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(54) **Title**: MARINE SUBSEA RISER SYSTEMS AND METHODS

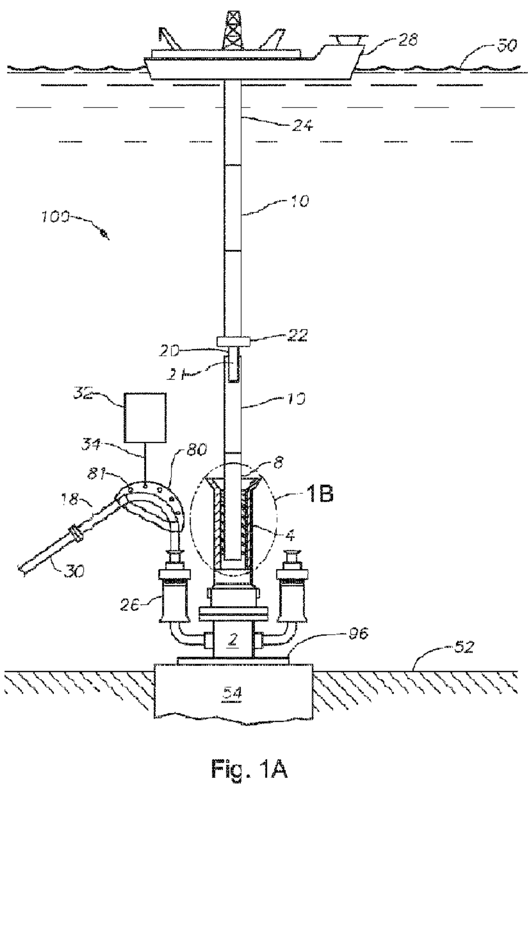

Fig. 1A

(57) **Abstract**: A riser system connects a subsea source of hydrocarbons to a collection vessel. The system includes a riser, a lower end of the riser fluidly coupled to a seal stem, the seal stem in turn fluidly attached to a lower riser assembly through a polished bore receptacle. The upper end of the riser is connected to the collection vessel, the riser being maintained in a near vertical position. Methods of installing and using the riser systems for killing and cementing wells are described.

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MARINE SUBSEA RISER SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/479,695 filed April 27, 2011.

BACKGROUND

Technical Field

[0002] The present disclosure relates in general to systems and methods useful in marine hydrocarbon exploration, production, well drilling, well completion, well intervention, and containment and disposal fields.

Related Information

[0003] Riser systems have been used during drilling, production/injection, completion/workover, and export operations. For a review, see Sparks, C.P., "Fundamentals of Marine Riser Mechanics", 2007, especially the introduction, pp. 1-19. Figure 1-3a of Sparks discloses a drilling riser deployed below a drill ship, commonly known as a mobile offshore drilling unit (MODU). The drilling riser connects at the seabed to a lower marine riser package (LMRP) and blow out preventer (BOP). U.S. published patent application number 20100025044, published February 4, 2010, discloses that for well control and intervention for wells completed with vertical subsea trees, a Completion WorkOver Riser (CWOR) system is typically used.

[0004] For other examples of riser systems, see published U.S. Pat. App. No. 20070044972. Other patents mentioning further features of production risers systems, including quick-connect/disconnect systems include U.S. Pat. Nos. 4,234,047; 4,646,840; 4,762,180; 6,082,391; and 6,321,844.

[0005] American Petroleum Institute Recommended Practice 2RD, (API-RP-2RD, First Edition June 1998), "Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)" is a standard known by those practicing in the subsea oil and gas production industry. Bai et al., *Subsea Engineering Handbook*, page 437, (published December 2010), also discloses riser systems. Webb et al., "Dual Activities Without the

Second Derrick – A Success Story", SPE 112869 (2008) discloses a spar platform, wherein the spar serves essentially as a well protection facility for a plurality of dry tree wells.

[0006] Polished bore receptacles (PBR) are used downhole in the oil and gas production industry, and typically are attached to a liner or liner hanger in a wellbore near a production zone. The PBR provides a bore to receive a sealing member on a tubing string. PBRs are described in U.S. Patent Nos. 4,482,014; 4,601,343; 5,743,335; 6,585,053; 6,688,395; and 7,516,719 as well as U.S. Pub. Pat. Appln. 20080289813, published Nov. 27, 2008. Latch rings may be used to limit the travel of tubing within a PBR, and are described in U.S. Pat. Nos. 5,413,171 and 6,202,745.

[0007] While use of riser systems and methods of installation have increased, there remains a need for a riser system to enable closed flow connection from a subsea source of hydrocarbons to a drilling/well test vessel during containment periods, and which may be employed in well test and injection scenarios during normal production operations.

SUMMARY

[0008] In accordance with the present disclosure, marine subsea riser systems and methods of using the same are described which reduce or overcome many of the faults of previously known systems and methods. The systems may be fully or partially deployed before, during, and/or after a subsea component has been compromised (for example, but not limited to, a subsea well breach, damaged subsea BOP, damaged subsea riser or other subsea conduit, damaged subsea manifold), and may be used in any marine environment, but are particularly useful in deep and ultra-deep subsea marine environments. In the containment and disposal context, systems and methods described herein may be used in any marine environment which contains equipment that is leaking or for which a leak is imminent or suspected to occur, either at the surface, or more particularly subsea. The apparatus, systems, and methods may also be used for exploration, production, drilling, completion, and intervention.

[0009] A first aspect of the disclosure is a riser system connecting a subsea source to a surface vessel, which may be a drill ship such as a MODU or drilling rig, the system comprising: a near-vertical riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel; a seal stem, a lower end of the riser fluidly and mechanically connected to the seal stem, the seal stem comprising one or more exterior elastomeric sealing elements; a lower riser assembly (LRA) comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, at least one of the intake ports fluidly connected to the subsea source; a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member; the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the PBR, seal stem, and riser.

[0010] In certain system embodiments the riser includes a plurality of riser joints, such as drill pipe joints. In certain system embodiments the vessel further includes a dynamic positioning system, and the riser is maintained in the near-vertical position by the dynamic positioning system. As used herein the phrases “near-vertical” and “substantially vertical” are used interchangeably and mean that the riser profile is generally vertical, but that some horizontal offset and vertical setdown at the surface are allowed. Riser offset and setdown influences riser stretch, and hence, riser tension and sag. Some riser axial stretch (and shrink) is allowed, owing to vessel lateral and vertical movements, and riser internal changes due to temperature, pressure and/or fluid density changes. The term “near-vertical” is also meant to distinguish the riser from catenary risers and exports lines. In certain system embodiments the member includes a subsea wellhead housing having a lower end and an upper end, the lower end capped with an end forging that is attached to a foundation in the seabed.

[0011] A second aspect of this disclosure is a method of installing a subsea marine riser system, the method comprising: attaching a first end of a member to an end forging, a first end of a polished bore receptacle (PBR) to the member, the PBR comprising a polished bore and a guide funnel on an end opposite the first end, and attaching the end forging to a subsea foundation so that the PBR is substantially vertical; directing a drill string riser toward the guide funnel, the drill string comprising a seal stem comprising one or more elastomeric seal elements; and stabbing the seal stem into the PBR and establishing a pressure tight seal between the elastomeric seal elements and the polished bore.

[0012] Certain method embodiments include connecting a subsea flexible conduit and gooseneck assembly to the member and to a subsea source. In certain embodiments the latter steps may be accomplished using one or more subsea installation vessels, such as remotely-operated vehicles (ROVs). In certain other method embodiments the steps of directing and stabbing are performed using a mobile offshore drilling unit (MODU). Certain method embodiments include assisting the directing and/or the stabbing steps using one or more ROVs. Certain method embodiments include constructing the drill string riser using high strength steel tubulars using threaded coupled connectors. Still other installation methods include supporting the PBR using structural supports extending from the subsea foundation to a point approximately midway up the PBR.

[0013] A third aspect of this disclosure is a method of producing a fluid from a subsea source, the method comprising: deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member; fluidly connecting at least one of the intake ports to the subsea source using a flexible conduit; lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements; stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the PBR, seal stem, and riser; and initiating flow from the subsea source through the subsea flexible conduit, the LRA, the PBR, the seal stem, and the riser.

[0014] A fourth aspect of the disclosure is a method of killing a well producing a fluid from a subsea source, the method comprising: deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient outtake ports extending from the bore to the external surface to accommodate flow of a kill density fluid from the surface vessel to a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member; fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit; lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements; stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and PBR; and initiating flow of kill density fluid from the surface vessel through the riser, seal stem, PBR, LRA, and subsea flexible conduit.

[0015] A fifth aspect of the disclosure is a method of cementing a subsea wellbore using a surface marine vessel, the method comprising: deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient outtake ports extending from the bore to the external surface to accommodate flow of a cementing fluid from the surface vessel to a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member; fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit; lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements; stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and PBR; and initiating flow of a cementing fluid from the surface vessel through the riser, seal stem, PBR, LRA, and subsea flexible conduit.

[0016] Methods described herein may benefit from the methods described in assignee's Attorney Docket No. 500010-00 corresponding to U.S. Provisional Application No. 61/479,769, filed April 27, 2011, incorporated herein by reference, to establish flow up the seal stem and riser. The 500010-00 application describes deploying a riser and a collection tool subsea upstream from a plume of hydrocarbons emanating from a subsea source of hydrocarbons. In the present application, the collection tool would be the seal stem. Certain methods might include displacing seawater from the riser and seal stem by forcing low-density fluid into the riser and seal stem. When bubbles of low-density fluid are observed emanating from the lower end of the seal stem the method includes positioning the seal stem connected to a distal end of the riser to stab the seal stem into a PBR previously secured to the seabed while the riser and seal stem remain filled with the low-density fluid, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore of the PBR to create a pressure-tight flow path through the riser, seal stem, and PBR. Flow of the low-density fluid may then be reduced gradually and a choke opened gradually, establishing flow of hydrocarbons up the seal stem and riser.

[0017] These and other features of the systems, apparatus, and methods of the disclosure will become more apparent upon review of the brief description of the drawings, the detailed description, and the claims that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The manner in which the objectives of this disclosure and other desirable characteristics can be obtained is explained in the following description and attached drawings in which:

[0019] FIG. 1A is a schematic side elevation view, partially in cross-section, of one system and method embodiment within the present disclosure;

[0020] FIG. 1B is a detailed cross-section of a portion of the embodiment of FIG. 1;

[0021] FIG. 2 is a schematic side elevation view, partially in cross-section of a seal stem useful in systems and methods within the present disclosure;

[0022] FIGS. 3A and 3B are schematic side elevation views, partially in cross-section, of one embodiment of a lower riser assembly, PBR and gooseneck assembly in accordance with the present disclosure;

[0023] FIGS. 4A and 4B are schematic side elevation views, partially in cross-section, of one embodiment of a subsea manifold and gooseneck assembly;

[0024] FIG. 5 is a schematic side elevation view, of a PBR attached to a wellhead and subsea pile foundation in accordance with an embodiment of the present disclosure;

[0025] FIG. 6 is a schematic perspective view of the structure illustrated schematically in FIG. 5;

[0026] FIG. 7 is a detailed schematic cross-sectional view of a PBR and seal stem useful in systems and methods of the present disclosure;

[0027] FIG. 8 is a schematic cross-sectional view of a pressure balancing feature that may be used in certain system and method embodiments; and

[0028] FIGS. 9-12 are logic diagrams of four method embodiments in accordance with the present disclosure.

[0029] It is to be noted, however, that the appended drawings are not to scale and illustrate only typical embodiments of this disclosure, and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments. Identical reference numerals are used throughout the several views for like or similar elements.

DETAILED DESCRIPTION

[0030] In the following description, numerous details are set forth to provide an understanding of the disclosed methods, systems, and apparatus. However, it will be understood by those skilled in the art that the methods, systems, and apparatus may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible. All U.S. published patent applications and U.S. Patents referenced herein are incorporated herein by reference. In the event definitions of terms in the referenced patents and applications conflict with how those terms are defined in the present application, the definitions for those terms that are provided in the present application shall be deemed controlling.

[0031] Described herein are riser systems connecting a subsea source to a surface vessel, which may be a drill ship such as a MODU or other vessel including a drilling rig. Certain embodiments include a near-vertical riser having a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel. Certain system embodiments described herein include a seal stem, a lower end of the riser fluidly and mechanically connected to the seal stem, the seal stem including one or more exterior elastomeric sealing elements. Certain embodiments further include a lower riser assembly (LRA) including a generally cylindrical member having a longitudinal bore, a lower end, an upper end, and an external generally cylindrical surface, the member including sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, at least one of the intake ports fluidly connected to the subsea source. Certain systems include a polished bore receptacle (PBR) having a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the generally cylindrical member. In certain embodiments the exterior elastomeric sealing elements of the seal stem sealingly engage the polished bore to create a pressure-tight flow path through the PBR, seal stem, and riser.

