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[Continued on next page]

(54) Title: SYSTEMS AND METHODS FOR CONTROLLING FLOW FROM A WELLBORE ANNULUS

(57) Abstract: A rotating control device for sealing an annulus includes an outer housing, and a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through a throughbore of the outer housing, wherein the seal assembly includes an inner housing, a first proximity sensor disposed along an inner surface of the outer housing, and a first sensor element disposed along an outer surface of the inner housing, wherein the first proximity sensor is configured to measure the rotational speed of the seal assembly in response to rotation of the seal assembly in the outer housing.

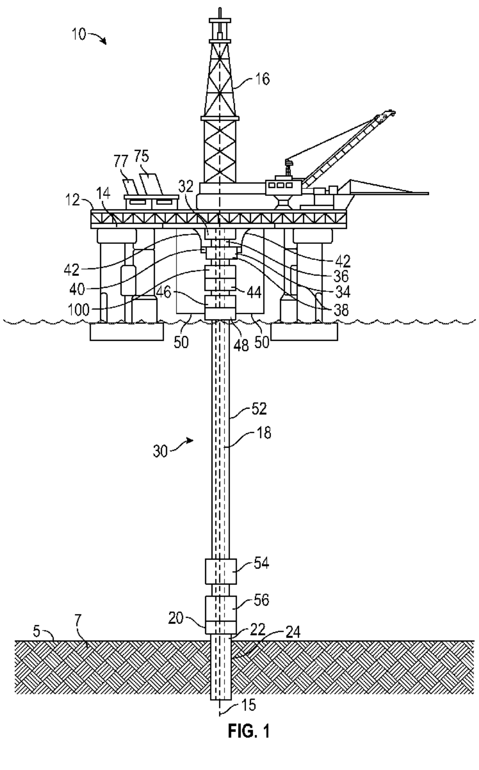

FIG. 1

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SYSTEMS AND METHODS FOR CONTROLLING FLOW FROM A WELLBORE ANNULUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. provisional patent application Serial No. 62/303,878 filed March 4, 2016, and entitled "Systems and Methods for Controlling Flow from a Wellbore Annulus," which is hereby incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND

[0003] Embodiments disclosed herein relate generally to oil and gas drilling and completion operations. More particularly, embodiments disclosed herein relate to systems and methods for controlling the flow of drilling fluid or mud from the annulus of a wellbore.

[0004] To drill a wellbore in an earthen formation to a subterranean reservoir, a drilling rig is positioned over the desired location of the wellbore and a drillstring suspended from the drilling rig through a blowout preventer (BOP) mounted to a wellhead at the surface and into the subterranean formation. During the drilling process, drilling fluid or mud is pumped through the drill string and exits the face of a drill bit connected to the lower end of the drillstring. The drilling fluid exiting the drill bit is recirculated to the surface via the annulus between the drillstring and the inner surface of the wellbore and then through the annulus between the drilling and the inner surface of the BOP. In onshore drilling applications, a rotating control device (RCD) is typically mounted to an upper end of the BOP and controls the flow and pressure of drilling fluid out the BOP annulus, and hence, control the flow and pressure of drilling fluid from the wellbore annulus. For instance, the RCD often includes an inner rotating seal for sealingly engaging the outer surface of the drillstring as the drillstring rotates and an annular outer seal that sealingly engages the BOP, thereby effectively capping the upper end of the annulus. The RCD may include one or more side outlets for allowing the passage of drilling fluid from the annulus of the wellbore.

[0005] Some offshore applications also include RCDs or similar devices for controlling flow and pressure from the annulus. For instance, in offshore applications, the drillstring typically extends from a drilling vessel at the surface of the water through a marine riser extending between the drilling vessel and the subsea BOP mounted to the wellhead at the sea floor into the wellbore. The recirculated drilling fluid flows through the wellbore annulus, the BOP annulus, and the annulus between the drillstring and the inner surface of the marine riser to the drilling vessel. In some applications, an RCD is coupled to an upper end of the marine riser proximal the drilling vessel. The RCD includes an inner rotating seal for sealingly engaging the outer surface of the drillstring as the drillstring rotates and an annular outer seal that sealingly engages the upper end of the marine riser, thereby effectively capping the upper end of the annulus in the marine riser, and hence, capping the BOP annulus and the wellbore annulus. The RCD may include one or more side outlets for allowing the passage of fluid from the annulus formed within the marine riser, or alternatively, a diverter spool may be provided below the RCD to provide a flowpath for drilling fluid flowing through the annulus in the marine riser.

SUMMARY

[0006] An embodiment of a rotating control device for sealing an annulus extending from a subterranean wellbore, the rotating control device comprises an outer housing including a central axis, a first end, a second end opposite the first end, an outer surface extending axially from the first end to the second end, and an inner surface extending axially from the first end to the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and wherein the outer housing comprises a plurality of circumferentially-spaced bores extending radially from the outer surface to the throughbore, a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through the throughbore of the outer housing, wherein the seal assembly comprises an outer surface including a receptacle, a plurality of actuatable locking pins, wherein each locking pin is moveably disposed in one of the bores of the outer housing and is configured to move radially relative to the outer housing between a locked position with a radially inner end the locking pin seated in the receptacle and an unlocked position with the radially inner end of the locking pin removed from the receptacle. In some embodiments, the inner surface of the outer housing comprises an annular shoulder configured to engage a mating annular shoulder on the outer surface of the seal assembly. In some embodiments, the

annular shoulder of the outer housing comprises a frustoconical surface configured to slidingly engage a mating frustoconical surface of the annular shoulder of the seal assembly. In certain embodiments, the radially inner end of each locking pin comprises a chamfered profile configured to engage a corresponding chamfered profile of the outer surface of the seal assembly and urge the annular shoulder of the seal assembly in engagement with the annular shoulder of the outer housing. In certain embodiments, each locking pin comprises a fluid passage configured to be pressurized to transition the locking pin between the unlocked position and the locked position. In some embodiments, the rotating control device further comprises a position sensor disposed in one of the locking pins, wherein the position sensor is configured to output a signal indicating the position of the locking pin in the locked position or the unlocked position. In some embodiments, the rotating control device further comprises a stab plate coupled to the outer surface of the outer housing, wherein the stab plate comprises: a first fluid connector in fluid communication with a first fluid conduit, a second fluid connector in fluid communication with a second fluid conduit, and an electrical connector in signal communication with the position sensor, wherein at least one of the locking pins is configured to transition from the unlocked position to the locked position in response to pressurization of the first fluid conduit, wherein at least one of the locking pins is configured to transition from the locked position to the unlocked position in response to pressurization of the second fluid conduit. In certain embodiments, the radially inner end of each locking pin comprises a shoulder extending orthogonal the central axis of the outer housing. In certain embodiments, the outer housing includes a first passage extending from the inner surface to the outer surface and a second passage extending from the inner surface to the outer surface, the seal assembly comprises an inner housing including a first passage extending from an inner surface to an outer surface of the inner housing and a second passage extending from the inner surface to the outer surface of the inner housing, the first passage of the outer housing is in fluid communication with the first passage of the inner housing, and wherein the first passage of the outer housing and the first passage of the inner housing are configured to supply a lubricating fluid to a bearing chamber of the inner housing, and the second passage of the outer housing is in fluid communication with the second passage of the inner housing, and wherein the second passage of the outer housing and the second passage of the inner housing are configured to receive the lubricating fluid from the bearing chamber. In some embodiments, the first and second passages of the outer housing each include a check valve, and the first and second passages of the inner housing each include a check valve. In some embodiments, the rotating control device further comprises a first proximity sensor disposed along the inner surface of the outer housing, and a first sensor element disposed along an outer surface of an inner housing of the seal assembly, wherein the first proximity sensor is configured to measure the rotational speed of the seal assembly in response to rotation of the seal assembly in the outer housing. In some embodiments, the rotating control device further comprises a second proximity sensor disposed along the inner surface of the housing, and a second sensor element disposed along the outer surface of the inner housing, wherein the second sensor element is configured to detect a leak in a sealing element of the seal assembly in response to leakage across the sealing element.

[0007] An embodiment of a rotating control device for sealing an annulus extending from a subterranean wellbore, the rotating control device comprises an outer housing including a central axis, a first end, a second end opposite the first end, an outer surface extending axially from the first end to the second end, and an inner surface extending axially from the first end to the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and wherein the outer housing comprises a plurality of circumferentially-spaced bores extending radially from the outer surface to the throughbore, a plurality of actuatable locking pins, wherein each locking pin is moveably disposed in one of the bores of the outer housing and is configured to move radially relative to the outer housing between a locked position with a radially inner end the locking pin seated in the receptacle and an unlocked position with the radially inner end of the locking pin removed from the receptacle. In some embodiments, the rotating control device further comprises a seal assembly configured to be removably disposed within the outer housing, wherein the seal assembly comprises an outer surface including a receptacle configured to receive a radially inner end of each locking pin of the outer housing. In some embodiments, the seal assembly has a first position seated within the throughbore of the outer housing and a second position removed from the throughbore of the outer housing. In certain embodiments, the seal assembly is configured to be lowered into the throughbore of the outer housing at the first end of the outer housing. In certain embodiments, the inner surface of the outer housing comprises an annular shoulder and the outer surface of the seal assembly comprises an annular shoulder configured to axially abut the annular shoulder of the outer housing in the first position. In some embodiments, each locking pin comprises a fluid passage configured to be pressurized to transition the locking pin between the unlocked position and the locked position. In some embodiments, each locking pin comprises a position sensor configured to indicate the position of the locking pin in the locked position or the unlocked position.

[0008] An embodiment of a rotating control device for sealing an annulus extending from a subterranean wellbore comprises an outer housing including a central axis, a first end, a second end opposite the first end, an inner surface extending axially from the first end to the second end, and an outer surface extending between the first end and the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and wherein the outer housing includes a first passage extending from the inner surface to the outer surface and a second passage extending from the inner surface to the outer surface, and a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through the throughbore of the outer housing, wherein the seal assembly comprises an inner housing including a first end, a second end opposite the first end, an inner surface extending axially from the first end to the second end of the inner housing, and an outer surface extending between the first end and the second end of the inner housing, wherein the inner housing includes a first passage extending from the inner surface to the outer surface of the inner housing and a second passage extending from the inner surface to the outer surface of the inner housing, wherein the first passage of the outer housing is in fluid communication with the first passage of the inner housing, and wherein the first passage of the outer housing and the first passage of the inner housing are configured to supply a lubricating fluid to a bearing chamber of the inner housing, wherein the second passage of the outer housing is in fluid communication with the second passage of the inner housing, and wherein the second passage of the outer housing and the second passage of the inner housing are configured to receive the lubricating fluid from the bearing chamber. In some embodiments, the first and second passages of the outer housing each include a check valve, and the first and second passages of the inner housing each include a check valve. In some embodiments, the rotating control device further comprises a plurality of fluid conduits in fluid communication with the first and second passages of the outer housing, and a sensor coupled to one of the fluid conduits, wherein the sensor is configured to measure at least one of pressure and temperature of fluid disposed in the fluid conduit. In some embodiments, the rotating control device further comprises a stab plate coupled to the outer housing and including a fluid connector coupled to an end of one of the fluid conduits. In certain embodiments, the rotating control device further comprises a lubrication system coupled to the plurality of fluid conduits, wherein the lubrication system is configured to circulate lubricating fluid in a continuous circuit through the bearing chamber of the inner housing of the seal assembly. In certain embodiments, the rotating control device further comprises a sensor coupled to the outer housing and in fluid communication with the bore of the outer housing, wherein the sensor is configured to measure at least one of pressure and temperature of fluid disposed in the bore of the outer housing.

An embodiment of a rotating control device for sealing an annulus extending from a subterranean wellbore comprises an outer housing including a central axis, a first end, a second end opposite the first end, an inner surface extending axially from the first end to the second end, and an outer surface extending from the first end to the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through the throughbore of the outer housing, wherein the seal assembly comprises an inner housing including a first end, a second end opposite the first end of the inner housing, an inner surface extending axially from the first end of the inner housing to the second end of the inner housing, and an outer surface extending from the first end of the inner housing to the second end of the inner housing, a first proximity sensor disposed along the inner surface of the outer housing, and a first sensor element disposed along the outer surface of the inner housing, wherein the first proximity sensor is configured to measure the rotational speed of the seal assembly in response to rotation of the seal assembly in the outer housing. In some embodiments, the first sensor element comprises a magnetic member. In some embodiments, the rotating control device further comprises a second proximity sensor disposed along the inner surface of the housing, a second sensor element disposed along the outer surface of the inner housing, wherein the second sensor element is configured to detect a leak in a sealing element of the seal assembly in response to leakage across the sealing element. In certain embodiments, the second sensor element comprises a sensor element assembly comprising: a housing, a piston slidably disposed in the housing, a biasing member configured to bias the piston towards a radially inner position, and a burst disc configured to rupture in response to leakage across the sealing element. In certain embodiments, in response to the rupture of the burst disc, the piston is configured to be actuated into a radially outer position. In some embodiments, in response to the piston of the sensor element assembly being disposed in the radially outer position, the second proximity sensor is configured to output a signal. In certain embodiments, the rotating control device further comprises a transducer disposed along the outer surface of a sleeve disposed in the inner housing of the seal assembly, wherein the transducer is configured to measure the pressure of fluid disposed in a bore of the sleeve, and a transmitter disposed along the inner surface of the outer housing, wherein the transducer is configured to wirelessly communicate signals indicative of the pressure of fluid disposed in the bore of the sleeve to the transmitter.

[0009] An embodiment of a method for sealing an annulus of a marine riser with a rotating control device (RCD) comprises (a) coupling an outer housing of the RCD to the marine riser, (b) lowering a seal assembly into the outer housing of the RCD after (a), wherein the seal assembly is configured to seal against a drillstring extending through the outer housing and the marine riser, and (c) extending a plurality of locking pins radially inward from the outer housing into a receptacle in an outer surface of the seal assembly after (b) to secure the seal assembly within the outer housing. In some embodiments, the method further comprises (d) flowing a fluid from an annulus disposed between the seal assembly and the outer housing through a port extending through the outer housing. In some embodiments, (b) comprises landing an annular landing profile of the seal assembly against a corresponding landing profile of the outer housing. In certain embodiments, (c) comprises engaging a chamfered profile of an inner end of each locking pin against a corresponding chamfered profile of the receptacle of the seal assembly. In certain embodiments, (c) comprises pressurizing a fluid passage extending through each locking pin to displace each locking pin into the receptacle of the outer surface of the seal assembly.

[0010] Embodiments described herein comprise a combination of features and advantages intended to address various shortcomings associated with certain prior devices, systems, and methods. The foregoing has outlined rather broadly the features and technical advantages of the invention in order that the detailed description of the invention that follows may be better understood. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description, and by referring to the accompanying drawings. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a detailed description of various exemplary embodiments, reference will now be made to the accompanying drawings in which:

[0012] Figure 1 is a schematic view of an embodiment of an offshore drilling system in accordance with the principles disclosed herein;

[0013] Figure 2 is a front view of the rotating control device (RCD) of Figure 1;

[0014] Figure 3 is a cross-sectional view of the RCD of Figure 2 taken along section 3-3 of Figure 2;

[0015] Figure 4 is a front view of the seal assembly of the RCD of Figure 2;

[0016] Figure 5 is an exploded side view of the seal assembly of Figure 4;

[0017] Figure 6 is a cross-sectional view of the seal assembly of Figure 4 taken along section 6-6 of Figure 4;

[0018] Figure 7 is a front view of one of the actuatable locking pins of the RCD of Figure 2;

[0019] Figure 8 is a cross-sectional view of the actuatable locking pin of Figure 7 taken along section 8-8 of Figure 7 and in a "locked" position;

[0020] Figure 9 is a cross-sectional view of the actuatable locking pin of Figure 7 taken along section 9-9 of Figure 7 and in an "unlocked" position;

[0021] Figure 10 is a schematic view of an embodiment of an offshore drilling system in accordance with the principles disclosed herein;

[0022] Figure 11 is a perspective view of the RCD of Figure 10;

[0023] Figure 12 is a schematic top cross-sectional view of another embodiment of an RCD for use with either the offshore system of Figure 1 or the offshore system of Figure 10 in accordance with principles disclosed herein;

[0024] Figure 13 is a schematic side cross-sectional view of another embodiment of an RCD for use with either the offshore system of Figure 1 or the offshore system of Figure 10 in accordance with principles disclosed herein;

[0025] Figure 14 is a schematic top cross-sectional view of another embodiment of an RCD for use with either the offshore system of Figure 1 or the offshore system of Figure 10 in accordance with principles disclosed herein;

[0026] Figure 15 is a schematic side cross-sectional view of the RCD of Figure 14;

[0027] Figure 16 is a schematic top cross-sectional view of another embodiment of an RCD shown in an unlocked position for use with either the offshore system of Figure 1 or the offshore system of Figure 10 in accordance with principles disclosed herein;

[0028] Figure 17 is a schematic side cross-sectional view of the RCD of Figure 16 shown in the unlocked position;

[0029] Figure 18 is a schematic top cross-sectional view of the RCD of Figure 16 shown in a locked position;

[0030] Figure 19 is a schematic side cross-sectional view of the RCD of Figure 16 shown in the locked position;

[0031] Figure 20 is a side cross-sectional view of another embodiment of an RCD for use with either the offshore system of Figure 1 or the offshore system of Figure 10 in accordance with principles disclosed herein;

[0032] Figure 21 is another side cross-sectional view of the RCD of Figure 20;

[0033] Figure 22 is a perspective view of another embodiment of an RCD for use with the offshore system shown in Figure 1 in accordance with principles disclosed herein;

[0034] Figure 23 is a first side cross-sectional view of the RCD of Figure 22;

[0035] Figure 24 is a second side cross-sectional view of the RCD of Figure 22;

[0036] Figure 25 is a third side cross-sectional view of the RCD of Figure 22;

[0037] Figure 26 is a zoomed-in cross-sectional view of the RCD of Figure 22; and

[0038] Figure 27 is another side cross-sectional view of the RCD of Figure 22 including an embodiment of a protective sleeve in accordance with principles disclosed herein.

DETAILED DESCRIPTION OF THE DISCLOSED EMBODIMENTS

[0039] The following discussion is directed to various exemplary embodiments. However, one skilled in the art will understand that the examples disclosed herein have broad application, and that the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to suggest that the scope of the disclosure, including the claims, is limited to that embodiment.

[0040] Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function. The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

[0041] In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to... ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices, components, and connections. In addition, as used herein, the terms "axial" and "axially" generally mean along or parallel to a central axis (e.g., central axis of a body or a port), while the terms "radial" and "radially" generally mean perpendicular to the central axis. For instance, an axial distance refers to a distance measured along or parallel to the central axis, and a radial distance means a distance measured perpendicular to the central axis. As used herein, the term "well site personnel" is used broadly to include any individual or group of individuals who may be disposed or stationed on a rig or worksite or offsite at a remote monitoring location (such as a remote office location). The term also would include any personnel involved in the drilling and/or production operations at or for an oil and gas well such as, for example, technicians, operators, engineers, analysts, etc.

[0042] Referring now to Figure 1, an embodiment of an offshore drilling system 10 for drilling a subsea wellbore 24 in an earthen formation 7 is shown. In this embodiment, system 10 generally includes a drilling vessel 12 disposed at the surface 3 of the water 3 (i.e., at the waterline), a wellhead 20 disposed at the sea floor 5, a BOP stack 56 mounted atop the wellhead 20, a lower marine riser package (LMRP) 54 mounted atop BOP stack 56, casing 24 extending from wellhead 20 into wellbore 24, and a marine riser system 30 extending from the drilling vessel 12 to LMRP 54. Wellbore 24, casing 24, wellhead 20, BOP stack 56, LMRP 54, and riser system 30 share a common, generally vertically oriented central or longitudinal axis 15.

[0043] Drilling vessel 12 includes a drilling floor 14 and a derrick 16 extending upwards from the drilling floor 14. In the embodiment shown in Figure 1, drilling vessel 12 is a floating offshore structure, and more particularly, a floating semi-submersible platform. However, in other embodiments, the drilling vessel (e.g., vessel 12) may comprise other drilling vessels known in the art, such as drilling ships, tension leg platform, jack-up platform, and the like.

[0044] Marine riser system 30 provides a conduit for flowing drilling fluid or mud through the water between the drilling vessel 12 and the LMRP 54, BOP stack 56, and wellhead 24 disposed at the sea floor 5. More specifically, during drilling operations, drilling fluid is pumped from drilling vessel 12 down a drillstring 18 (shown with dashed lines) suspended from vessel 12 through marine riser system 30, LMRP 54, BOP stack 56, wellhead 20, and casing 24 into wellbore 22. The drilling fluid exits the drillstring 18 at a drill bit (not shown) connected to the lower end of drillstring 18 in the wellbore 24. Upon exiting the drillstring 18, the drilling fluid circulates back to the drilling vessel 12 through a series of contiguous, interconnected annuli radially positioned between drillstring 18 and the inner surfaces of wellbore 22, casing 24, wellhead 20, BOP stack 56, LMRP 54, and riser system 30.

[0045] Referring still to Figure 1, and moving downward from vessel 12, in this embodiment, marine riser system 30 includes a diverter bowl 32 disposed just below and proximal drilling floor 14, a telescopic joint 34 having an upper end coupled to bowl 32, a tension ring 40 attached to joint 34, a rotating control device (RCD) 100 coupled to a lower end of joint 34, an annular blowout preventer (BOP) 44 coupled to RCD 100, a diverter spool 48 coupled to annular BOP 44, and a tubular marine riser 52 extending from annular BOP 44 to LMRP 54. Diverter bowl 32 defines the upper end of the marine riser system 30 and generally functions to divert annular flow (e.g., gas flows) during installation of marine riser system 30. Joint 34 includes an inner housing 36 and an outer housing 38 that can slide axially relative to each other, thereby allowing joint 34 to axially extend and contract. This functionality compensates for heave (relative vertical movement) between the marine riser system 30 and the drilling vessel 12. In this manner, heave experienced by drilling vessel 12 is accommodated without damaging components of marine riser system 30. In some embodiments, an annular packer is positioned between the inner housing 36 and the outer housing 38 to seal therebetween.

[0046] Tension ring 40 is disposed about and securely attached to the outside of outer housing 38 and suspended from a plurality of tension cables 42 extending from vessel 12. Thus, tension ring 40 and cables 42 support the components of marine riser system 30 suspended from outer housing 38 and apply tensile loads thereto.

[0047] RCD 100 is coupled to the lower end of telescopic joint 34. As will be described in more detail below, RCD 100 seals the upper end of the continuous annulus extending through marine riser system 30 from wellbore 24, thereby allowing flow of drilling fluid through the annulus to be controlled and pressurized. Annular BOP 44 is coupled to the lower end of RCD 100 and can be actuated in response to an uncontrolled influx of fluids from formation 7 into wellbore 24 to completely seal and close the annulus extending through marine riser system 30, thereby shutting in wellbore 24. A plurality of accumulators 46 are provided along riser system 30 for operating annular BOP 44. Accumulators 46 may also be utilized to actuate components of RCD 100, as will be discussed further herein.

[0048] Diverter spool 48 is coupled to the lower end of accumulators 46 and diverts fluid flowing through the annulus of marine riser system 30 to the drilling vessel 12. In particular, diverter spool 48 includes a plurality of circumferentially-spaced return conduits or lines 50 in fluid communication with the annulus. In this embodiment, return lines 50 are in the form of goosenecks extending from diverter spool 48 to vessel 12. Thus, drilling fluid flowing through the annulus of marine riser system 30 can be selectively directed to drilling vessel 12 via the plurality of return conduits 50. In this embodiment, each return conduit 50 includes one or more valves (not shown) that can be opened or closed to permit or prevent, respectively, fluid flow therethrough. Due to the seal provided by RCD 100 at the upper end of riser system 30, and provided one or more of the vales in return conduits 50 are open, fluid flowing through the annulus of marine riser 30 is forced to flow through return conduits 50 to drilling vessel 12. At drilling vessel 12, the drilling fluid is cleaned and conditioned to remove any cuttings or other contaminants, and then pumped back down drillstring 18.

[0049] Referring now to Figures 2-5, in this embodiment, RCD 100 has a central or longitudinal axis 105 coaxially aligned with axis 15 of riser system 30 and generally includes an outer housing 102, a rotating or rotatable seal assembly 130 slidingly received within outer housing 102, and a plurality of circumferentially-spaced actuatable locking pins 310 that selectively lock seal assembly 130 within outer housing 102. Outer housing 102 includes a first or upper end 102a, a second or lower end 102b, an inner surface 106 extending between ends 102a, 102b, and an outer surface 108 extending axially between ends 102a, 102b. Inner surface 106 defines a central throughbore 104 extending axially through housing 102 (i.e., between ends 102a, 102b). An annular connection flange 110 is provided at upper end 102a and lower end 102b. Each connection flange 110 includes an annular seal assembly 112 comprising an annular groove that receives an annular seal member for sealing against mating flanges provided on the adjacent components of marine riser system 30.

[0050] In this embodiment, outer housing 102 also includes a plurality of uniformly circumferentially spaced bores 114 extending radially through housing 102 from outer surface 108 to inner surface 106. Although bores 114 are shown as being generally cylindrical in Figures 2-5, in other embodiments, bores 114 may include varying cross-sectional shapes (e.g., square, rectangular, hexagonal, etc.). An annular recess is provided on outer surface 108 at the radially outer end of each bore 114. One locking pin 310 is disposed in each bore 114. In this embodiment, inner surface 106 of outer housing 102 includes an annular frustoconical, generally upward facing landing surface 118 axially positioned below and adjacent bores 114. However, in other embodiments, landing surface 118 need not be frustoconical in shape. Landing surface 118 is disposed at an acute angle α relative to axis 105. In embodiments described herein, angle α is preferably between 0° and 90°, and more preferably about 30°. Seal assembly 130 is sized and shaped to seat against mating landing surface 118.

[0051] Referring now to Figures 3-5, seal assembly 130 seals against the outer surface of drillstring 18 as drillstring 18 is both rotated about its longitudinal axis and advanced axially (with respect to axes 15, 105) through marine riser system 30. In this embodiment, seal assembly 130 is installed in outer housing 102 after installation of outer housing 102 along marine riser system 30. Particularly, outer housing 102 of RCD 100 is coupled to telescopic joint 34 and annular BOP 44, and then RCD 100 is displaced beneath the drill floor 14 of drilling vessel 12 as shown in Figure 1. Next, seal assembly 130 is inserted into outer housing 102 utilizing a running tool or drill string, and then secured within outer housing 102 with the plurality of locking pins 310. Likewise, seal assembly 130 can be removed from outer housing 102 using the running tool or drill string while outer housing 102 remains in place as part of marine riser system 30.

