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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 November 2017 (16.11.2017)

(10) International Publication Number
WO 2017/193217 A1

(51) International Patent Classification:
E21B 19/22 (2006.01) *E21B 19/08* (2006.01)
E21B 19/06 (2006.01)

(21) International Application Number:
PCT/CA2017/050569

(22) International Filing Date:
11 May 2017 (11.05.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/335,023 11 May 2016 (11.05.2016) US

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) Title: CONTINUOUS DRILLING SYSTEM

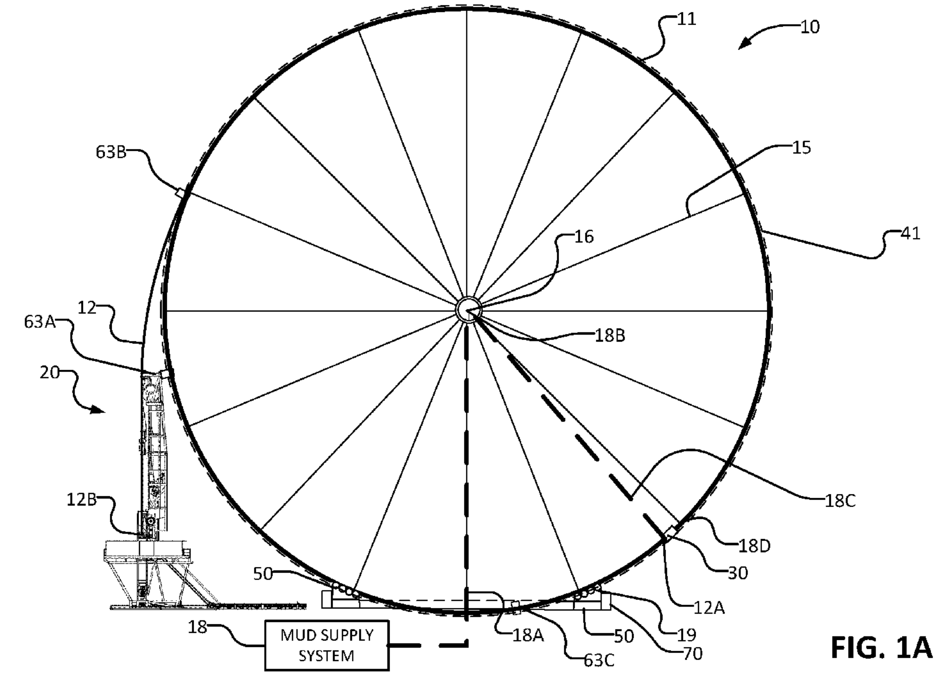

FIG. 1A

(57) Abstract: A drill string management apparatus is disclosed. The apparatus may comprise a reel that stores a length of drill string and supplies the drill string to a drilling system. The drill string may be wrapped around a circumference of a reel in a coil. The radius of the coil may be large enough that the drill string is not deformed inelastically by wrapping it around the reel. The apparatus may be designed to allow the drill string to rotate about its longitudinal axis, even as the drill string is wrapped in a coil around the reel.

WO 2017/193217 A1

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TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

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

CONTINUOUS DRILLING SYSTEM

Cross-Reference to Related Applications

[0001] This application claims priority from US application No. 62/335023 filed 11 May 2016. For purposes of the United States, this application claims the benefit under 35 U.S.C. §119 of US application No. 62/335023 filed 11 May 2016 and entitled CONTINUOUS DRILLING SYSTEM which is hereby incorporated herein by reference for all purposes.

Field

[0002] This invention relates to subsurface drilling. Example applications are drilling for petroleum and/or natural gas. The application relates to apparatus and methods for handling drill string sections.

Background

[0003] Subsurface drilling uses a drill string made up of a series of sections that are connected to one another end-to-end. The sections that couple together longitudinally to make a drill string may be called “drill string sections”, “joints”, “tubulars”, “drill pipes”, or “drill collars”. Most commonly, the sections each have a pin end and a box end with complementary threads. The sections may be screwed together end-to-end to create a drill string of arbitrary length. The threads may be a proprietary thread or are commonly API standard threads. The sections typically have lengths of 31 feet (about 10 meters) or 45 feet (about 15 meters).

[0004] When a well is being drilled, a drill bit is provided at the downhole end of the drill string. The drill bit drills a borehole that is somewhat larger in diameter than the drill string such that there is an annulus surrounding the drill string in the borehole. As the well is drilled, drilling fluid is pumped down through the drill string to the drill bit where it exits and returns to the surface through the annulus. The drilling fluid serves to counteract downhole pressures and keep the wellbore open. The drilling fluid also carries rock and other cuttings to the surface. As drilling progresses and the well bore gets deeper, new drill string sections are added at the uphole end of the drill string.

Sometimes two or three sections are coupled together in advance to form ‘stands’. Stands may be added at the uphole end of the drill string.

