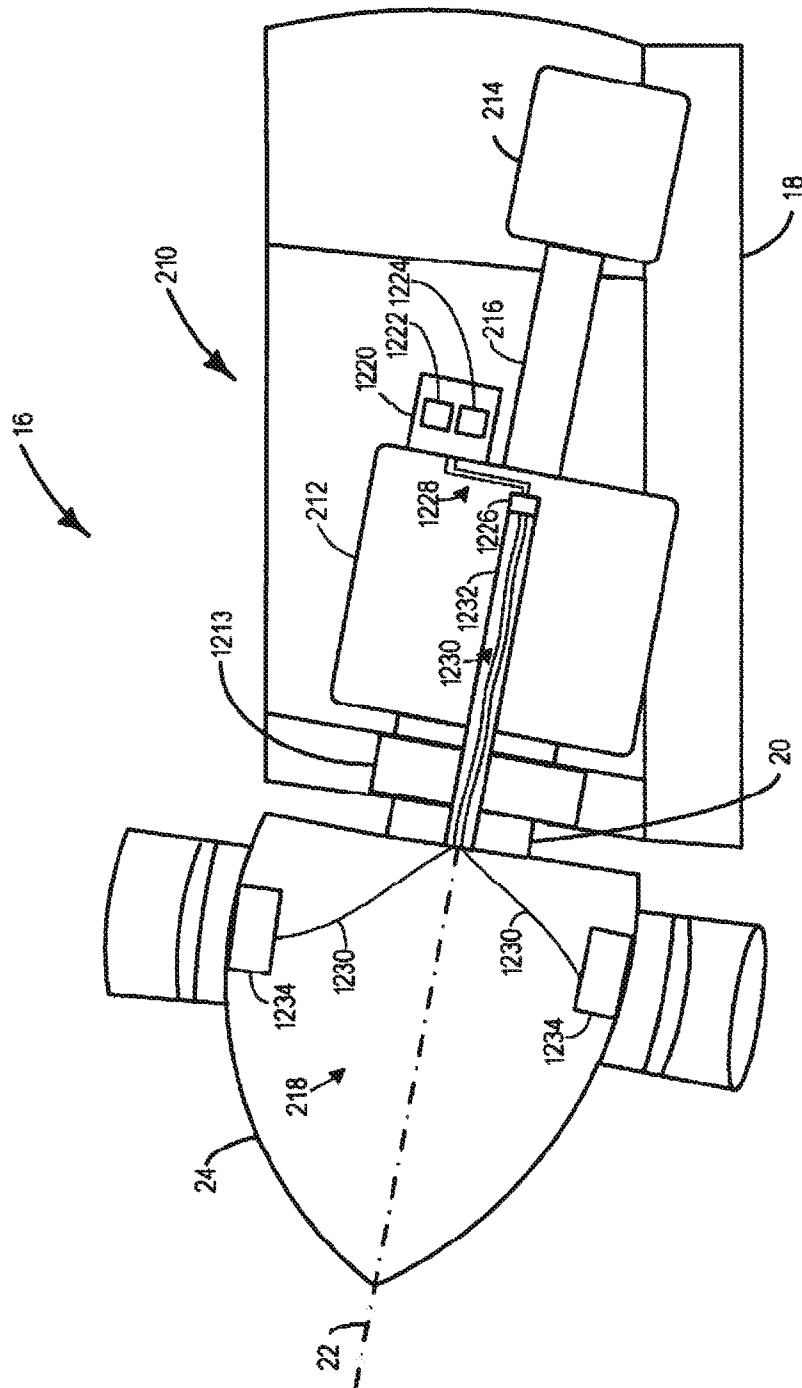