[0052] In this embodiment, seal assembly 130 is coaxially aligned with axis 105 and generally includes a housing assembly 132, a rotating or rotatable sleeve assembly 180 radially disposed within housing assembly 132, and a bearing assembly 230 radially disposed between assemblies 132, 189. Housing assembly 132 includes a first or upper housing member 134 and a second or lower housing member 150 secured to upper housing member 134 with bolts. As best shown in Figure 3, housing assembly 132 lands within outer housing 102 and is releasably locked therein by pins 310, thereby releasably securing seal assembly 130 with outer housing 102.

[0053] Upper housing member 134 of housing assembly 132 has a first or upper end 134a defining the upper end of seal assembly 130, a second or lower end 134b opposite upper end 134a, an inner surface 138 extending axially between ends 134a, 134b, and an outer surface 140 extending axially between ends 134a, 134b. Inner surface 138 defines a throughbore 136 extending axially through housing member 134. Upper housing member 134 also includes a radially outer flanged section 142 at upper end 134a that forms an annular downward facing shoulder 142s that axially abuts lower housing member 150. In addition, upper housing member 134 includes a plurality of circumferentially spaced radial lubrication ports 146 proximal lower end 134b. Each port 146 extends radially between surfaces 138, 140. Ports 146 allow for the passage of lubricant to bearing assembly 230. Upper housing member 134 further includes an annular seal groove 148 extending into outer surface 140 and disposed adjacently above (i.e., closer to upper end 134a) radial ports 146. An annular seal member is disposed in groove 148 and sealingly engages lower housing member 150.

[0054] A plurality of circumferentially-spaced apertures 145 extend axially upward into flanged section 142. Each aperture 145 receives a releasable fastener for coupling a retainer ring 147 to the lower end of flanged section 142. The coupling of retainer ring 147 to the lower end of flanged section 142 forms an annular groove extending into the inner surface 138 of upper housing member 134, where the annular groove is configured to receive a rotary seal 149 for sealingly engaging the rotating sleeve assembly 180 as sleeve assembly 180 rotated within housing assembly 132.

[0055] Referring still to Figures 3-5, lower housing member 150 has a first or upper end 150a, a second or lower end 150b, an inner surface 154 extending axially between ends 150a, 150b, and an outer surface 156 extending axially between ends 150a, 150b. Inner surface 154 defines a throughbore 152 extending axially through member 150. In this embodiment, inner surface 154 includes a reduced diameter section 158 radially adjacent rotating sleeve assembly 180. Reduced diameter section 158 prevents axial misalignment of rotating sleeve assembly 180 and bearing assembly 230 with longitudinal axis 105 of RCD 100. Particularly, reduced diameter section 158 prevents rotating sleeve assembly 180 and bearing assembly 230 from shifting angularly within outer housing 102, or in other words, prevents a longitudinal axis of rotating sleeve assembly 180 and bearing assembly 230 from being disposed at an angle relative longitudinal axis 105. In addition, the inner surface 154 includes an annular seal groove 162 disposed proximal upper end 150a. An annular seal member is disposed in groove 162 and sealingly engages the outer surface 140 of upper housing member 134. Thus, radial ports 146 of upper housing member 134 are axially flanked by seal groove 148 (and associated seal member) of upper housing member 134 and seal groove 162 (and associated seal member) of lower housing member 150, thereby sealing radial ports 146 from the surrounding environment. Inner surface 154 further includes an annular shoulder 163 facing the upper end 150a of lower housing 150.

[0056] The outer surface 156 of lower housing member 150 includes a landing profile 164 having frustoconical surface 165 for engaging mating landing surface 118 of outer housing

102. Thus, in this embodiment, landing surface 165 of lower housing member 150 is disposed at the same angle α relative to axis 105 as landing surface 118. Outer surface 156 also includes an annular groove or receptacle 166 and disposed axially between upper end 150a and landing profile 164. Annular groove 166 is sized and positioned to receive locking pins 310 for releasably locking seal assembly 130 to outer housing 102. In particular, annular groove 166 includes an annular angled or chamfered profile 167 for slidingly engaging a corresponding landing profile of the actuatable locking pins 310. However, in other embodiments, annular groove 166 need not include chamfered profile 167. A pair of annular seal assemblies 168 are provided axially below groove 166 and radially between outer surface 156 of lower housing member 150 and inner surface 106 of outer housing 120 for sealing therebetween.

[0057] In this embodiment, lower housing member 150 further includes a plurality of apertures 170 extending into lower end 150b that are aligned with, but radially offset from longitudinal axis 105. Each aperture 170 receives a releasable fastener for coupling a retainer ring 172 to the lower end 150b of lower housing member 150. The coupling of retainer ring 172 to the lower end 150b of lower housing member 150 forms an annular groove extending into the inner surface 154 of lower housing member 150, where the annular groove is configured to receive a rotary seal 174 for sealingly engaging the rotating sleeve assembly 180 as sleeve assembly 180 rotated within housing assembly 132. Thus, rotary seal 174 and annular seals 168 act in conjunction to restrict fluid communication or a fluid flow through throughbore 104 of outer housing 102 that does not pass through rotating sleeve assembly 180, thereby sealing an annulus 103 disposed between rotating sleeve assembly 180 and the outer housing 102.

[0058] Referring now to Figures 3, 5, and 6, rotating sleeve assembly 180 seals against the outer surface drillstring 18 as it both rotates and move axially through sleeve assembly 180. Rotating sleeve assembly 180 rotates relative to housing assembly 132 via bearing assembly 230. In this embodiment, rotating sleeve assembly 180 has a longitudinal axis disposed coaxially aligned with axis 105 and generally includes a rotating sleeve 182, an annular mounting member 200, and a sealing member or boot 210.

[0059] Rotating sleeve 182 couples rotating sleeve assembly 180 with bearing assembly 230, which is in turn supported by housing assembly 132. Rotating sleeve 182 has a first or upper end 182a, a second or lower end 182b, an inner surface 186 extending axially between ends 182a, 182b, and an outer surface 188 extending axially between ends 182a, 182b. Inner surface 186 defines a central throughbore 184 extending through sleeve 182. Outer surface 188 includes a first or upper annular groove 190 disposed proximal upper end 182a and a second or lower annular groove 192 disposed proximal lower end 182b. Annular grooves 182a, 182b secure components of bearing assembly 230 to rotating sleeve 182. Rotating sleeve 182 also includes a radially outer flanged section 194 at lower end 182b for securing sleeve 182 to mounting member 200. In this embodiment, flanged section 194 includes an annular seal groove 196 extending axially into rotating sleeve 182 at lower end 182b. An annular seal member is disposed in grove 196 and sealingly engages mounting member 200.

[0060] Mounting member 200 of rotating sleeve assembly 180 physically supports and couples sealing boot 210 with rotating sleeve 182. In this embodiment, mounting member 200 has a first or upper end 200a, a second or lower end 200b, and a radially outer flanged section 202 disposed at upper end 200a. Flanged section 202 includes a plurality of circumferentially spaced apertures (not shown) for receiving fasteners that secure mounting member 200 to rotating sleeve 182. In this embodiment, the upper end 200a of mounting member 200 also includes an annular seal groove 204 axially opposed with seal groove 196 of rotating sleeve 182. The annular seal member disposed in groove 196 extends into grove 204 and forms an annular seal between mounting member 200 and rotating sleeve 182.

[0061] Sealing boot 210 comprises a durable, resilient elastomeric material sized and configured to sealingly engage the outer surface of drillstring 18 extending therethrough. Sealing boot 210 has a first or upper end 210a, a second or lower end 210b, a central throughbore 212 extending axially between ends 210a, 210b, and an outer surface 216 extending axially between ends 210a, 210b. The inner surface of boot 210 that defines throughbore 212 includes a frustoconical surface axially positioned between ends 210a, 210b. Thus, the diameter of throughbore 212, and hence the inner diameter of boot 210, generally decreases moving from upper end 210a toward lower end 210b. In this embodiment, sealing boot 210 is molded onto mounting member 200 such that sealing boot 210 is fixably secured to and supported by mounting member 200. Further, because the lower end 200b of mounting member 200 does not extend to lower end 210b of sealing boot 210, the portion of sealing boot 210 proximal lower end 210b is unsupported by mounting member 200, providing greater flexibility to the portion of sealing boot 210 proximal lower end 210b.

[0062] Given the flexibility and resiliency of the lower end 210b of sealing boot 210, the inner surface 214 of sealing boot 210 can maintain a continuous seal against the outer surface of drillstring 18, even if the outer surface of drillstring 18 varies in diameter along its longitudinal length. For instance, in some applications, drillstring 18 comprises a plurality of discrete tubular members or drill pipes threadably connected end-to-end at pipe joints, where each pipe joint has a greater outer diameter than the “shank” or body of each individual drill pipe. Thus, in order to maintain a continuous seal against the outer surface of drillstring 18, the diameter 218 of throughbore 212 proximal lower end 210b must expand radially outwards to account for the greater outer diameter of each tool joint as drillstring 18 is displaced longitudinally through throughbore 104 of outer housing 102. To assist in allowing the lower end 210b of sealing boot 210 to expand radially outwards to account for larger diameter tool joints, sealing boot 210 includes a plurality of longitudinally extending (i.e., extending parallel with longitudinal axis 105) grooves 220 (shown in Figure 4) that extend radially into outer surface 216. In this manner, when the lower end 210b of sealing boot 210 to expands for a tool joint or other larger diameter section of drillstring 18, material comprising sealing boot 210 may flow into longitudinal grooves 220, allowing inner surface 214 to maintain a seal against the outer surface of the variable outer diameter of drillstring 18.

[0063] Referring still to Figures 3, 5, and 6, bearing assembly 230 of RCD 100 allows for the rotation of rotating sleeve assembly 180 about longitudinal axis 105 as drillstring 18 rotates and moves axially through sleeve assembly 180. In this embodiment, bearing assembly 230 has a central or longitudinal axis coaxially aligned with axis 105 and generally includes a first or upper annular retainer 232, a second or lower annular retainer 240, a first or upper inner annular bearing race 250, an annular bearing spacer 260, a second or lower annular inner bearing race 270, a first or upper plurality of conical roller bearings 280, a second or lower plurality of conical roller bearings 284, and an outer annular bearing race 290.

[0064] Upper retainer 232 and lower retainer 242 physically support the other components of bearing assembly 230 and restrict relative axial movement between bearing assembly 230 and rotating sleeve assembly 180 via coupling with rotating sleeve assembly 180. In this embodiment, upper retainer 232 includes a first or upper end 232a, a second or lower end 232b, and a central throughbore 234 extending axially between ends 232a, 232b. Upper retainer 232 also includes a plurality of circumferentially spaced apertures 236 disposed proximal upper end 232a and extending radially therethrough. Each aperture 236 is configured to receive a corresponding pin that extends therethrough and into upper annular groove 190 of rotating sleeve 182 to restrict relative axial movement between upper retainer 232 and rotating sleeve 182. Similarly, lower retainer 240 includes a first or upper end 240a, a second or lower end 240b, and a central throughbore 242 extending axially between ends

240a, 240b. Lower retainer 240 also includes a plurality of circumferentially spaced apertures 244 disposed proximal upper end 240a and extending radially therethrough. Each aperture 244 is configured to receive a corresponding pin that extends therethrough and into lower annular groove 192 of rotating sleeve 182 to restrict relative axial movement between lower retainer 240 and rotating sleeve 182.

[0065] Bearing races 250, 270, 290 physically support and position upper roller bearings 280 and lower bearings 284. Bearing races 250, 270, 290 also transmit both radial and axial thrust loads applied to bearings 280, 284 to housing assembly 132. In this embodiment, upper bearing race 250 has a first or upper end 250a, a second or lower end 250b, and a throughbore 252 extending axially between ends 250a, 250b. The upper end 250a of upper bearing race 250 engages the lower end 232b of upper retainer 232, while the lower end 250b of upper bearing race 250 engages bearing spacer 260, thereby restricting axial movement of upper bearing race 250. Upper bearing race 250 also includes an inclined bearing seat 254 that extends into an outer surface of upper bearing race 250.

[0066] Inclined bearing seat 254 positions the upper roller bearings 280 such that a longitudinal axis of each upper roller bearing 280 is disposed at an angle relative longitudinal axis 105. In this arrangement, both radial and thrust loads may be transferred from upper bearing race 250 to upper roller bearings 280, and from upper roller bearings 280 to outer bearing race 290. Particularly, upper roller bearings 280 are inclined via inclined seat 254 such that axial thrust loads in the downward direction are transferred between upper bearing race 250 and outer bearing race 290 via upper roller bearings 280.

[0067] Axially positioned between upper bearing race 250 and lower bearing race 270 is bearing spacer 260, which spaces upper roller bearings 280 apart from lower roller bearings 284. In this embodiment, bearing spacer 260 has a first or upper end 260a, a second or lower end 260b, and a central throughbore 262 extending axially between ends 260a, 260b. As mentioned above, the upper end 260a of bearing spacer 260 engages the lower end 250b of upper bearing race 250 to assist in positioning upper bearing race 250.

[0068] In this embodiment, lower bearing race 270 has a first or upper end 270a, a second or lower end 270b, and a throughbore 272 extending axially between ends 270a, 270b. Upper end 270a engages the lower end 260b of bearing spacer 260, while the lower end 270b engages the upper end 240a of lower retainer 240, thereby restricting axial movement of lower bearing race 270. Lower bearing race 270 also includes an inclined bearing seat 274 that extends into an outer surface of lower bearing race 270. Inclined bearing seat 274 positions the lower plurality of roller bearings 284 such that a longitudinal axis of each lower roller bearing 284 is disposed at an angle relative longitudinal axis 105 of RCD 100. In this arrangement, lower roller bearings 284 are inclined via inclined seat 274 such that axial thrust loads in the upward direction are transferred between lower bearing race 270 and outer bearing race 290 via lower roller bearings 284.

[0069] Outer bearing race 290 is disposed radially about upper bearing race 250, lower bearing race 270, and roller bearings 280, 284. Outer bearing race 290 supports upper roller bearings 280 and lower roller bearings 284, and transfers radial and axial thrust loads imparted to roller bearings 280, 284 to the lower housing member 150 of housing assembly 132. In this embodiment, outer bearing race 290 has a first or upper end 290a, a second or lower end 290b, and a throughbore 292 extending between upper end 290a and lower end 290b, where throughbore 292 is defined by an inner surface 294. In the embodiment shown, the lower end 290b of outer bearing race 290 is seated against the annular shoulder 163 of lower housing member 154 for physically supporting seal assembly 130 within outer housing 102. In this embodiment, the inner surface 294 of outer bearing race 290 includes a first or upper inclined section 296, and a second or lower inclined section 298. Both inclined sections 296, 298 are disposed at an angle β relative longitudinal axis 105. Particularly, upper inclined section 296 is disposed at the same angle β relative to axis 105 as upper roller bearings 280, and thereby receives radial loads and axial thrust loads in the downwards direction from upper roller bearings 280. Similarly, lower inclined section 298 is disposed at the same angle β relative to axis 105 as lower roller bearings 284, and thereby receives radial loads and axial thrust loads in the upwards direction from lower roller bearings 284. In embodiments described herein, angle β may comprise an angle between 5° and 30°.

[0070] Referring now to Figures 7-9, actuatable locking pins 310 selectively lock seal assembly 130 within outer housing 102, thereby preventing relative axial movement therebetween. In this embodiment, locking pins 310 are hydraulically actuated via hydraulic lines (not shown) extending between drilling vessel 12 and RCD 100. In other embodiments, the locking pins 310 receive hydraulic pressure from other sources, such as accumulators 46 previously described and shown in Figure 1.

[0071] Each actuatable locking pin 310 has a radially oriented central or longitudinal axis 315 that intersects axis 105. In this embodiment, each actuatable locking pin 310 is the same, and thus, one pin 310 will be described it being understood the other pins 310 are the same. Locking pin 310 generally includes an outer housing 312 and a sliding pin 350 disposed within outer housing 312. Outer housing 312 includes a first or inner housing member 314 and a second or outer housing member 330. Inner housing member 314 has a first or radially outer end 314a (relative to axis 105), a second or radially inner end 314b (relative to axis 105), a generally cylindrical inner surface 318 extending axially (relative to axis 315) between ends 314a, 314b, and a generally cylindrical outer surface 320 extending axially (relative to axis 315) between ends 314a, 314b. Inner surface 318 defines a central throughbore 316 extending axially through the corresponding pin 310.

[0072] In this embodiment, the outer surface 320 of inner housing member 314 includes a threaded connector 320t for threadably engaging a corresponding threaded connector 114t disposed on the inner surface of bore 114 of outer housing 102, thereby releasably coupling locking pin 310 to outer housing 102. A pair of axially spaced annular seals 322 are disposed in corresponding annular grooves along outer surface 320. Seals 322 sealingly engage the inner surface of bore 114 of outer housing 102. Inner surface 318 includes an annular shoulder 324 facing outer housing member 330. Inner housing member 314 also includes a radially outwards flanged section 326 for engaging outer housing member 330.

[0073] Outer housing member 330 releasably couples with inner housing member 314 and includes a first or radially outer end 330a (relative to axis 105), a second or radially inner end 330b (relative to axis 105), a generally cylindrical inner surface 334 extending axially (relative to axis 315) between ends 330a, 330b, and a generally cylindrical outer surface 336 extending axially (relative to axis 315) between ends 330a, 330b. Inner surface 334 defines a central throughbore 332 extending axially through outer housing member 330. An annular seal 338 is disposed in an annular groove disposed along inner surface 334. Seal 338 sealingly engages the outer surface of sliding pin 350. In addition, inner surface 334 includes an annular shoulder 340 facing inner housing member 314.

[0074] An annular seal 342 is disposed in an annular groove along outer surface 336. Seal 342 sealingly engages inner housing member 314. In addition, outer housing member 330 includes a radially outer flanged section 344 disposed proximal inner end 330b. Housing members 330, 314 are releasably coupled by a plurality of circumferentially-spaced fasteners 346 extending through opposed flanged sections 344, 326

[0075] As best shown in Figures 8 and 9, sliding pin 350 is slidably disposed within outer housing 312 and has a first or radially outer end 350a (relative to axis 105), a second or radially inner end 350b (relative to axis 105), and a generally cylindrical outer surface 352 extending axially (relative to axis 315) between ends 350a, 350b. In this embodiment, three annular seals are provided along the outer surface 352 of sliding pin 350 – a first annular seal 354 disposed proximal inner end 350b, a second annular seal 356 disposed proximal outer end 350a, and a third annular seal 358 disposed axially (relative to axis 315) between seals 354, 356. Each seal 354, 356, 358 is disposed in corresponding annular groove in outer surface 352. In this arrangement, first seal 354 and third seal 358 sealingly engage the inner surface 318 of inner housing member 314 while second seal 356 sealingly engages the inner surface 334 of outer housing member 330.

[0076] The outer surface 352 of sliding pin 350 also includes an inclined or chamfered profile 360 at inner end 350b. However, in other embodiments, sliding pin 350 need not include chamfered profile 360. In this embodiment, chamfered profile 360 mates and slidingly engages the corresponding chamfered profile 167 of lower housing member 150. In this arrangement, when chamfered profile 360 of sliding pin 350 physically engages chamfered profile 167, housing assembly 132 is urged axially downward (relative to axis 105), thereby increasing the force or pressure between the landing profile 164 of lower housing member 150 and the landing surface 118 of outer housing 102. Thus, the chamfered action or interface between sliding pin 350 and lower housing member 150 increases the seating force between housing assembly 132 and outer housing 102. The outer surface 352 of sliding pin 350 also includes a first annular shoulder 362 facing inner end 350b and a second annular shoulder 364 spaced from first shoulder 362 and facing outer end 350a.

[0077] In this embodiment, sliding pin 350 includes a plurality of fluid passages for routing pressurized fluid for actuating sliding pin 350 between a first or “locked” position shown in Figure 8, and a second or “unlocked” position in Figure 9. Specifically, sliding pin 350 includes a first or opening passage 366, a second or closing passage 368, and a lubrication passage 370, each passage 366, 368, 370 extending between outer end 350a and outer surface 352. More specifically, a terminal end 366a of opening passage 366 is disposed between first seal 354 and third seal 358, a terminal end 368a of closing passage 368 is disposed between second seal 356 and third seal 358, and a terminal end 370a of lubrication passage 370 is disposed between second seal 356 and third seal 358. End 358a of closing passage 368 is disposed between ends 366a, 370a of passages 366 and 370.

[0078] As shown particularly in Figure 8, in the locked position, the inner end 350b of sliding pin 350 is disposed within and fully seated in mating annular groove 166 of lower housing member 150 with chamfered profile 360 of sliding pin 360 engaging mating chamfered profile 167 of annular groove 166. In addition, in the locked position, annular shoulder 324 of inner housing member 314 axially abuts first shoulder 362 of sliding pin 350, while second shoulder 364 of sliding pin 350 is spaced apart from shoulder 340 of outer housing member 330. In the unlocked positon shown in Figure 9, the inner end 350b of sliding pin 350 is completely removed from annular groove 166 of lower housing member 150, and chamfered profile 360 of sliding pin 360 is spaced apart from mating chamfered profile 167 of annular groove 166. In addition, in the unlocked position, annular shoulder 324 of inner housing member 314 is spaced apart from first shoulder 362 of sliding pin 350, while second shoulder 364 of sliding pin 350 axially abuts shoulder 340 of outer housing member 330.

[0079] Sliding pin 350 can be actuated from the unlocked position shown in Figure 9 to the locked position shown in Figure 8 by depressurizing passage 366 and flowing a pressurized fluid into or otherwise pressurizing closing passage 368, which applies a fluid pressure against the annular shoulder 340 of outer housing member 330 and second shoulder 364 of sliding pin 350, thereby axially displacing sliding pin 350 through outer housing 312 until chamfered profile 360 of sliding pin 350 matingly engages the chamfered profile 167 of lower housing member 150. In some embodiments, passage 366 is depressurized by flowing fluid into end 366a of passages 368 from throughbore 316 of inner housing member 314, and then flowing the fluid passing through end 366a out of passage 366 to reduce the fluid pressure therein. The reduction of fluid pressure in passage 366 prevents hydraulic lock from restricting the displacement of sliding pin 350 through outer housing 312.

[0080] In some embodiments, a pilot valve (not shown) is connected between closing passage 368 and the fluid or pressure source in fluid communication with and configured to pressurized closing passage 368. In this arrangement, the pilot valve is configured to prevent inadvertent depressurization of closing passage 368 and subsequent actuation of sliding pin 350 from the locked position to the unlocked position. Particularly, the pilot valve is configured to allow for the communication of fluid or fluid pressure to closing passage 368 while restricting the depressurization or fluid flow out of closing passage 368 unless a separate pressure or electric signal is communicated to the pilot valve to actuate the pilot valve and thereby depressurize closing passage 368. Therefore, in the event of a reduction in the fluid pressure applied to closing passage 368, closing passage 368 would remain pressurized with sliding pin 350 held in the locked position until either a positive pressure or electric signal is communicated to the pilot valve to release the fluid pressure retained within closing passage 368. In this manner, sliding pin 350 will remain in the locked position coupling or locking seal assembly 130 within outer housing 102 even if fluid pressure in communication with closing passage 368 is inadvertently lost or reduced.

[0081] Sliding pin 350 can be actuated from the locked position shown in Figure 8 into the unlocked positon shown in Figure 9 by depressurizing passage 368 and then flowing a pressurized fluid into opening passage 366, which applies a fluid pressure against the annular shoulder 324 of inner housing member 314 and first shoulder 362 of sliding pin 350, thereby axially displacing sliding pin 350 through outer housing 312 until second shoulder 364 of sliding pin 350 engages the shoulder 340 of outer housing member 330. Particularly, the pressure applied to closing passage 368 is reduced and a pressure or electric signal is communicated to the pilot valve in fluid communication with passage 368 to thereby allow pressure trapped within passage 368 by the pilot valve to be vented therefrom. Passage 368 is depressurized to prevent hydraulic lock from restricting the movement of sliding pin 350, and passage 368 may be depressurized in a manner similar to that described above with respect to passage 366. Although sliding pins 350 are described above as actuated in response to a fluid pressurization or fluid flow, in other embodiments, sliding pins 350 may be actuated pneumatically or via an electrical actuator.

[0082] Lubrication passage 370 is configured to provide a fluid passage for the application of a lubricant between the outer surface 352 of sliding pin 350 and the inner surface 334 of outer housing member 330 to minimize friction therebetween as sliding pin 350 is actuated between the locked and unlocked positions. Thus, during operation of RCD 100 lubrication passage 370 remains depressurized to prevent hydraulic lock from restricting the actuation of sliding pin 350. In some embodiments, a grease gun or other lubricant delivery system may be placed in fluid communication with lubrication passage 370 such that lubricant may be flowed through passage 370 and applied between the surface 352 and 334. As shown in Figures 8 and 9, the terminal end 370a of lubrication passage 370 is disposed between annular seal 356 of sliding pin 350 and the annular seal 338 of outer housing 330 when sliding pin is in either the locked or unlocked positions, preventing the lubricant passing through terminal end 370a from mixing with hydraulic fluid in communication with passages 366 and 368.

[0083] Referring now to Figure 10, another embodiment of an offshore well system 400 for drilling a subsea wellbore 24 is shown. Offshore system 400 shares many features in common with offshore system 10 discussed above. Such shared features are labeled similarly. In this embodiment, offshore system 400 has a generally vertically oriented central or longitudinal axis 415 and includes a marine riser system 410, LMRP 54, and BOP stack 56. Marine riser system 410 is substantially the same as riser system 30 previously described. In particular, marine riser system 410 includes a diverter bowl 32, a telescopic joint 34, a tension ring 40, an annular BOP 44, accumulators 46, and a riser 52, each as previously described. However, in this embodiment, riser system 410 includes a rotating control device (RCD) 500 positioned above tension ring 40 (instead of RCD 100), and further, no diverter spool 48 is provided. Return conduits 50 previously provided in connection with diverter spool 48 are replaced with a plurality of side outlets or return lines 502 extending from RCD 500. Similar to return conduits 50, return conduits 502 of RCD 500 provide a flow path for drilling fluid in the annulus to return to drilling vessel 12. Thus, in this embodiment, drilling fluid returns from wellbore 24 pass through the annulus within riser system 410 to RCD 500, and are routed directly from RCD 500 through return conduits 502 extending therefrom to vessel 12. In this manner, the side outlets of RCD 500 and associated return conduits 502 replace the functionality of diverter spool 48 and return conduits 50 of marine riser system 30.