[0005] The first (farthest downhole) sections of a drill string are typically made up of heavy drill collars which, through their weight, apply pressure to the drill bit. This part of the drill string is typically called a bottom hole assembly or “BHA”. The BHA may include, for example some or all of: a bit, downhole motor, directional survey instruments, formation evaluation instruments, telemetry devices, stabilizers, rotary steerable directional tools and various specialty tools. Above the BHA, the drill string sections may be lighter in weight.

[0006] Drilling is typically done using a drill rig. The drill rig includes equipment for rotating the drill string. In some cases, this equipment comprises a rotary table. In other cases, this equipment comprises a top drive. In either case, at the drill rig, as drilling progresses, new sections are added to the top of the drill string. This process, often referred to as “a connection”, is done using equipment on the drill rig. Traditional connection techniques typically require interruption of drilling fluid circulation which discontinues hole cleaning and precludes the possibility of applying constant pressure on downhole formations. Further, typical connection techniques require interruption of drill string movement, which may increase the risk of the drill string sticking downhole. In particular, adding a new section typically involves supporting the drill string, uncoupling the top end of the drill string from the kelly or top drive that was supporting it, coupling a new section to the top end of the drill string, connecting the uphole end of the new section to the kelly or top drive and resuming drilling. Typically the weight of the drill string is carried by slips on the drill rig floor while a new section is being added to the drill string.

[0007] Periodically, as drilling progresses, it is usually necessary to retrieve the drill string from the well bore. This may be required, for example, to replace the drill bit if the drill bit is becoming worn. This also may be required in cases where there is downhole equipment of some kind that needs to be retrieved to the surface for servicing. The process of bringing a drill string back to the surface and returning the drill string into a partially completed well bore is called “tripping”. Since well bores may be many thousands of feet or meters deep, tripping may take a long time to complete. Operating a drill rig is very expensive. Consequently, tripping can contribute large costs.

[0008] Some systems have been proposed for making tripping a drill string more efficient. These include US Patent No. 8844616. These systems have various disadvantages. Practical alternatives to these systems are required.

[0009] There is a general need for ways to improve the efficiency of subsurface drilling. There is a particular need to reduce the time taken to make drilling connections and to trip a drill string.

[0010] Some drilling operations also use coiled tubing. Coiled tubing is, as its name suggests, supplied in a coil. The tubing is typically made of steel and is typically bent past its yield point to form a coil. Coiled tubing is plastically deformed several times during each drilling cycle including unwinding the coiled tubing from the coil and eventually bending the coiled tubing to re-form the coil. Coiled tubing is not rotated during drilling. Instead, a mud motor at a downhole end of the coiled tubing is operated by the flow of drilling mud through the coiled tubing to turn a drill bit. The diameter of coiled tubing is typically constrained to relatively small diameters suitable only for secondary drilling in existing wellbores.

[0011] Traditional drilling operations often suffer from difficulties in transferring information to and from the BHA. Such information transfer may be limited by the segmented nature of the drill string and the need to progressively add joints. Examples of information transferred to and from the BHA include, but are not limited to directional measured data, formation evaluation data and mechanical measurements.

[0012] Data is commonly transferred by mud pulse telemetry which is limited to extremely small bandwidth (low data rate). This limits data accessibility and precludes real-time data acquisition and control. Mud pulse telemetry is available only during active circulation so, for example, there may be no data transmission available during normal tripping.

[0013] Alternatively, wired drillpipe has been used to realize greater communication bandwidth. Wired drillpipe is very expensive, requires special drillpipe and other tools and has reliability challenges. Further, electric wireline run inside the drill string (as is necessary for mechanical protection) may create additional difficulty when adding additional drill string segments. It remains desirable to have a simple and reliable means for high-bandwidth communication between surface equipment and the BHA.

[0014] Energy transfer from surface equipment to the BHA is commonly limited to mechanical rotation of the drill string (rotary drilling) and drilling fluid hydraulics (e.g. drilling with a downhole mud motor, common for directional drilling). Rotary drilling allows minimal trajectory control and mud-driven downhole motors have limited life and create extra demands on a drilling rig's mud circulation system.

[0015] It is desirable to independently power the BHA, separate from drill string rotation and drilling fluid circulation, for example by electric or independent hydraulic means. Independent power requires power transmission from the surface via by, for example, electric cable or hydraulic tubing. These are impractical on a traditional drilling rig because of the connection requirement, similar to the communication wireline described above.

<u>Summary</u>

[0016] This invention has a number of aspects. These include, without limitation:

- apparatus useful for continuous drilling;
- methods for continuous drilling;
- components and sub-assemblies of apparatus as described herein.

[0017] One aspect of the invention provides an apparatus for drilling. The apparatus may have a reel mounted for rotation about an axis. A coupling may be mounted on the reel. The coupling may be configured for attachment to an uphole end of a drill string and rotatable relative to the reel to allow rotation of the attached drill string around a longitudinal axis of the drill string while the drill string is coiled around the reel. An optional tensioner may be operable to apply tension to a tail end of the drill string.