[0032] In certain system embodiments the seal stem may include a latch ring that allows reduction of travel of the seal stem in the PBR. In certain system embodiments the subsea source is fluidly connected to one of the intake ports via a flexible conduit and a gooseneck assembly. In certain system embodiments the wellhead housing may further include one or more ports allowing pressure and/or temperature monitoring. In certain system embodiments the PBR is threaded into the wellhead housing.

[0033] In certain system embodiments the riser upper end may be connected to a drill ship or drilling rig on the vessel.

[0034] In certain system embodiments the LRA may further include one or more hot stab ports for ROV intervention and/or maintenance. In certain system embodiments the lower end of the LRA may be connected to a subsea mooring, and may further comprise one or more structural supports for the PBR extending from the subsea mooring to a point about midway up the PBR. In certain system embodiments the subsea mooring may be a suction pile, although any stable and fixed object on the seabed may be used as a foundation. In certain system embodiments an upper end of the PBR may include a guide funnel.

[0035] In certain system embodiments at least some portions of the riser may include sections of pipe joined by threaded joints. In certain system embodiments the riser joints may be constructed using high strength steel tubulars using threaded coupled connectors.

[0036] In certain system embodiments the LRA may be fluidly connected to an active subsea wellhead via one or more flexible conduits. In certain system embodiments the subsea flexible conduit may include a lazy wave flexible jumper with at least one distributed buoyancy module connected from the base of the riser to a subsea manifold on the seafloor, the manifold fluidly connected to the subsea source or sources.

[0037] In certain system embodiments the LRA may further include an additional assembly or sub fluidly connecting the LRA to a source of a functional fluid. In certain system embodiments the LRA may include one or more ROV hot-stab ports allowing a flow assurance fluid to flow into both the LRA and the riser, the flow assurance fluid selected from the group consisting of nitrogen or other gas phase, heated seawater or other water, or organic chemicals such as methanol, and the like.

[0038] In certain system embodiments the seal between the PBR and the seal stem may be such that the riser and seal stem may be disconnected from the PBR, allowing the PBR and LRA to be disconnected from the surface vessel in either an emergency or planned event (i.e. drive/drift off or hurricane evacuation).

[0039] In certain system embodiments the gooseneck may include, in order starting at the generally cylindrical member, an API flange, a section of tubing, a high pressure subsea connector, a subsea API connector and API flange, and a bend restrictor.

[0040] In certain system embodiments the generally cylindrical member may include a forged, high-strength steel intake spool fluidly connected to a gooseneck assembly, the gooseneck assembly fluidly connected to a flexible conduit, the generally cylindrical member also including a connector allowing connection to a source of a functional fluid.

[0041] In certain system embodiments the subsea source may be a malfunctioning subsea BOP, the system further comprising one or more umbilicals, one of the umbilicals fluidly connected to locations on the subsea BOP selected from the group consisting of a kill line of the subsea BOP, a choke line of the subsea BOP, and both the kill and choke lines of the subsea BOP. In certain system embodiments the subsea source may be a malfunctioning subsea BOP, the system further including one or more umbilicals, one of the umbilicals fluidly connected to a subsea BOP stack manifold.

[0042] In certain system embodiments the riser system may further include one or more umbilicals, wherein one of the umbilicals is fluidly connected to a subsea manifold. In certain other system embodiments the riser system may further include a modified bumper sub in the drill string.

[0043] In yet other system embodiments the riser system may further include the seal stem extending into the generally cylindrical member a distance sufficient to create upper and lower seals between the generally cylindrical member and the seal stem, wherein the intake ports are between the upper and lower seals, the seal stem further including one or more inlet ports positioned between the upper and lower seals.

[0044] As used herein the phrase “subsea source” includes, but is not limited to: 1) production sources such as subsea wellheads, subsea BOPs, other subsea risers, subsea manifolds, subsea piping and pipelines, subsea storage facilities, and the like, whether producing, transporting and/or storing gas, liquids, or combinations thereof, including both organic and inorganic materials; and 2) subsea containment sources of all types, including leaking or damaged subsea BOPs, risers, manifolds, tanks, and the like. Certain system embodiments include those wherein the containment source is a failed subsea blowout preventer.

[0045] Still other system and method embodiments include those wherein the riser and/or the LRA may comprise one or more vent subs to facilitate circulation of a flow assurance fluid, for example a hydrate-preventing fluid, for example a gas phase to contain either a low or high pressure gas cushion, or heated seawater or other water, or methanol or other organic fluid, or combination of these. Certain hydrate inhibition method embodiments include those wherein the hydrate-inhibitor liquid chemical may be selected from the group consisting of alcohols and glycols. In certain embodiments a flow assurance fluid may include a gas atmosphere consisting essentially of nitrogen, where the phrase “consisting essentially of nitrogen” means that the gas atmosphere is mostly nitrogen plus any allowable impurities that would not affect the ability of the nitrogen to prevent hydrocarbon gas hydrate formation. In certain system embodiments the vent sub may include one or more valves controllable by a subsea vehicle.

[0046] Certain system embodiments include those wherein the LRA gooseneck assembly may include at least one emergency shutdown valve. In certain embodiments the emergency shutdown valve may include one hydraulically-operated and one electrically-operated emergency shutdown valve, one or both controlled using an umbilical connected to a collection vessel at the surface.

[0047] Certain system embodiments include those wherein the LRA gooseneck assembly may include a flow control valve for controlling flow in the riser.

[0048] Certain system embodiments include those wherein the subsea flexible conduit may include a lazy wave flexible jumper with distributed buoyancy modules connected to the subsea flexible conduit randomly or non-randomly from a point of connection of the subsea flexible conduit to the gooseneck assembly to a subsea manifold on the seafloor, the manifold fluidly connected to the subsea source or sources.

[0049] In certain system embodiments the pile foundation may be a suction pile foundation in the seabed, the suction pile foundation including a plunger.

[0050] Certain system embodiments include external wet insulation on the exterior surface of the riser for flow assurance. In certain embodiments the wet insulation may include a syntactic foam material. In certain embodiments the syntactic foam material may include a plurality of layers of syntactic polypropylene.

[0051] Still other system and method embodiments include those wherein the system may include one or more concentric free-standing risers positioned laterally apart in the sea from the system including a riser, seal stem, PBR, and LRA. In such embodiments, the latter system may be deployed quickly while awaiting arrival of the free-standing riser system. In certain embodiments, the two systems may be used in the same containment or production operation.

[0052] Certain installation method embodiments may include, in the event of a hurricane or planned disconnect, disconnecting the riser and seal stem from the PBR in a controlled manner using upward force, which force may have a lateral component. Even if not performed in a controlled manner, such as during an unplanned weather event, or ship malfunction event, the systems may be designed such that the seal stem may disconnect from the PBR without extensive damage to the seal stem, riser, and PBR.

[0053] Systems and methods of this disclosure may include well intervention operations. The systems and methods described herein may provide other benefits, and the methods are not limited to particular end uses; other obvious variations of the apparatus, systems and methods may be employed.

[0054] The primary features of the systems, methods, and apparatus of the present disclosure will now be described with reference to the drawing figures, after which some of the construction and operational details will be further explained. The same reference numerals are used throughout to denote the same items in the figures.

[0055] In accordance with the present disclosure, illustrated schematically in FIG. 1A is an embodiment 100 of a system of this disclosure that may be employed for deepwater subsea containment, disposal, production, and well intervention. While many of the apparatus, systems, and methods described herein were developed and used in the context of containment and disposal, it is explicitly noted that the apparatus, systems, and methods described herein, many features of which have never before been used or even contemplated heretofore, are not restricted to containment and disposal operations, but may be used in conjunction with any "subsea source", as that term is defined herein. In embodiment 100 of FIG. 1A, the system includes a lower riser assembly or LRA, in this embodiment including a wellhead housing 2. The wellhead housing 2 can be a substantially cylindrical member. Wellhead housing 2 fluidly and mechanically connects to a polished bore receptacle or PBR 4, which includes a polished bore 5 as more clearly identified in the detailed cross-sectional view of FIG. 1B. PBR accepts in its polished bore 5 a seal stem 8. Seal stem 8 includes one or more elastomeric seals 6, again as more clearly detailed in FIG. 1B. Seal stem 8 may include a latch ring 9, which functions (when present) to reduce travel of seal stem 8 within PBR 4. Latch ring 9 functions by holding elastomeric seals 6 in a static position during most of the operating range, thus increasing confidence in the sealing mechanism and increasing the seal longevity, while increasing the operating pressure range of systems using a latch ring. FIG. 7 is a detailed cross-section of a latch ring. Seal stem 8 is attached, typically by threaded connection, to a drill string 10 composed of a number of drill pipe sections. During installation from a surface vessel 28 at sea surface 50, a funnel-shaped guide 12 on PBR 4 helps guide drill string 10 and seal stem 8 into PBR 4. Optionally included in drill string 10 is a modified bumper sub 20 having a head 22 that may swivel in response to rotation of ship 28. Modified bumper sub 20 may also include a telescoping section 21, and may have seals and splines removed to afford less friction in operation. Drill string section 24 extends up to and fluidly and mechanically connects with vessel 28 in a known fashion.

[0056] Still referring to FIG. 1A, a flexible jumper 30 is illustrated as fluidly connected to a gooseneck 18 and a male/female subsea connector 26, and wellhead 2, as more fully detailed in the description of FIGS. 3A and 3B hereinbelow. Wellhead 2 is affixed to a bottom plate 96, typically and most conveniently by welding, although this is not strictly required, other means such as bolting being possible. Bottom plate 96 is in turn attached by welding, bolting, or some other mechanism to a seabed foundation 54, which may be any solid foundation. In embodiment 100, foundation 54 is a suction pile sunken into seabed 52 just so far that a portion of suction pile 54 remains above seabed 52. Gooseneck 18 is supported by a buoyancy device 32 attached via a tether chain 34 to a rigging adapter 80. Rigging adapter 80 may have a multiple holes 81 for applying buoyant support at different angles to gooseneck 18 as required or desired.

[0057] Turning now to FIG. 2, there is schematically illustrated in side elevation and partial cross-section a seal stem 8 that may be useful in the systems and methods of the present disclosure. As an example, seal stem 8 may presently be purchased from Allamon Tool Company, Inc., Montgomery, Texas, USA. As illustrated, seal stem 8 is threadably connected to a drill string section 10. Seal stem 8 includes an internal bore 11, and several elastomeric sealing elements 56 (three in this embodiment) positioned between four brass sleeves 58A, B, C, and D. Seal stem end 60 is the end that is stabbed into PBR 4 during installation. In operation, as seal stem 8 is forced up or down by pressure and/or temperature changes in fluid traversing bore 11, elastomeric seals 56 resist this movement by forming a pressure tight seal between the seal stem and polished bore 5 of PBR 4. Seal stem 8 typically includes an expandable metal body 13 having a pressure rating of about 10,000 psi (69 Mpa) at temperatures of about 300-400°F (about 150-200 C) and diameters ranging from about 5 to about 14 inches (from about 13 to about 35 cm), or from about 5 to about 7 inches (about 13 to about 18 cm). PBRs are available from several sources, including Weatherford International and Baker Hughes.

[0058] FIGS. 3A and 3B are schematic side elevation views, partially in cross-section, of one embodiment of a lower riser assembly, PBR and gooseneck assembly in accordance with the present disclosure. In this embodiment, the wellhead 2 is mounted on a subsea PBR manifold 62. A pair of supports 14, 16 are illustrated, which provide structural support for PBR 4 during instances when seal stem 8 is being removed from PBR 4, either by choice or unintentionally. A touchdown point 64 is indicated where flexible conduit 30 would intersect seabed 52 were it to travel straight. Flexible conduit 30 may be in the form of a lazy wave using one or more buoyancy modules, 32, to control location of touchdown point 64. Distance of touchdown point 64 from foundation (manifold 62 in this embodiment) is regulated by various standards, such as published by the API. As more clearly illustrated in FIG. 3B, gooseneck 18 is fluidly and mechanically connected to wellhead housing 2 by a series of subsea connectors and flanges, including male/female subsea connector 26, which includes an ROV-operable clamp 66, such as available under the trade designation OPTIMA from Vector Group, Inc. Houston, Texas (USA), an API flange 69 connecting gooseneck 18 to wellhead housing 2, a bottom end fitting 68 connecting flexible jumper 30 to an API 7 1/16 inch (18cm) 5KSI (34 MPa) connector 72, an articulating RAC hub 70 (available from Oil States Industries, Inc. Arlington, Texas (USA), an RAC connector 74 (also available from Oil States Industries, Inc.), and API 3 1/8-inch (8cm) connector (15K, 103 MPa) 76, and a subsea adapter 78 which allows gooseneck 18 to be fluidly and mechanically connected to connector 76.