[0084] Referring now to Figure 11, RCD 500 shares many features in common with RCD 100 discussed above. Such shared features are labeled similarly. In this embodiment, RCD 500 has a central or longitudinal axis 505 coaxially aligned with axis 415 and generally includes an outer housing 504, a seal assembly 130 disposed within outer housing 504, and a plurality of actuatable locking pins 310 for releasably coupling seal assembly 130 to outer housing 504. Seal assembly 130 and locking pins 310 are each as previously described.

[0085] Outer housing 504 of RCD 500 is substantially the same as outer housing 102 with the exception that outer housing 504 includes a pair of circumferentially-spaced annulus side outlets 506 that extend radially between inner surface 106 and outer surface 108 of housing 504. In this arrangement, side outlets 506 provide fluid communication between throughbore 104 of housing 504 and return conduits 502, which allow for the flow of fluid from wellbore 24 to the drilling vessel 12. An annular seal groove 508 and a plurality of circumferentially spaced apertures 510 are disposed about each side outlet 506. A flange at the end of one return conduit 502 is secured to housing 504 via bolts threaded into apertures 510 of each side outlet 506, and an annular seal is disposed in each seal groove 508 to seal between housing 504 and the flange bolted thereto.

[0086] Referring now to Figure 12, another embodiment of a RCD 600 for use with either offshore system 10 shown in Figure 1 or offshore system 400 shown in Figure 10 (e.g., in place of RCD 100, 500) is shown. In this embodiment, RCD 600 has a central or longitudinal axis 605 and includes a generally cylindrical outer housing 602 and a plurality of circumferentially spaced actuation assemblies 610 coupled thereto. Outer housing 602 of RCD 600 includes an inner surface 604 defining a central throughbore 606 extending axially through outer housing 602. Shown schematically in Figure 12, outer housing 602 may include features similar to those shown and described with respect to outer housing 102 of RCD 100 shown in Figures 2-5 and outer housing 502 of RCD 500 shown in Figure 11. Actuation assemblies 610 of RCD 600 are configured to selectably lock or secure a seal assembly (not shown), such as seal assembly 130 shown in Figures 2-5 or the like, to outer housing 602.

[0087] In the embodiment of Figure 12, each actuation assembly 610 of RCD 600 includes an actuatable locking pin 612 and a retaining arm 620 pivotally coupled to outer housing 602 at a pivot joint 622. The actuatable locking pin 612 of each actuation assembly 610 is disposed in a radially extending bore in outer housing 602 while retaining arm 620 is disposed in a recess disposed along the inner surface 604 of outer housing 602. The locking pin 612 of each actuation assembly 610 is configured to rotate or pivot its corresponding retaining arm 620 between a radially withdrawn or retracted unlocked position (shown in Figure 12) and a radially advanced locked position. In the unlocked position, arm 620 is radially spaced from the seal assembly disposed within bore 606, however, in the locked position, a radially inner engagement surface 624 of the retaining arm 620 physically engages the outer surface of the seal assembly disposed within bore 606 to secure the seal assembly to outer housing 602. Particularly, locking pins 612 each include a generally cylindrical outer housing 614 and a sliding pin 616 slidably disposed within a central bore of outer housing 614. In certain embodiments, locking pins 612 are configured similarly to locking pins 310 shown in Figures 7-9. Thus, sliding pins 616 may be radially displaced within their respective outer housings 614 in response to hydraulic signals or pressures communicated to and from locking pins 612, where radial displacement of sliding pins 616 actuates corresponding retaining arms 620 between their unlocked and locked positions via physical engagement between a radially inner end of each sliding pin 616 and its corresponding retaining arm 620.

[0088] Referring now to Figure 13, another embodiment of a RCD 630 for use with either offshore system 10 shown in Figure 1 or offshore system 400 shown in Figure 10 is shown (e.g., in place of RCD 100, 500). In this embodiment, RCD 630 has a central or longitudinal axis 635 and includes a generally cylindrical outer housing 632 and a plurality of circumferentially spaced actuation assemblies 640 coupled thereto. Outer housing 632 includes an inner surface 634 defining a central throughbore 636 extending axially through outer housing 632. Shown schematically in Figure 13, outer housing 632 may include features similar to those shown and described with respect to outer housing 102 of RCD 100 shown in Figures 2-5 and outer housing 502 of RCD 500 shown in Figure 11. Actuation assemblies 640 of RCD 630 are configured to selectably lock or secure a seal assembly, such as seal assembly 130 shown in Figures 2-5 or the like, to outer housing 632.

[0089] In the embodiment shown in Figure 13, inner surface 634 of housing 632 includes an annular shoulder 638 extending radially inward therefrom. Annular shoulder 638 is configured to enage and physically support a seal assembly 650 disposed within bore 636 of outer housing 632. Seal assembly 650 has a first or upper end 650a and a second or lower end 650b, and includes a sealing member or boot 652 extending from lower end 650b for sealing a rotating tubular member extending through bore 636. Shown schematically in Figure 13, in certain embodiments the seal assembly 650 and sealing member 652 are configured similarly to seal assembly 130 and sealing member 210 shown in Figures 3-6 and described above. In this embodiment, each actuation assembly 640 includes a housing 642 extending radially through outer housing 632 and a locking pin 644 slidably disposed within the housing 642. In certain embodiments, locking pins 644 are configured similarly to locking pins 310 shown in Figures 7-9. Once seal assembly 650 has been received within bore 636 of outer housing 632 such that the lower end 650b of seal assembly 650 is seated against annular shoulder 638, the locking pin 644 of each actuation assembly 640 may be actuated or displaced into a radially inner position (shown in Figure 13) where a radially inner terminal end of each locking pin 644 is disposed directly adjacent or physically engages the upper end 650a of seal assembly 650. In this arrangement, seal assembly 650 is axially locked into position between annular shoulder 638 and actuated locking pins 644. Locking pins 644 may be actuated into a radially outer position (not shown) to allow for relative movement of seal assembly 650 and outer housing 632 to allow for retrieval of seal assembly 650 therefrom.

[0090] Referring now to Figures 14 and 15, another embodiment of a RCD 660 for use with either offshore system 10 shown in Figure 1 or offshore system 400 shown in Figure 10 is shown (e.g., in place of RCD 100, 500). In this embodiment, RCD 660 has a central or longitudinal axis 665 and includes the outer housing 632 sown in Figure 13 and a plurality of circumferentially spaced actuation assemblies 662 for selectably locking seal assembly 650 to outer housing 632. Particularly, each actuation assembly 662 includes a housing 664 extending radially through outer housing 632, a locking pin 666 extending through housing 664, a circumferentially extending retaining plate 668, and a connector 670 connecting the retaining plate 668 to a radially inner terminal end of the locking pin 666. In certain embodiments, locking pins 666 are configured similarly to locking pins 310 shown in Figures 7-9. The retaining plate 668 of each actuation assembly 662 extends partially along the circumference of the inner surface 634 of outer housing 632. As with actuation assemblies 640 discussed above with respect to Figure 13, the locking pin 666 is actuatable between a radially withdrawn or retracted unlocked position (shown in Figure 15) allowing for insertion or removal of seal assembly 650 from outer housing 632 and a radially advanced locked position (shown in Figure 14) restricting relative axial movement between seal assembly 650 and outer housing 632. Particularly, in the radially inner position of locking pin 666, seal assembly 650 is axially locked between an axially lower end of each retaining plate 668 and the annular shoulder 638 of outer housing 632, where the circumferentially extending shape of each plate 668 provides additional physical support against the upper end 650a of seal assembly 650. In certain embodiments, when the locking pins 666 are disposed in the radially outer position, retaining plates 668 are disposed in an annular groove (not shown) extending radially into inner surface 634. In other embodiments, retaining plates 668 may be allowed to extend into bore 636 when locking pins 666 are disposed in the radially outer position while still providing sufficient radial clearance for the insertion of seal assembly 650 therein.

[0091] Referring now to Figures 16-19, another embodiment of a RCD 680 for use with either offshore system 10 shown in Figure 1 or offshore system 400 shown in Figure 10 is shown (e.g., in place of RCD 100, 500). In this embodiment, RCD 680 has a central or longitudinal axis 685 and includes a generally cylindrical outer housing 682 and a plurality of circumferentially spaced actuation assemblies 700 coupled thereto. Outer housing 682 of RCD 680 includes an inner surface 684 defining a central throughbore 686 extending axially through outer housing 682. Shown schematically in Figures 16-19, outer housing 682 may include features similar to those shown and described with respect to outer housing 102 of RCD 100 shown in Figures 2-5 and outer housing 502 of RCD 500 shown in Figure 11.

[0092] In the embodiment shown, outer housing 682 of RCD 680 includes an inner surface 684 defining a central throughbore 686 extending axially through outer housing 632. Inner surface 684 includes a plurality of circumferentially spaced locking lugs or flanges 688 extending radially inwards towards longitudinal axis 685. Each locking lug 688 is circumferentially aligned with a corresponding actuation assembly 690 disposed axially beneath and adjacent the locking lug 688. RCD 680 also includes a seal assembly 690 having a first or upper end 690a and a second or lower end 690b, and a sealing member 692 coupled to lower end 690b for sealing against a rotating tubular member extending through bore 686 of outer housing 682. Shown schematically in Figures 16-19, in certain embodiments the seal assembly 690 and sealing member 692 are configured similarly to seal assembly 130 and sealing member 210 shown in Figures 3-6 and described above. In the embodiment shown, a generally cylindrical outer surface 694 of seal assembly 690 includes a plurality of circumferentially spaced locking lugs or flanges 696 extending radially outwards therefrom.

[0093] Locking lugs 696 are spaced along the circumference of the outer surface 694 of seal assembly 690 in a manner similar to the spacing of locking lugs 688 along the circumference of the inner surface 684 of outer housing 682. In this manner, seal assembly 690 includes an unlocked angular position (shown in Figures 16 and 17) where locking lugs 696 of seal assembly 690 do not circumferentially overlap with corresponding locking lugs 688 of outer housing 682, and a locked angular position (shown in Figures 18 and 19) where each locking lug 696 circumferentially aligns or overlaps with a corresponding locking lug 688. In this arrangement, seal assembly 690 is permitted to travel axially through bore 686 of outer housing 682 when disposed in the unlocked position, while relative axial movement is at least partially restricted between outer housing 682 and seal assembly 690 when seal assembly 690 is disposed in the locked position.

[0094] During installation of seal assembly 690 within outer housing 682, seal assembly 690 is lowered through bore 686 in the unlocked position until seal assembly 690 axially clears locking lugs 688. Once actuation assembly 700 has axially cleared locking lugs 688, seal assembly 690 is rotated into the locked position such that relative upward movement by seal assembly 690 within bore 686 is restricted via physical engagement of locking lugs 696, 688. In this position, seal assembly 690 is locked to outer housing 682 via actuating each of the plurality of actuation assemblies 700. Particularly, each actuation assembly 700 includes a housing 702 extending radially through outer housing 682 and a locking pin 704 disposed within housing 702. In certain embodiments, locking pins 706 are configured similarly to locking pins 310 shown in Figures 7-9. With seal assembly 690 disposed axially beneath locking lugs 688 and angularly in the locked position, the locking pin 704 of each actuation assembly 700 is actuated from a radially outer position (shown in Figures 16 and 17) to a radially inner position (shown in Figures 18 and 19) where a radially inner terminal end of each locking pin 704 is received within a corresponding aperture 698 extending radially into the outer surface 694 of each locking lug 696, thereby restricting axial and radial movement between seal assembly 690 and outer housing 682. In order to retrieve seal assembly 690 from outer housing 682, the locking pin 704 of each actuation assembly 700 may be retracted, and seal assembly 690 may be rotated into the unlocked position, thereby providing for relative axial movement between seal assembly 690 and outer housing 682.

[0095] Referring now to Figures 20 and 21, another embodiment of a RCD 710 for use with either offshore system 10 shown in Figure 1 or offshore system 400 shown in Figure 10 is shown (e.g., in place of RCD 100, 500). In this embodiment, RCD 710 has a central or longitudinal axis 715 and includes a generally cylindrical outer housing 712, a seal assembly 730 disposed therein, and a plurality of circumferentially spaced actuatable locking pins 310 for selectably locking seal assembly 730 to outer housing 712. Outer housing 712 includes a centrally disposed bore 714 extending between upper and lower ends of outer housing 712 and defined by a generally cylindrical inner surface 716. In the embodiment of Figures 20 and 21, inner surface 716 of outer housing 712 includes a first diameter section 716a extending from the upper end of housing 712, a second diameter section 716b extending from first section 716a, a third diameter section 716c extending from second section 716b, and a fourth diameter section 716d extending from third section 716c, where first section 716a is greater in diameter than second section 716b, second section 716b is greater in diameter than third section 716c, and third section 716c is greater in diameter than fourth section 716d. A radially extending annular shoulder is formed between the intersection of each diameter section 716a-716d, including an annular landing profile 718 extending between third section 716c and fourth section 716d for engaging a corresponding landing shoulder of the seal assembly 730 to position seal assembly 730 within outer housing 712. In certain embodiments, when seal assembly 730 is landed within outer housing 712, a clearance remains between the annular shoulders formed between sections 716a and 716b, and 716b and 716c, and the corresponding annular shoulders of seal assembly 730.

[0096] In the embodiment shown in Figures 20 and 21, outer housing 712 also includes a first or upper radially extending lubrication passage 720a and a second or lower radially extending lubrication passage 720b axially spaced from upper passage 720a, where passages 720a and 720b are configured to communicate a fluid to an internal chamber of seal assembly 730 for lubricating and/or controlling the temperature or pressure within the chamber of seal assembly 730. Outer housing 712 further includes a plurality of circumferentially spaced and radially extending apertures 722, where each aperture 722 receives an actuatable locking pin 310 for selectably locking seal assembly 730 to outer housing 712.

[0097] Seal assembly 730 includes features in common with seal assembly 130 described above, and shared features are labeled similarly. In the embodiment of Figures 20 and 21, seal assembly 730 generally includes an inner housing 732, bearing assembly 230, and a rotating sleeve assembly 750. Inner housing 732 includes a central bore 734 extending between upper and lower ends of inner housing 732 and defined by an inner surface 736, and a generally cylindrical outer surface 738 extending between the upper and lower ends of housing 732. In this embodiment, the outer surface 738 of inner housing 732 includes a radially extending annular shoulder 740 including a chamfered or angled landing profile for engaging the chamfered profile 360 of each locking pin 310 to secure seal assembly 730 to outer housing 712. The chamfered engagement between shoulder 740 and locking pins 310 provides an axial downward force against seal assembly 730 to pin seal assembly 730 against landing profile 718 of outer housing 712. The outer surface 738 of inner housing 732 also includes a first diameter section 738a extending from annular shoulder 740, a second diameter section 738b extending from first section 738a, a third diameter section 738c extending from second section 738b, and a fourth diameter section 738d extending from second section 738c, where first section 738a is greater in diameter than second section 738b, second section 738b is greater in diameter than third section 738c, and third section 738c is greater in diameter than fourth section 738d. A radially extending annular shoulder is disposed at the intersection of each diameter section 738a-738d of outer surface 738, including a landing profile 739 disposed between third section 738c and fourth section 738d of outer surface 738 for matingly engaging the landing profile 718 of outer housing 712 to position seal assembly 730 within outer housing 712.

[0098] Inner housing 732 also includes a first or upper radially extending lubrication passage 742a and a second or lower lubrication passage 742b axially spaced from upper passage 742a, where passages 742a and 742b are configured to receive fluid from passages 720a and 720b of outer housing 712 for lubricating components of bearing assembly 230. In this arrangement, when seal assembly 730 is seated within outer housing 712 as shown in Figures 20 and 21, upper passage 742a of inner housing 732 is in fluid communication with upper passage 720a of outer housing 712 and lower passage 742b is in fluid communication with lower passage 720b. Moreover, the inner surface 716 of outer housing 712 includes an annular grove extending therein at both upper passage 720a and lower passage 720b for providing fluid communication between passages 720a/742a and 720b/742b irrespective of the angular orientation between seal assembly 730 and outer housing 712. A first or upper set of annular seals 744a are disposed along outer surface 738 adjacent upper passage 742a and a second or lower set of annular seals 744b are disposed along outer surface 738 adjacent lower passage 742b such that upper seals 744a seal the interface between passages 720a/744a and lower seals 744b seal the interface between passages 720b/744b.

[0099] In the embodiment shown in Figures 20 and 21, rotating sleeve assembly 750 generally includes a rotating sleeve 752 rotatably coupled to inner housing 732 via bearing assembly 230 and a pair of sealing members or boots 210. Rotating sleeve 752 includes a first or upper end 752a, a second or lower end 752b, and a centrally disposed bore 754 extending between upper end 752a and lower end 752b. Bore 754 of rotating sleeve 752 has a first or upper diameter section 754a extending from upper end 752a and a second or lower diameter section 754b extending from lower end 752b, where upper section 754a has a greater diameter than lower section 754b for receiving the upper sealing member 210 therein. In addition, rotating sleeve includes a first or upper flange 756a disposed at upper end 752a for coupling sleeve 752 with the upper sealing member 210 and second or lower flange 756b disposed at lower end 752b for coupling sleeve 752 with lower the lower sealing member 210. In some embodiments, the outer diameter of upper flange 756a is sized to be slightly less than the diameter of upper diameter section 716a of outer housing 712 to limit angular offset between the longitudinal axis of outer housing 712 and the longitudinal axis of seal assembly 730 as seal assembly 730 is lowered into position within outer housing 712. In this manner, upper flange 756a is configured to act as a stabilizer or centralizer to prevent seals 744a, 744b, and seal assembly 168 from inadvertently contacting or sliding against the inner surface 716 of outer housing 712 as seal assembly 730 is lowered through bore 714 of outer housing 712. However, a radial clearance is provided between the outer surface of upper flange 756a and the inner surface 716 of outer housing 712 to prevent rotating sleeve 752 from contacting inner surface 716 once seal assembly 730 has been locked into position within outer housing 712 via locking pins 310. In certain embodiments, seal assembly 730 is lowered into position about a tubular or drill pipe extending through bore 714 of outer housing 712. In this embodiment, engagement between the upper seal member 210 and the drill pipe may further stabilize seal assembly 730 as it is lowered into position within outer housing 712.

[00100] In this embodiment, seal assembly 730 includes a first or upper rotary seal 760a and a second or lower rotary seal 760b axially spaced from upper seal 760a, where seals 760a and 760b are each disposed along the inner surface 736 of inner housing 732 and sealingly engage the outer surface of rotary sleeve 752 to restrict fluid communication therebetween. In this arrangement, a sealed chamber 762 is formed between rotary seals 760a and 760b and disposed within inner housing 732. In this manner, fluid may be circulated through chamber 762 via pumping fluid into chamber 762 via upper passages 720a and 742a, and pumping fluid out of chamber 762 via corresponding lower passages 720b and 742b. In certain embodiments, the fluid circulated through chamber 762 lubricates bearing assembly 230, and manages the temperature and/or pressure within chamber 762 to extend the service life of bearing assembly 230. In some embodiments, bearing assembly 230 may include fins or other mechanisms for enhancing heat transfer between bearing assembly 230 and the fluid circulated through chamber 762. In some embodiments, the pressurization of chamber 762 via passages 720a/742a and 720b/742b may reduce a pressure differential across the seals of seal assembly 168 to increase the sealing integrity of bore 714. In this embodiment, seal assembly 730 also includes an additional rotary seal 764 that engages a radially extending flange 766 of rotating sleeve 752 for physically supporting sleeve 752 and reducing a moment on the upper end 752a of rotating sleeve 752.

[00101] In the embodiment shown, second diameter section 716b of inner surface 716 of the outer housing 712 has a greater axial length than third section 716c and fourth section 716d. Similarly, second diameter section 738b of outer surface 738 of the inner housing 732 has a greater axial length than third section 738c and fourth section 738d. In some embodiments, the diameter of first diameter section 738a is slightly less than the diameter of first section 716a, the diameter of second section 738b is slightly less than the diameter of second section 716b, the diameter of third section 738b is slightly less than the diameter of third section 716c, and the diameter of fourth section 738b is slightly less than the diameter of fourth section 716d. In this arrangement, upper seals 744a may sealingly engage the second section 716b of inner surface 716, lower seals 744b may sealingly engage the third section 716c, and the seals of seal assembly 168 may sealingly engage the fourth section 716d. In some embodiments, the gradual alteration of diameter of inner surface 716 and outer surface 738 increases the radial clearance between seals 744a, 744b, and 168 and inner surface 716 of

outer housing 712 as the seal assembly 730 is lowered into position to reduce the possibility of damaging those seals during that process. Particularly, given the relatively short axial length of diameter sections 716c and 716d relative section 716a, lower seals 744b and the seal of assembly 168 only slidingly engage sections 716c and 716d of inner surface 716 for a relatively short axial distance as seal assembly 730 is lowered into position within outer housing 712, thereby preserving and protecting seals 144b and 168. Moreover, upper seals 744a are disposed at an upper end of second diameter section 738b of outer surface 738 such that seals 744a only slidingly engage a relatively small portion of the overall axial length of second section 716b as seal assembly 730 is installed within outer housing 712, thereby protecting and preserving upper seals 744a. In some embodiments, the edges of the annular grooves in fluid communication with passages 720a and 720b of outer housing 712 are radiused to mitigate the possibility of damaging seals 744a, 744b, and 168 as seal assembly 730 is installed within outer housing 712.

[00102] Referring now to Figures 22-25, another embodiment of a RCD 800 for use with offshore system 10 of Figure 1 is shown (e.g., in place of RCD 100). Thus, in the embodiment shown in Figures 22-25, RCD 800 comprises a below-tension-ring (BTR) RCD that is located beneath tension ring 40 shown in Figure 1. Although in this embodiment RCD 800 is configured for use with offshore system 10 of Figure 1, in other embodiments, RCD 800 may be used with the offshore system 400 shown in Figure 10, and thus, may comprise an above-tension-ring (ATR) RCD located above tension ring 40. In the embodiment shown in Figures 22-25, RCD 800 has a central or longitudinal axis 805 and includes a generally cylindrical outer housing 802, a seal assembly 850 disposed therein, and a plurality of circumferentially spaced actuatable locking pins 840 for selectably locking seal assembly 850 to outer housing 802. Outer housing 802 of RCD 800 has a first or upper end 802a, a second or lower end 802b, a central throughbore or passage 804 extending between ends 802a, 802b, and defined by a generally cylindrical inner surface 806, and a generally cylindrical outer surface 808 extending between ends 802a and 802b.

[00103] In the embodiment shown in Figures 22-25, outer housing 802 of RCD 800 includes a plurality of circumferentially spaced side outlet ports 810 (shown in Figure 23) each extending radially between inner surface 806 and outer surface 808. Outlet ports 810 are similar in configuration and function as the side outlets 506 of the RCD 500 shown in Figure 11. In the embodiment shown in Figures 22-25, RCD 800 includes at least one side outlet housing 812 mounted to the outer surface 808 of outer housing 802, where side outlet 812 includes a bore or passage 814 extending therein that is in fluid communication with at least one of the outlet ports 810 of outer housing 802. Side outlet 816 includes a connector 816, such as a flanged connector, for releasably coupling with a corresponding connector of a return conduit (e.g., return conduit 502 shown in Figure 10) of offshore system 400.

[00104] Outer housing 802 includes an umbilical stab plate or panel 818 secured to the outer surface 808 thereof. Stab plate 818 includes electrical and fluid connections for establishing signal communication with various components of RCD 800 as will be described in more detail below. Stab plate 818 can be accessed prior to installation of RCD 800. For instance, electrical and fluid connections may be made up with stab plate 818 prior to installation of RCD 800. Alternatively, stab plate 818 may be accessed by a remotely operated underwater vehicle (ROV) to connect and disconnect signal conduits or umbilicals to the various connectors coupled with stab plate 818. In the embodiment shown in Figures 22-25, stab plate 818 is coupled with or secures a first electrical connector 820a, a second electrical connector 820b, a first or inlet lubricant connector 822a, a second or outlet lubricant connector 822b, a first or locking connector 824a, and a second or unlocking connector 824b.

[00105] Each electrical connector 820a and 820b connects a plurality of electrical cables 826 extending to various electrical components of RCD 800. In some embodiments, prior to installing RCD 800 in offshore system 10, electrical cables or conduits in signal communication with a control or monitoring system 75 of the offshore system 10 are connected to electrical connectors 820a and 820b to provide signal communication between electrical connectors 820a and 820b. In other embodiments, an ROV may be used to connect the electrical cables of monitoring system 75 with electrical connectors 820a and 820b following installation of RCD 800 in offshore system 10.

[00106] In the embodiment shown in Figures 22-25, outer housing 802 includes a bore pressure and temperature sensor 830 coupled with housing 802, where bore sensor 830 is in signal communication with first electrical connector 820a via an electrical cable 826 extending therebetween. Bore sensor 830 is configured to monitor the pressure and temperature of fluid disposed in the bore 804 of outer housing 802, where the pressure and temperature measurements provided by bore sensor 830 may be communicated in real-time to system 75 of offshore system 10 via the electrical connection provided by first electrical connector 420. Although in the embodiment shown in Figures 22-25 bore sensor 830 comprises a pressure and temperature sensor, in other embodiments, bore sensor 830 may be

configured to measure various properties of fluid disposed in the bore 804 of outer housing 802, such as fluid flow, fluid content, etc.

[00107] In the embodiment shown in Figures 22-25, the outer housing 802 of RCD 800 also includes a first or inlet lubrication passage 828a and a second or return lubrication passage 828b (shown in Figure 25), with passages 828a and 828b each extending radially between the inner surface 806 and outer surface 808 of outer housing 802. Similar to the functionality provided by passages 720a and 720b of RCD 710 shown in Figures 20 and 21, passages 828a and 828b of the outer housing 802 of RCD 800 are configured to communicate a fluid to an internal chamber of seal assembly 850 for lubricating and/or controlling the temperature or pressure within the chamber of seal assembly 850. In the embodiment shown in Figures 22-25, a first fluid conduit 832a extends between inlet lubricant connector 822a and inlet lubrication passage 828a to provide fluid communication therebetween while a second fluid conduit 832b extends between return lubricant connector 822b and return lubricant passage 828b to provide fluid communication therebetween. In some embodiments, prior to installing RCD 800 in offshore system 10, fluid conduits in fluid communication with an RCD lubrication system 77 of offshore system 10 may be connected with lubricant connectors 822a and 822b of RCD 800 to establish a lubrication loop configured to provide continuous circulation of lubricant through the seal assembly of 850 of RCD 800. In other embodiments, the fluid conduits of lubrication system 77 may be connected to lubricant connectors 822a and 822b following the installation of RCD 800 in offshore system 10, such as via an ROV or personnel of offshore system 10.