[0018] In some embodiments, a material of the drill string has a yield point and a minimum radius of curvature of the reel is sufficiently large that a maximum stress of the drill string is less than the yield point.

[0019] In some embodiments, the coupling comprises a rotary drive.

[0020] In some embodiments, a drilling fluid supply system is connected to supply drilling fluid to the uphole end of the drill string.

[0021] In some embodiments, a first standpipe extends to a first rotary coupling at the axis of the reel, a radially-extending conduit extends from the first rotary coupling to a peripheral portion of the reel, and the radially extending conduit is in fluid communication with a bore of the drill string by way of a second rotary coupling.

[0022] In some embodiments, the tensioner is mounted to the reel and is movable circumferentially relative to the reel. The tensioner may include a tensioner arm extending at an angle to a radius of the reel such that the tensioner arm extends generally tangentially to the reel. A hoist may be coupled between the tensioner arm and the reel. The hoist may be operable to alter the angle by moving a distal end of the tensioner arm radially toward or away from the reel. The tensioner arm may be curved. The tensioner may include first and second carriages mounted to travel along the tensioner arm. Each of the first and second carriages may have a drill string gripper and actuators coupled to move the first and second carriages along the tensioner arm. The grippers may have elevator plates pivotally mounted to the carriages. The elevator places may have cutouts having edge contours dimensioned to receive portions of the drill string between joints of the drill string. The first and second carriages may be respectively driven by first and second chain drives.

[0023] In some embodiments, the apparatus includes a sensor configured to provide a signal to a controller. The signal may indicate a tension in at least a portion of the drill string. The controller may be configured to control the tensioner based at least in part on the signal.

[0024] In some embodiments, an umbilical cable extends along the drill string. The umbilical cable may include a plurality of conductors. The conductors of the umbilical cable may be connected to corresponding conductors mounted to the reel by way of a rotary electrical connection. In some embodiments, a pressure sensor is connected to deliver downhole pressure readings to surface equipment by way of one or more of the conductors of the umbilical cable (and/or by way of another data telemetry system).

[0025] In some embodiments, the drill string is made of a plurality of tubulars coupled together by threaded joints. In some embodiments, the drill string is made of a plurality of tubulars welded together end to end. In some embodiments, the drill string is made of a plurality of tubulars coupled together at shrink fit connections. The drill string may have an outside diameter of 4 inches or more. The drill string may include 100 or more tubulars coupled end to end.

[0026] In some embodiments, the reel has rollers that support the drill string. The rollers may be oriented to rotate when the drill string is rotated about the longitudinal axis of the drill string. The rollers may be arranged in sets of rollers spaced circumferentially around the reel. Different sets of the rollers may be offset relative to one another in an axial direction relative to the reel so as to follow helical wraps of the drill string on the reel. In some embodiments, the reel has a peripheral support surface and the peripheral support surface has one or more dry-sliding bearing supports to support and allow rotation of the drill string on the reel.

[0027] In some embodiments, the reel has a width sufficient to accommodate at least 6 full turns of the drill string. In some embodiments, the reel has a support deck rotatable about the axis relative to at least a portion of the reel. In some embodiments, the reel has a diameter of at least 30 meters. In some embodiments, the reel has a diameter of at least 50 meters. In some embodiments, the reel has a diameter in the range of about 30 to 125 meters.

[0028] In some embodiments, a fender structure may extend around a periphery of the reel, the fender structure rotatable about the axis of the reel independently of the reel. The fender structure may have circumferentially spaced-apart bars spaced radially outwardly from the support deck. The fender structure may have a thermally insulated wall spaced radially outwardly from the support deck. The thermally insulated wall may cover one side of an annular enclosure around the support deck wherein the apparatus comprises a heater arranged to heat an interior of the annular enclosure. One or more active retention members may be provided. Each active retention member may be operable between a first configuration in engagement with the drill string to prevent the drill string from moving away from the reel and a second configuration in which the drill string is free to move away from the reel.

[0029] In some embodiments, a drilling system may be provided having plural elevators arranged to carry the weight of a portion of the drill string that is downhole and hoists operable to transfer the weight of the drill string from one of the elevators to another. In some embodiments, a drilling system may be provided having a tower, a pair of parallel chain loops supported for circulation on the tower, a drive connected to circulate the chain loops, a plurality of crossheads connected pivotally between the chain loops at spaced-apart locations along the chain loops, each of the crossheads supporting an elevator for a tubular string and one or more actuators coupled to adjust an elevation of each elevator relative to the chain loops. In some embodiments a top drive is connectable to the drill string and laterally shiftable to clear a well center of the drill string.

[0030] In some embodiments, the apparatus may include a second reel mounted for rotation about a second axis, a second coupling mounted on the second reel, the second coupling configured for attachment to an uphole end of a second drill string and rotatable relative to the second reel to allow rotation of the attached second drill string around a longitudinal axis of the second drill string while the second drill string is coiled around the second reel. A second tensioner operable to apply tension to a tail end of the second drill string may optionally be provided.