[0059] FIGS. 4A and 4B are schematic side elevation views, partially in cross-section, of one embodiment of a subsea manifold 94 and gooseneck assembly 82 that may be useful in practicing the methods and systems of the present disclosure. Manifold 94 may be a choke/kill manifold (CKM) for a subsea BOP, for example. Flexible jumper 30 is illustrated, the same flexible jumper 30 from FIGS. 3A and 3B. A second touchdown point 65 is noted, as well as a swivel connector 92 connecting gooseneck 82 and manifold 94. Supports 95 extend from manifold 94 to swivel connector 92. Another rigging adapter 90 is provided on gooseneck 82, and gooseneck 82 is fluidly and mechanically connected to flexible jumper 30 via a 3-inch to 7-inch (7.6cm to 18cm) adapter 88, and API 7 1/16-inch (18cm) (5K, 34 MPa) adapter 86, and a bottom end fitting 84.

[0060] FIG. 5 is a schematic side elevation view of a PBR attached to a wellhead and subsea pile foundation in accordance with an embodiment of the present disclosure, and FIG. 6 is a schematic perspective view of the structure illustrated schematically in FIG. 5. Subs 98 and 102 are provided in this embodiment connected to wellhead housing 2. Sub 98 may be, for example a vent or connection for a pressure relief valve (PRV), while sub 102 may provide a connection for a functional fluid, such as a flow assurance fluid, for example, but not limited to methanol, glycol, or heated water. FIG. 6 illustrates four supports 14, 15, 16, and 17 for PBR extending from a top of suction pile 54 to a midpoint up PBR 4. Support 14, 15, 16, and 17 may include, for example, carbon steel, or stainless steel, or titanium, or other exotic corrosion-resistant metal, or non-corrosion resistant metal having a corrosion-resistant coating. Supports 14, 15, 16, and 17 may each form an angle "α" measured from a line parallel to plate 96 ranging from about 45 to about 85 degrees, or from about 70 to about 80 degrees. FIG. 6 illustrates suction pile 54 supported on a skid 104, which may be on vessel 28, for example. Suction pile includes a pump-out connection, 106.

[0061] FIG. 7 is a detailed schematic cross-sectional view of a PBR and seal stem 8 useful in systems and methods of the present disclosure, illustrating in detail a latch ring 9 having upper and lower beveled outer edges 9A, 9B, respectively, as well as a rectangular inner edge

9C. Outer beveled edges 9A, 9B fit into respective beveled edges 4A, 4B in PBR 4, and rectangular edge 9C fits in to a square groove 3 in seal stem 8.

[0062] FIG. 8 is a schematic cross-sectional view of a pressure-balancing feature that may be used in certain system and method embodiments. In certain embodiments, wellbore conditions may be such that they force seal stem 8 and riser 10 upwards, and seal stem 8 out of PBR 4. In certain embodiments, seal stem 8 may be modified to include a bottom end plate 110 and one or more orifices 112. In addition, wellhead 2 may be modified to include seal rings, collets, dog connectors, or similar connections 114, 116, as illustrated in FIG. 8, forming a chamber or annulus 118 between wellhead housing 2 and seal stem 8. As fluid enters annulus 118 from gooseneck 18, pressure is now equalized in upward and downward directions, and since the annular area is the same in both directions, the net effect is zero force up or down, and seal stem is no longer forced upward out of PBR 4.

[0063] FIGS. 9-12 are logic diagrams of four method embodiments in accordance with the present disclosure. Method embodiment 200 illustrated in FIG. 9 is one embodiment of a method of installing a subsea marine riser system, the method including the steps of attaching a first end of a member, for example a generally cylindrical member, to a foundation plate (box 202). The method then includes attaching a first end of a polished bore receptacle (PBR) to the member, the PBR including a polished bore and a guide funnel on an end opposite the first end (box 204), then attaching the foundation plate to a subsea foundation so that the PBR is substantially vertical (box 206). The method continues by directing a drill string riser toward the guide funnel, the drill string including a seal stem including one or more elastomeric seal elements (box 208), and stabbing the seal stem into the PBR and establishing a pressure tight seal between the elastomeric seal elements and the polished bore (box 212). A subsea flexible conduit and gooseneck assembly is then connected to the member and to a subsea source using a subsea installation vessel (box 216). As illustrated in FIG. 9, steps 208 and 212 may be carried out using a MODU, box 218, and at least two steps may be assisted by one or more ROVs, as indicated in boxes 210, 214.

[0064] FIG. 10 illustrates another method embodiment 300, which is a method of producing a fluid from a subsea source. In embodiment 300, a first step includes deploying subsea from a surface vessel a lower riser assembly (LRA) including a member, for example a generally cylindrical member, having a longitudinal bore, a lower end, an upper end, and an external surface, the member including sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) including a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member (box 302). Method embodiment 300 continues with the steps of fluidly connecting at least one of the intake ports to the subsea source using a flexible conduit (box 304), and lowering a riser from the surface vessel, the riser including a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in a substantially vertical position by dynamic positioning of the vessel, the riser including a seal stem fluidly and mechanically connect to its lower end, the seal stem, including one or more exterior elastomeric sealing elements (box 306). Method embodiment 300 continues with the steps of stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the PBR, seal stem, and riser (box 308), and initiating flow from the subsea source through the subsea flexible conduit, the LRA, the PBR, the seal stem, and the riser (box 310).

[0065] Another method embodiment 400 is illustrated in logic diagram format in FIG. 11. Embodiment 400 includes a method of killing a well producing a fluid from a subsea source. The first step of method embodiment 400 includes the step of deploying subsea from a surface vessel a lower riser assembly (LRA) including a member, for example a generally cylindrical member, having a longitudinal bore, a lower end, an upper end, and an external surface, the member including sufficient outtake ports extending from the bore to the external surface to accommodate flow of a kill density fluid from the surface vessel to a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) including a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member (box 402). Method embodiment 400 continues with the steps of fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit (box 404), and lowering a riser from the surface vessel, the riser including a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in a substantially vertical position by dynamic positioning of the vessel, the riser including a seal stem fluidly and mechanically connected to its lower end, the seal stem including one or more exterior elastomeric sealing elements (box 406). Method embodiment 400 then includes the steps of stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and PBR (box 408), and initiating flow of kill density fluid from the surface vessel through the riser, seal stem, PBR, LRA, and subsea flexible conduit (box 410).

[0066] Another method embodiment 500 is illustrated in logic diagram format in FIG. 12. Embodiment 500 is a method of cementing a subsea wellbore using a surface marine vessel. The first step of method embodiment 500 includes the step of deploying subsea from a surface vessel a lower riser assembly (LRA) including a member, for example a generally cylindrical member, having a longitudinal bore, a lower end, an upper end, and an external generally cylindrical surface, the member including sufficient outtake ports extending from the bore to the external surface to accommodate flow of a cementing fluid from the surface vessel to a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) including a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member (box 502). Method embodiment continues with the steps of fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit (box 504), and then lowering a riser from the surface vessel, the riser including a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser including a seal stem fluidly and mechanically connected to its lower end, the seal stem including one or more exterior elastomeric sealing elements (box 506). Method embodiment 500 then includes the steps of stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and PBR (box 508), and initiating flow of a cementing fluid from the surface vessel through the riser, seal stem, PBR, LRA, and subsea flexible conduit (box 510).

[0067] It should be noted that other vessels may be present during installation, or during containment and production operations. For example, separate ship-based floating production and storage systems on sea surface 50 may be present, as well as processing vessels, collection vessels, service vessels, and the like. Other vessels may be provided for subsea installation, operational and ROV assistance to system 100, and hydrate prevention and remediation, if needed. Other system 100 components may a choke/kill manifold (“CKM”); a flare or other optional gas disposal/containment apparatus, such as a natural gas handling and storage system and method as described in assignee’s US Pat. No. 6,298,671; a multipurpose intervention vessel, which may include various subsea connector conduits, umbilicals from chemical dispersant and hydrate inhibition systems; a hydrate inhibition system service vessel which may also supply power and/or hydraulic assistance through one or more umbilicals; a subsea umbilical distribution box, and electrical power and/or hydraulic umbilical lines. A riser tension monitoring system may be provided, and may include a plurality of such monitoring systems randomly or non-randomly spaced along the riser. The ability to pump a functional fluid, such as methanol or heated water, into ROV hot stab receptacles is another option, as is the ability to pump a functional fluid such as nitrogen or other gas phase into the bottom of the riser or at a subsea manifold into the flexible subsea conduits as a way to get the fluid underneath an actual or potential, complete or partial hydrate plug or other flow restriction.

[0068] Suction pile assemblies useful in the systems and methods within the present disclosure and their installation are described for example in US published patent application 2002/0122696, and typically include a cylindrical casing, a top plate, a flanged connection near or on its top plate for pumping seawater in or out of cylindrical casing, and various connections to help manipulate the suction pile. A funnel connection and vertical extension provide guidance when landing a piston, such as available from Balltec, of Lancashire, UK. Installation of a suction pile in the seabed proceeds by pumping out seawater from the device. Subsea pressure forces the cylindrical casing into the seafloor. The suction piles may be 14 feet (4.3m) in diameter and 70 feet (21m) long.

[0069] The LRA in one embodiment can include a 15K Vetco H-4 subsea wellhead, specially machined with 2 x 7-1/6 inch (5 x 18 cm) 10,000 psi (69 MPa) inlets to accommodate either multiple flexible jumper connections, or one production jumper and an ROV interface for methanol injection.

[0070] Systems and methods of this disclosure may employ a riser positioning system and riser tension monitoring sub-system. A riser positioning system typically includes a riser position clamp and a pair of acoustic sources or beacons. Suitable acoustic beacons are available from Sonardyne International Ltd in the UK, and from Sonardyne Inc., Houston, TX. Acoustic positioning is well known and requires no further explanation herein; however, its use in subsea containment and disposal methods and systems is not known. The riser position clamp with two acoustic beacons may be deployed anywhere on the riser. These beacons may be integrated with the containment vessel dynamic positioning (DP) systems in order to provide continuous relative location of the top of the riser that feeds directly into the management of vessel station-keeping limits. The riser tension monitoring unit may be strain-based and may be installed anywhere along the length of the riser, and in multiple locations.

[0071] In embodiments, certain connections may be expected to experience heavy fatigue. The teachings of Shilling, et al., "*Development of Fatigue Resistant Heavy Wall Riser Connectors for Deepwater HPHT Dry Tree Riser Systems*", OMAE2009-79518, may be useful in these embodiments.

[0072] The systems and methods of the present disclosure are scalable over a wide range of water depths, well pressures and conditions. The riser ideally will be capable of handling over 40,000 bbl. per day (about 4800 cubic meters per day) with a 6-inch (15 cm) ID flow path in the riser. The riser joints may for example include 0.563-inch (1.430cm) wall thickness X-80 steel material rated to 6,500 psi (45 MPa). X-80 steel may be used in order to successfully weld on premium riser connectors that had external and internal metal-to-metal seals and met the fatigue performance requirements of the anticipated service life. (X-80, or X80, is a number associate with American Petroleum Institute (API) standard 5L).

[0073] In general, the riser may have an outer diameter (OD) ranging from about 1 inch up to about 50 inches (2.5 cm to 127cm), or from about 2 inches up to about 40 inches (5cm to 102cm), or from about 4 inches up to about 30 inches (10cm to 76cm), or from about 6 inches up to about 20 inches (15cm to 51cm).

[0074] Over the past several years, BP has participated in the development of a comprehensive 15/20Ksi (103/138 MPa) dry tree riser qualification program which focuses on demonstrating the suitability of using high strength steel materials and specially designed thread and coupled (T&C) connections that are machined directly on the riser joints at the mill. See Shilling et al., "*Development of Fatigue Resistant Heavy Wall Riser Connectors for Deepwater HPHT Dry Tree Riser Systems*", OMAE2009-79518. These connections may eliminate the need for welding and facilitate the use of high strength materials like C-110 and C-125 metallurgies that are NACE qualified. As used herein, "NACE" refers to the corrosion prevention organization formerly known as the National Association of Corrosion Engineers, now operating under the name NACE International, Houston, Texas. Use of high strength steel and other high strength materials significantly reduces the wall thickness required, enabling riser systems to be designed to withstand pressures much greater than can be handled by X-80 materials and installed in much greater water depths due to the reduced weight and hence tension requirements. The T&C connections eliminate the need for third party forgings and expensive welding processes – considerably improving system delivery time and overall cost. It will be understood, however, that the use of third party forgings and welding is not ruled out for risers and LRAs described herein, and may actually be preferable in certain situations. The skilled artisan, having knowledge of the particular depth, pressure, temperature, and available materials, will be able to design the most cost effective, safe, and operable system for each particular application without undue experimentation.