[00108] In the embodiment shown in Figures 22-25, a temperature and pressure sensor 832 is coupled to the lower fluid conduit 832b to measure the pressure and temperature of lubricating fluids circulating between the return lubricant passage 828b of outer housing 802 and return lubricant connector 822b. An electrical cable 826 extends between lubricant temperature and pressure sensor 832 and the first electrical connector 820a to place electrical connector 820a in signal communication with lubricant sensor 832. Either before or after the installation of RCD 800 in offshore system 10, an electrical conduit of lubrication system 77 of offshore system 10 may be connected to, or otherwise placed in signal communication with, first electrical connector 820a of RCD 800 such that lubrication sensor 832 may provide real-time pressure and temperature measurements of lubricating fluid circulated through seal assembly 850 to lubrication system 77. Although in the embodiment shown in Figures 22-25 lubrication sensor 832 comprises a pressure and temperature sensor, in other embodiments,

lubrication sensor 832 may be configured to measure various properties of fluid flowing through the lower fluid conduit 832b of outer housing 802, such as fluid flow, fluid content, etc. In some embodiments, lubrication system 77 of the offshore system 10 may include a hydraulic power unit (HPU) for circulating lubricating fluids through lubrication system 77, where the HPU may include a level sensor for monitoring the level of lubricating fluid therein to detect leakage of the lubricating fluid from the closed circuit or lubrication loop formed in lubrication system 77.

[00109] Locking pins 840 of the RCD 800 are similar to locking pins 310 shown in Figures 7-9, and shared features are labeled similarly. In the embodiment shown in Figures 22-25, each locking pin 840 includes an outer housing 842 and a sliding pin 844 slidably disposed in the outer housing 842. Unlike the sliding pin 350 of locking pin 310, an outer surface of sliding pin 844 does not include a cammed profile, and instead, includes a locking shoulder 846 configured to matingly engage a corresponding locking shoulder of seal assembly 850 to secure seal assembly 850 to outer housing 802. Additionally, unlike locking pins 310 described above, each locking pin 840 includes a position sensor 848 that extends into and couples with the sliding pin 844 of each locking pin 840. Also unlike locking pins 310, the locking shoulder 846 of each sliding pin 844 extends orthogonal the central axis of outer housig 802 (i.e., central axis 805) of RCD 800.

[00110] The position sensor 848 of each locking pin 840 is configured to measure an axial position of the sliding pin 844 of the locking pin 840. Particularly, position sensor 848 is configured to measure whether the sliding pin 844 of the locking pin 840 is disposed in a radially outer unlocked position, where relative axial movement between seal assembly 850 and outer housing 802 is permitted, and a radially inner locked position (shown in Figure 24), where relative axial movement between seal assembly 850 and outer housing 802 is restricted. Each position sensor 848 is connected to an electrical cable 826 extending between the sensor 848 and one of the electrical connectors 820a and 820b of RCD 800. In this manner, the position of the sliding pins 844 of locking pins 840 may be communicated to monitoring system 75 via the electrical connection provided by electrical connectors 820a and 820b with monitoring system 75. Thus, position sensors 848 are configured to provide confirmation as to the position of sliding pins 848 of locking pins 840. In the embodiment shown in Figures 22-25, position sensors 848 comprise linear variable differential transformer (LVDT) sensors; however, in other embodiments, position sensors 848 may

comprise other sensors known in the art for measuring position, such as magnetic proximity sensors.

[00111] As mentioned above, the stab plate 818 of RCD 800 includes locking connector 824a and unlocking connector 824b. In the embodiment shown in Figures 22-25, outer housing 802 of RCD 800 includes fluid conduits 834 that provide fluid communication between locking connector 824a and the closing passage 368 of each locking pin 840, and between unlocking connector 824b and the opening passage 366 of each locking pin 840. Either before or after installation of RCD 800 in the offshore system 10 shown in Figure 1, fluid conduits of control and monitoring system 75 of offshore system 10 may be connected to the locking connector 824a and unlocking connector 824b of RCD 800 to allow system 75 to control the locking and unlocking of locking pins 840 of RCD 800. In this arrangement, the locking and unlocking of the locking pins 840 of RCD 800 may be controlled remotely at the drilling vessel 12 via control and monitoring system 75.

[00112] In the embodiment shown in Figures 22-25, the outer housing 802 of RCD 800 additionally includes a first or upper proximity sensor 836a and a second or lower proximity sensor 836b (shown in Figure 24), where both upper proximity sensor 836a and lower proximity sensor 836b each extend into the bore 804 of outer housing 802. As will be discussed further herein, proximity sensors 836a and 836b are each configured to output a proximity or position signal in response to the positioning of a sensor element within the proximity of sensors 836a and 836b. Each proximity sensor 836a and 836b is connected to an electrical cable 826 extending between proximity sensors 836a and 836b and the second electrical connector 820b of RCD 800. In this configuration, the position or proximity signals outputted by proximity sensors 836a and 836b may be communicated in real-time to the monitoring system 75 of the offshore system 10 shown in Figure 1.

[00113] Seal assembly 850 of RCD 800 includes features in common with the seal assembly 730 of RCD 710 shown in Figures 20 and 21 and the seal assembly 130 of RCD 100 shown in Figures 3-6, and shared features are labeled similarly. In the embodiment shown in Figures 22-25, seal assembly 850 generally includes an inner housing 852, bearing assembly 230, and a rotating sleeve assembly 870. Inner housing 852 includes a central bore or bearing chamber 854 extending between upper and lower ends of inner housing 852 and defined by an inner surface 856, and a generally cylindrical outer surface 858 extending between the upper and lower ends of housing 852. In this embodiment, the outer surface 858 of inner housing 852 includes a radially extending annular shoulder 860 configured to matingly

engage the locking shoulder 846 of the sliding pin 844 of each locking pin 840 when sliding pins 844 are disposed in the radially inner locked position.

[00114] In this embodiment, inner housing 852 of seal assembly 850 includes a first or upper radially extending lubrication passage 862a and a second or lower lubrication passage 862b (shown in Figure 25) axially spaced from upper passage 862a, where lubrication passages 862a and 862 extend between the inner and outer surfaces 856 and 858, respectively, of inner housing 852. Lubrication passages 862a and 862b are in fluid communication with lubrication passages 828a and 828b, respectively, of outer housing 802. In this configuration, lubricating fluids or lubricant may be pumped or flowed into bearing chamber 854 of inner housing 852 via lubrication passages 828a and 862a and out of bearing chamber 854 via lubrication passages 862b and 828b to thereby circulate lubricating fluids to the bearing assembly 230 disposed in bearing chamber 854 of inner housing 852.

[00115] To prevent or mitigate loss of lubricating fluids during operation of RCD 800, RCD 800 includes a first pair of check valves 863a and 863b positioned in lubrication passages 828a and 828b, respectively, of outer housing 802, and a second pair of check valves 865a and 865b positioned in passages 862a and 862b, respectively, of inner housing 852. Particularly, the first or upper check valve 863a positioned in the inlet lubrication passage 828a of outer housing 828b is configured to prevent fluid flow from passage 828a into the first fluid conduit 832a while the second or lower check valve 863b positioned in the return lubrication passage 828b of outer housing 802 is configured to prevent fluid flow from second fluid conduit 832b into the return conduit 828b. Additionally, the first or upper check valve 865a positioned in the upper lubrication passage 862a of inner housing 852 is configured to restrict fluid flow from bearing chamber 854 into passage 862a, while the second or lower check valve 865b positioned in the lower lubrication passage 862b of inner housing 852 is configured to restrict fluid flow from lower lubrication passage 828b into bearing chamber 854. In the embodiment shown in Figures 22-25, annular seals disposed along the outer surface 856 of inner housing 852 seal the fluid connection formed between inlet lubrication passage 828a and the upper lubrication passage 862a and the fluid connection formed between return lubrication passage 828b and lower lubrication passage 862b.

[00116] Rotating sleeve assembly 870 of the seal assembly 850 of RCD 800 generally includes a rotating sleeve 872 rotatably coupled to inner housing 852 via bearing assembly 230 and a pair of sealing members or boots 210 (shown as 210a and 210b in Figures 22-25)

coupled to rotating sleeve 872. Rotating sleeve 872 includes a central bore or passage 874 defined by a generally cylindrical inner surface 876, and a generally cylindrical outer surface 878. A first or upper boot 210a is coupled to sleeve 872 proximal an upper end of sleeve 872 while a second or lower boot 210b is coupled to a lower end of sleeve 872.

[00117] Referring now to Figures 22-26, the outer surface 878 of sleeve 872 includes a first or upper proximity sensor element 880a and a second or lower sensor element 880b axially spaced from upper sensor element 880a (shown in Figures 24 and 26). Upper sensor element 880a comprises a magnetic member 880a and is axially aligned with upper proximity sensor 836a when seal assembly 850 is landed in the outer housing 802 of RCD 800. Particularly, upper proximity sensor 836a is configured to output a position or proximity signal when upper sensor element 880a is substantially circumferentially aligned with upper proximity sensor 836a. Thus, proximity sensor 836a is configured to detect the proximity of the magnetic member or upper sensor element 880a.

[00118] In this arrangement, upper proximity sensor 836a comprises a revolutions per minute (RPM) or rotational speed sensor of rotating sleeve 872. Specifically, when sleeve 872 rotates relative outer housing 802 during operation of RCD 800, upper proximity sensor 836a will output a position signal each time upper sensor element 880a rotates past sensor 836a. In this manner, the frequency of position signals outputted by upper proximity sensor 836a correlates with the rotational speed of rotating sleeve 872, where faster rotation of sleeve 872 translates to more rotations of upper sensor element 880a past upper proximity sensor 836a over a given period of time. Thus, in the embodiment shown in Figures 22-26, the combination of upper proximity sensor 836a and upper sensor element 880a form a rotational speed sensor 882.

[00119] In the embodiment shown in Figures 22-26, lower sensor element 880b of rotating sleeve 872 comprises a sensor element assembly 880b that includes a housing 884, a piston 886 slidably disposed in the housing 884, a magnetic member or sensor element 888, and a biasing member 890, a burst disc 892 (shown in Figure 26). Magnetic member 888 is coupled to a radially outer end of piston 886. Biasing member 890 is disposed about piston 886 and is configured to bias piston 886 into a radially inwards position (shown in Figure 26) towards the central axis 805 of RCD 800. Burst disc 892 is coupled to a radially inner end of housing 884. In the embodiment shown in Figures 22-26, the inner surface 876 of rotating sleeve 872 includes a passage 879 extending radially therein that receives sensor element

assembly 880b. Positioned in passage 879, burst disc 892 restricts fluid communication between the bore 874 of sleeve 872 and the radially inner end of piston 886.

[00120] In the embodiment shown in Figures 22-26, burst disc 892 of sensor element assembly 880b is configured to burst or rupture in response to the application of a predetermined fluid pressure to burst disc 892, where rupturing of burst disc 892 provides fluid communication between the radially inner end of piston 886 and the bore 874 of rotating sleeve 872. Additionally, biasing member 890 of sensor element assembly 880b is configured to retain piston 886 in the radially inner position as sleeve 872 rotates within the outer housing 802 of RCD during the operation of RCD 800. In other words, biasing member 890 biases against or counteracts the radially outwards directed centripetal force applied to piston 886 during rotation of sleeve 872. In the event that a leak occurs between the lower boot 210b and an outer surface of the drillstring 18 (shown in Figure 1) extending through RCD 800, then fluid pressure in the bore 874, and particularly in the annulus 875 formed between the inner surface 876 of sleeve 872 and the outer surface of drillstring 18, will increase as fluid pressure is communicated between the bore 804 of outer housing 802 and annulus 875. Piston 886 is configured to actuate or be displaced from the radially inner position into a radially outer position in response to the communication of fluid pressure from annulus 875 to the radially inner end of piston 886 following the rupturing of burst disc 892.

[00121] In response to the increase in fluid pressure in annulus 875, burst disc 892 is configured to rupture to allow the fluid pressure in annulus 875 to be communicated to the radially inner end of piston 886. In the radially outer position, the lower proximity sensor 836b, which is axially aligned with sensor element assembly 880b when seal assembly 850 is landed in outer housing 802, is configured to output a position or proximity signal when piston 886 and the magnetic member 888 coupled thereto are substantially circumferentially aligned with sensor 836b. Thus, similar to the functionality of upper proximity sensor 836a and sensor element 880a, lower proximity sensor 836b will output a position or proximity signal each time piston 886 rotates past sensor 836b when piston 886 is disposed in the radially outer position, where the position sensor outputted by lower proximity sensor 836b may be communicated to control and monitoring system 75 of offshore system 10 via the second electrical connector 820b. In this configuration, the combination of lower proximity sensor 836b and sensor element assembly 880b forms a leak sensor 894 configured to detect leakage between the lower boot 210b and the outer surface of drillstring 18 during the operation of RCD 800. In some embodiments, the leakage detection functionality provided

by leak sensor 894 may be used to determine when seal assembly 850 should be pulled out or removed from the outer housing 802 of RCD 800 to allow lower boot 210b to be replaced, eliminating unnecessary maintenance to seal assembly 850 while allowing seal assembly 850 to be repaired before both upper and lower boots 210a and 210b, respectively, are permitted to leak through wear occurring during the operation of RCD 800. For instance, given that lower boot 210b is exposed to the pressure of fluid disposed in the lower end of central bore 804 of outer housing 802 (i.e., the section of bore 804 extending between the sealing engagement between seal assembly 850 and inner surface 806 and the lower end 802b of outer housing 802), in some applications lower boot 210b may be exposed to a harsher operating environment and may be required to seal across a higher differential pressure than upper boot 210a, causing lower boot 210b to fail before upper boot 210a. In such applications, by removing and repairing or replacing seal assembly 850 following the detection of leakage across lower boot 210b, seal assembly 850 may be repaired or replaced before leakage results across both upper boot 210a and lower boot 210b.

[00122] In the embodiment shown in Figures 22-25, RCD 800 further includes a sleeve sensor assembly 868 (shown in Figure 24) generally comprising a sleeve pressure and temperature transducer 869a and an outer housing transmitter 869b in signal communication with sleeve transducer 869a. Sleeve transducer 869a is disposed in a receptacle formed in rotating sleeve 872 and is in fluid communication with central bore 874 of sleeve 872. Outer housing transmitter 869b is disposed along the inner surface 806 of outer housing 802 and is connected to one of the electrical connectors 820a or 820b via an electrical cable 826 (not shown in Figure 24). In the embodiment shown in Figures 22-25, sleeve transducer 869a of sleeve sensor assembly 868 is battery powered and configured to measure pressure and temperature of fluid disposed in the central bore 874 of rotating sleeve 872, and particularly the pressure and temperature of fluid disposed in annulus 875 when drillstring 18 is disposed in bore 874. In other embodiments, sleeve transducer 869a may be configured to measure various properties of fluid disposed in central bore 874 of rotating sleeve 872, such as fluid flow, fluid content, etc.

[00123] Sleeve transducer 869a of sleeve sensor assembly 868 is additionally configured to wirelessly transmit sensors signal indicative of the measured pressures and temperatures of fluid in bore 874 to outer housing transmitter 869b, where outer transmitter 869b is configured to receive said sensor signals and transmit them to one of the electrical connectors 820a or 820b of RCD 800. In this configuration, sleeve sensor assembly 860 is configured to

indicate pressure and temperature of fluid disposed in central bore 874 of rotating sleeve 872 in real-time. Additionally, the wireless communication between sleeve transducer 869a and outer housing transmitter 869b allows transducer 869a to communicate signals indicative of pressure and temperature of fluid in bore 874 of sleeve 872 as sleeve 872 rotates relative outer housing 802. Further, increases in fluid pressure in central bore 874 of rotating sleeve 872 may indicate leakage of fluid past lower boot 210b, allowing an operator of RCD 800 to repair or replace seal assembly 850 before a leak is formed in both boots 210a and 210b. While RCD 800 is shown in the embodiment of Figure 22-25 as including sleeve sensor assembly 868, in other embodiments, RCD 800 may not include sleeve sensor assembly 868.Referring now to Figures 22-25 and 27, an embodiment of a protective sleeve 900 for landing in the outer housing 802 of RCD 800 is shown in Figure 27. Sleeve 900 is configured to be inserted into and locked (via locking pins 840) within outer housing 802 to protect features of RCD 800 from fluid or tools displaced through bore 804 of outer housing 802 when seal assembly 850 is not needed for the operation of offshore system 10, such as when offshore system 10 is not engaged in managed pressure drilling (MPD). Particularly, sleeve 900 is configured to protect landing profiles or shoulders formed in the inner surface 806 of outer housing 802, including the shoulder seal assembly 850 lands against, as well as electronic components of RCD 800, such as the radially inner ends of proximity sensors 836a and 836b.

[00124] In the embodiment shown in Figures 22-25 and 27, protective sleeve 900 is generally cylindrical in shape and includes a central bore or passage 902 defined by a generally cylindrical inner surface 904 extending between upper and lower ends of sleeve 900, and a generally cylindrical outer surface 906 extending between the upper and lower ends of sleeve 900. The outer surface includes a plurality of annular seals disposed therein for restricting fluid communication across the annulus formed between the outer surface 906 of sleeve 900 and the inner surface 806 of outer housing 802 to thereby protect the above described features of inner surface 806 and RCD 800. Additionally, the outer surface 906 of sleeve 900 includes an annular shoulder 908 formed therein for matingly engaging the locking shoulders 846 of the sliding pins 844 of locking pins 840 to selectively lock sleeve 900 to outer housing 802. Particularly, following the landing of sleeve 900 in outer housing 802, sliding pins 844 of locking pins 840 may be actuated into the radially inner locked position to engage shoulder 908 and thereby lock sleeve 900 and to outer housing 802.

[00125]

[00126] In the manner described, embodiments described herein (e.g., systems 10 and/or 100) include RCDs (e.g., RCDs 100, 500, 600, 630, 660, 680, 710, and/or 800) comprising an outer housing (e.g., outer housings 102, 504, 602, 632, 682, 712, and/or 802) and a seal assembly (e.g., seal assemblies 130, 650, 690, 730, and/or 850) receivable within the outer housing and configured to seal against an outer surface of a tubular member (e.g., drillstring 18) extending therethrough while, at the same time, allowing for relative rotation between the tubular member and the outer housing. Additionally, embodiments of RCDs described herein include locking pins (e.g., locking pins 310, 612, 644, 666, 706, and/or 840) actuatable between a radially outer unlocked position permitting relative axial movement between the seal assembly and outer housing of the RCD, and a radially inner locked position restricting relative axial movement between the seal assembly and the outer housing, in response to the application of fluid pressure thereto. Embodiments of locking pins described herein advantageously allow the seal assembly of the RCD to be locked and unlocked remotely via communicating fluid pressure to the locking pins.

[00127] Additionally, embodiments of locking pins described herein provide the advantage of not intruding into a central bore of the outer housing when disposed in the unlocked position (i.e., the radially inner terminal end of each locking pin is flush with or recessed within the inner surface of the outer housing when in the unlocked position), thereby allowing full bore access to the outer housing of the RCD when the seal assembly is not received therein. Further, embodiments of locking pins described herein provide a secure axial locking of the seal assembly of the RCD to the outer housing thereof by physically engaging a surface or shoulder of the seal assembly with a mating surface or shoulder of each locking pin when the locking pins are disposed in the radially inner positions. Embodiments of locking pins described herein are also accessible from the outside of the RCD, being disposed in the outer housing thereof, such that hydraulic, electrical, or other connections may be conveniently provided and accessed from the exterior of the RCD.

[00128] Embodiments of RCDs described herein also include the feature of a lubrication system (e.g., lubrication system 77) for providing a closed lubrication loop or circuit extending from an exterior of the RCD to a bearing assembly (e.g., bearing assembly 230) of the RCD. Embodiments of lubrication systems described herein are configured to provide a continuous circulation of lubricant to a bearing assembly of the RCD. By providing continuous circulation of lubricant from an exterior of the RCD to the bearing assembly disposed therein, the lubricant may be conditioned (e.g., pressure and/or temperature

controlled, filtered, etc.) and fluid properties of the lubricant (e.g., pressure, temperature, etc.) may be monitored in real-time. Additionally, the amount of lubricant in the lubrication system may be monitored to determine the presence of any leaks therein. Further, embodiments of lubrication systems described herein include mechanisms (e.g., check valves 863a/863b and 865a/865b) configured to prevent leakage or reverse flow through the lubrication system.

[00129] Embodiments of RCDs described herein further include sensor assemblies (e.g., sensors 830, 832, 848, 868, 882, and/or 894) and associated components (e.g., stab plate 818) configured to measure properties of the RCD and transmit sensor signals indicative of those measured properties in real-time to a rig or platform of the system in which the RCD is used. For instance, embodiments of RCDs described herein include sensors configured to provide pressure and temperature measurements of the bore of the outer housing of the RCD, pressure and temperature measurements of a bore of a rotating sleeve of the seal assembly of the RCD, pressure and temperature sensors for the lubrication system of the RCD, position sensors for the locking pins of the RCD, rotational speed or RPM sensors for measuring rotational speed of the rotating sleeve, and leak sensors configured to detect the presence of a leak in one of the sealing elements of the sealing element of the RCD. Using the embodiments of sensors described herein, operation and performance of the RCD may be monitored, thereby allowing for safer operation of the RCD and the ability to repair or maintain the RCD prior to failure thereof (e.g., leakage past each sealing element of the RCD, etc.) in response to failure or leak detections made by the sensors.

[00130] While disclosed embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teachings herein. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the systems, apparatus, and processes described herein are possible and are within the scope of the disclosure. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims. Unless expressly stated otherwise, the steps in a method claim may be performed in any order. The recitation of identifiers such as (a), (b), (c) or (1), (2), (3) before steps in a method claim are not intended to and do not specify a particular order to the steps, but rather are used to simplify subsequent reference to such steps.

CLAIMS

What is claimed is:

1. A rotating control device for sealing an annulus extending from a subterranean wellbore, the rotating control device comprising:

an outer housing including a central axis, a first end, a second end opposite the first end, an outer surface extending axially from the first end to the second end, and an inner surface extending axially from the first end to the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and wherein the outer housing comprises a plurality of circumferentially-spaced bores extending radially from the outer surface to the throughbore;

a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through the throughbore of the outer housing, wherein the seal assembly comprises an outer surface including a receptacle; and

a plurality of actuatable locking pins, wherein each locking pin is moveably disposed in one of the bores of the outer housing and is configured to move radially relative to the outer housing between a locked position with a radially inner end the locking pin seated in the receptacle and an unlocked position with the radially inner end of the locking pin removed from the receptacle.

2. The rotating control device of claim 1, wherein the inner surface of the outer housing comprises an annular shoulder configured to engage a mating annular shoulder on the outer surface of the seal assembly.

3. The rotating control device of claim 2, wherein the annular shoulder of the outer housing comprises a frustoconical surface configured to slidingly engage a mating frustoconical surface of the annular shoulder of the seal assembly.

4. The rotating control device of claim 2, wherein the radially inner end of each locking pin comprises a chamfered profile configured to engage a corresponding chamfered profile of the outer surface of the seal assembly and urge the annular shoulder of the seal assembly in engagement with the annular shoulder of the outer housing.

5. The rotating control device of claim 1, wherein each locking pin comprises a fluid passage configured to be pressurized to transition the locking pin between the unlocked position and the locked position.

6. The rotating control device of claim 1, further comprising a position sensor disposed in one of the locking pins, wherein the position sensor is configured to output a signal indicating the position of the locking pin in the locked position or the unlocked position.

7. The rotating control device of claim 6, further comprising a stab plate coupled to the outer surface of the outer housing, wherein the stab plate comprises:

a first fluid connector in fluid communication with a first fluid conduit;

a second fluid connector in fluid communication with a second fluid conduit; and

an electrical connector in signal communication with the position sensor;

wherein at least one of the locking pins is configured to transition from the unlocked position to the locked position in response to pressurization of the first fluid conduit;

wherein at least one of the locking pins is configured to transition from the locked position to the unlocked position in response to pressurization of the second fluid conduit.

8. The rotating control device of claim 2, wherein the radially inner end of each locking pin comprises a shoulder extending orthogonal the central axis of the outer housing.

9. The rotating control device of claim 1, wherein:

the outer housing includes a first passage extending from the inner surface to the outer surface and a second passage extending from the inner surface to the outer surface;

the seal assembly comprises an inner housing including a first passage extending from an inner surface to an outer surface of the inner housing and a second passage extending from the inner surface to the outer surface of the inner housing;

the first passage of the outer housing is in fluid communication with the first passage of the inner housing, and wherein the first passage of the outer housing and the first passage of the inner housing are configured to supply a lubricating fluid to a bearing chamber of the inner housing; and the second passage of the outer housing is in fluid communication with the second passage of the inner housing, and wherein the second passage of the outer housing and the second passage of the inner housing are configured to receive the lubricating fluid from the bearing chamber.

10. The rotating control device of claim 9, wherein:

the first and second passages of the outer housing each include a check valve; and

the first and second passages of the inner housing each include a check valve.

11. The rotating control device of claim 1, further comprising:

a first proximity sensor disposed along the inner surface of the outer housing; and

a first sensor element disposed along an outer surface of an inner housing of the seal assembly;

wherein the first proximity sensor is configured to measure the rotational speed of the seal assembly in response to rotation of the seal assembly in the outer housing.

12. The rotating control device of claim 11, further comprising:

a second proximity sensor disposed along the inner surface of the housing; and

a second sensor element disposed along the outer surface of the inner housing;

wherein the second sensor element is configured to detect a leak in a sealing element of the seal assembly in response to leakage across the sealing element.

13. A rotating control device for sealing an annulus extending from a subterranean wellbore, the rotating control device comprising:

an outer housing including a central axis, a first end, a second end opposite the first end, an outer surface extending axially from the first end to the second end, and an inner surface extending axially from the first end to the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and wherein the outer housing comprises a plurality of circumferentially-spaced bores extending radially from the outer surface to the throughbore;

a plurality of actuatable locking pins, wherein each locking pin is moveably disposed in one of the bores of the outer housing and is configured to move radially relative to the outer housing between a locked position with a radially inner end the locking pin seated in the receptacle and an unlocked position with the radially inner end of the locking pin removed from the receptacle.

14. The rotating control device of claim 13, further comprising:

a seal assembly configured to be removably disposed within the outer housing, wherein the seal assembly comprises an outer surface including a receptacle configured to receive a radially inner end of each locking pin of the outer housing.

15. The rotating control device of claim 14, wherein the seal assembly has a first position seated within the throughbore of the outer housing and a second position removed from the throughbore of the outer housing.

16. The rotating control device of claim 15, wherein the seal assembly is configured to be lowered into the throughbore of the outer housing at the first end of the outer housing.

17. The rotating control device of claim 14, wherein the inner surface of the outer housing comprises an annular shoulder and the outer surface of the seal assembly comprises an annular shoulder configured to axially abut the annular shoulder of the outer housing in the first position.