[0031] Another aspect of the invention provides a method for deploying a drill string into a borehole. The method may include the steps of providing a drill string arranged to lie along a curving path outside of and adjacent to a borehole, extending a tail end portion of the drill string into the borehole, each point of the curving path having a radius of curvature greater than a threshold radius such that the drill string is elastically bent to follow the curving path and rotating the drill string about a longitudinal axis of the drill string while the drill string lies along the curving path.

[0032] In some embodiments, the method includes rotating the drill string about the longitudinal axis while tripping the drill string into or out of the borehole. In some embodiments, the method includes providing a drill bit coupled to the tail end of the drill string, and rotating the drill string about the longitudinal axis while allowing the drill bit to extend into the borehole.

[0033] In some embodiments a drilling fluid is flowed through the drill string. This may be done while rotating the drill string about the longitudinal axis, tripping the drill string into the borehole and/or tripping the drill string out of the borehole. In some embodiments, a pressure of the drilling fluid is monitored in real time at a location proximate the tail end of the drill string and a flow of the drilling fluid is controlled based at least in part on the monitored pressure.

[0034] In some embodiments, arranging the drill string to follow the curved path includes wrapping the drill string around a first reel to form a coil around the reel. In some embodiments, the first reel has a diameter of at least 30 meters. In some embodiments, the first reel has a diameter of at least 50 meters. In some embodiments, the first reel has a diameter in the range of about 30 to 125 meters. In some embodiments, wrapping the drill string around the first reel includes making at least 4 full turns of the drill string around the first reel.

[0035] In some embodiments, a weight of a portion of the drill string that is in the borehole is supported by an elevator of a drilling system adjacent to the first reel. Rotating the drill string about the longitudinal axis may include applying a first torque to a portion of the drill string passing through the drilling system. In some embodiments, while rotating the drill string about the longitudinal axis a second torque is applied to an uphole end of the drill string on the first reel. In some embodiments the drill string is rotated about the longitudinal axis by applying a torque to an uphole end of the drill string.

[0036] In some embodiments, the tail end portion of the drill string is removed from the borehole and the first reel is rotated to wrap the tail end portion of the drill string onto the first reel and a tensioner is operated on the first reel to maintain the drill string under tension.

[0037] In some embodiments, the provided drill string has a diameter of about 4 inches (about 10 cm) or more. In some embodiments the provided drill string has a plurality of tubulars welded together end to end. In some embodiments, the drill string has 100 or more tubulars coupled end to end.

[0038] In some embodiments, an umbilical cable is fed into an interior of the drill string and the cable is carried into the drill string by flowing the drilling fluid.

[0039] In some embodiments, a support deck of the first reel is aligned with a well center of the borehole.

[0040] In some embodiments, a second drill string is wrapped around a second reel to form a second coil around the second reel. In some embodiments, the first reel is moved away from a well center of the borehole and a support deck of the second reel is aligned with the well center of the borehole. In some embodiments, a tail portion of the second drill string is extended into the borehole and the second drill string is rotated about a longitudinal axis of the second drill string while the second drill string forms the second coil around the second reel. In some embodiments, a casing is wrapped around one or both of the first and second reels and installing the casing in the borehole.

[0041] Advantageously certain embodiments of the technology described in the present disclosure may facilitate much quicker tripping of drill strings. Speed improvements may be facilitated by continuous or nearly continuous motion of the drill string into or out of a borehole and a saving of the time required for preparing and making connections between tubulars in conventional drilling systems.

[0042] Further aspects and example embodiments are illustrated in the accompanying drawings and/or described in the following description.

<u>Brief Description of the Drawings</u>

[0043] The accompanying drawings illustrate non-limiting example embodiments of the invention.

[0044] Figure 1A is a side elevation view of apparatus suitable for use in continuous drilling according to an example embodiment.

[0045] Figure 1B is a side elevation view of apparatus suitable for use in continuous drilling according to another example embodiment.

[0046] Figure 1C is an elevated perspective view of the apparatus suitable for use in continuous drilling according to the example embodiment of Figure 1B.

[0047] Figure 1D is a cross section through a portion of the deck of the apparatus of Figure 1B as taken at section B-B indicated in Figure 1B.

[0048] Figure 1E is a detail view showing an example arrangement for coupling an uphole end of a drill string to a reel.

[0049] Figure 2 is a cross section through a portion of a deck that may be incorporated into apparatus of the type shown in Figures 1A-1C.

[0050] Figure 3 is a cross section through a portion of a deck that includes holding actuators according to some example embodiments.

[0051] Figure 4 is a perspective view showing apparatus according to an example embodiment.

[0052] Figure 5 is an expanded partial view of a section of a reel of the continuous drilling apparatus of Figure 4 that includes a rotary drive terminating an uphole end of a drill string.

[0053] Figure 6 is a cross section through a deck of the apparatus of Figure 4.