[0075] The risers and the primary components of the LRAs, seal stems, and PBRs described herein (offtake ports, intake ports, generally cylindrical members, high pressure subsea connectors, adapters, and the like) are largely comprised of steel alloys. While low alloy steels may be useful in certain embodiments where water depth is not greater than a few thousand (for example 5000) feet (about 1524 meters), activities in water of greater depths, with wells reaching 20,000 ft. (about 6000 meters) and beyond is expected to result in operating temperatures and pressures that are well above those presently allowed in current API specifications. In these "high temperature, high pressure" (HTHP) applications, high strength low alloy steel metallurgies such as C-110 and C-125 steel may be more appropriate. The Research Partnership to Secure Energy for America (RPSEA) and Deepstar programs have initiated a long term, large scale prequalification program to develop databases of fatigue data for, and derive rating factors on, high strength materials for riser applications with the contribution of major operators, engineering firms and material vendors. High strength steels (such as X-100, C-110, Q-125, C-125, V-140), Titanium (such as Grade 29 and possibly newer alloys) and other possible material candidates in the higher strength category will be tested for pipe applications, and pending those results, they may be useful as materials for the risers, LRAs, seal stems, and PBRs described herein. Higher strength forging materials (such as F22, 4330M, Inconel 718 and Inconel 725) either have been or will soon be tested for component applications in the coming years, and may prove useful for one or more components of the described LRA assemblies, seal stems, PBRs and/or risers. The test matrix will be designed to reflect various production environments and different types of riser configurations, such as single catenary risers (SCR's), dry tree risers, and drilling and completion risers. The project is currently scheduled to be divided into three separate Phases. Phase 1 will address tensile and fracture toughness, FCGR and S-N tests (both smooth and notched) on strip specimens of high strength pipes, high strength forging materials and nickel base alloy forgings in air, seawater, seawater plus Cathodic Protection (CP) and sour environment (non-inhibited) and a completion fluid known as INSULGEL (BJ Services Company, USA) with sour environment (non-inhibited) contamination (2008). Phase 2 is scheduled to be Intermediate Scale Testing (2009), and Phase 3, Full Scale Testing with H_2S/CO_2/sea water (2010). For further information, see Shilling, et al., *Development of Fatigue Resistant Heavy Wall Riser Connectors for Deepwater HPHT Dry Tree Riser Systems*, OMAE (2009) 79518 (copyright 2009 ASME). See also RPSEA RFP2007DW1403, *Fatigue Performance of High Strength Riser Materials*, Nov. 28, 2007. As stated previously, the skilled artisan, having knowledge of the particular depth, pressure, temperature, and available materials, will be able design the most cost effective, safe, and operable system for each particular application without undue experimentation.

[0076] Materials of construction for gaskets, flexible conduits, and hoses useful for constructing and using the systems and methods described herein will depend on the specific water depth, temperature and pressure at which they are employed. Although elastomeric gaskets may be employed in certain situations, metal gaskets have been increasingly used in subsea application. For a review of the art circa 1992, see Milberger, et al., "*Evolution of Metal Seal Principles and Their Application in Subsea Drilling and Production*", OTC-6994, Offshore Technology Conference, Houston Texas, 1992. See also APT STD 601 – *Standard for Metallic Gaskets for Raised-face Pipe flanges & Flanged Connections.* See also API Spec 6A – *Specification for Wellhead and Christmas Tree Equipment.*

[0077] Gaskets are not, per se, a part of the present systems and methods, but as certain LRA embodiments may employ gaskets, mention is made of the following U.S. Patents which describe gaskets which may be suitable for use in particular embodiments, as guided by the knowledge of the ordinary skilled artisan: U.S. Pat. No. 3,637,223; 3,918,485; 4,597,448; 4,294,477; and 7,467,663.

[0078] Another gasket that may be used subsea is that known under the trade designation Pikotek VCS, available from Pikotek, Inc., Wheat Ridge, Colorado (USA). Rather than relying strictly on a seal formed by deforming a metal ring into concentric grooves machined into opposing flange faces, the gasket known under the trade designation Pikotek VCS uses a matrix-reinforced, high-density composite material, permanently laminated to a corrosion-resistant, metal alloy core (316 stainless or 2205 duplex). This type of gasket is believed to be described in U. S. Pat. No. 4,776,600.

[0079] Various burst disks maybe used on subsea equipment, such as subsea manifolds. Such burst disks may in certain embodiments be retrievable burst disks. In certain embodiments the LRA may have a retrievable burst disk, allowing venting of the LRA to the atmosphere. A burst disk may allow pumping of a functional fluid into the LRA. Burst disks may allow pressure and/or temperature measurement of the flow stream inside the LRA or riser.

[0080] Hoses, which may also be referred to herein as flexible jumpers in certain embodiments, suitable for use in the systems and methods of this disclosure may be selected from a variety of materials or combination of materials suitable for subsea use, in other words having high temperature resistance, high chemical resistance and low permeation rates. Some fluoropolymers and nylons are particularly suitable for this application except for conduits of extremely long length (several kilometers or more) where permeation may be problematic. A good survey of hoses and materials may be found in US Pat. No. 6,901,968 presently assigned to Oceaneering International Services, London, Great Britain, which describes so called "High Collapse Resistant Hoses" of the type used in deep sea applications, which, in use, must be able to resist collapsing due to the very large pressures exerted thereon. The ‘968 patent describes a fluid conduit and multi-conduit umbilicals for use in the transportation of chemicals with small molecular size and shape, for example methanol, ethanol and other hydrocarbon fluids used in the oil industry. The conduit includes a flexible fluid hose encapsulated by at least one metalized layer that is formed and arranged to minimize permeation of a fluid being transported in the fluid hose. In use in a multi-conduit umbilical the metalized layer minimizes permeation into adjacent fluid hoses containing chemicals. In certain embodiments it may be necessary or desirable to splice one hose to another hose, or to replace a damaged hose.

[0081] The systems of the present disclosure may, in certain embodiments, be installed by drilling MODU and then accommodate flexible jumper installation after the riser has been run. In embodiments using a drilling MODU, the subsea flexible 30 may be connected several days later to the LRA by one or more subsea installation vessels, for example one or more ROVs or AUVs, after the riser is stabbed into the PBR.

[0082] In certain embodiments, conventional pressure relief valves may be modified and employed subsea, for example on various subsea manifolds, risers, and LRA. Conventional surface pressure relief valves may include a three-way valve body, a bonnet enclosing a spring, and a cap enclosing an adjusting screw for the spring, a nozzle and seat arrangement in the inlet, and an open discharge outlet. The bonnet typically has a removable plug. These conventional pressure relief valves may be modified or “marinized” by removing the removable plug in the bonnet and drilling one or more holes in the cap. This allows seawater to enter the cap and bonnet, equalizing pressure there with pressure in the discharge outlet (local pressure at depth). The spring and nozzle in these modified pressure relief valves may be changed to a material more compatible with seawater and hydrocarbon use to avoid corrosion issues.

[0083] To avoid the corrosion issues, rather than drilling one or more holes in the cap and removing the plug from conventional pressure relief valves, a dead weight arrangement may be employed. A guided weight system may be added to the conventional design, whereby a dead weight (for example a block of metal) is placed in contact with the bonnet on its top, and the spring is removed. One or more guides might guide the weight. Weights could be added or removed subsea, for example by an ROV. The weight may seal to the upper opening of the bonnet via any of various very hard and wear-resistant alloys, such as Inconel 625 overlaid by the material known under the trade designation Stellite, which is an alloy containing cobalt, chromium, carbon, tungsten, and molybdenum. As a rough example, a pressure relief valve having a 3 inch (7.6cm) diameter nozzle set to relieve at 500 psi (3.4 MPa) would require a steel weight 710 mm in diameter, 600 mm thick, weighing about 1,800 kg.

[0084] In certain embodiments a source point interface may be required to connect the PBR and LRA to a source. For example, in the event of a blowout, in certain embodiments, a riser may be damaged and in some cases may be lying on the seabed. A riser insertion tubing tool may be employed in those instances, the riser insertion tube connecting via a flexible conduit to the LRA. Riser insertion tubing tools and methods of use are described in Assignees’ Attorney Docket No. 500032 corresponding to U.S. Provisional Application No. 61/479,704, filed April 27, 2011, incorporated herein by reference. Subsea connectors such as those known under the trade designation OPTIMA mentioned herein may be employed at an interface between a flexjoint and the LMRP. If a PBR is used, a modified bumper sub having both telescoping action as well as swivel action may be employed between the PBR and a surface vessel.

[0085] From the foregoing detailed description of specific embodiments, it should be apparent that patentable methods and apparatus have been described. Although specific embodiments of the disclosure have been described herein in some detail, this has been done solely for the purposes of describing various features and aspects of the methods and apparatus, and is not intended to be limiting with respect to the scope of the systems, methods and apparatus. For example, vessel 28 may be a semi-submersible drilling vessel. It is contemplated that various substitutions, alterations, and/or modifications, including but not limited to those implementation variations which may have been suggested herein, may be made to the described embodiments without departing from the scope of the appended claims.

What is claimed is:

1. A riser system connecting a subsea source to a surface vessel, said system comprising:

a near-vertical riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel;

a seal stem, a lower end of the riser fluidly and mechanically connected to the seal stem, the seal stem comprising one or more exterior elastomeric sealing elements;

a lower riser assembly comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, at least one of the intake ports fluidly connected to the subsea source; and

a polished bore receptacle comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member;

the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the polished bore receptacle, seal stem, and riser.

2. The riser system according to claim 1, wherein the riser comprises a plurality of riser joints.

3. The riser system according to claim 1, wherein the vessel comprises a dynamic positioning system, and wherein the riser is maintained in the near-vertical position by the dynamic positioning system.

4. The riser system according to claim 1, wherein the member comprises a subsea wellhead housing having a lower end and an upper end, the lower end capped with an end forging that is attached to a foundation in the seabed.

5. The riser system according to claim 1, wherein the seal stem comprises a latch ring that allows reduction of travel of the seal stem in the polished bore receptacle.

6. The riser system according to claim 1, wherein the subsea source is fluidly connected to one of the intake ports via a flexible conduit and a gooseneck assembly.

7. The riser system according to claim 1, wherein the lower riser assembly further comprises one or more hot stab ports for ROV intervention and/or maintenance.

8. The riser system according to claim 4, the wellhead housing further comprising one or more ports allowing pressure and/or temperature monitoring.

9. The riser system according to claim 1, wherein the riser upper end is connected to a drill ship or drilling rig on the vessel.

10. The riser system according to claim 1, the lower end of the lower riser assembly connected to a subsea mooring, and further comprising one or more structural supports for the polished bore receptacle extending from the subsea mooring to a point about midway up the polished bore receptacle.

11. The riser system according to claim 10, wherein the subsea mooring is a suction pile.

12. The riser system according to claim 4, wherein the polished bore receptacle is threaded in to the wellhead housing.

13. The riser system according to claim 1, wherein at least some portions of the riser comprise sections of pipe joined by threaded joints.

14. The riser system according to claim 1, wherein the riser joints are constructed using high strength steel tubulars using threaded coupled connectors.

15. The riser system according to claim 1, wherein an upper end of the polished bore receptacle comprises a guide funnel.

16. The riser system according to claim 6, wherein the subsea flexible conduit comprises a lazy wave flexible jumper with at least one distributed buoyancy module connected from the base of the riser to a subsea manifold on the seafloor, the manifold fluidly connected to the subsea source.

17. The riser system according to claim 1, wherein the lower riser assembly is fluidly connected to an active subsea wellhead via one or more flexible conduits.

18. The riser system according to claim 1, wherein the lower riser assembly comprises one or more ROV hot-stab ports allowing a flow assurance fluid to flow into both the lower riser assembly and the riser, the flow assurance fluid selected from the group consisting of nitrogen or other gas phase, heated seawater or other water, and one or more organic chemicals.

19. The riser system according to claim 1, wherein the seal between the polished bore receptacle and the seal stem is such that the riser and seal stem may be disconnected from the polished bore receptacle, allowing the polished bore receptacle and lower riser assembly to be disconnected from the surface vessel in an either an emergency or planned event.

20. The riser system according to claim 1, the lower riser assembly further comprising an additional assembly or sub fluidly connecting the lower riser assembly to a source of a flow assurance fluid.

21. The riser system according to claim 6, wherein the gooseneck assembly comprises, in order starting at the generally cylindrical member, an API flange, a section of tubing, a high pressure subsea connector, a subsea API connector and API flange, and a bend restrictor.

22. The riser system according to claim 1, the member comprising a forged, high-strength steel intake spool fluidly connected to a gooseneck assembly, the gooseneck assembly fluidly connected to a flexible conduit, the member also comprising a connector allowing connection to a source of a flow assurance fluid.

23. The riser system of claim 1, wherein the subsea source is a malfunctioning subsea BOP, the system further comprising one or more umbilicals, one of the umbilicals fluidly connected to locations on the subsea BOP selected from the group consisting of a kill line of the subsea BOP, a choke line of the subsea BOP, and both the kill and choke lines of the subsea BOP.

24. The riser system of claim 1, wherein the subsea source is a malfunctioning subsea BOP, the system further comprising one or more umbilicals, one of the umbilicals fluidly connected to a subsea BOP stack manifold.

25. The riser system of claim 1, further comprising one or more umbilicals, wherein one of the umbilicals is fluidly connected to a subsea manifold.