18. The rotating control device of claim 14, wherein each locking pin comprises a fluid passage configured to be pressurized to transition the locking pin between the unlocked position and the locked position.

19. The rotating control device of claim 18, wherein each locking pin comprises a position sensor configured to indicate the position of the locking pin in the locked position or the unlocked position.

20. A rotating control device for sealing an annulus extending from a subterranean wellbore, comprising:

an outer housing including a central axis, a first end, a second end opposite the first end, an inner surface extending axially from the first end to the second end, and an outer surface extending between the first end and the second end, wherein the inner surface defines a throughbore extending axially through the outer housing, and wherein the outer housing includes a first passage extending from the inner surface to the outer surface and a second passage extending from the inner surface to the outer surface; and

a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through the throughbore of the outer housing, wherein the seal assembly comprises an inner housing including a first end, a second end opposite the first end, an inner surface extending axially from the first end to the second end of the inner housing, and an outer surface extending between the first end and the second end of the inner housing, wherein the inner housing includes a first passage extending from the inner surface to the outer surface of the inner housing and a second passage extending from the inner surface to the outer surface of the inner housing;

wherein the first passage of the outer housing is in fluid communication with the first passage of the inner housing, and wherein the first passage of the outer housing and the first passage of the inner housing are configured to supply a lubricating fluid to a bearing chamber of the inner housing;

wherein the second passage of the outer housing is in fluid communication with the second passage of the inner housing, and wherein the second passage of the outer housing and the second passage of the inner housing are configured to receive the lubricating fluid from the bearing chamber.

21. The rotating control device of claim of claim 20, wherein:

the first and second passages of the outer housing each include a check valve; and

the first and second passages of the inner housing each include a check valve.

22. The rotating control device of claim 20, further comprising:

a plurality of fluid conduits in fluid communication with the first and second passages of the outer housing; and

a sensor coupled to one of the fluid conduits, wherein the sensor is configured to measure at least one of pressure and temperature of fluid disposed in the fluid conduit.

23. The rotating control device of claim 22, further comprising a stab plate coupled to the outer housing and including a fluid connector coupled to an end of one of the fluid conduits.

24. The rotating control device of claim 22, further comprising a lubrication system coupled to the plurality of fluid conduits, wherein the lubrication system is configured to circulate lubricating fluid in a continuous circuit through the bearing chamber of the inner housing of the seal assembly.

25. The rotating control device of claim 20, further comprising a sensor coupled to the outer housing and in fluid communication with the bore of the outer housing, wherein the sensor is configured to measure at least one of pressure and temperature of fluid disposed in the bore of the outer housing.

26. A rotating control device for sealing an annulus extending from a subterranean wellbore, comprising:

an outer housing including a central axis, a first end, a second end opposite the first end, an inner surface extending axially from the first end to the second end, and an outer surface extending from the first end to the second end, wherein the inner surface defines a throughbore extending axially through the outer housing;

a seal assembly disposed within the outer housing and configured to seal against a rotating tubular member extending axially through the throughbore of the outer housing, wherein the seal assembly comprises an inner housing including a first end, a second end opposite the first end of the inner housing, an inner surface extending axially from the first end of the inner housing to the second end of the inner housing, and an outer surface extending from the first end of the inner housing to the second end of the inner housing;

a first proximity sensor disposed along the inner surface of the outer housing; and

a first sensor element disposed along the outer surface of the inner housing;

wherein the first proximity sensor is configured to measure the rotational speed of the seal assembly in response to rotation of the seal assembly in the outer housing.

27. The rotating control device of claim 26, wherein the first sensor element comprises a magnetic member.

28. The rotating control device of claim 26, further comprising:

a second proximity sensor disposed along the inner surface of the housing;

a second sensor element disposed along the outer surface of the inner housing;

wherein the second sensor element is configured to detect a leak in a sealing element of the seal assembly in response to leakage across the sealing element.

29. The rotating control device of claim 28, wherein the second sensor element comprises a sensor element assembly comprising:

a housing;

a piston slidably disposed in the housing;

a biasing member configured to bias the piston towards a radially inner position; and

a burst disc configured to rupture in response to leakage across the sealing element.

30. The rotating control device of claim 29, wherein, in response to the rupture of the burst disc, the piston is configured to be actuated into a radially outer position.

31. The rotating control device of claim 30, wherein, in response to the piston of the sensor element assembly being disposed in the radially outer position, the second proximity sensor is configured to output a signal.

32. The rotating control device of claim 30, further comprising:

a transducer disposed along the outer surface of a sleeve disposed in the inner housing of the seal assembly, wherein the transducer is configured to measure the pressure of fluid disposed in a bore of the sleeve; and

a transmitter disposed along the inner surface of the outer housing;

wherein the transducer is configured to wirelessly communicate signals indicative of the pressure of fluid disposed in the bore of the sleeve to the transmitter.

33. A method for sealing an annulus of a marine riser with a rotating control device (RCD), the method comprising:

(a) coupling an outer housing of the RCD to the marine riser;

(b) lowering a seal assembly into the outer housing of the RCD after (a), wherein the seal assembly is configured to seal against a drillstring extending through the outer housing and the marine riser; and

(c) extending a plurality of locking pins radially inward from the outer housing into a receptacle in an outer surface of the seal assembly after (b) to secure the seal assembly within the outer housing.

34. The method of claim 33, further comprising (d) flowing a fluid from an annulus disposed between the seal assembly and the outer housing through a port extending through the outer housing.

35. The method of claim 33, wherein (b) comprises landing an annular landing profile of the seal assembly against a corresponding landing profile of the outer housing.

36. The method of claim 33, wherein (c) comprises engaging a chamfered profile of an inner end of each locking pin against a corresponding chamfered profile of the receptacle of the seal assembly.

37. The method of claim 33, wherein (c) comprises pressurizing a fluid passage extending through each locking pin to displace each locking pin into the receptacle of the outer surface of the seal assembly.

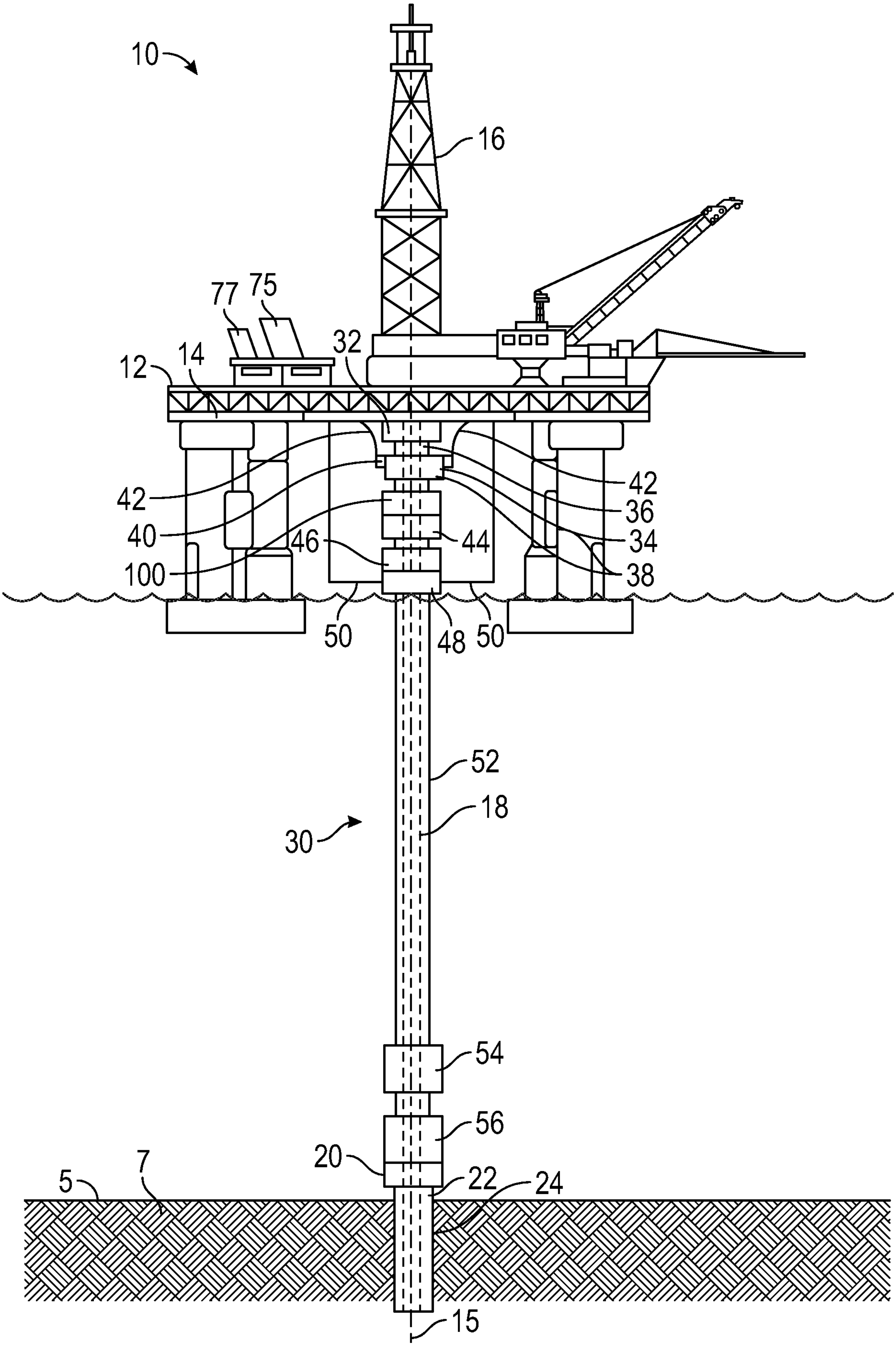

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FIG. 1

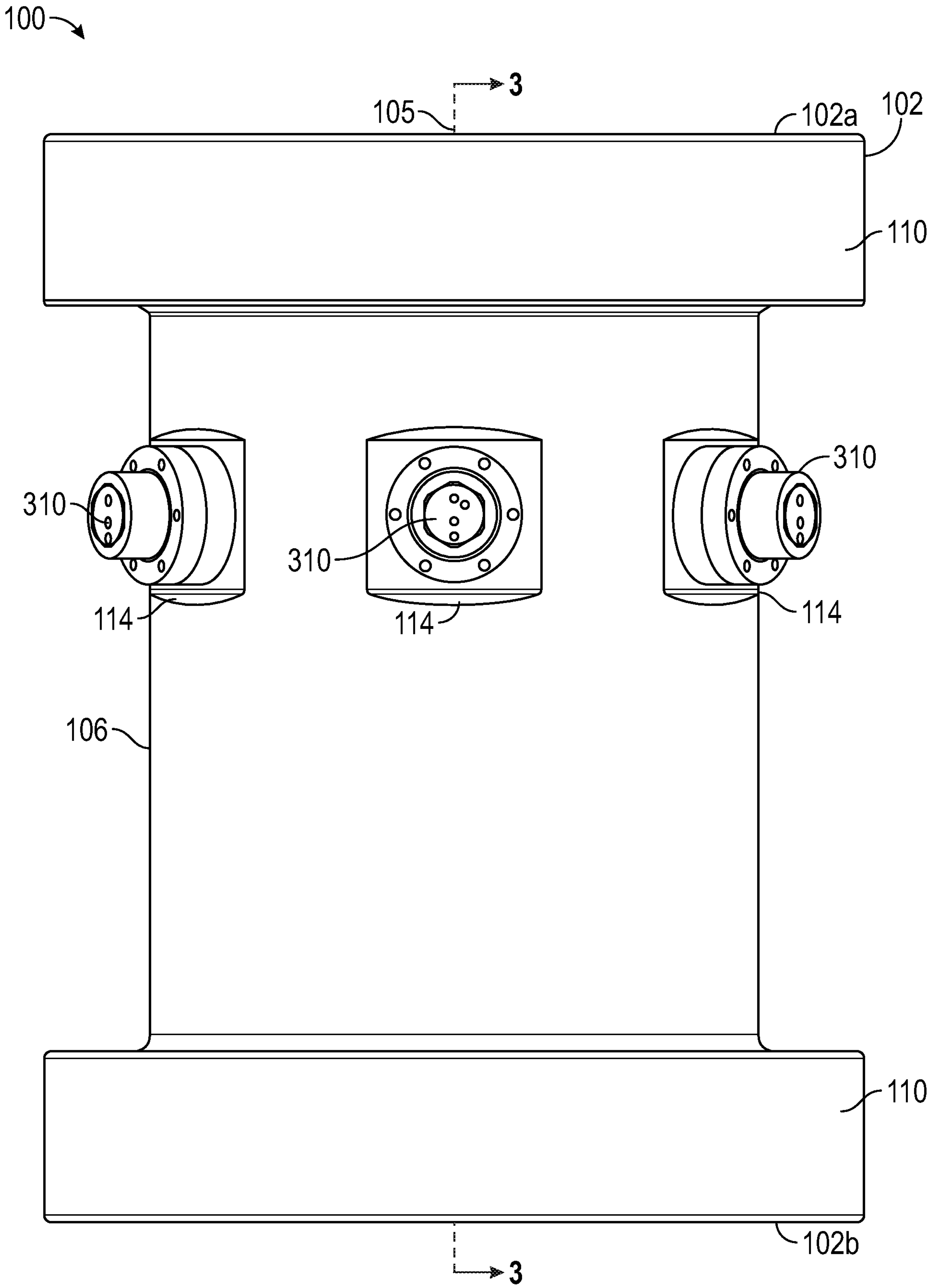

FIG. 2

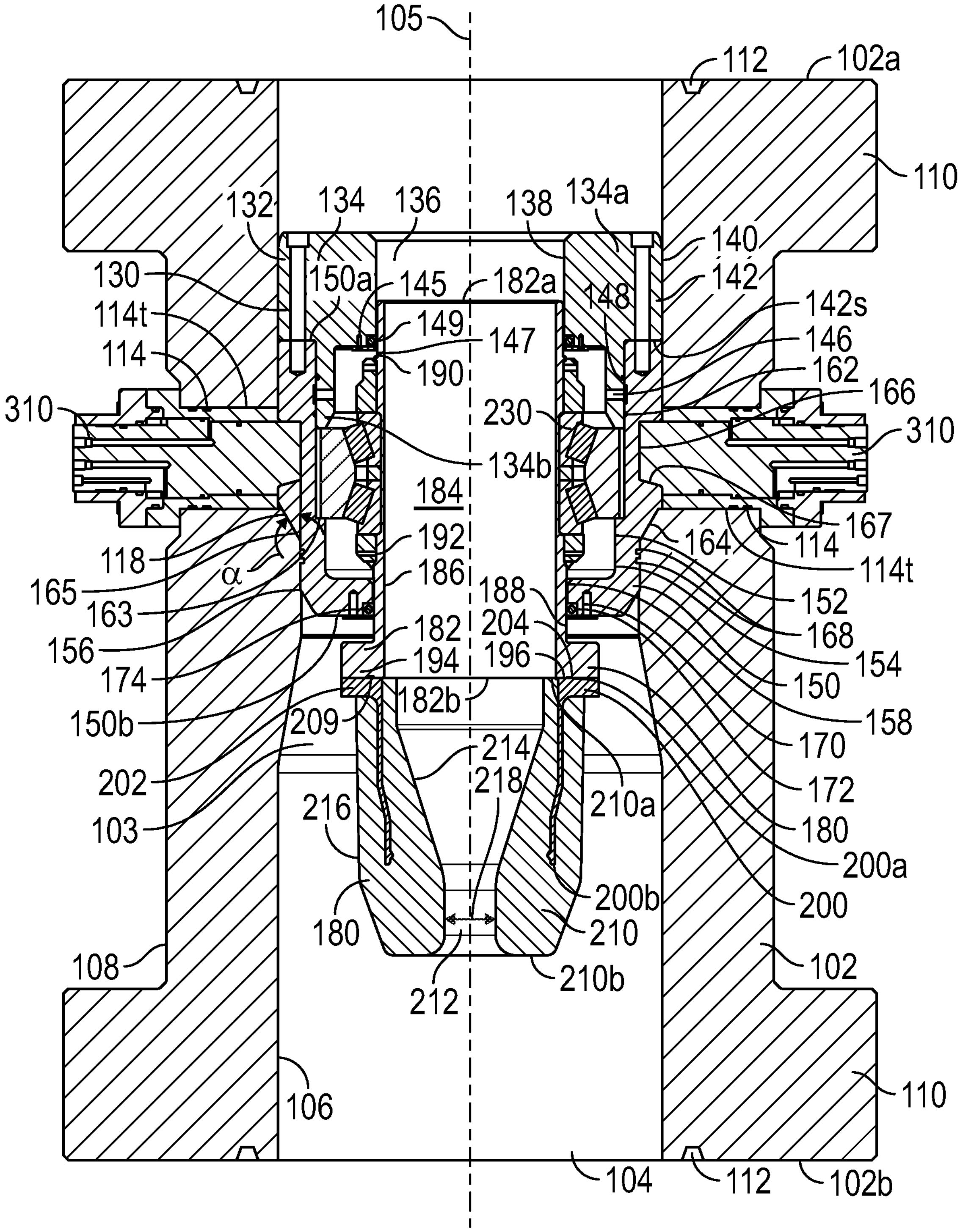
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FIG. 3

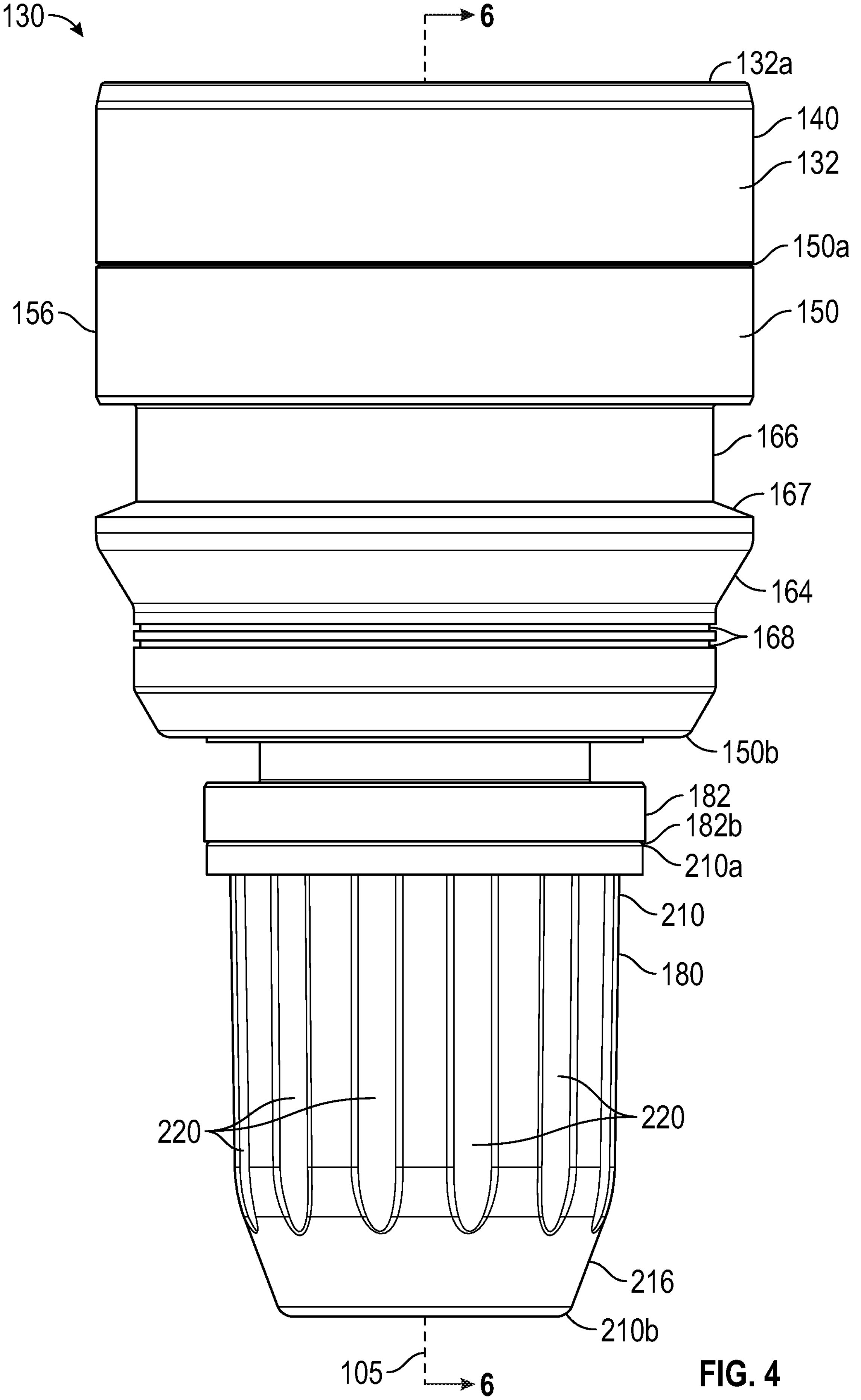
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FIG. 4

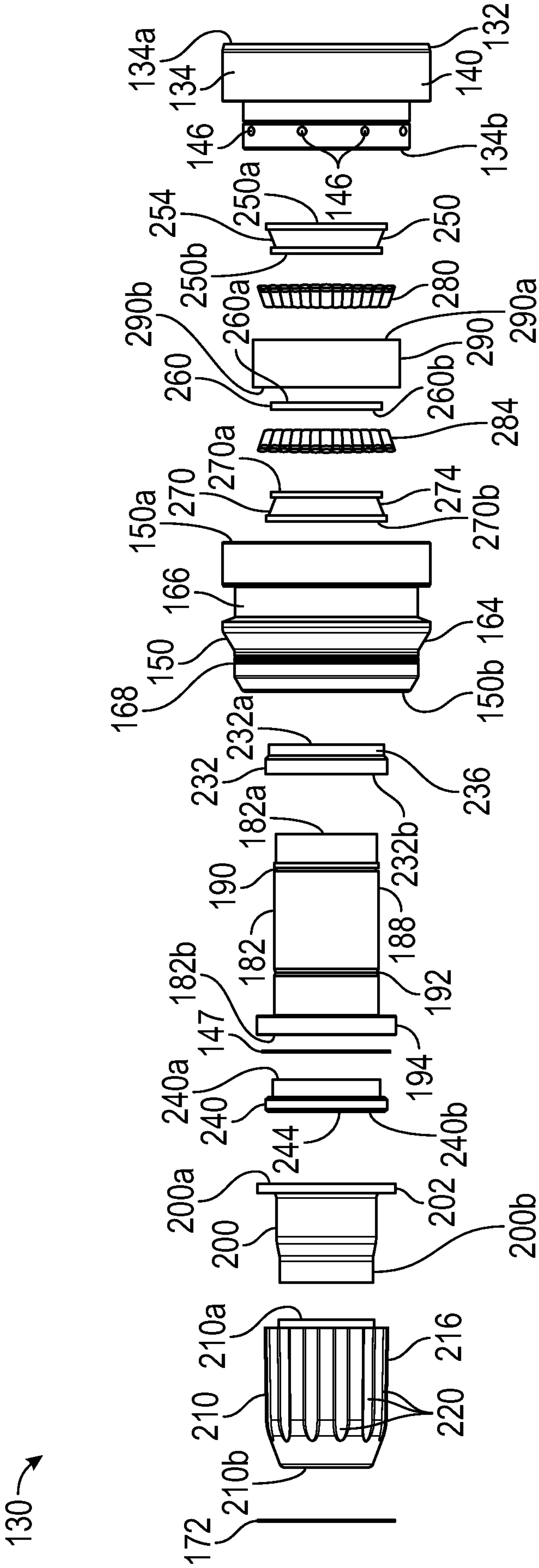
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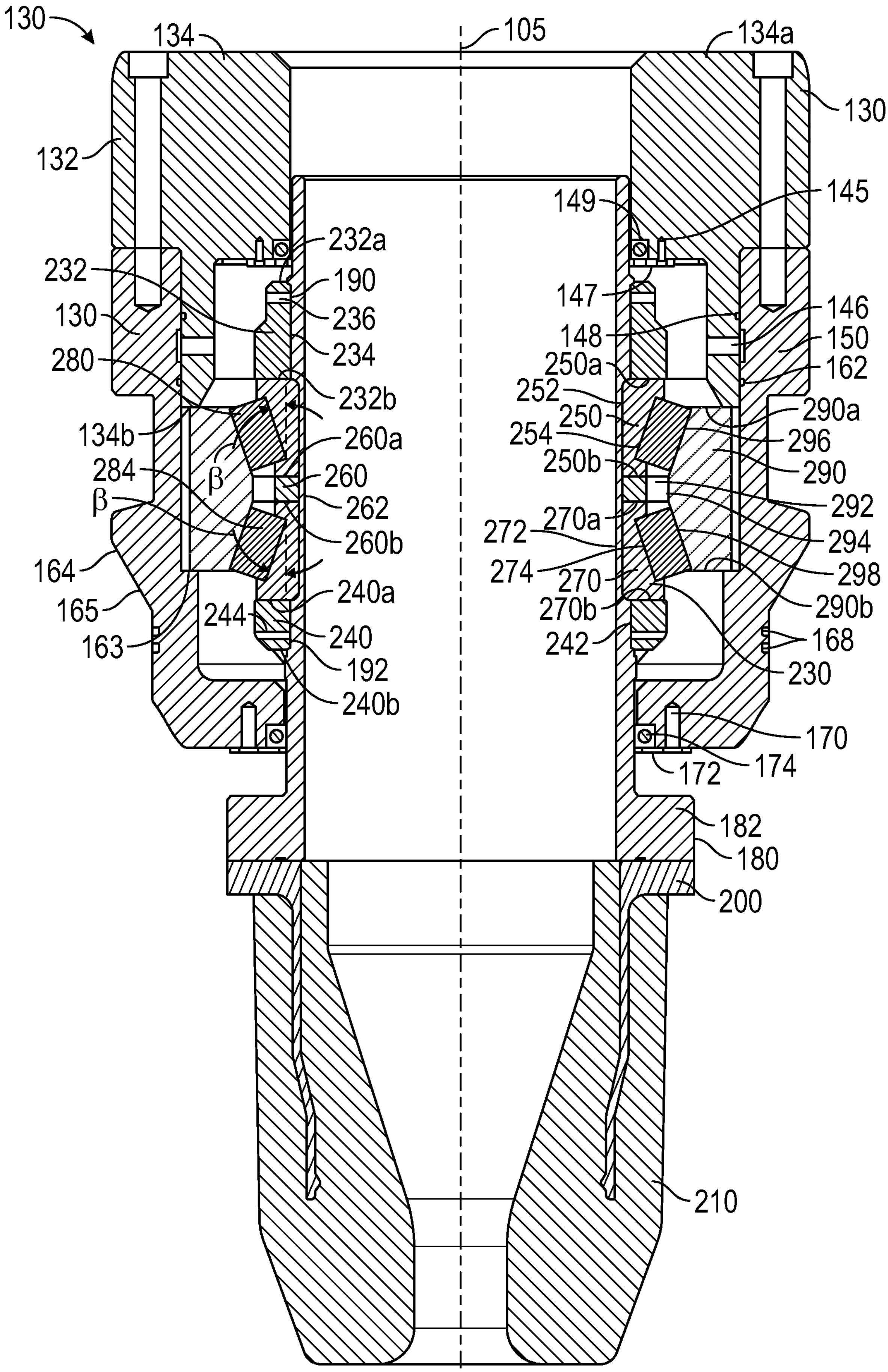
FIG. 5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274
298
164
270
240a
290b
165
270b
244
168
240
163
242
192
230
240b
170
174
172
182
180
200
210