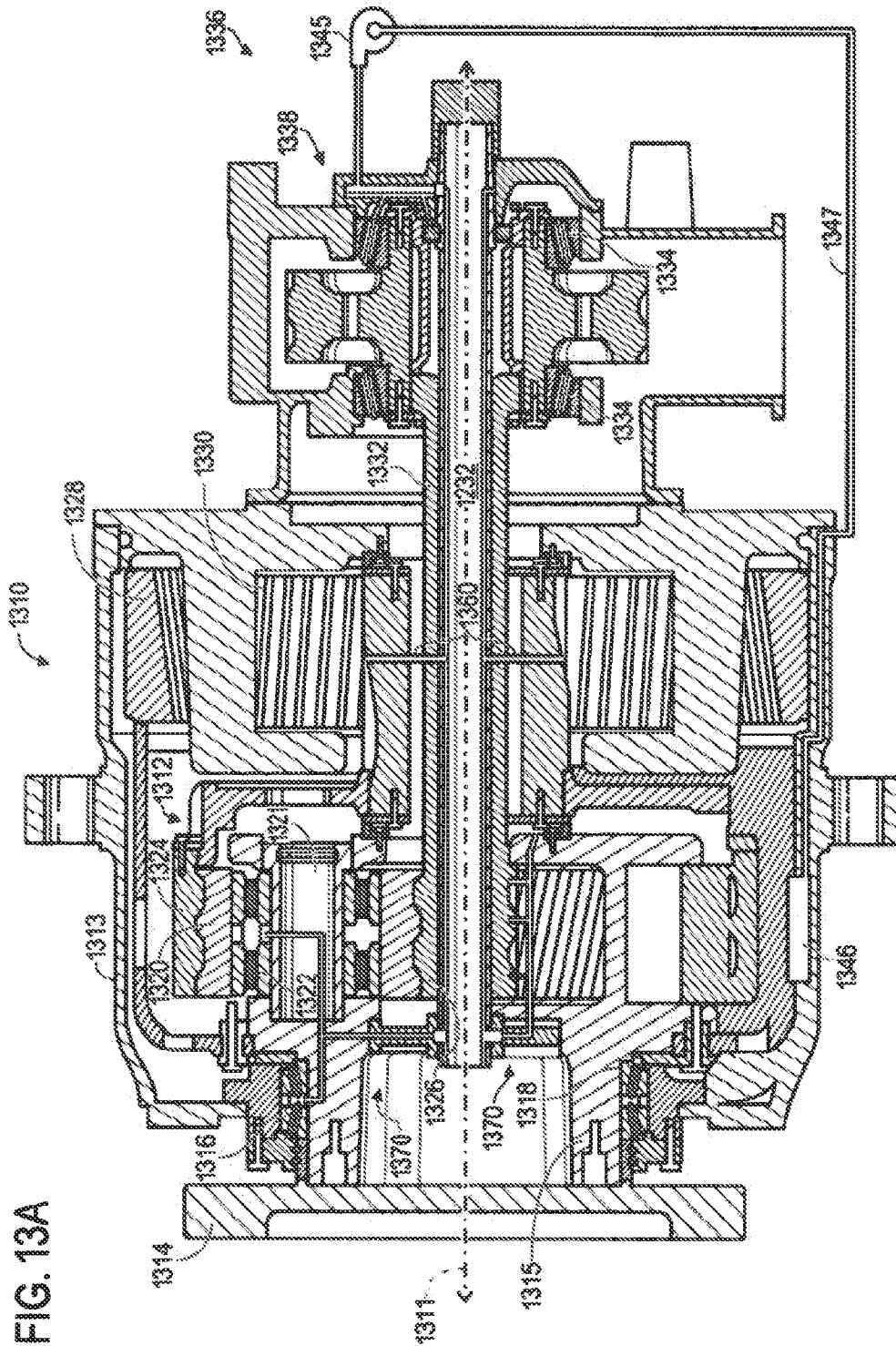