[0054] Figure 7 is a side elevation view of the apparatus of Figure 4 with a tensioning apparatus located to control a tail of a drill string being retrieved from a drilling apparatus.

[0055] Figure 8 is an expanded partial view of a section of the reel of the continuous drilling apparatus of Figure 4 from which the drill string is fed to a drilling apparatus.

[0056] Figure 8A is a perspective view showing an example tensioner. Figure 8B shows an example arrangement of cam surfaces operable to move elevator plates to disengaged positions.

[0057] Figure 9 is a side elevation view of the apparatus of Figure 4 with a tensioning apparatus located to control a tail of a drill string being wound onto the reel.

[0058] Figure 10 is an expanded partial view of a section of the reel of the continuous drilling apparatus of Figure 9 showing the tensioning apparatus.

[0059] Figure 11 is a perspective view of a continuous drilling system according to an example embodiment that includes two reels.

[0060] Figure 12 is a table that provides example expected stresses for various sizes of drill pipe.

[0061] Figure 13 is a block diagram showing major elements of an example control system.

Detailed Description

[0062] Throughout the following description, specific details are set forth in order to provide a more thorough understanding of the invention. However, the invention may be practiced without these particulars. In other instances, well known elements have not been shown or described in detail to avoid unnecessarily obscuring the invention. Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive sense.

[0063] One aspect of this invention provides a system useful for subsurface drilling. The system exploits the fact that tubulars can be elastically bent and can be rotated while they are bent. Apparatus as described herein may be constructed such that tubulars are bent with a large enough radius that the yield point of the material (e.g. the point at which elastic deformation of the material transitions to plastic/inelastic deformation of the material) of the tubulars is not reached. For example, if a tubular is elastically deformed under a force, the tubular will return to its non-deformed shape after the force is released. On the other hand, if a tubular is inelastically deformed under a force, the tubular will maintain at least some of the inelastic deformation after the force is released. In some embodiments, a drill string is formed into a large-diameter coil. The drill string is fed from the coil to a drilling system. Apparatus according to some aspects of the invention includes the drilling system. Apparatus according to other aspects of the invention does not include the drilling system. The drilling system may support the weight of the portion of the drill string that is downhole when the drill string is being tripped into or out of a borehole.

[0064] Drilling may involve rotating the drill string from the surface, either to drive rotation of a drill bit or to steer the direction in which a borehole is being extended in the case of directional drilling. In some embodiments the drilling system drives rotation of the drill string. In other embodiments, rotation of the drill string is driven by the drill string management apparatus described below. In some embodiments both the drill string management apparatus and the drilling system both contribute to driving rotation of the tubular as drilling progresses.

[0065] It can also be desirable to rotate the drill string to make or break a threaded connection with another tubular or a drill string component. Rotation of the tubular for this purpose may be performed by either or both of the drilling system and the drill string management apparatus.

[0066] Figure 1A is a partially schematic illustration showing a drill string management apparatus 10 according to an example embodiment of the invention. In the illustrated embodiment, apparatus 10 comprises a reel 11 that stores a length of drill string 12 and supplies drill string 12 to a drilling system 20. Drill string 12 is wrapped around a circumference of reel 11 in a coil. The radius of the coil may be large enough that drill string 12 is not deformed plastically when it is wrapped around reel 11 of apparatus 10.

[0067] The minimum radius of curvature which can be achieved while keeping stresses within drill string 12 below a desired threshold will vary depending upon the diameter, wall thickness, and material from which drill string 12 is made. In some embodiments the radius is selected so that the maximum stress in drill string 12 remains below the yield point of the material of drill string 12 (the diameter may be chosen such that the maximum stress caused by winding drill string 12 around apparatus 10 and using apparatus 10 is less than a desired fraction of the yield point of the material of drill string 12).

[0068] The selected radius also affects fatigue in the material of drill string 12. As the radius of reel 11 is increased, the more cycles (e.g. more rotations about the longitudinal axis of drill string 12) can be performed without drill string 12 becoming susceptible to fatigue effects such as fatigue cracking. There is therefore a tradeoff of reduced diameter of reel 12 at the cost of reduced fatigue life of drill string 12. The fatigue life required of drill string 12 may depend on the intended application.

[0069] If the radius of curvature of drill string 12 is such that a maximum total stress in the material of drill string 12 when drill string 12 is coiled on reel 11 is less than the yield stress of the material by a safety factor of 2 ½ or 3 or more then the fatigue life may be effectively very long (for example, failure due to fatigue may not be expected for at least on the order of 10^7 cycles). In some embodiments the safety factor is 2 or more.

[0070] Reel 11 may, for example, be constructed in a manner similar to a Ferris wheel. Reel 11 in the illustrated embodiment has a plurality of spokes 15 which extend from a center of rotation 16 to a peripheral support deck 14 around which drill string 12 is wrapped. Reel 11 may be constructed such that support deck 14 can be rotated to feed drill string 12 to drilling apparatus 20 or rotated in the opposite direction to retrieve drill string 12 from drilling apparatus 20. Reel 11 is supported on a base 50.