FIG. 6

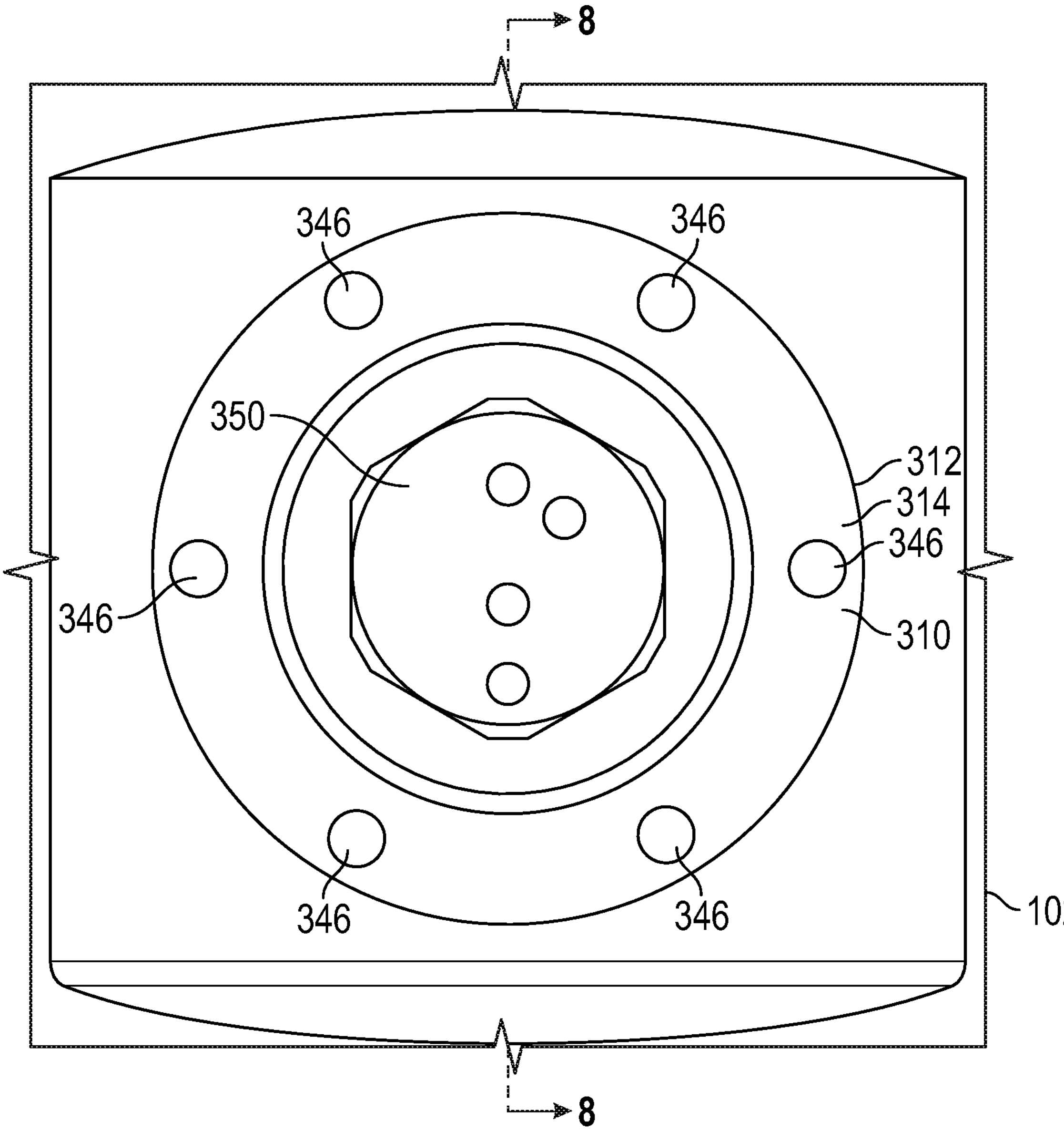
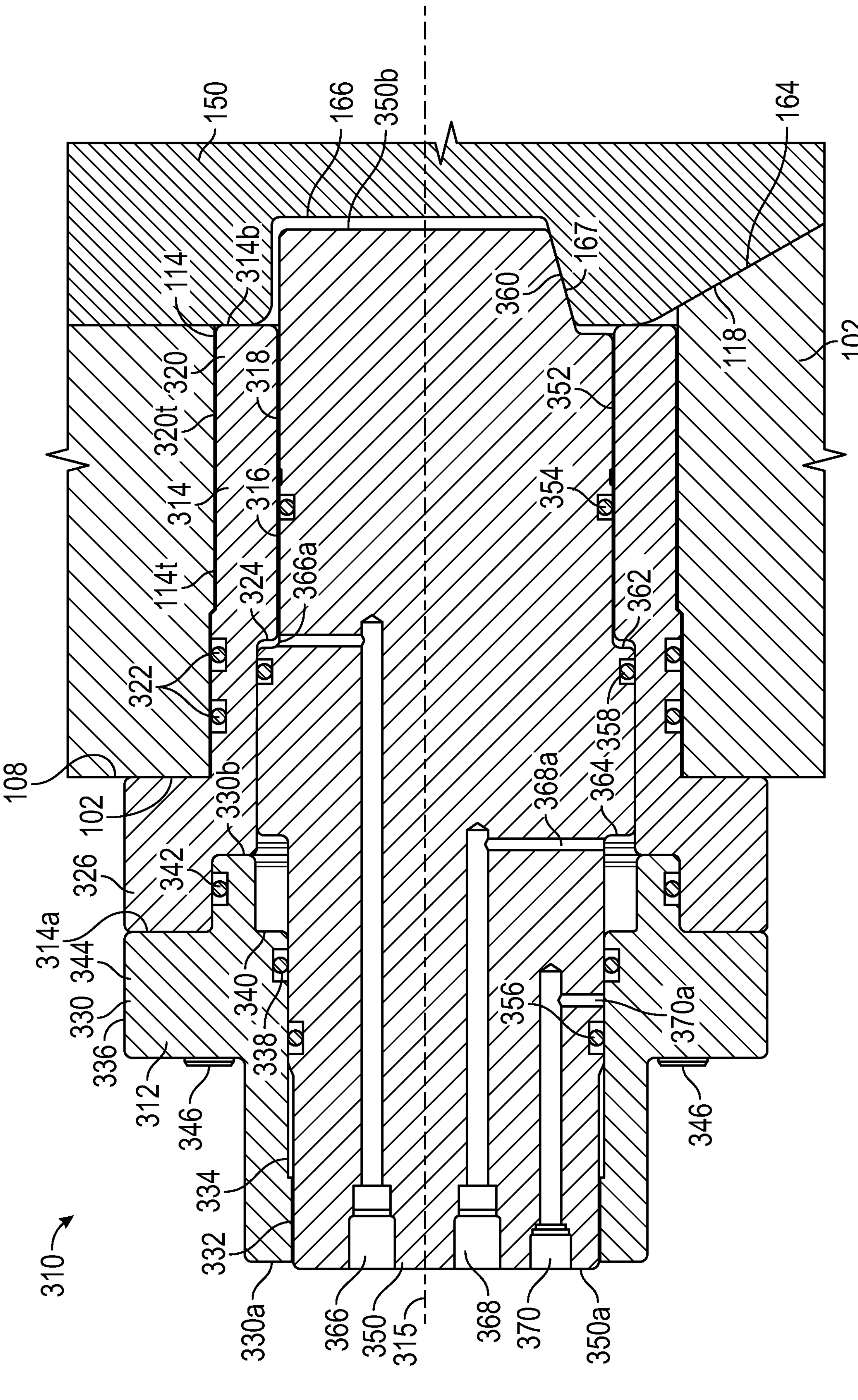


FIG. 7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350b
164
314b
114
167
360
320
318
118
102
320t
352
314
316
354
114t
324
366a
362
322
358
108
364
102
368a
330b
326
342
314a
344
340
356
370a
330
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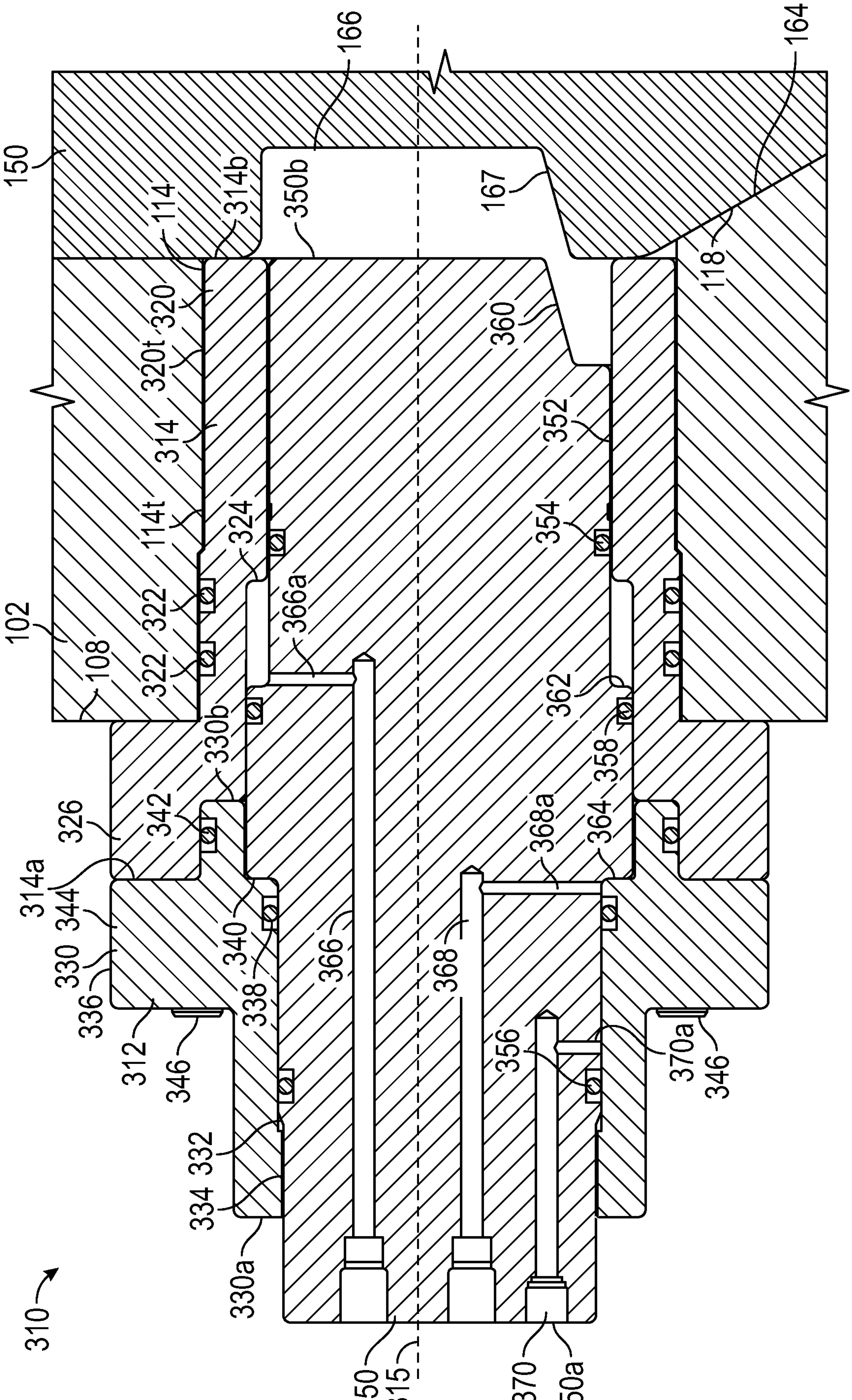
330a
366
350
315
368
370
350a

FIG. 8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320t
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362
330b
358
326
342
368a
364
314a
344
340
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330a
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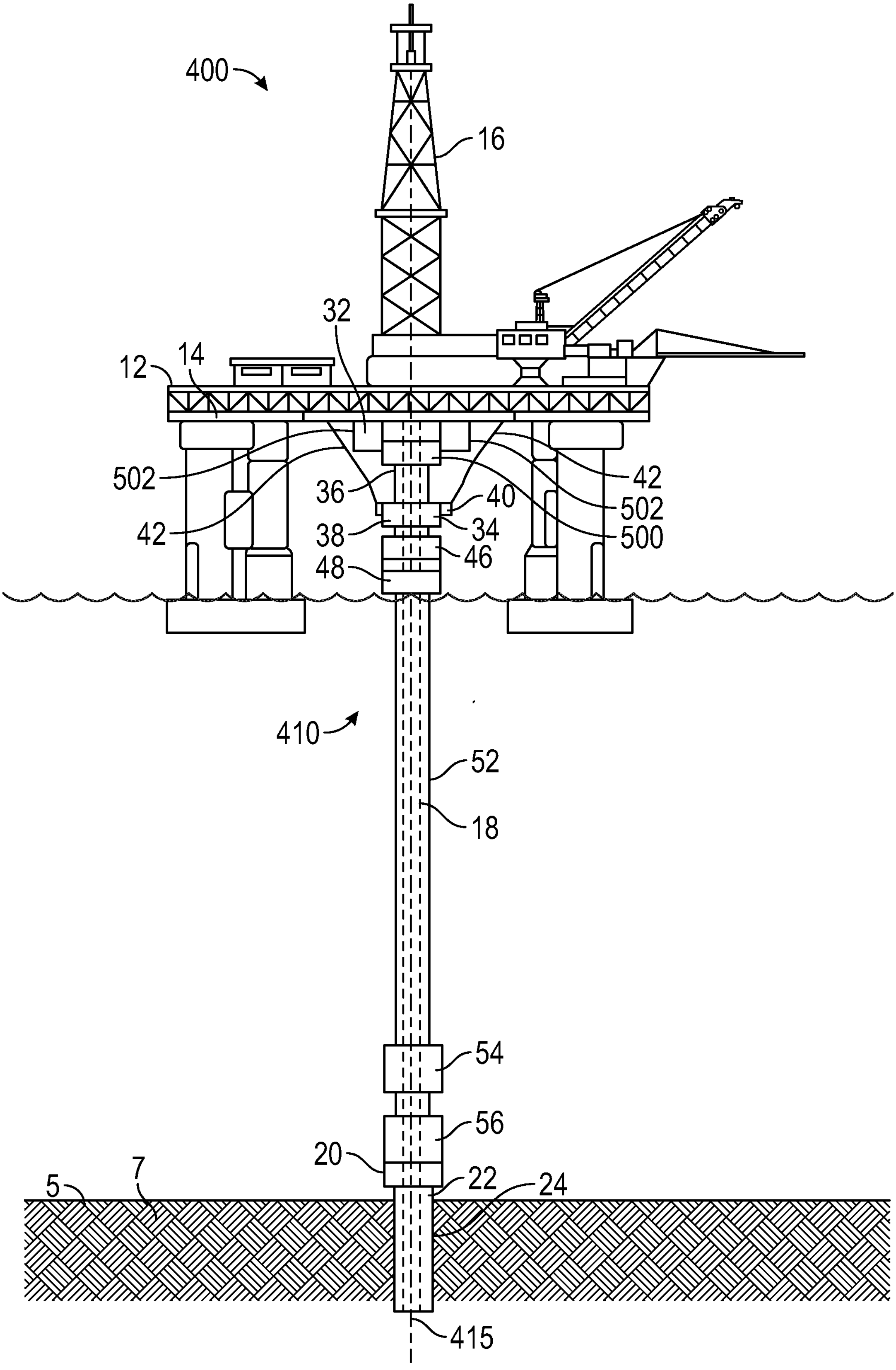
315
370
350a

FIG. 9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56
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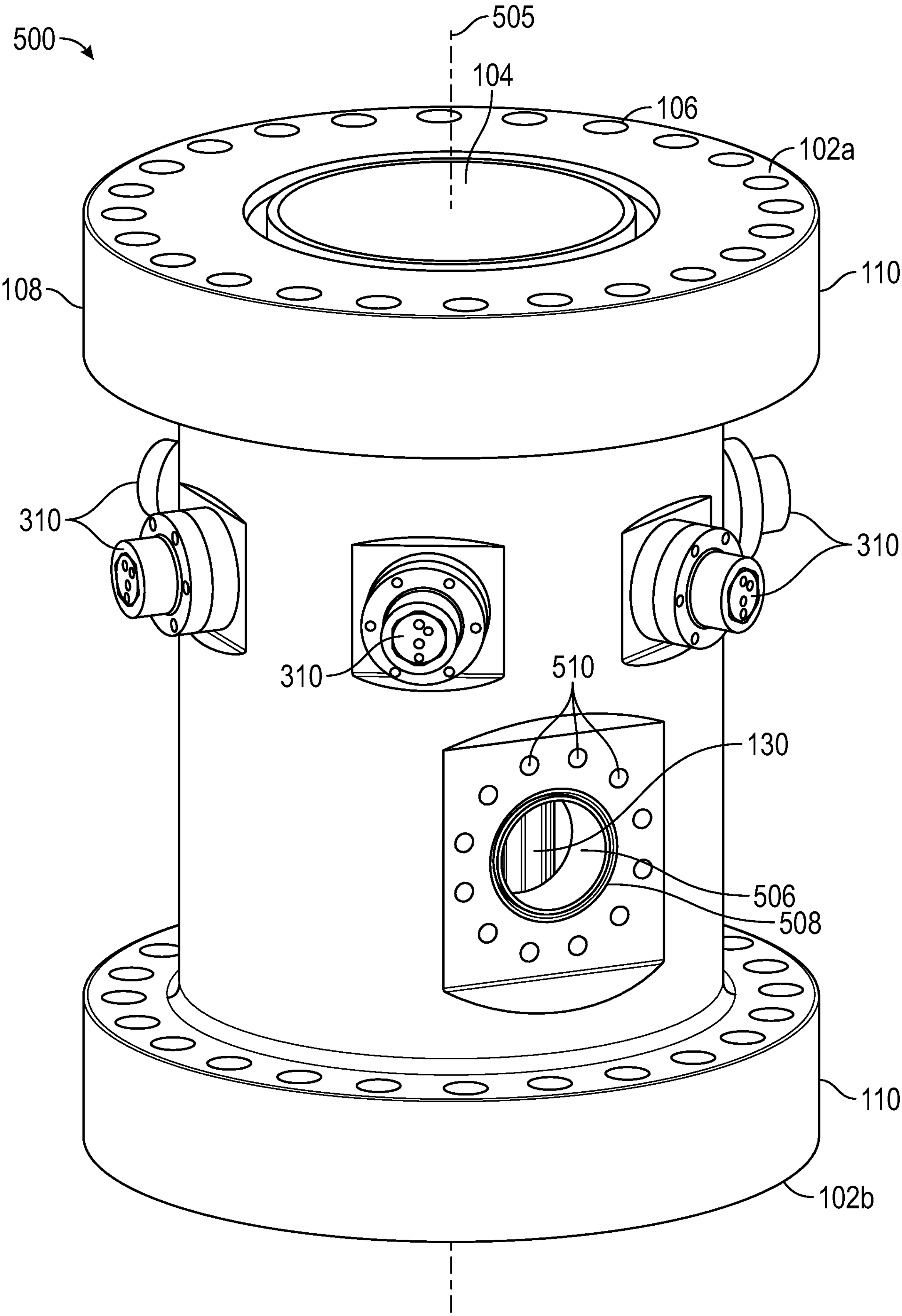
415

FIG. 10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130
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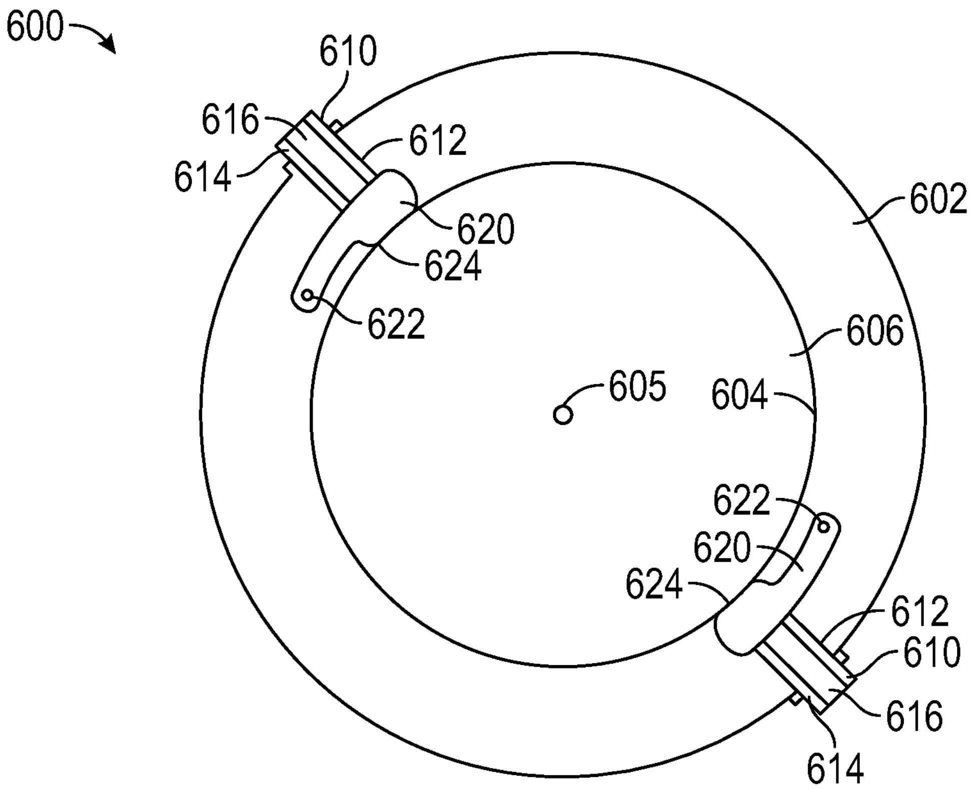
508
110
102b

FIG. 11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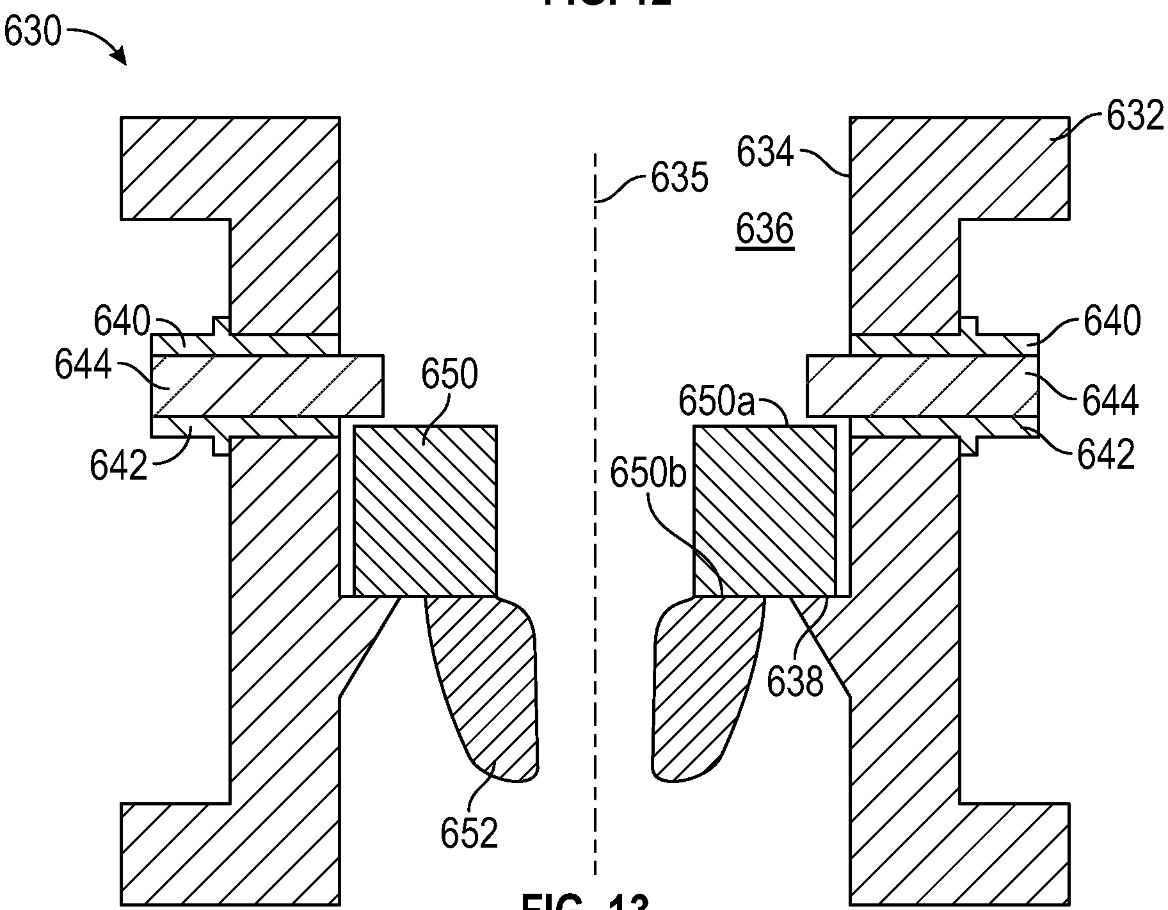
614