FIG. 12



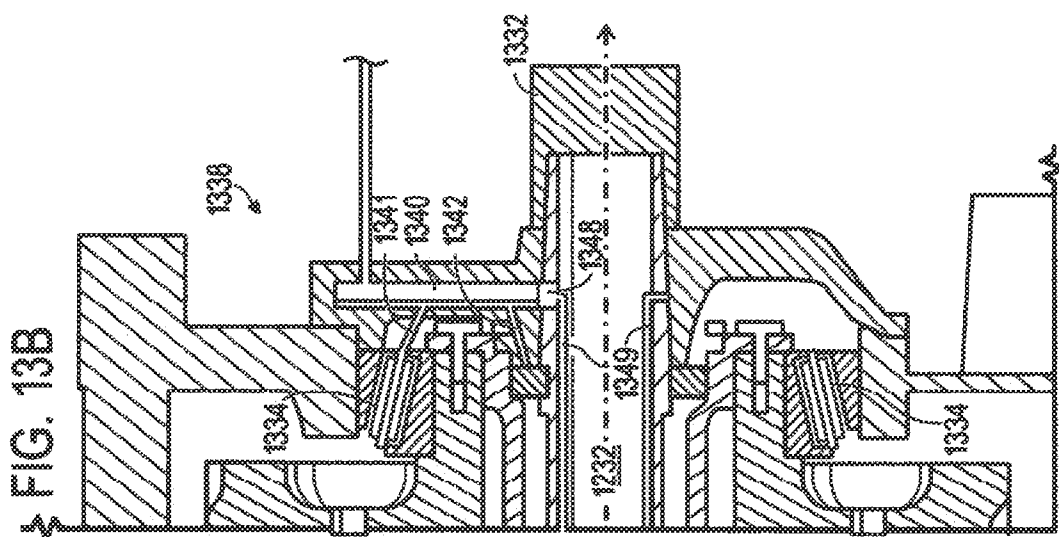
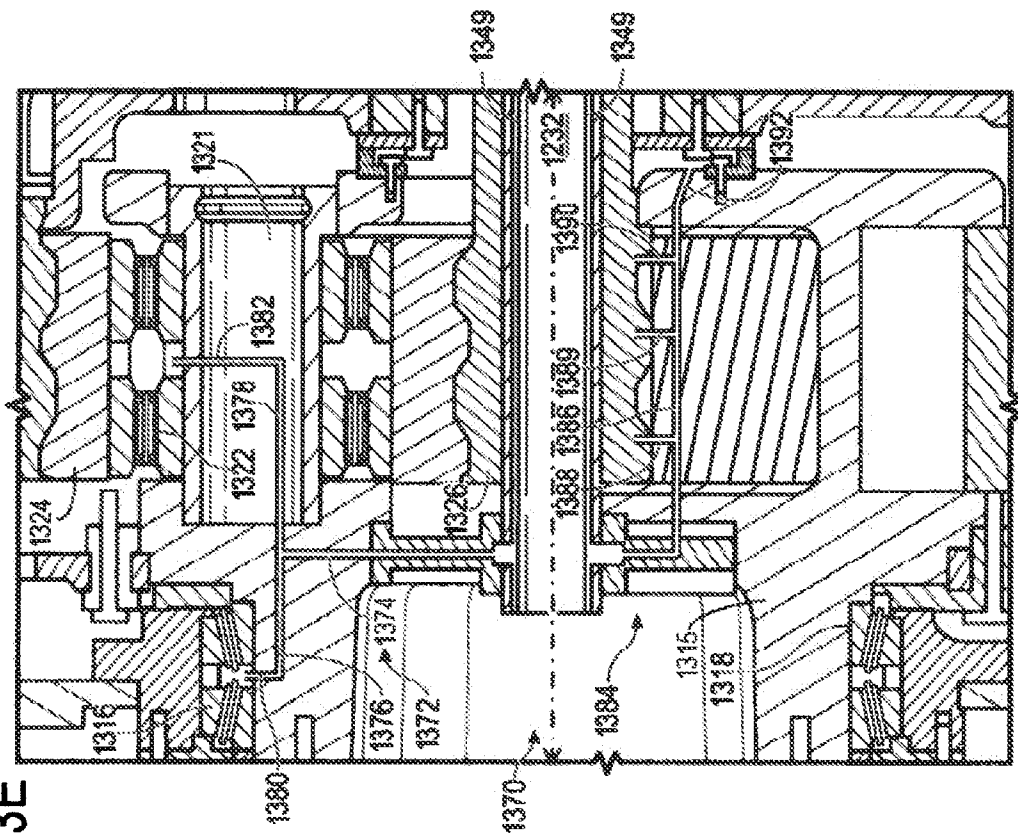