26. The riser system of claim 1, further comprising the seal stem extending into the member a distance sufficient to create upper and lower seals between the member and the seal stem, wherein the intake ports are between the upper and lower seals, the seal stem further comprising one or more inlet ports positioned between the upper and lower seals.

27. A method of installing a subsea marine riser system, the method comprising:

attaching a first end of a member to an end forging, a first end of a polished bore receptacle to the member, the polished bore receptacle comprising a polished bore and a guide funnel on an end opposite the first end, and attaching the end forging to a subsea foundation so that the polished bore receptacle is substantially vertical;

directing a drill string riser toward the guide funnel, the drill string comprising a seal stem comprising one or more elastomeric seal elements; and

stabbing the seal stem into the polished bore receptacle and establishing a pressure-tight seal between the elastomeric seal elements and the polished bore.

28. The method of claim 27, further comprising:

connecting a subsea flexible conduit and gooseneck assembly to the member and to a subsea source.

29. The method of claim 27, wherein the steps of directing and stabbing are performed using a mobile offshore drilling unit.

30. The method of claim 27, further comprising assisting the directing and/or the stabbing steps using one or more ROVs.

31. The method of claim 27, comprising constructing the drill string riser using high strength steel tubulars using threaded coupled connectors.

32. The method of claim 27, further comprising supporting the polished bore receptacle using structural supports extending from the subsea foundation to a point approximately midway up the polished bore receptacle.

33. A method of producing a fluid from a subsea source, the method comprising:

deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, the lower riser assembly having attached thereto a polished bore receptacle comprising a polished bore, a lower end of the polished bore receptacle fluidly and mechanically connected to the upper end of the member;

fluidly connecting at least one of the intake ports to the subsea source using a flexible conduit;

lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements;

stabbing the seal stem into the polished bore receptacle, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the polished bore receptacle, seal stem, and riser; and

initiating flow from the subsea source through the subsea flexible conduit, the lower riser assembly, the polished bore receptacle, the seal stem, and the riser.

34. A method of killing a well producing a fluid from a subsea source, the method comprising:

deploying subsea from a surface vessel a lower riser assembly comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient outtake ports extending from the bore to the external surface to accommodate flow of a kill density fluid from the surface vessel to a hydrocarbon fluid source, the lower riser assembly having attached thereto a polished bore receptacle comprising a polished bore, a lower end of the polished bore receptacle fluidly and mechanically connected to the upper end of the member;

fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit;

lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements;

stabbing the seal stem into the polished bore receptacle, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and polished bore receptacle; and

initiating flow of kill density fluid from the surface vessel through the riser, seal stem, polished bore receptacle, lower riser assembly, and subsea flexible conduit.

35. A method of cementing a subsea wellbore using a surface marine vessel, the method comprising:

deploying subsea from a surface vessel a lower riser assembly comprising a member having a longitudinal bore, a lower end, an upper end, and an external surface, the member comprising sufficient outtake ports extending from the bore to the external surface to accommodate flow of a cementing fluid from the surface vessel to a hydrocarbon fluid source, the lower riser assembly having attached thereto a polished bore receptacle comprising a polished bore, a lower end of the polished bore receptacle fluidly and mechanically connected to the upper end of the member;

fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit;

lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in an erect substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements;

stabbing the seal stem into the polished bore receptacle, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and polished bore receptacle; and initiating flow of a cementing fluid from the surface vessel through the riser, seal stem, polished bore receptacle, lower riser assembly, and subsea flexible conduit.