[0071] Reel 11 may be constructed to allow rotation of a coiled drill string about an axis of the coil in various ways. For example:

- Reel 11 may be supported by an axle which extends transversely along axis of rotation 16. The axle may be supported by a suitable support structure. Bearings are provided to allow reel 11 to rotate relative to the axle and/or to allow the axle to rotate relative to the support structure.
- Reel 11 may be supported by rollers 19 which allow reel 11 to rotate as a unit.
- Support deck 14 may be rotatable relative to the rest of reel 11 which could be fixed. For example, support deck 14 may be coupled to the rest of reel 11 by rollers engaging a track.

[0072] In the illustrated embodiment, reel 11 comprises spokes 15 which extend radially from the vicinity of center of rotation 16 to peripheral support deck 14. In some embodiments, spokes 15 are paired at circumferential locations along reel 11, as best depicted in Figure 1C. The number of spokes 15 may be varied. For example some embodiments have 20 to 50 pairs of spokes.

[0073] In some embodiments, a spoke 15 may cross another spoke 15, as best depicted in Figure 1C. By crossing spokes 15, the bracing angle of spokes 15 may be increased thereby increasing the lateral stiffness of reel 11. Providing a reel 11 having a high lateral stiffness can assist in resisting wind loading as well as permit reel 11 to be tilted during erection.

[0074] Drill string 12 may wrap several times around peripheral support deck 14. In some embodiments support deck 14 has a width sufficient to accommodate 9 or more side-by side wraps of drill string 12. A non-limiting example embodiment is dimensioned to hold up to 12 wraps of drill string 12.

[0075] Drill string 12 may have a very significant continuous length. For example, the length of drill string 12 wrapped around peripheral support deck 14 may exceed 1,000 feet (about 300 meters). In some embodiments, each wrap of drill string section 12 around peripheral support deck 14 has a length of 750 feet (about 230 meters) or more. For example, where peripheral support deck 14 supports drill string 12 such that a center line of drill string 12 extends in coils having a diameter of approximately 3,500 inches (about 90 meters) approximately 900 feet (about 280 meters) of drill string 12 is stored in each wrap (full turn) of drill string 12 about peripheral support deck 14. In some embodiments reel 11 can carry 10000 feet (about 3 km) of drill string 12 or more.

[0076] Drill string 12 may comprise tubulars coupled together by threaded connections as are common in drilling operations (i.e. drill string 12 may be made of conventional jointed pipe). The threaded connections may comprise API standard threaded connections, for example. In some alternative embodiments, drill string 12 (or one or more parts of drill string 12) comprises tubulars that are welded together end-to-end. In some alternative embodiments, drill string 12 may comprise a continuous tubular.

[0077] In some embodiments, drill string 12 is made from tubulars that are welded together as opposed to tubulars that are coupled together at threaded couplings. The resulting tubular may be slimmer overall than a drill string assembled with threaded couplings since larger diameter upsets at the couplings are not required. The welding may be performed in advance and does not need to be done while drilling is occurring. Welding heat treatment and qualification of the welds may be executed offline, in advance for high efficiency and high weld integrity. Welding may be done away from well center outside of the hazardous zone.

[0078] Figure 1D illustrates one possible arrangement for peripheral support deck 14. In this embodiment, peripheral sport deck 14 has sufficient width to accept at least 12 wraps of drill string 12 in spaces 14A.

[0079] Figures 4, 7 and 9 are additional views of the example embodiment of the apparatus described above. Figure 5 shows a section of the reel 11 of Figure 4 including rotary head 30.

[0080] Figure 2 illustrates another possible arrangement for peripheral support deck 14. In this embodiment, peripheral support deck 14 has a width sufficient to accept at least six wraps of drill string section 12 (wraps 12-1 through 12-6 are shown in Figure 2).

[0081] Apparatus 10 is designed to allow drill string 12 to rotate about its axis, even as drill string 12 is wrapped in a coil around support deck 14 of apparatus 10. The entire length of drill string 12, including that part of drill string 12 that is wrapped around reel 11 may rotate about its longitudinal axis. One benefit of this construction is that drilling apparatus 20 may rotate drill string 12 about its longitudinal axis while the bore hole is being drilled while a part of drill string 12 is coiled around reel 11.

[0082] Rotation of drill string 12 about its longitudinal axis may be facilitated by providing a rotatable coupling at or near the uphole end of drill string 12. The rotatable coupling may be mounted to support deck 14 for example. The rotatable coupling may be threaded to engage a tool joint at the uphole end of drill string 12. Rotation of drill string 12 about its longitudinal axis may also be facilitated by providing guides that keep drill string 12 arranged in a coil while permitting the desired longitudinal rotation. It is not necessary for drill string section 12 to be supported continuously all the way around peripheral support deck 14.