FIG. 12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642
642
650b
638
652

FIG. 13

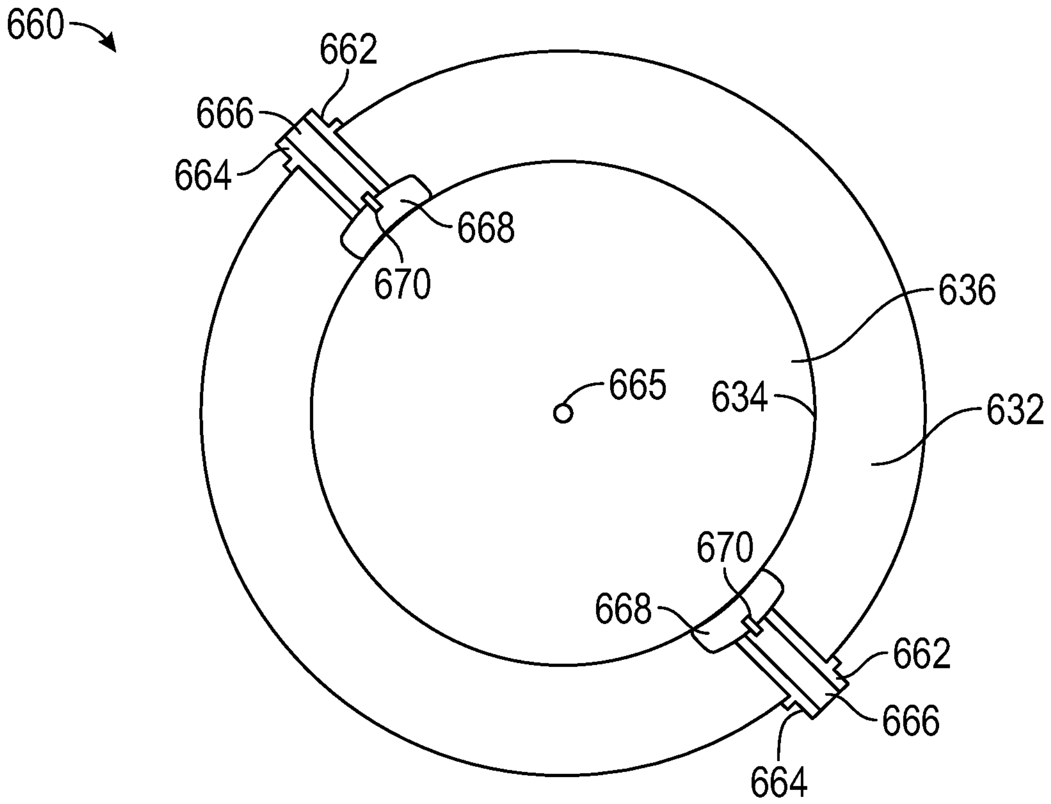
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FIG. 14

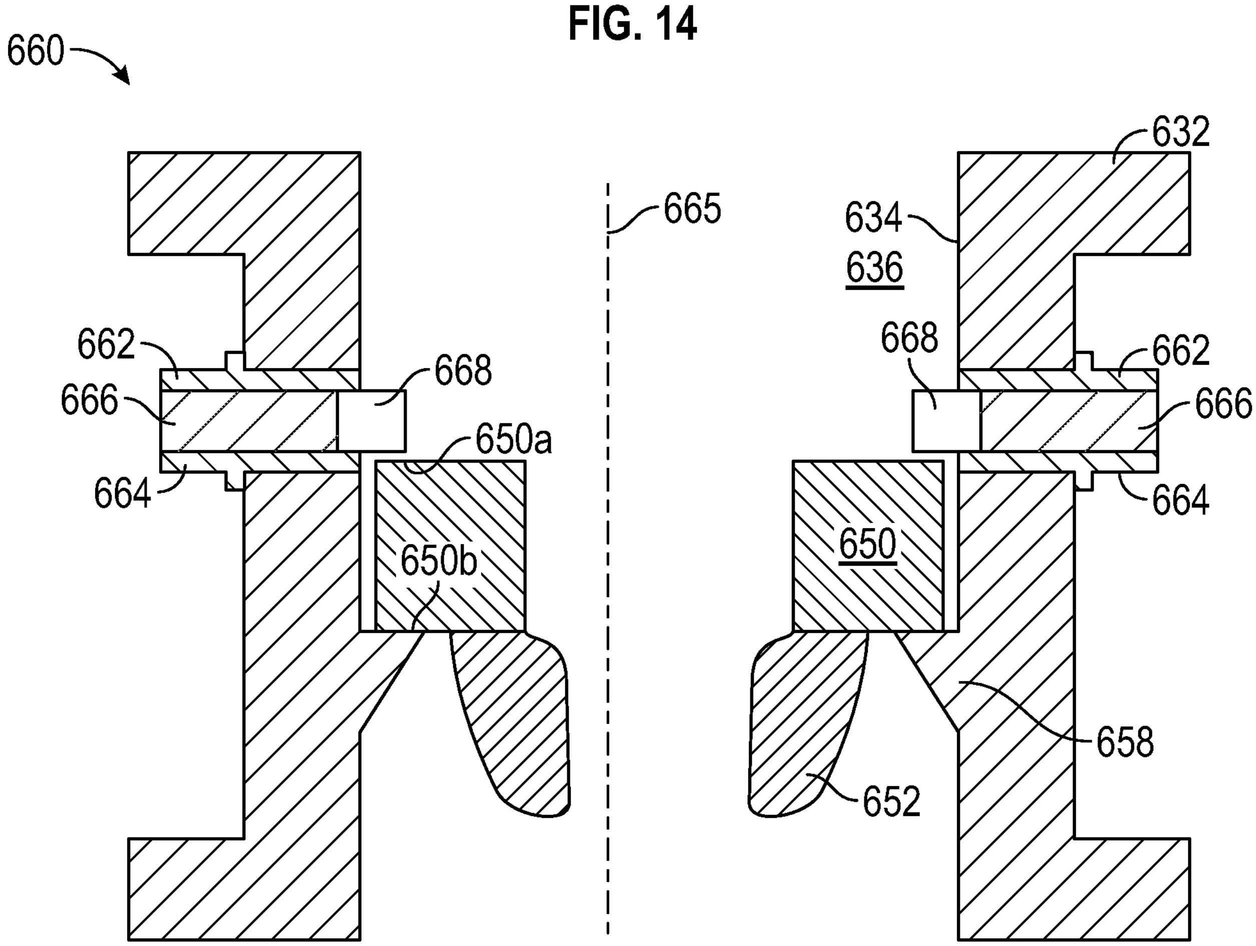
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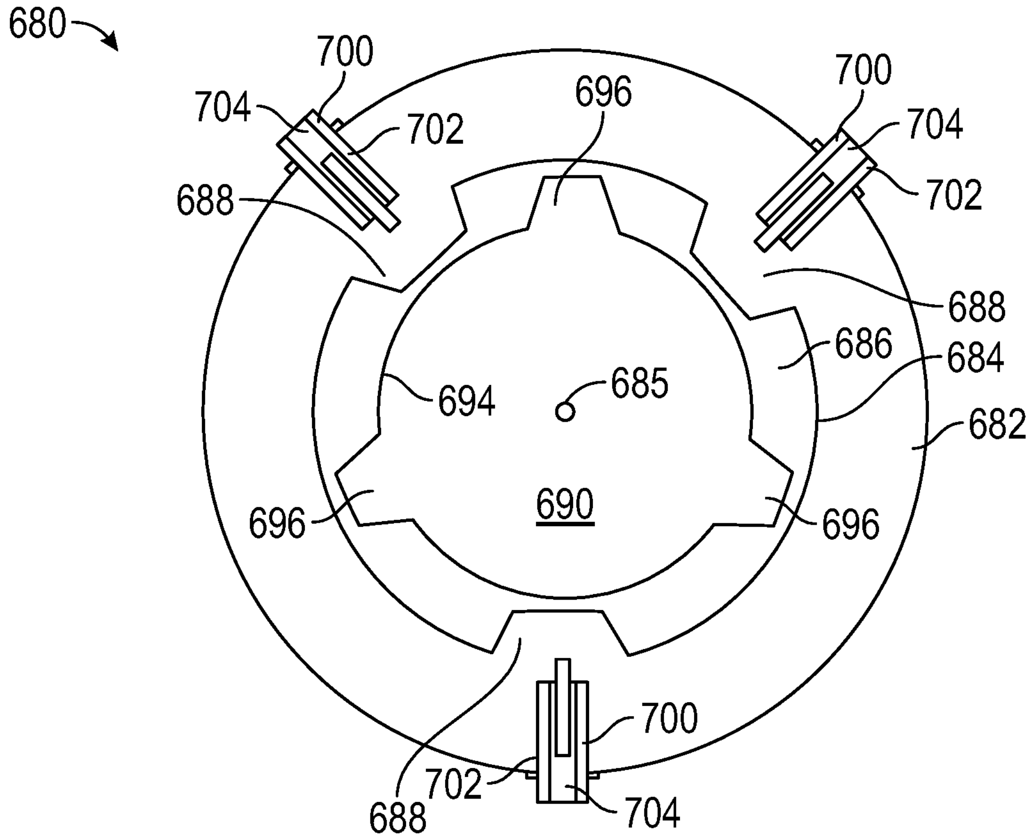
FIG. 15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694
685
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690
696
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702
688
704

FIG. 16

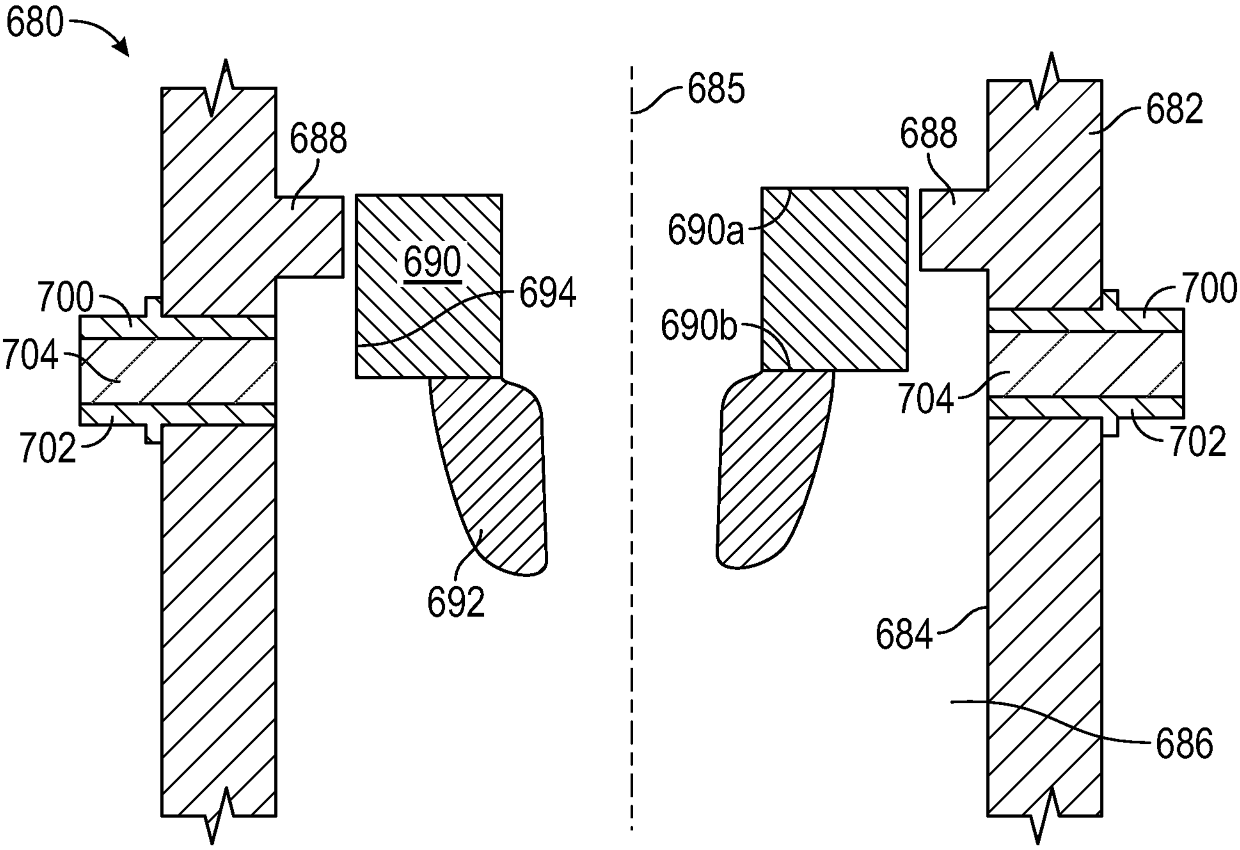
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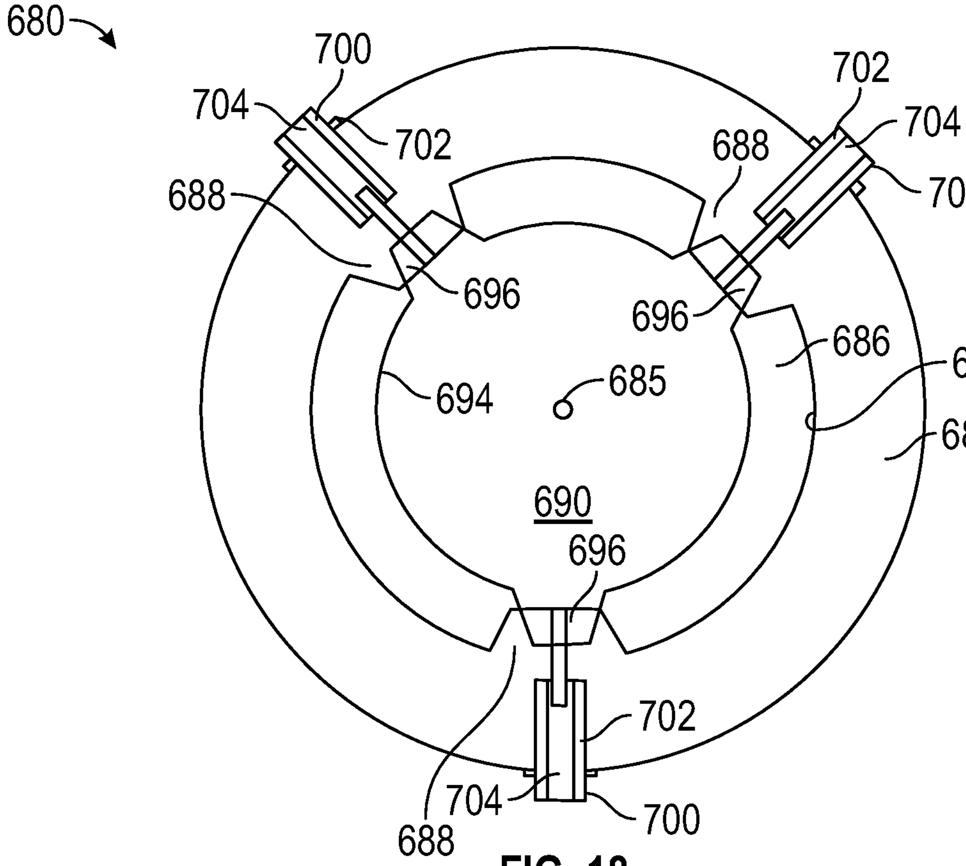
FIG. 17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702
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700
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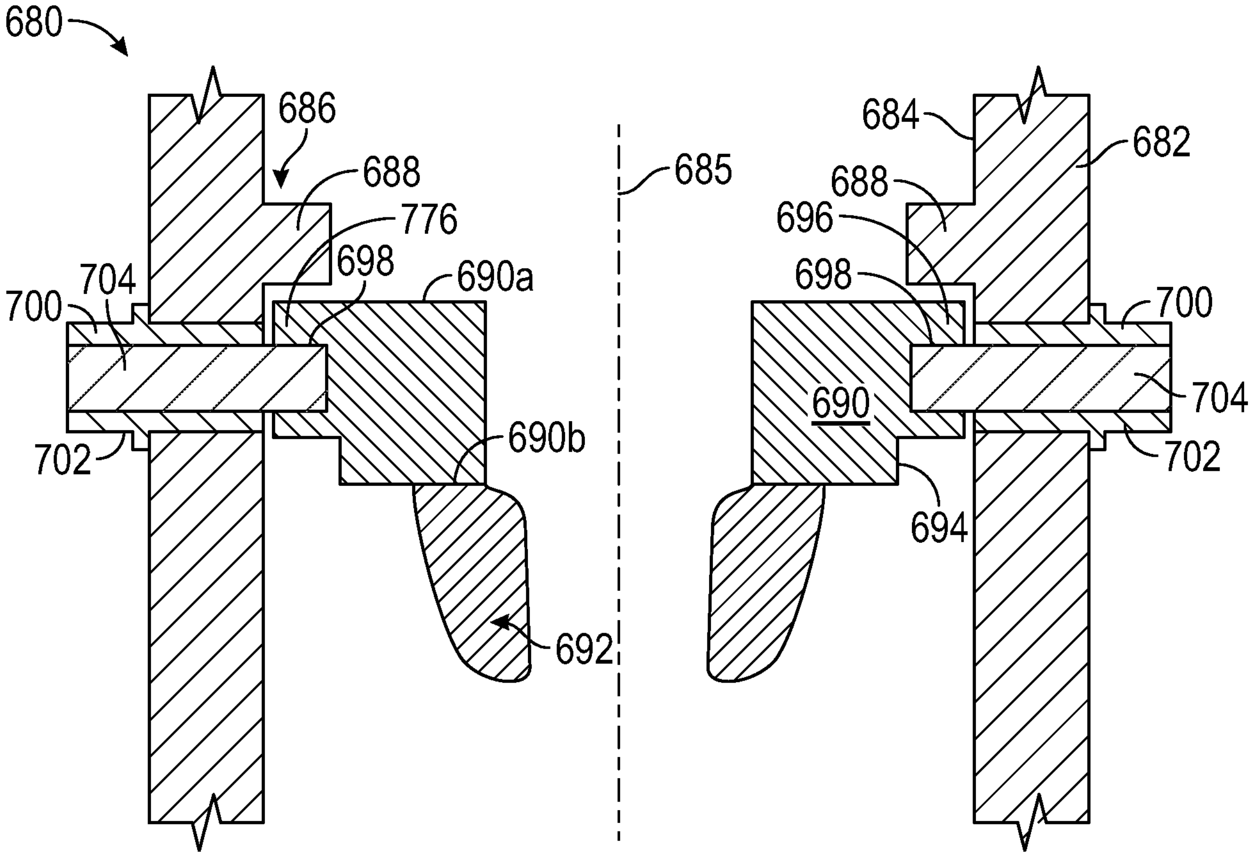
FIG. 18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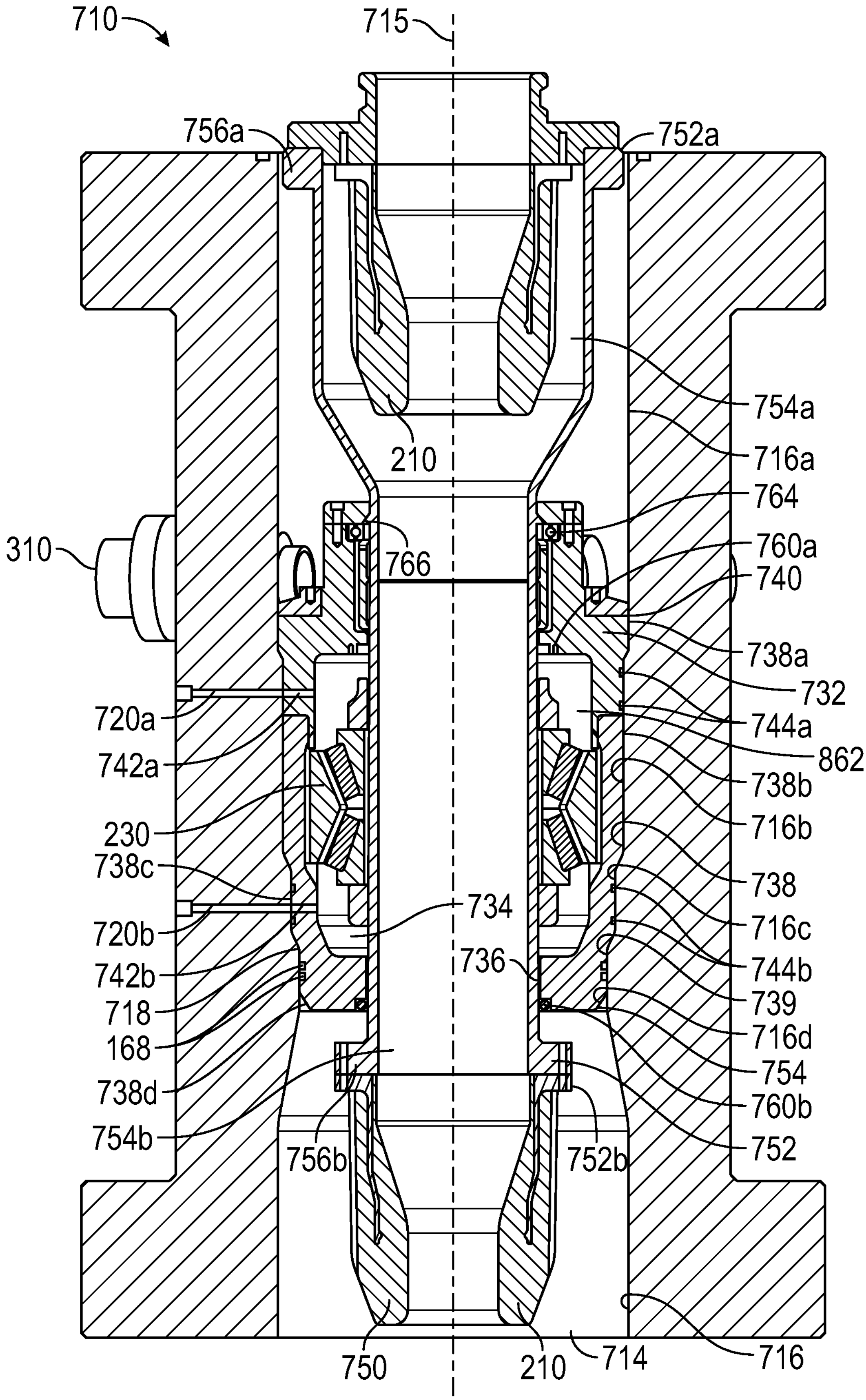
702
694

FIG. 19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754a
716a
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760a
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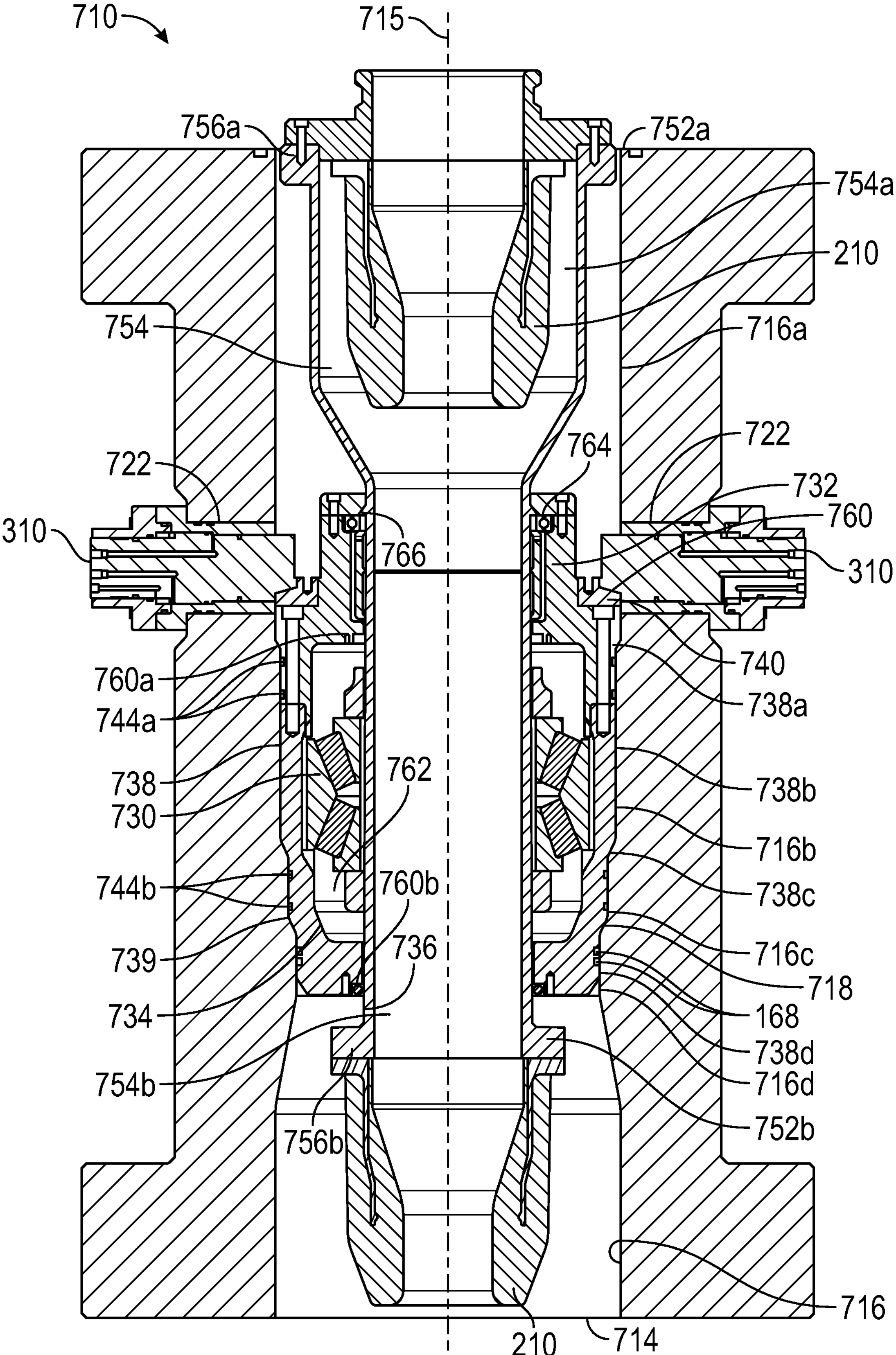
738a
732
720a
744a
742a
862
738b
230
716b
738c
738
734
720b
716c
736
742b
744b
718
739
168
716d
754
738d
760b
754b
752
756b
752b
750
210
714
716