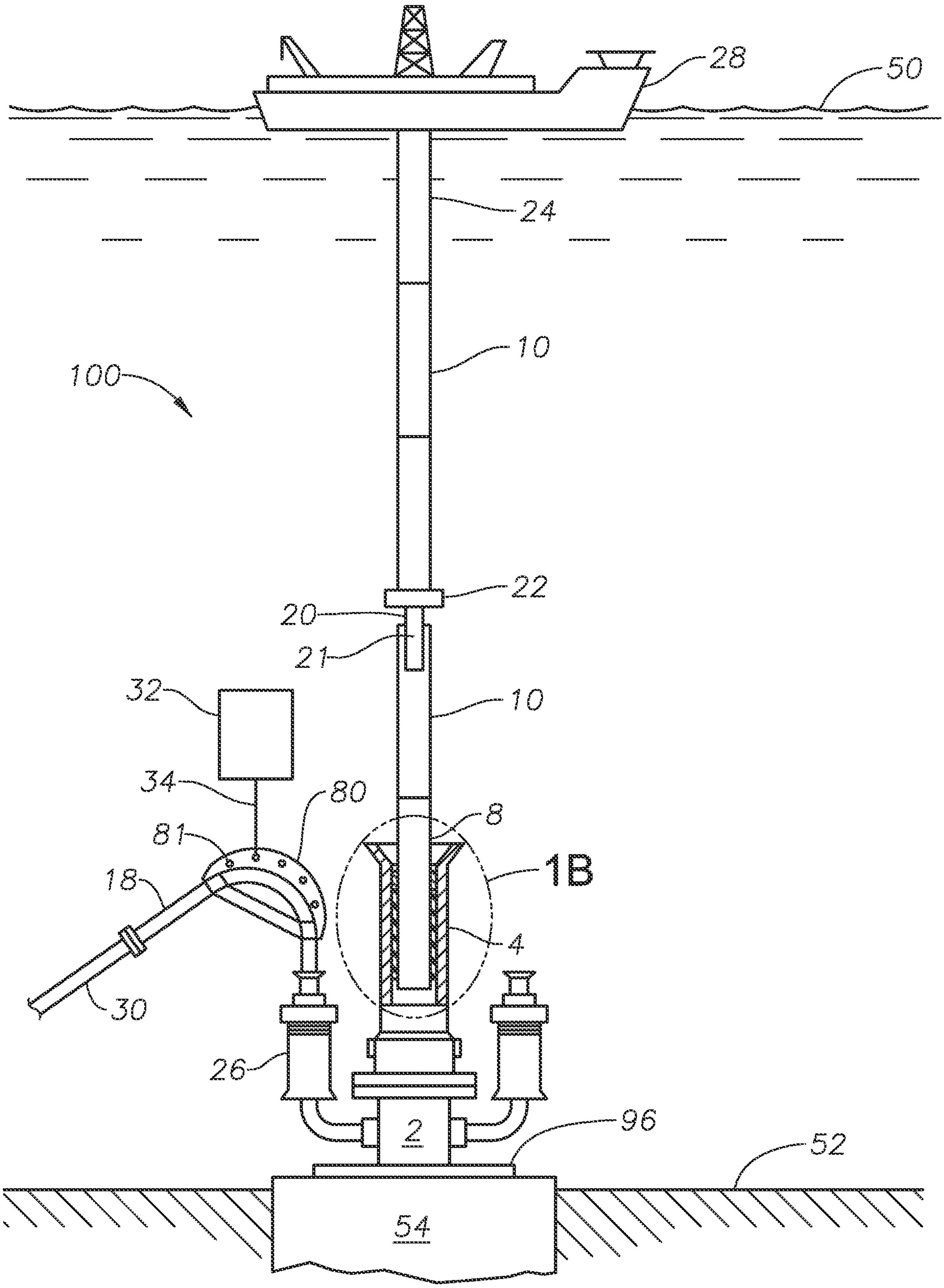

Fig. 1A

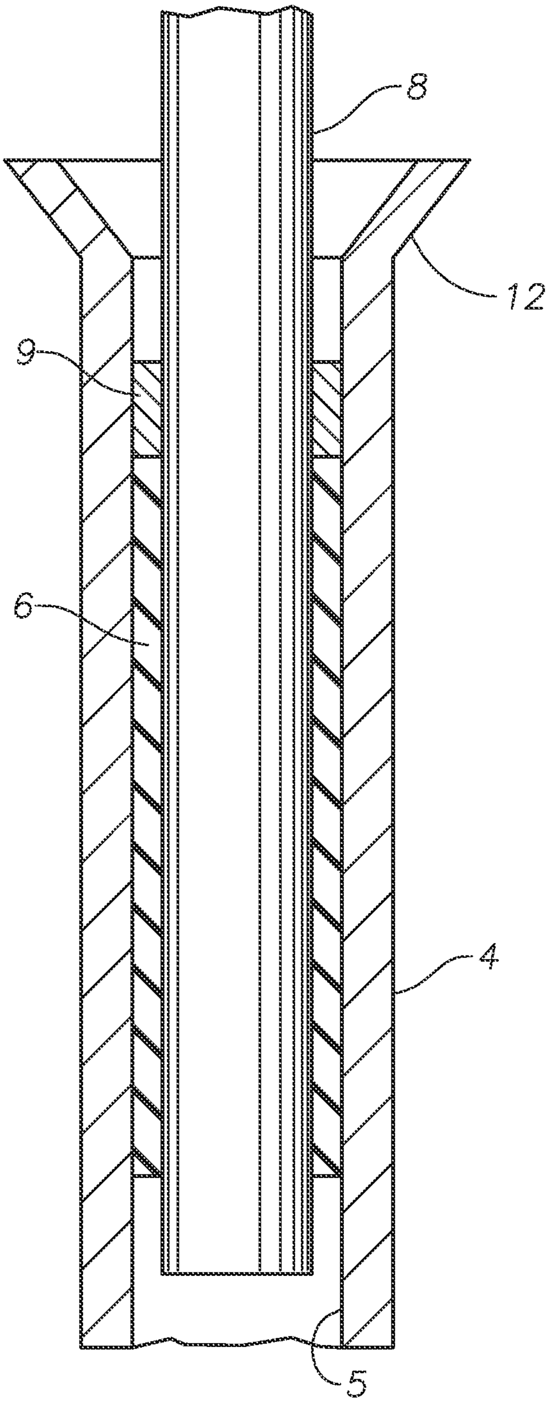

Fig. 1B

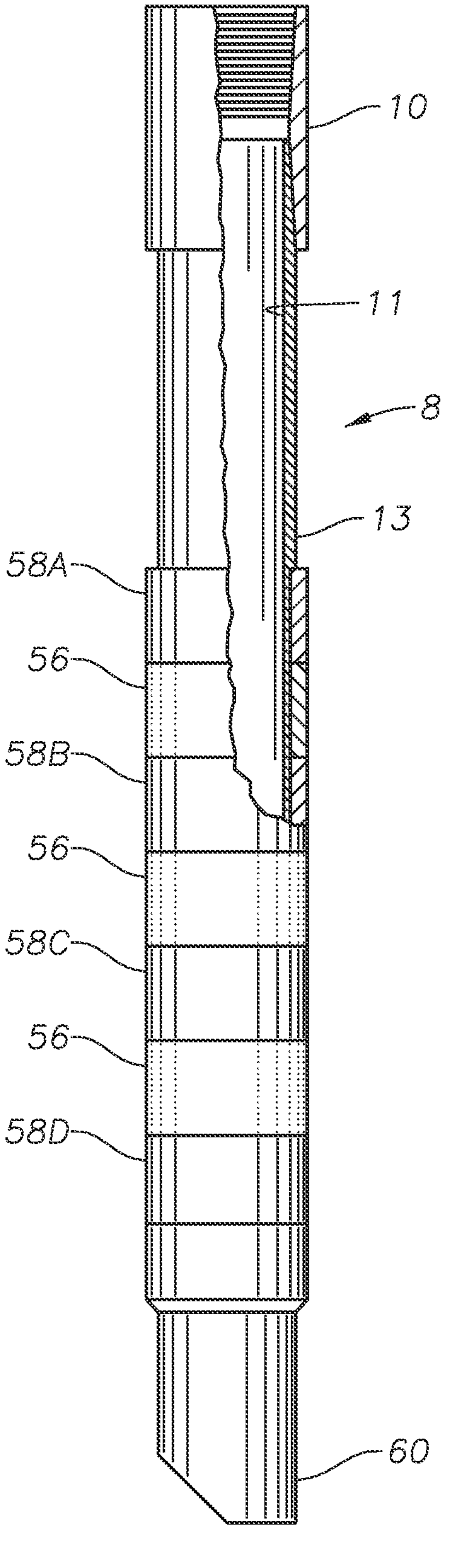

Fig. 2

Fig. 3A

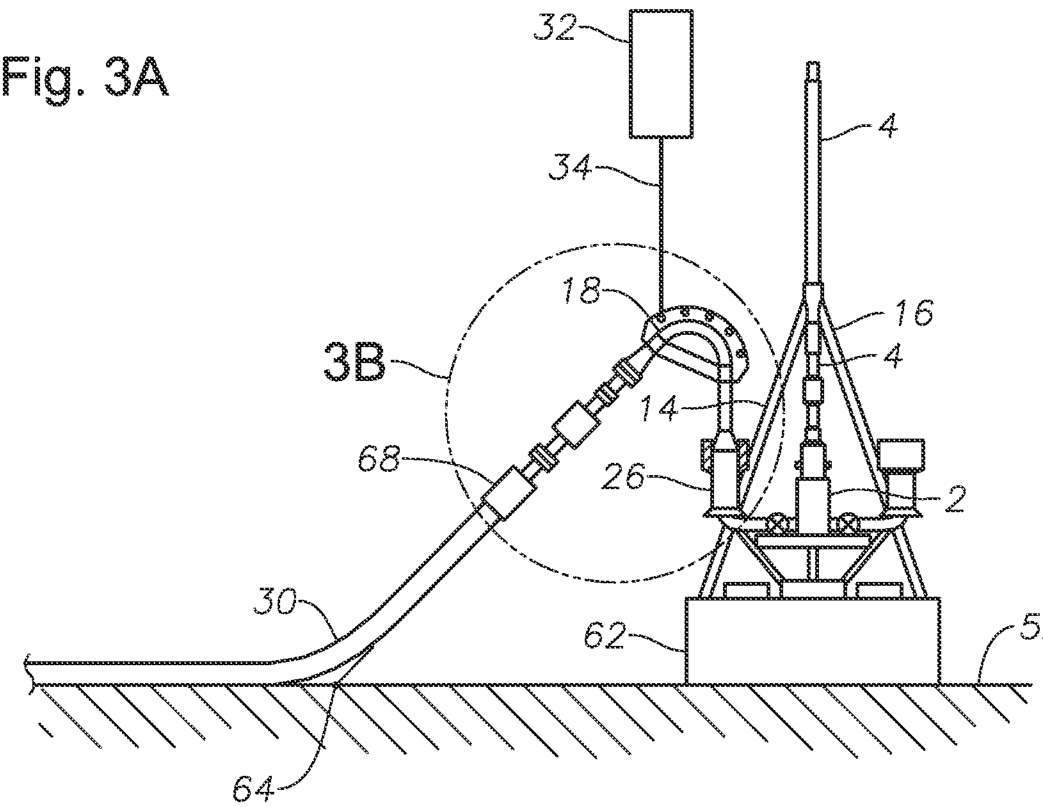
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Fig. 3B

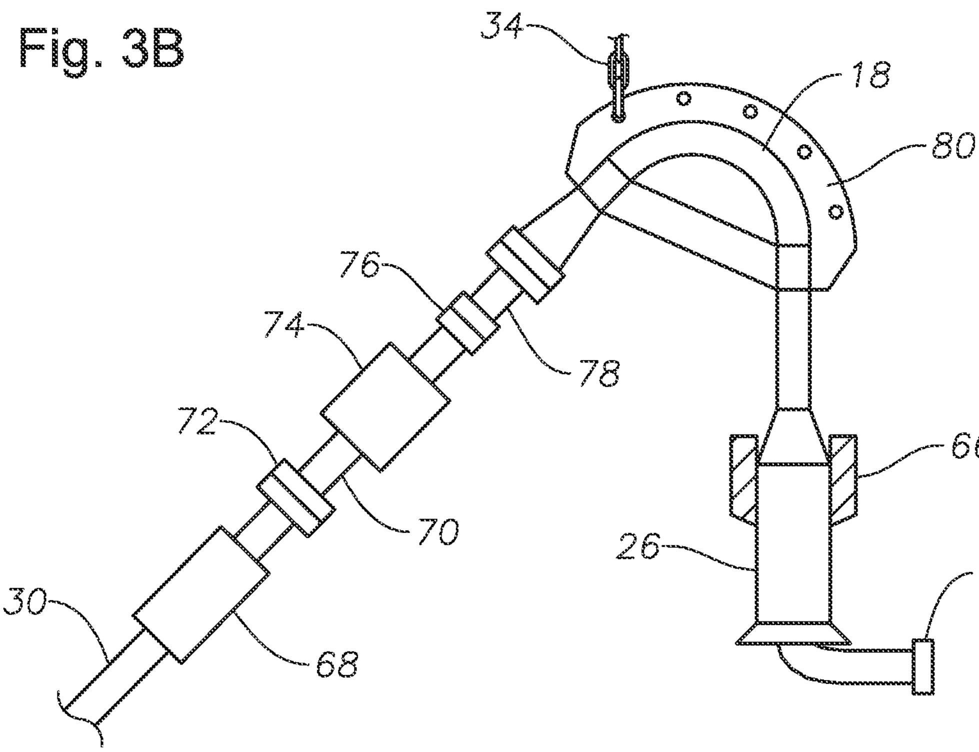
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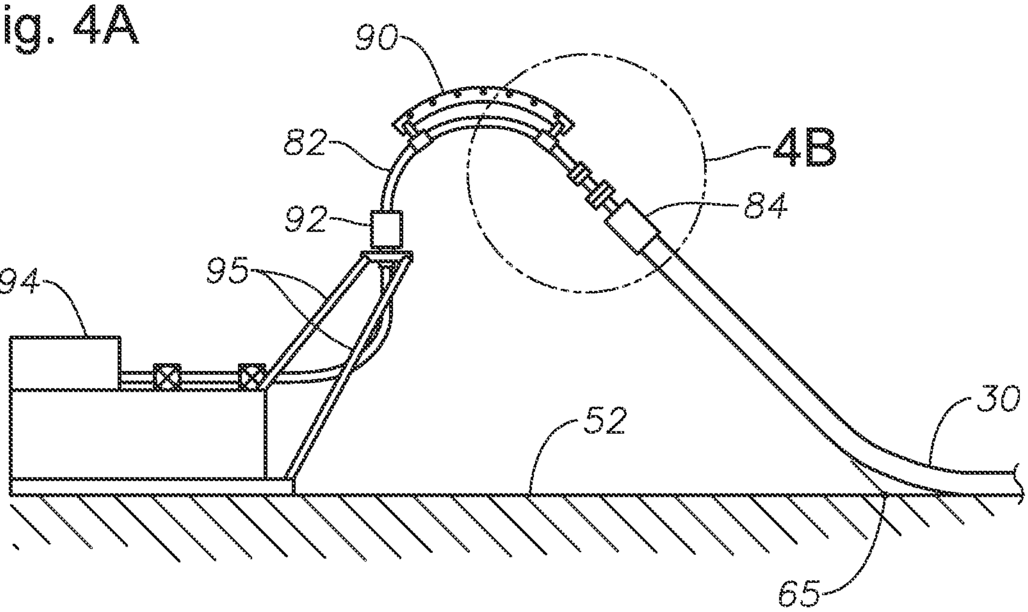
Fig. 4A