[0083] In some embodiments, drill string section 12 is supported and guided by spaced apart sets of rollers 35. For example, the embodiment illustrated in Figures 1B and 1C has pairs of spokes 15 interconnected at their outer ends by 36 segments of peripheral support deck 14. Each segment of peripheral support deck 14 may, for example, comprise one, two, three, or more sets of rollers 35 spaced apart along the segment and located at a set radial distance from axis of rotation 16. Different sets of rollers 35 may be offset relative to one another in an axial direction so as to follow the helical wraps of drill string 12 on deck 14. In the embodiment illustrated in Figure 2, each wrap of drill string section 12 is supported by rollers 35 which allow drill string section 12 to rotate about its longitudinal axis as indicated by arrows 36.

[0084] As an alternative to providing some or all rollers 35, dry-sliding bearing supports may be provided at some or all locations along the peripheral support surface.

[0085] Some embodiments include a driven rotary head 30 on reel 11. Rotary head is operable to apply torque to drill string 12. For example, rotary head 30 may be coupled to the uphole end of drill string section 12. Rotary head 30 may anchor drill string 12 to support deck 14 and permit longitudinal rotation of drill string 12.

[0086] Typically, the direction of rotation imparted to drill string 12 by apparatus 20 as drilling is progressing is selected so that any threaded couplings lying in the portion of drill string 12 between drilling apparatus 20 and the drill bit are tightened by the rotation of drill string 12. As a result, any drag which tends to resist rotation of the part of drill string 12 wrapped around support deck 14 of reel 11 will apply torque to drill string section 12 in a direction that could tend to unscrew threaded couplings between adjacent sections of drill string 12. To counteract this tendency, rotary head 30 may be operated to apply torque to drill string 12 in a direction such that any threaded couplings in drill string 12 are not loosened.

[0087] Rotary head 30 may optionally be sized to deliver sufficient torque for drilling purposes and/or to augment the torque delivered by drilling system 20. One non-limiting example of a suitable rotary head is the Poclain MS83 hydraulic motor with hollow shaft option for fluid passage (available from POCLAIN HYDRAULICS INC of Sturtevant Wisconsin USA).

[0088] A manual and/or remotely actuated drill stem valve may be provided at rotary head 30. Such a valve may be shut, for example, to keep fluid from flowing up drill string 12 from a borehole in the event that the well ‘kicks’.

[0089] In some alternative embodiments rotary head 30 drives rotation of drill string 12. Delivery of full drilling torque by rotary head 30 may increase the equivalent cyclic stress levels of the rotating wrapped drill string 12. Rotary head 30 may also be employed to thread joints together/apart as tubulars are coupled onto or uncoupled from drill string 12 supported on reel 11.

[0090] Rotary head 30 may be controlled to exceed the torque imparted to drill string 12 by friction between drill string section 12 and the surfaces that support it on support deck 14. Advantageously, the torque delivered by rotary head 30 is sufficient to avoid negative torque (i.e. torque in a direction that would uncouple tool joints in drill string 12). In this case, primary drilling torque is delivered by drilling system 20. Optionally, rotary head 30 is configured to deliver sufficient torque to drill string 12 to permit drilling and/or joint make-up. In such embodiments, it may not be necessary for drilling system 20 to drive rotation of drill string 12.

[0091] For typical drilling tubulars having diameters in the range of 4 inches to 6 5/8 inches (about 10 to 17 cm) made of steel drill pipe having a yield strength in the range of 75 to 150 ksi, the diameter of peripheral support deck 14 is preferably in the range of 100 to 400 feet (about 30 to 125 meters). A measure of the maximum tubular bending stress (e.g. the stress that occurs in the outermost portions of the tubular) may be obtained by multiplying the elastic modulus of the material of the drill string by the pipe diameter and dividing by the diameter of peripheral support deck 14. For example, for 5 inch diameter drill pipe on a 250 foot diameter reel, the tubular bending stress σ_B is 30×10^6 lb/inch^2 $\times$ 5 inches $\div$3,000 inches =50,000 pounds/inch^2. Figure 12 shows example expected stresses for various sizes of drill pipe.

[0092] The drill string will also be under a small axial stress due to the tension in the drill string required to keep the drill string wrapped on reel 11. This axial stress will typically be in the range of 2,000 lb/inch^2. A hoop stress due to a pressure of drilling fluid inside the drill string would be expected to be in the order of 35,000 lb/inch^2, resulting in a maximum combined stress of 63,000 lb/inch^2. The material of drill string 12 may be selected to have a yield stress larger than the maximum expected combined stress by a suitable safety factor. In some embodiments the safety factor is at least 2 or at least 2 ½ or at least 3. Lower safety factors may be acceptable for some applications (e.g. applications where rotational duty is lower e.g. where rotation is performed primarily or entirely for steering a lower safety factor may be acceptable)..

[0093] In some embodiments, continuous rotation of drill string 12 by rotary head 30 (or another source) may not be necessary. For example, where a downhole mud motor is employed, drill string 12 may be rotated for steering purposes and for connecting additional lengths of drill string 12 and may not require continuous rotation. In such embodiments, the number of cyclic loads experienced by drill string 12 is lessened, thereby reducing the effect of fatigue on the material of drill string 12 and, for example, a drill string 12 of lower strength material or a reel 11 of smaller diameter may be employed.