FIG. 13E



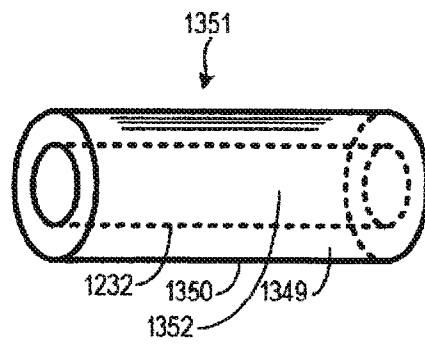


FIG. 13C

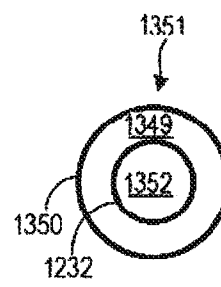


FIG. 13D

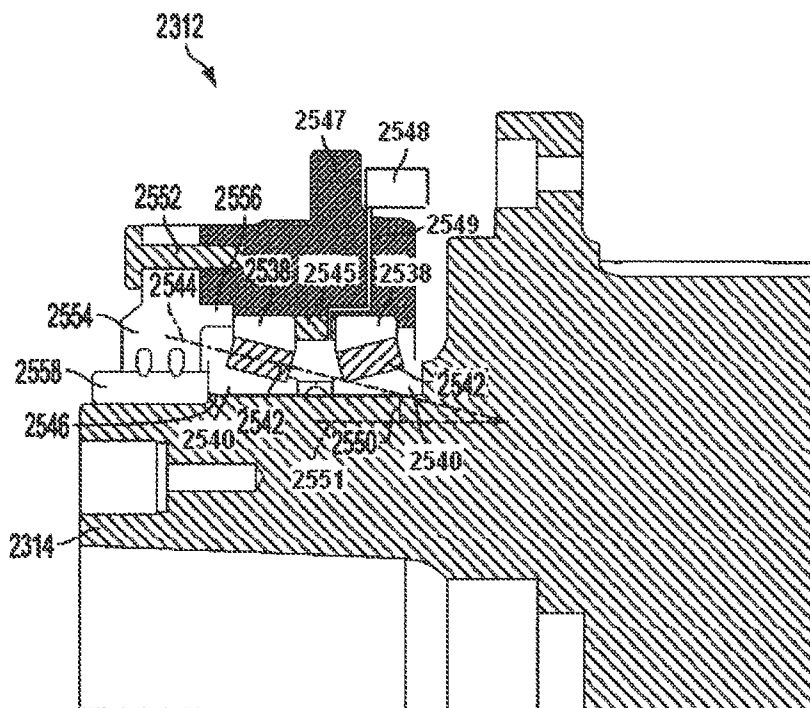


FIG. 16

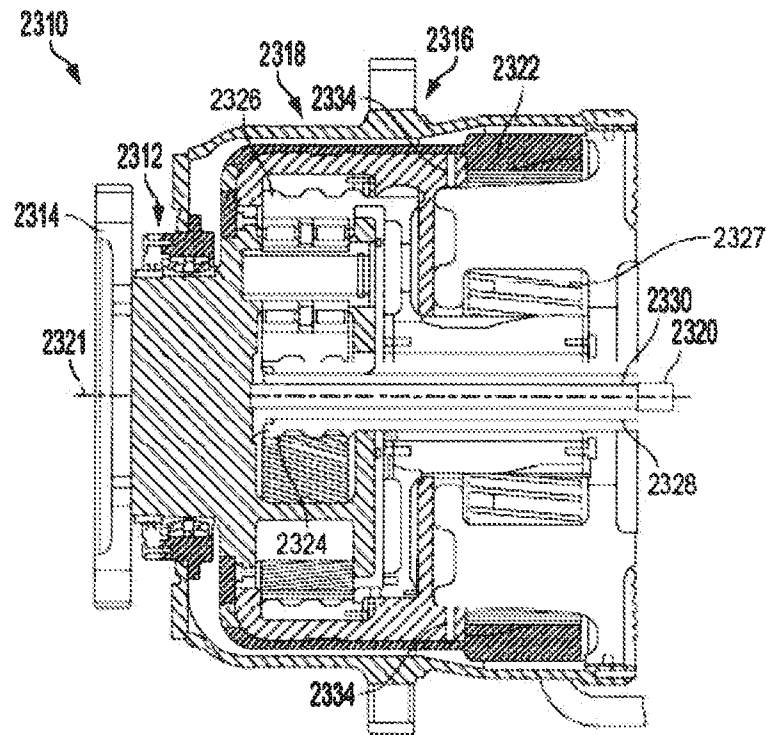