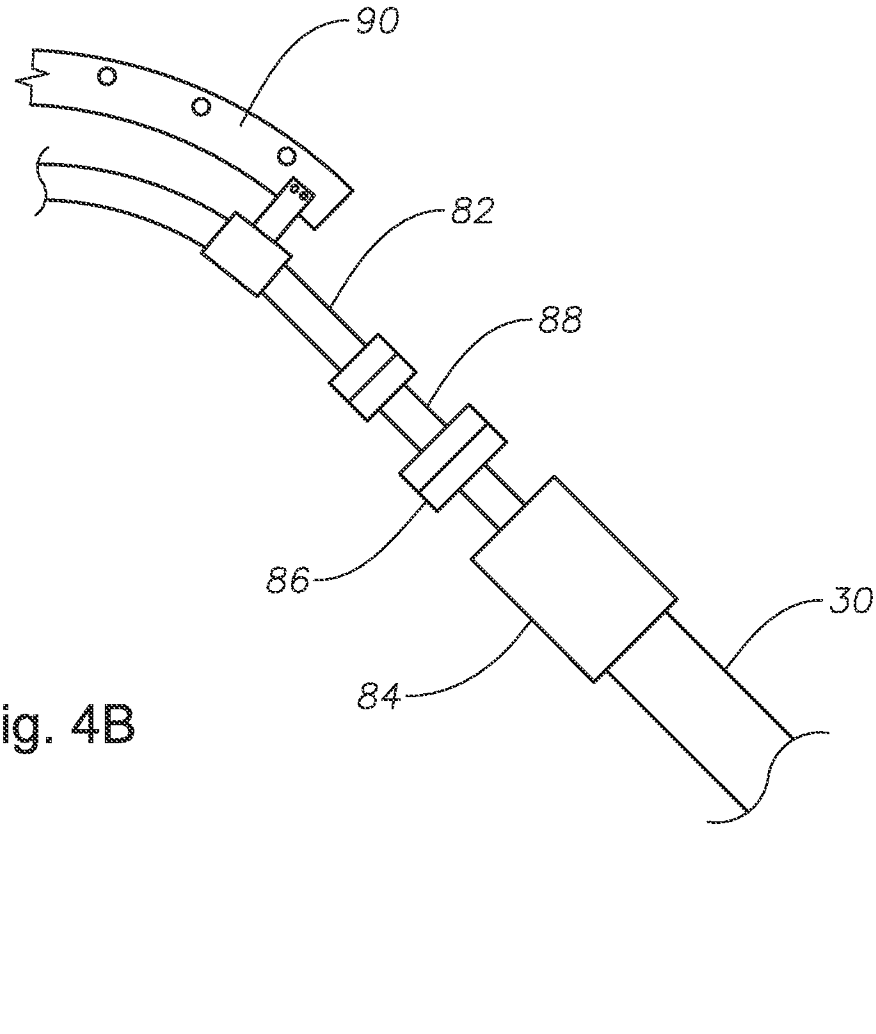


Fig. 4B

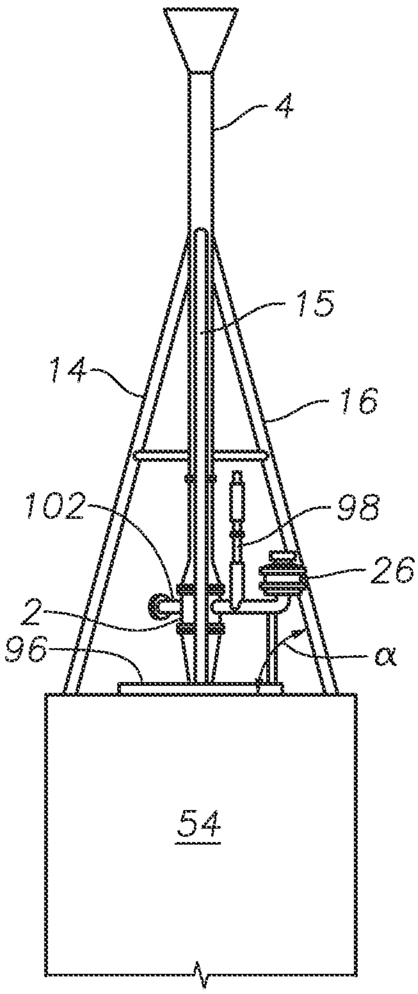


Fig. 5

Fig. 6

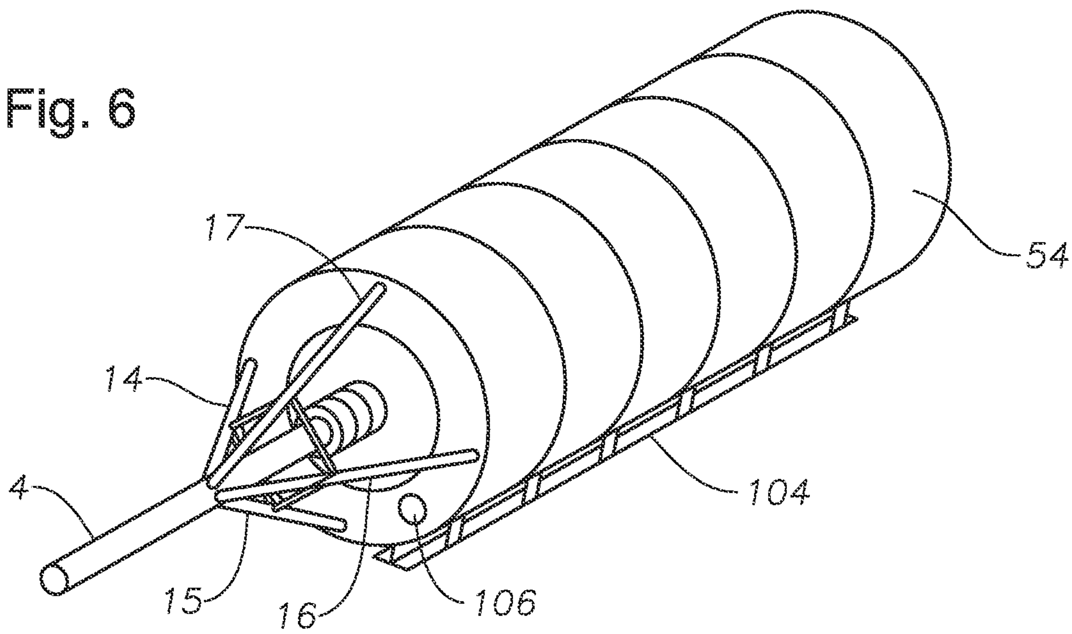
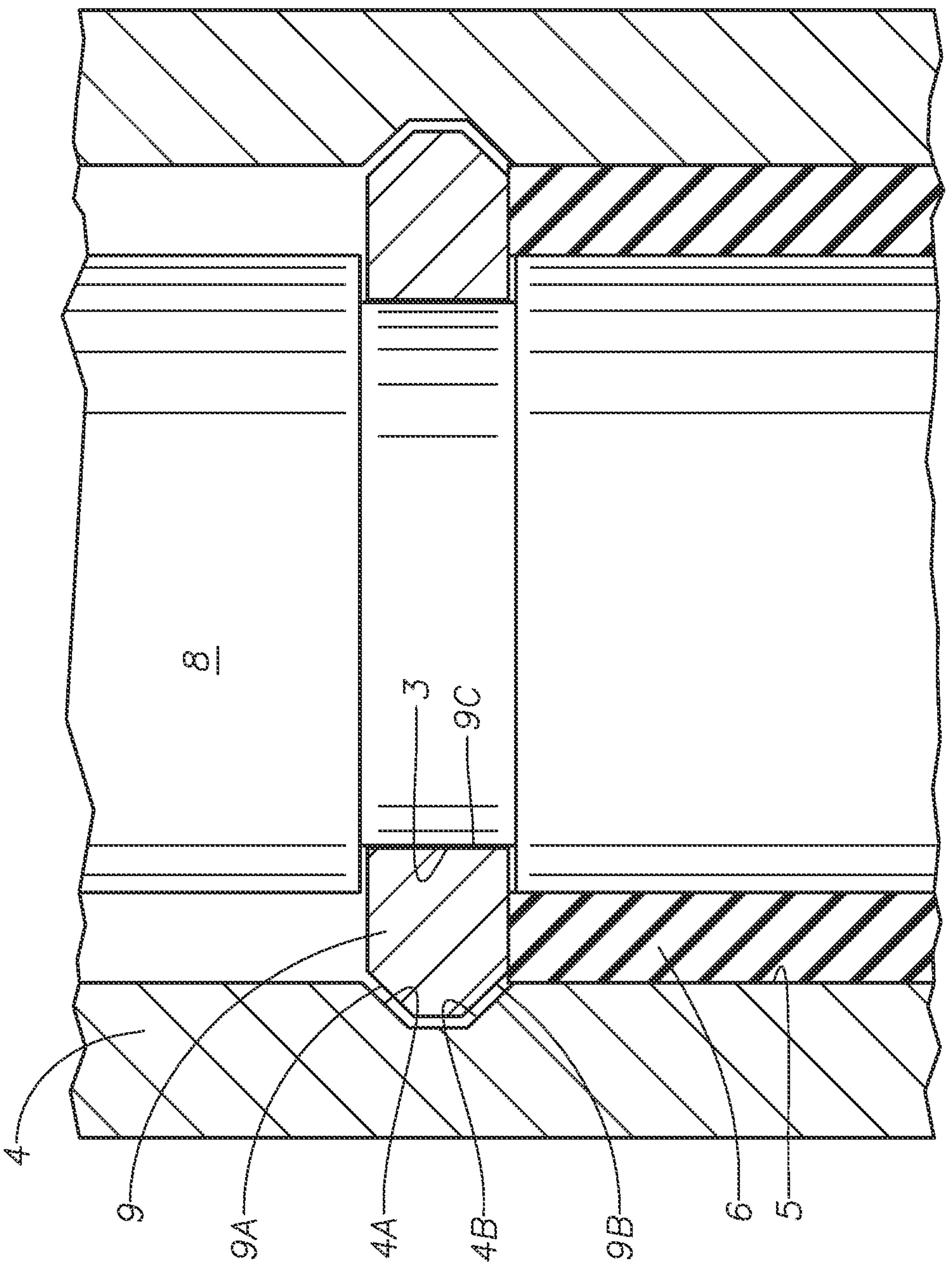


Fig. 7



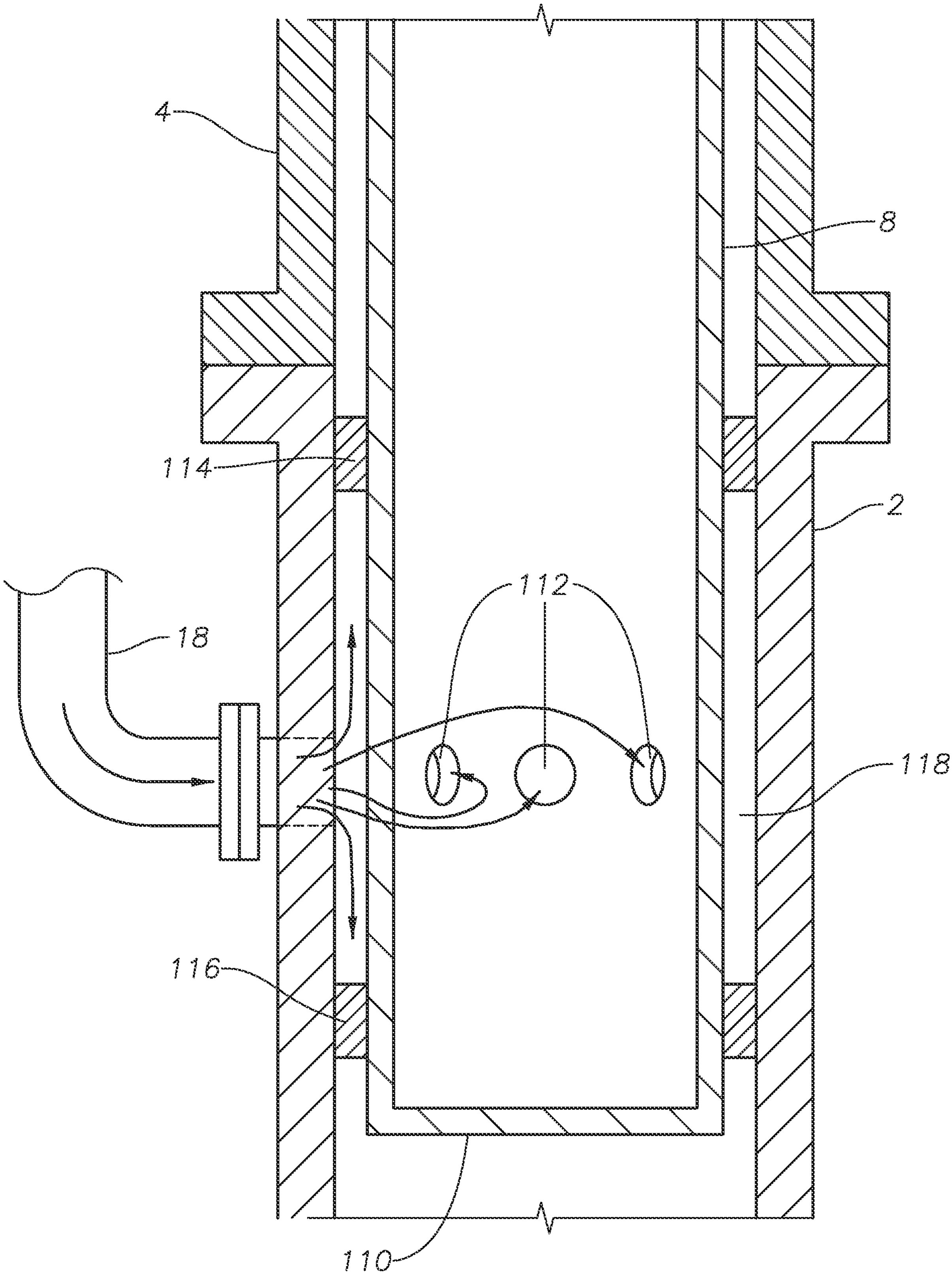


Fig. 8

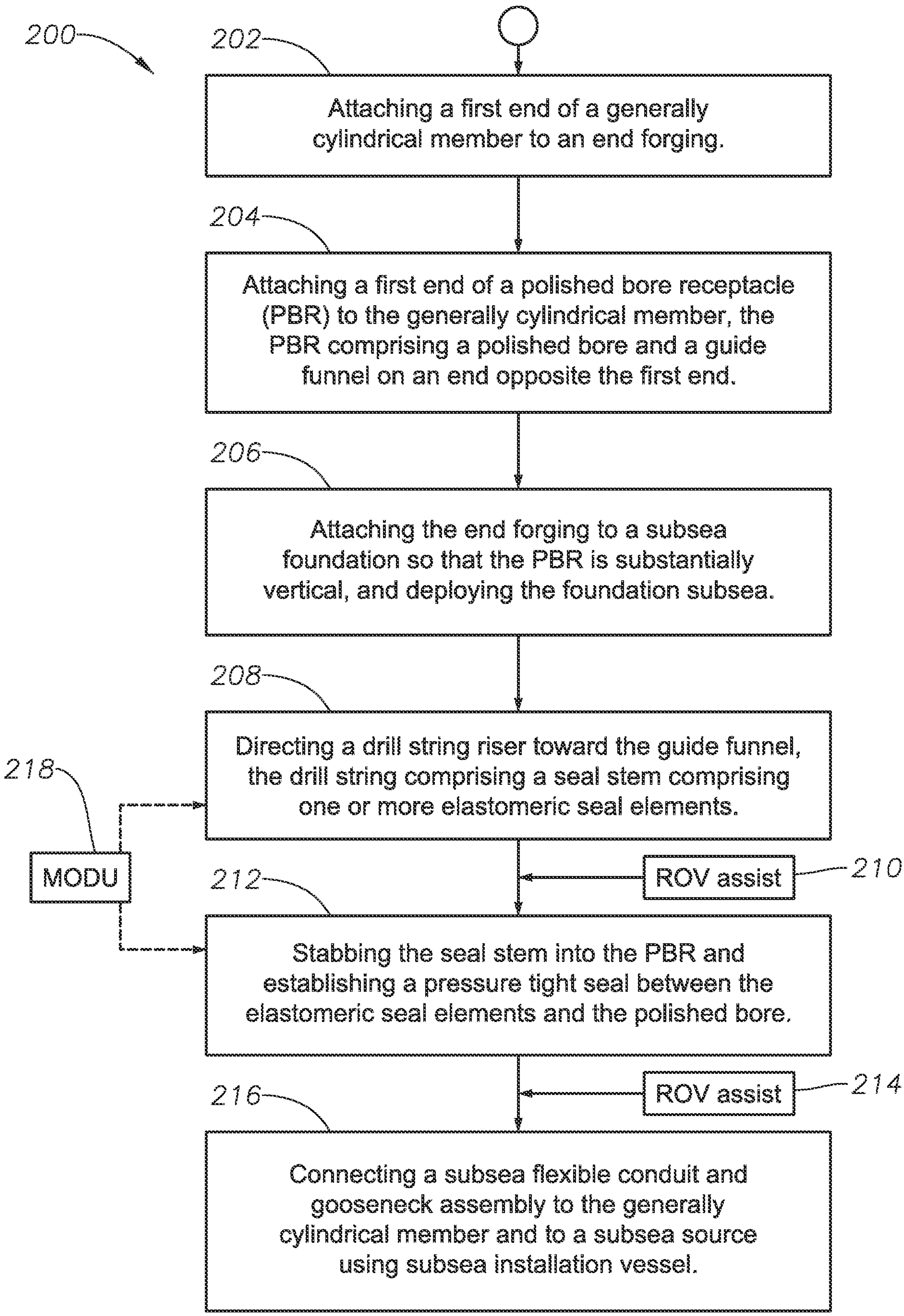

200
202
Attaching a first end of a generally cylindrical member to an end forging.
204
Attaching a first end of a polished bore receptacle (PBR) to the generally cylindrical member, the PBR comprising a polished bore and a guide funnel on an end opposite the first end.
206
Attaching the end forging to a subsea foundation so that the PBR is substantially vertical, and deploying the foundation subsea.
208
Directing a drill string riser toward the guide funnel, the drill string comprising a seal stem comprising one or more elastomeric seal elements.
218
MODU
ROV assist
210
212
Stabbing the seal stem into the PBR and establishing a pressure tight seal between the elastomeric seal elements and the polished bore.
ROV assist
214
216
Connecting a subsea flexible conduit and gooseneck assembly to the generally cylindrical member and to a subsea source using subsea installation vessel.