FIG. 20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716a
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722
732
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740
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738a
744a
738
762
738b
730
716b
744b
760b
738c
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716c
718
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168
738d
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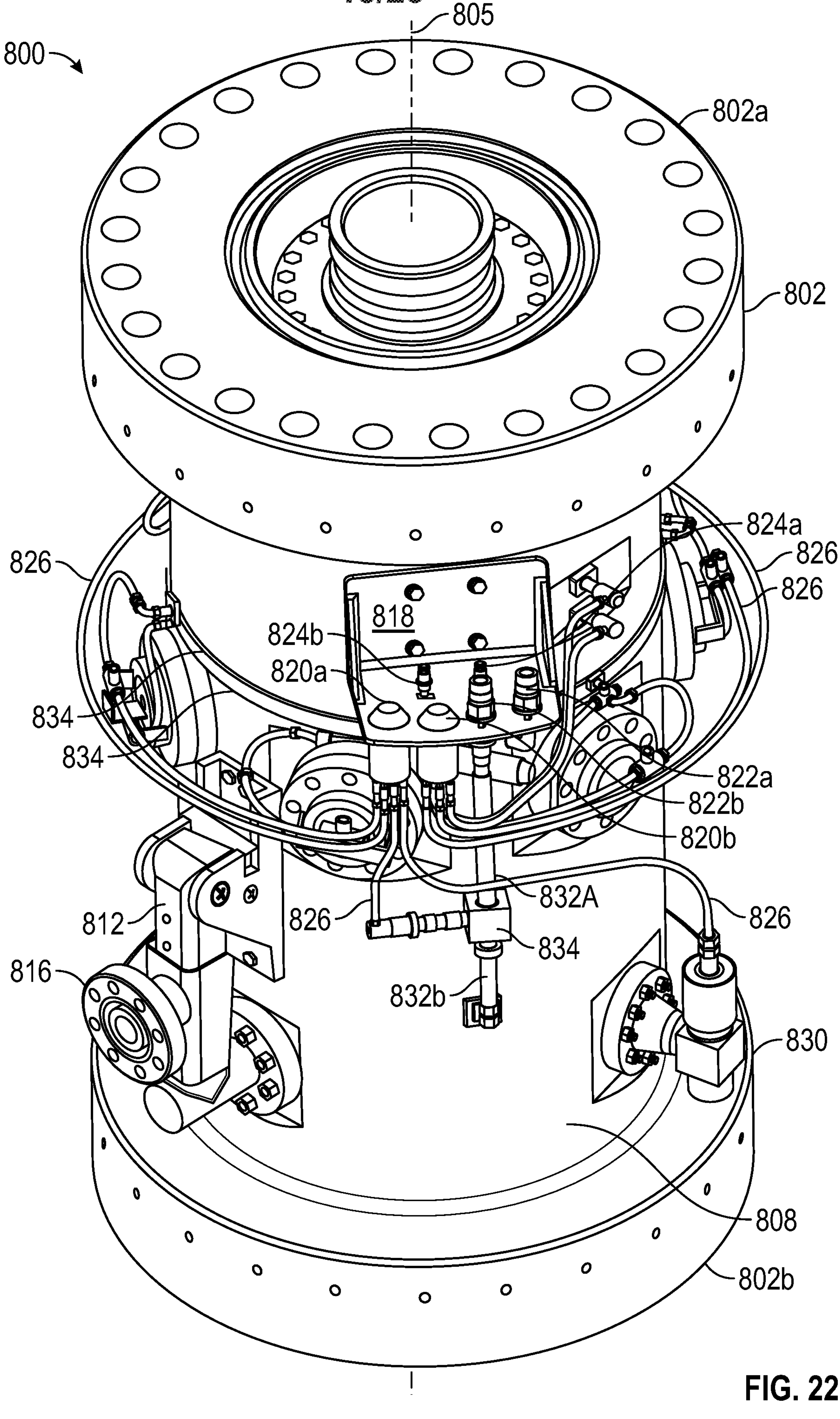
716d
752b
756b
716
210
714

FIG. 21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820a
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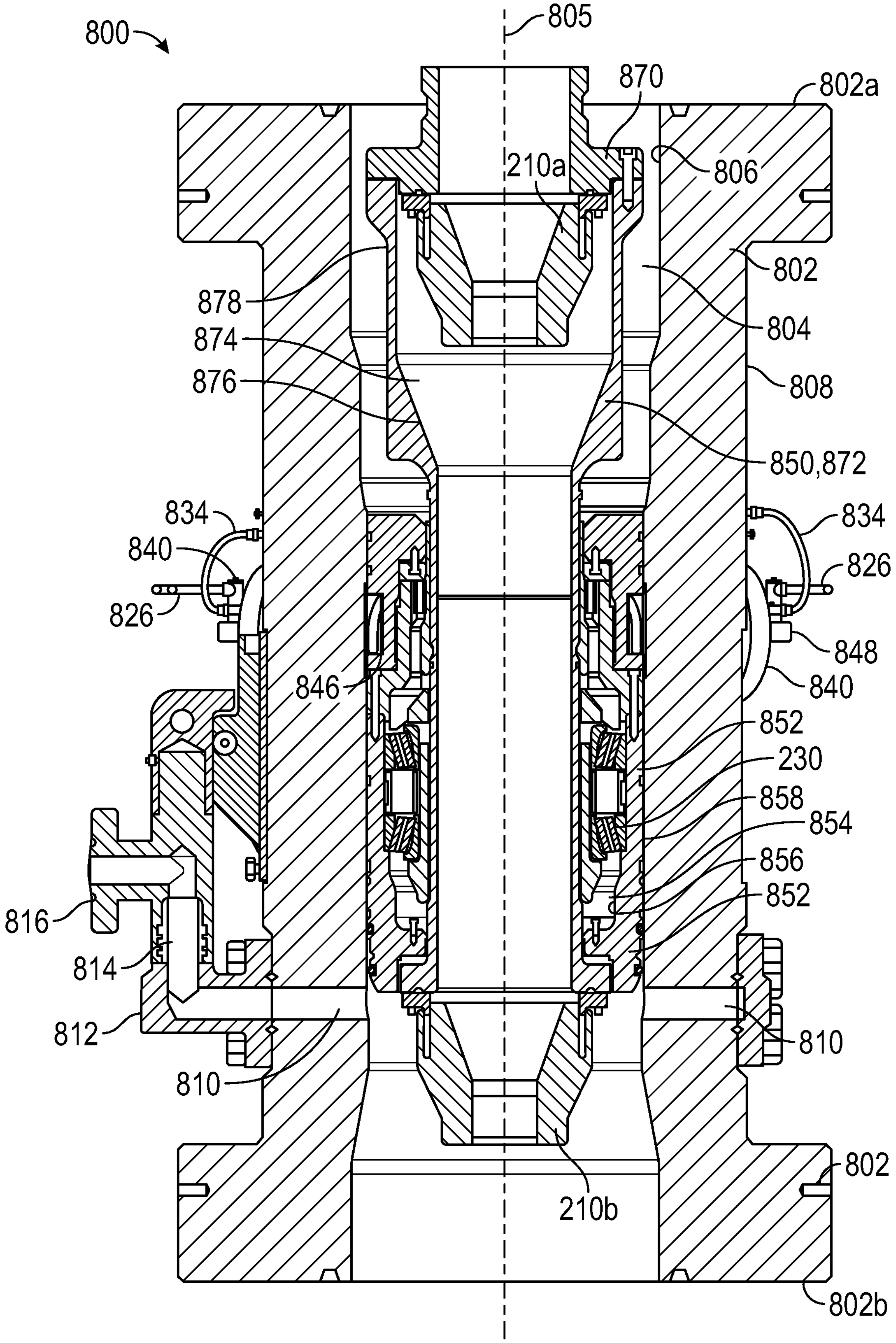
820b
832A
826
826
812
834
816
832b
830
808
802b

FIG. 22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876
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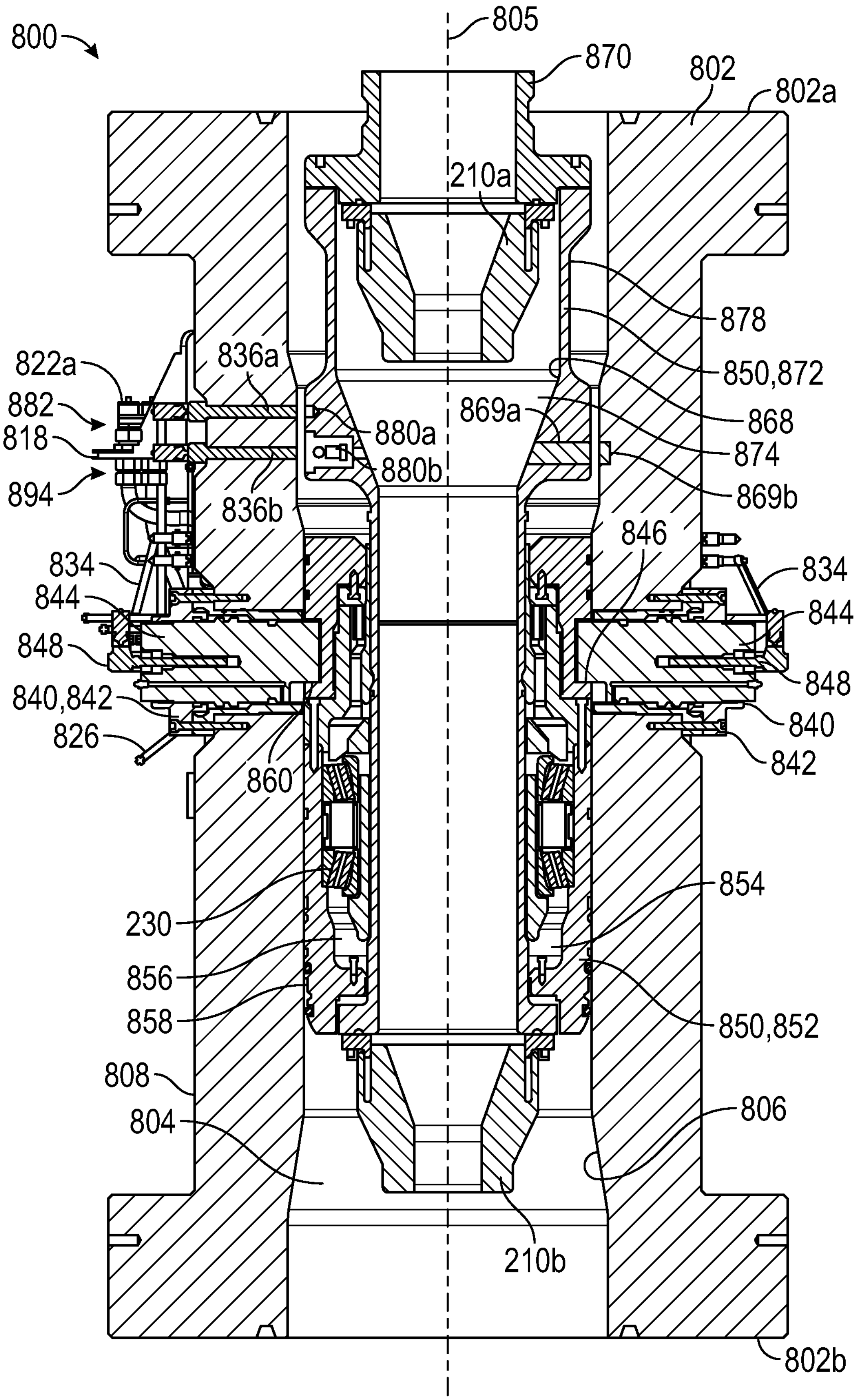
230
858
854
856
852
816
814
812
810
810
802
210b
802b

FIG. 23



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850,872
868
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836b
869a
846
834
844
848
840,842
826
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804
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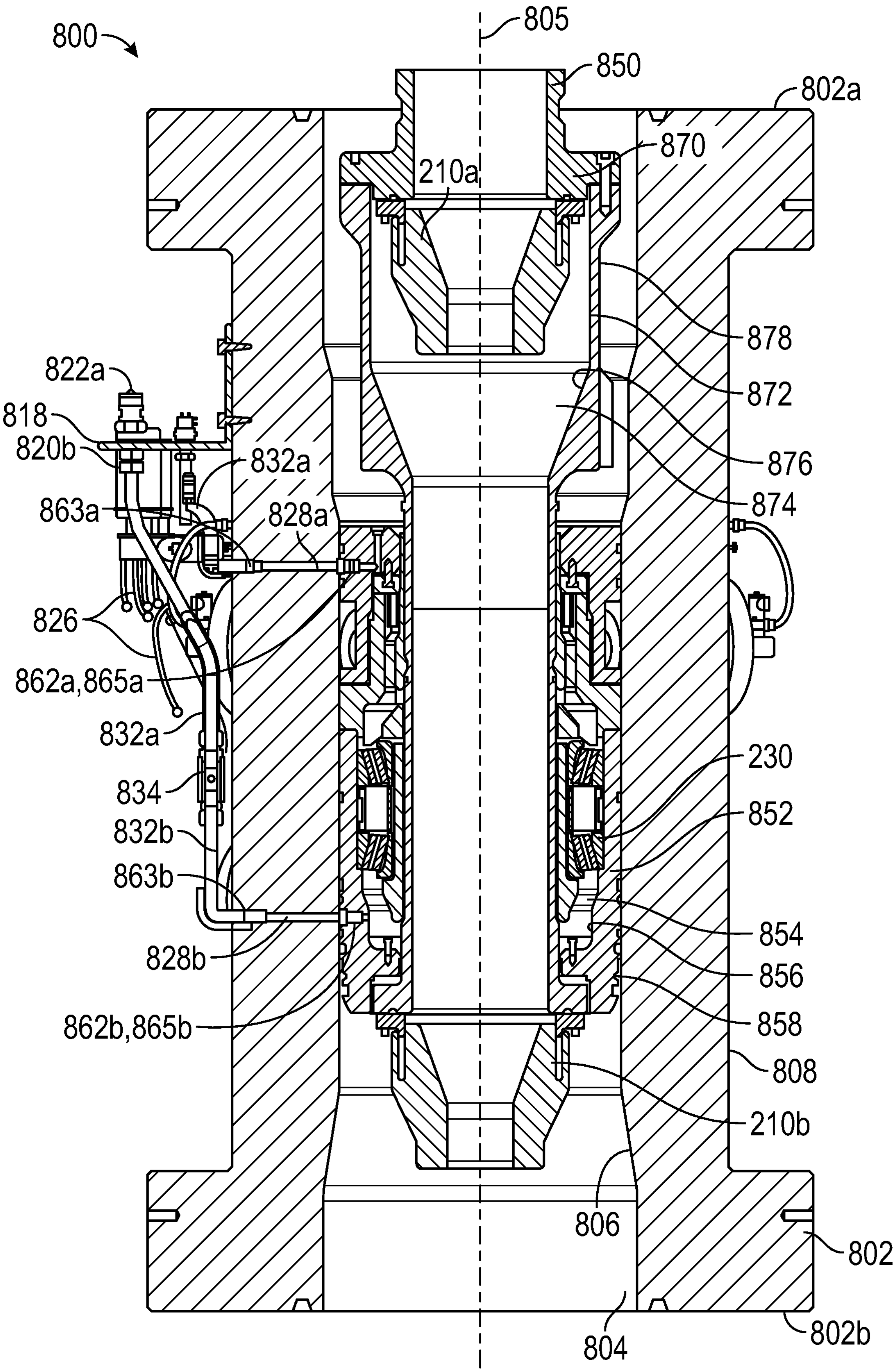
210b
802b

FIG. 24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862a,865a
832a
834
832b
863b
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862b,865b
230
852
854
856
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808
210b
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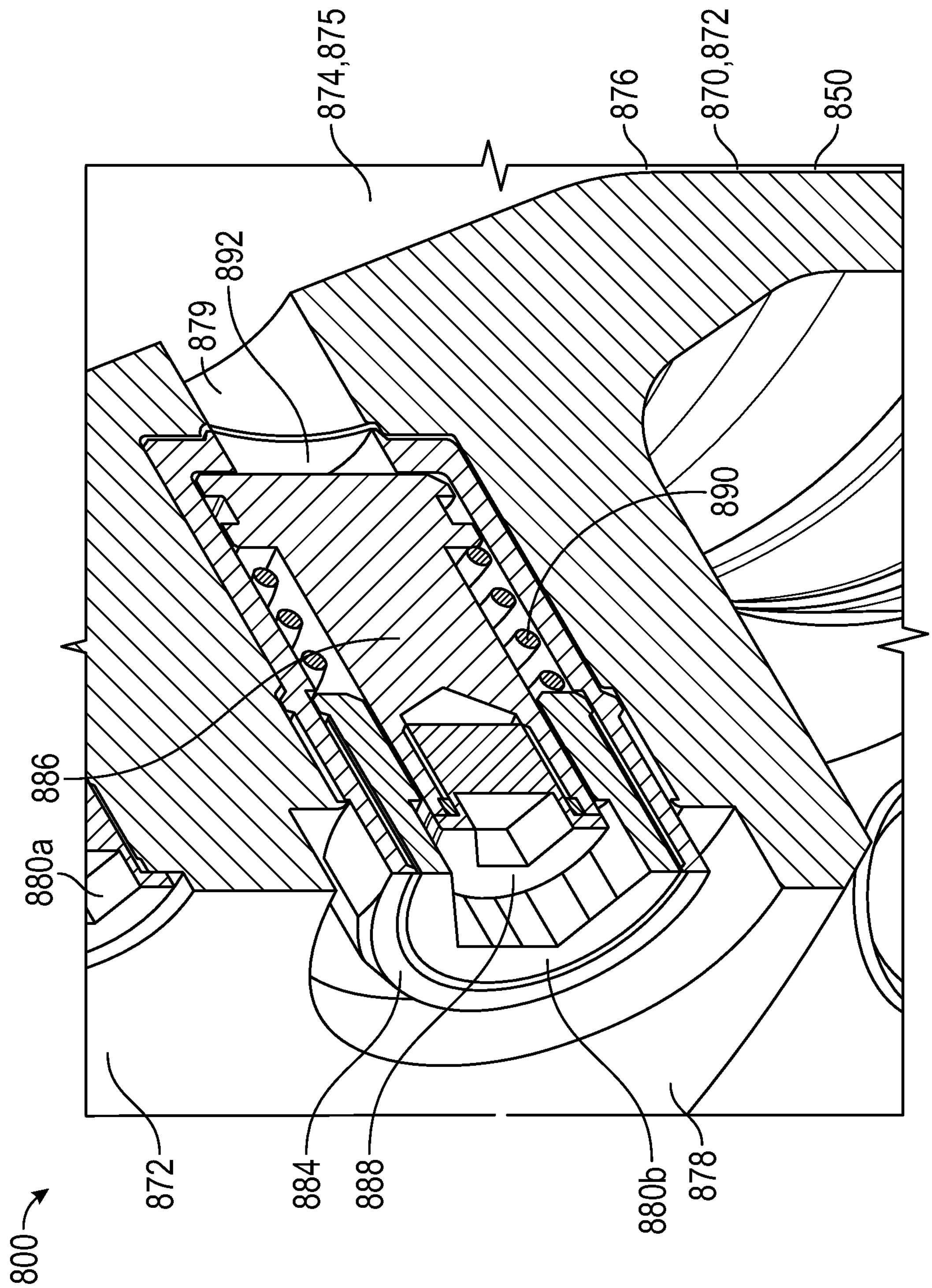
802
804
802b

FIG. 25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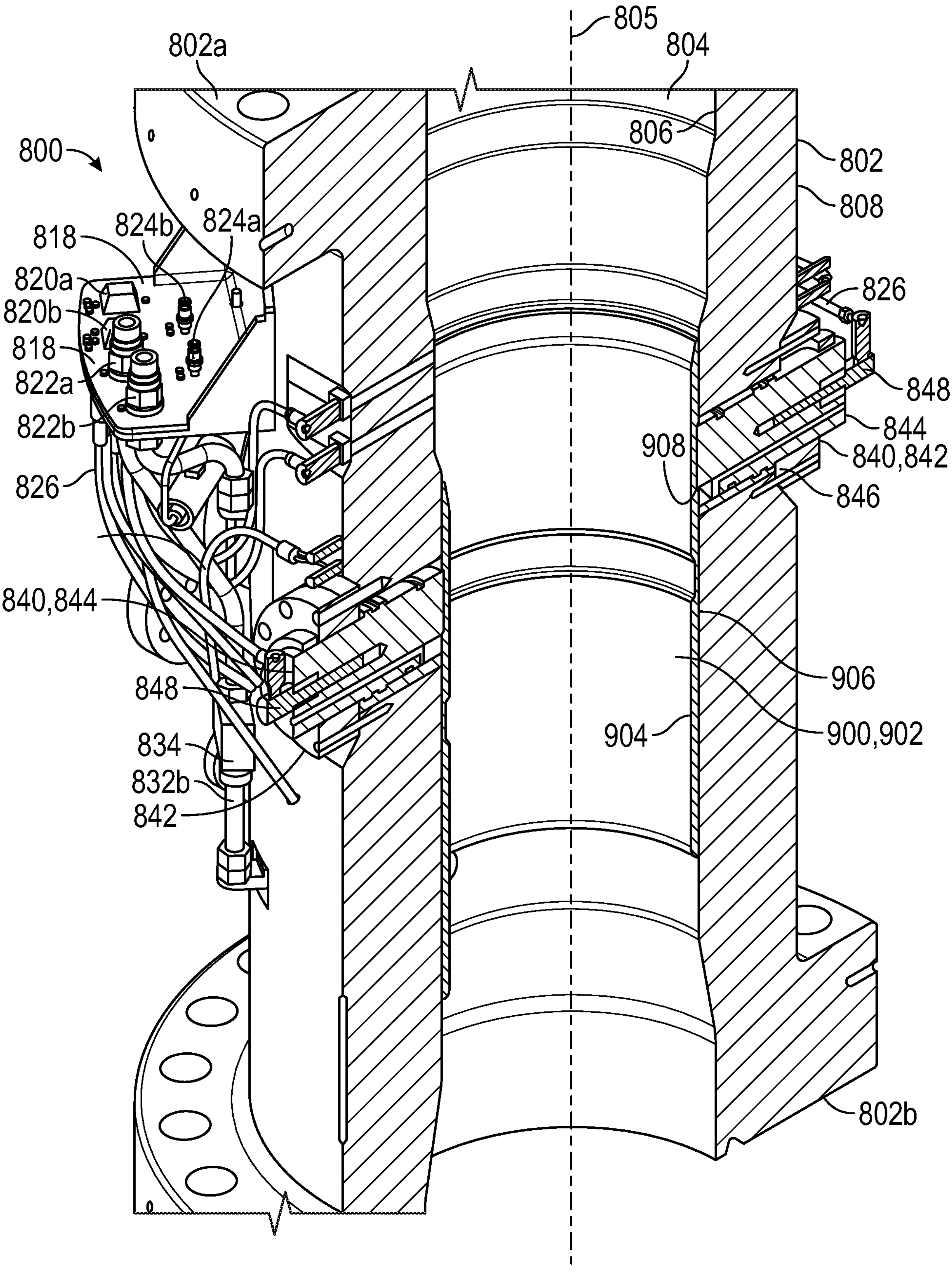
800

FIG. 26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832b
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802b

FIG. 27

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/021012

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B33/08
ADD.

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)
E21B

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/024195 A1 (HOYER CAREL W [GB] ET AL) 3 February 2011 (2011-02-03)	1-4,8, 13-17, 33-36
Y	paragraphs [0033], [0068] - [0076],	6,7
A	[0083], [0087], [0091]; figure 7	5,18,19, 37

X	US 2008/210471 A1 (BAILEY T F; CHAMBERS J W; CHAMPERS J W; HANNEGAN D M; HANNIGAN W M; WA) 4 September 2008 (2008-09-04)	1-4,8, 13-17, 33,35,36
A	paragraphs [0034], [0035], [0044], [0058], [0060], [0061]; figures 6A,7A,7C	5,18,19, 37

X	AU 2015 202 203 A1 (WEATHERFORD TECHNOLOGY HOLDINGS LLC) 14 May 2015 (2015-05-14)	1-4,8, 13-17, 33,35,36
A	paragraphs [0053] - [0055]; figure 6A	5,18,19, 37

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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
10 May 2017	12/07/2017

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer
Altamura, Alessandra

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2006/144622 A1 (BAILEY T F; CHAMBERS J W; GRAVOUIA M F; HANNEGAN D M) 6 July 2006 (2006-07-06) paragraphs [0112] - [0116]; figures 7A,7B,9	1-4,8, 13-17, 33,35,36 5,18,19, 37
Y	WO 2012/067628 A1 (HALLIBURTON ENERGY SERV INC [US]; GODFREY CRAIG W [US]; ANTONENKO PETE) 24 May 2012 (2012-05-24) figures 3A,3B page 5, lines 10-24 page 6, lines 11-17	6,7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/021012

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-8, 13-19, 33-37

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-8, 13-19, 33-37

   A rotating control device comprising an outer housing, a seal assembly, a plurality of actuatable locking pins comprising a fluid passage configured to be pressurized to transition the locking pins between the unlocked position and the locked position.

   ---

2. claims: 9, 10, 20-25

   A rotating control device comprising an outer housing, a seal assembly and passages in the outer housing and in an inner housing in the seal assembly for supplying lubricating fluid to a bearing chamber.

   ---

3. claims: 11, 12, 26-32

   A rotating control device comprising an outer housing, a seal assembly and a proximity sensor on the outer housing and a sensor element on an inner housing of the the seal assembly, wherein the sensors are configured to measure the relative rotational speed of the seal assembly and the outer housing.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/021012

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2011024195	A1	03-02-2011	AU	2010206020	A1	17-02-2011
			CA	2711621	A1	31-01-2011
			CA	2855020	A1	31-01-2011
			EP	2295712	A2	16-03-2011
			US	2011024195	A1	03-02-2011
			US	2013118749	A1	16-05-2013
			US	2014138094	A1	22-05-2014
			US	2016230491	A1	11-08-2016
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			AU	2008234631	A1	09-10-2008
			CA	2682663	A1	09-10-2008
			EP	2150680	A2	10-02-2010
			EP	2369128	A1	28-09-2011
			US	2008210471	A1	04-09-2008
			US	2011168392	A1	14-07-2011
			US	2013206386	A1	15-08-2013
			US	2014166273	A1	19-06-2014
			US	2015136407	A1	21-05-2015
			WO	2008120025	A2	09-10-2008
AU 2015202203	A1	14-05-2015	NONE			
US 2006144622	A1	06-07-2006	CA	2580177	A1	02-09-2007
			CA	2729427	A1	02-09-2007
			CA	2756090	A1	02-09-2007
			CA	2756093	A1	02-09-2007
			EP	1830034	A2	05-09-2007
			EP	2631419	A1	28-08-2013
			EP	2636841	A1	11-09-2013
			EP	2639400	A1	18-09-2013
			NO	340338	B1	03-04-2017
			US	2006144622	A1	06-07-2006
			US	2011036629	A1	17-02-2011
			US	2011168382	A1	14-07-2011
			US	2012138366	A1	07-06-2012
			US	2013192896	A1	01-08-2013
WO 2012067628	A1	24-05-2012	AR	083699	A1	13-03-2013
			AU	2010363985	A1	02-05-2013
			CA	2813732	A1	24-05-2012
			CN	103221629	A	24-07-2013
			WO	2012067628	A1	24-05-2012