FIG. 14

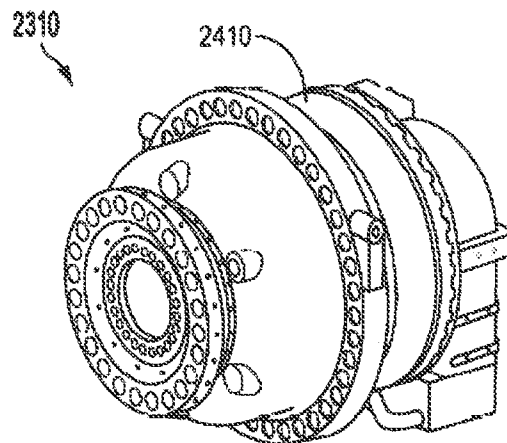


FIG. 15

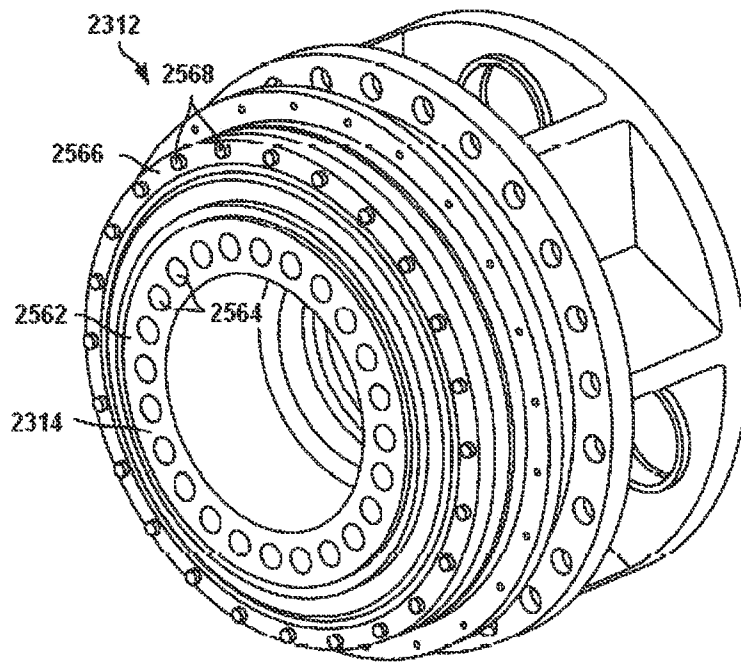


FIG. 17

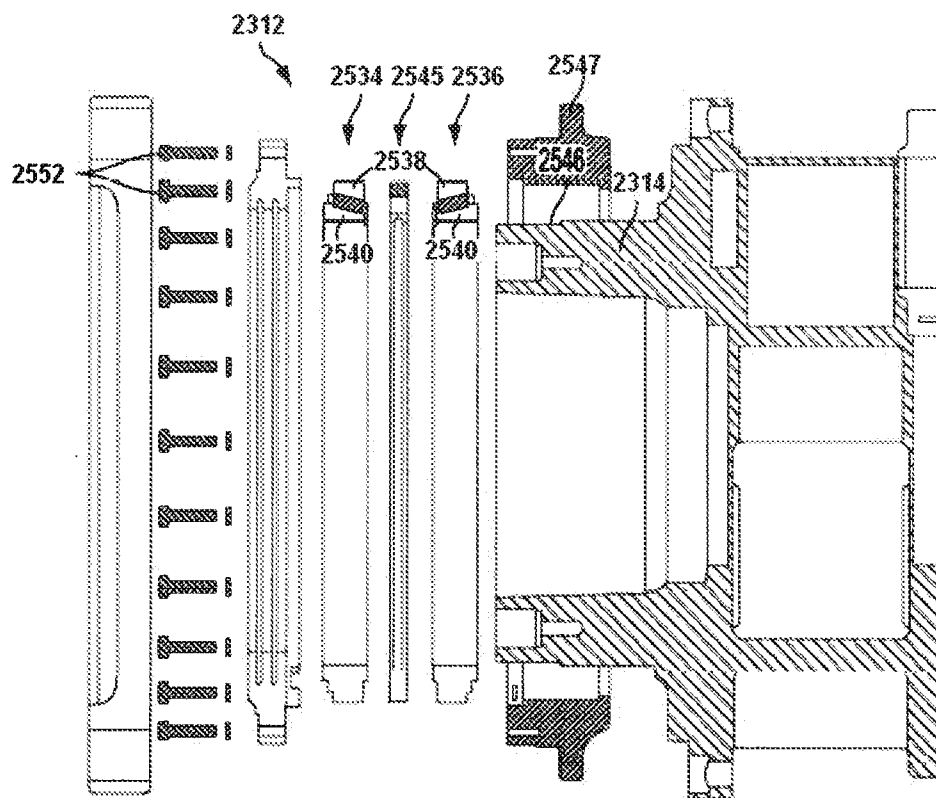


FIG. 18

2800

FIG. 19