Fig. 9

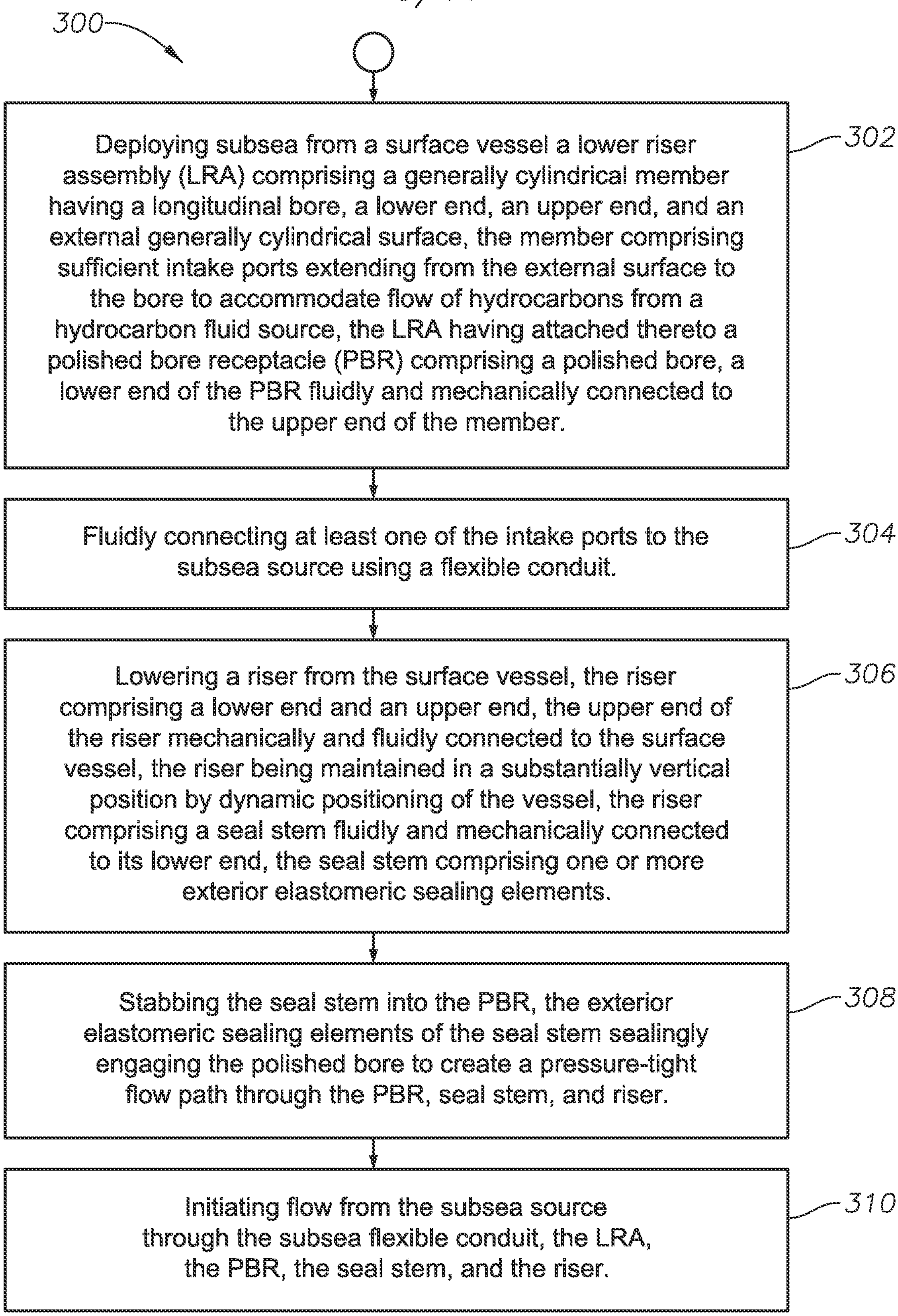

300
Deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a generally cylindrical member having a longitudinal bore, a lower end, an upper end, and an external generally cylindrical surface, the member comprising sufficient intake ports extending from the external surface to the bore to accommodate flow of hydrocarbons from a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member.
302
Fluidly connecting at least one of the intake ports to the subsea source using a flexible conduit.
304
Lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in a substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements.
306
Stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the PBR, seal stem, and riser.
308
Initiating flow from the subsea source through the subsea flexible conduit, the LRA, the PBR, the seal stem, and the riser.
310

Fig. 10

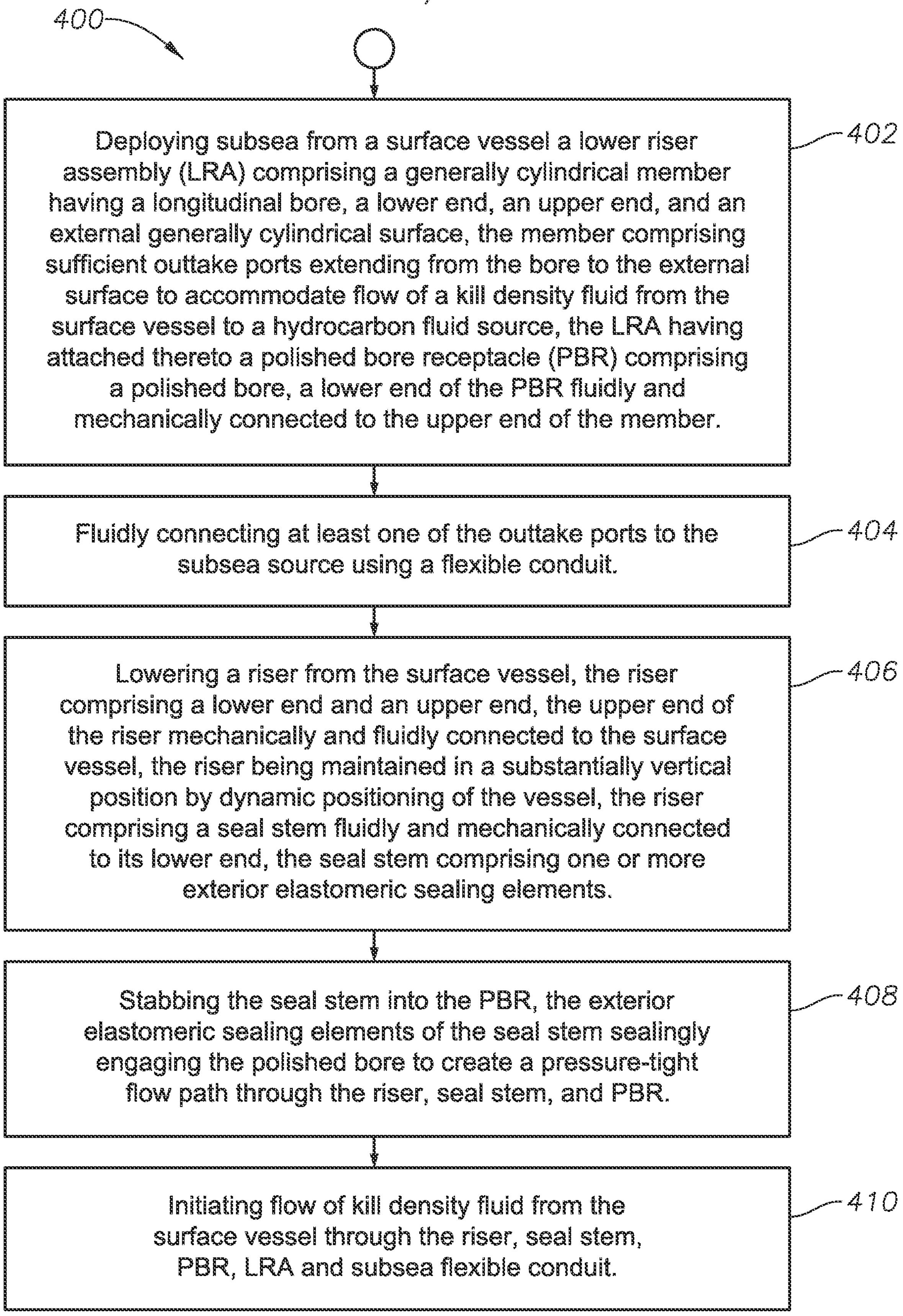

400
Deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a generally cylindrical member having a longitudinal bore, a lower end, an upper end, and an external generally cylindrical surface, the member comprising sufficient outtake ports extending from the bore to the external surface to accommodate flow of a kill density fluid from the surface vessel to a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member.
402
Fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit.
404
Lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in a substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements.
406
Stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and PBR.
408
Initiating flow of kill density fluid from the surface vessel through the riser, seal stem, PBR, LRA and subsea flexible conduit.
410

Fig. 11

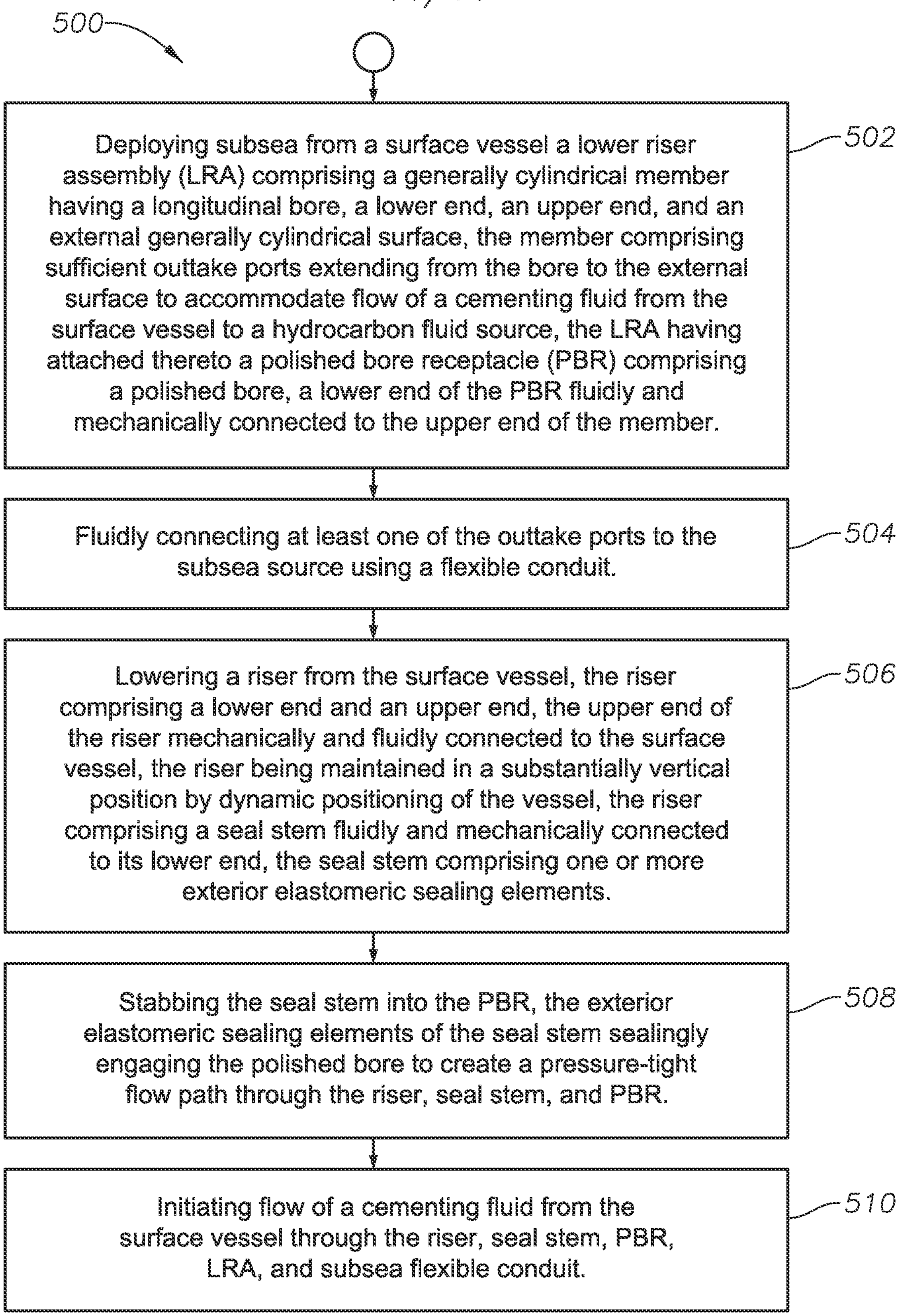

500
Deploying subsea from a surface vessel a lower riser assembly (LRA) comprising a generally cylindrical member having a longitudinal bore, a lower end, an upper end, and an external generally cylindrical surface, the member comprising sufficient outtake ports extending from the bore to the external surface to accommodate flow of a cementing fluid from the surface vessel to a hydrocarbon fluid source, the LRA having attached thereto a polished bore receptacle (PBR) comprising a polished bore, a lower end of the PBR fluidly and mechanically connected to the upper end of the member.
502
Fluidly connecting at least one of the outtake ports to the subsea source using a flexible conduit.
504
Lowering a riser from the surface vessel, the riser comprising a lower end and an upper end, the upper end of the riser mechanically and fluidly connected to the surface vessel, the riser being maintained in a substantially vertical position by dynamic positioning of the vessel, the riser comprising a seal stem fluidly and mechanically connected to its lower end, the seal stem comprising one or more exterior elastomeric sealing elements.
506
Stabbing the seal stem into the PBR, the exterior elastomeric sealing elements of the seal stem sealingly engaging the polished bore to create a pressure-tight flow path through the riser, seal stem, and PBR.
508
Initiating flow of a cementing fluid from the surface vessel through the riser, seal stem, PBR, LRA, and subsea flexible conduit.
510

Fig. 12