[0094] Rotation of reel 11 is preferably controllable to maintain a desired level of tension on the portion of drill string 12 that is wrapped around reel 11 while drill string 12 is deployed into a borehole. When drill string 12 is being fed out (e.g. during drilling or tripping into a borehole) tension may be controlled by braking rotation of reel 11 and/or by controlling a system driving rotation of reel 11 to maintain the portion of drill string 12 on reel 11 at the desired level of tension. When drill string 12 is being fed onto reel 11 from a borehole tension may be maintained by controlling the system driving reel 11 to apply the desired level of tension to drill string 12.

[0095] Various arrangements are possible for driving rotation of reel 11. These include the following non-limiting examples:

- Providing a gear drive. For example a gear on reel 11 may be driven by pinions or worm gears. The pinions or worm gears may be driven in any suitable way. The gear on reel 11 may comprise gear teeth provided on a rim of reel 11 or a gear otherwise mounted to reel 11.
- Providing a chain drive using roller chain or round chain to drive a sprocket mounted to reel 11.
- Providing a tractive friction drive, for example by using driven rollers which may also support the rim of reel 11 or which may engage sides of the rim of reel 11, for example.
- Providing a high torque drive which drives an axle of reel 11.
- Providing a linear motor which drives a periphery of reel 14.
- Providing a ratchet mechanism actuated by a hydraulic actuator.

- Providing a winch or set of winches which pulls a cable wrapped around reel 11.
- Any combination of the above.

[0096] As drilling progresses, drill string 12 is unwound from reel 11 and supplied to drilling system 20. As this occurs, it is desirable to move reel 11 such that the point at which drill string 12 leaves the periphery of deck 14 is more or less aligned with the well center of the borehole. This may be achieved by moving reel 11 transversely (e.g. by moving reel 11 relative to the base 50 that supports it and/or by moving the base 50 that supports reel 11 relative to the ground or other structure). This movement may be linear, angular (e.g. pivoting about a generally vertical axis), or a combination thereof. For example, reel 11 may be supported by tracks or a walking support comprising walking feet of the general type provided on walking pad drilling rigs or walking draglines. A walking system may, for example, operate on a slide and reset or roll and reset principle. The walking feet may be operated to move reel 11 parallel to axis 16 as drill string 12 is fed out or reeled in. Figure 11 shows an example walking support 70 comprising walking feet 72. In an alternative embodiment support deck 14 is made wide enough that the coil of drill string 12 may be moved axially relative to apparatus 10 to keep drill string 12 adequately aligned with well center as it is payed out or wound in.

[0097] A tensioner may be provided to maintain drill string 12 in tension on reel 11 when drill string 12 is not engaged with drilling apparatus 20. The tensioner may be used to keep drill string 12 under tension as drill string 12 is built on reel 11 by adding tubulars to drill string 12. A tensioner may also be applied to facilitate the hand off of tension between reel 11 and drilling apparatus 20 (e.g. by positioning a tail end 12B of drill string 12 where it can be engaged by drilling system 20).

[0098] It can be convenient to construct apparatus 10 to facilitate adding sections to drill string 12 or removing sections from drill string 12 at a loading/unloading location other than the location at which drill string 12 leaves reel 11 during drilling. For example, apparatus 10 may be constructed to allow for tubular sections to be added to and/or removed from reel 11 at loading/unloading reel 11 at a pipe deck level at or near to ground level. A make/break unit may be provided at the loading/unloading location.

[0099] Figure 10 shows an example implementation in which the loading/unloading location is underneath reel 11. A make/break unit 47 is provided at the loading/unloading location. In some embodiments the make/break unit comprises a fixed jaw and a rotatable jaw. The fixed jaw may be closer to the point that drill string 12 wraps onto reel 11.

[0100] Some embodiments provide a tensioner that is movable between the loading/unloading location and a drill string delivery location. For example, the tensioner may move with reel 11 in order to transfer the tail end of a tubular 12 coiled around reel 11 to the drilling system 20. In such embodiments the tensioner may be placed at the loading/unloading location and used to tension drill string 12 as drill string 12 is built up by adding tubulars to the free end of drill string 12. While drill string 12 is being built up the tensioner may be secured to base 50 such that reel 11 can rotate independently of the tensioner. As drill string 12 is being built up, reel 11 is driven so that drill string 12 becomes wrapped in a coil around reel 11. When drill string 12 has reached a desired length, reel 11 may be rotated to bring the free end of drill string 12 to a position where it can be handed off to a drilling system 20. The tensioner may be moved together with reel 11 so that drill string 12 may be maintained under tension while reel 11 is rotated to bring the tail 12A of drill string 12 to a desired position (e.g. to a position at which the tail end 12A of drill string 12 may be engaged to a drilling system 20 or a position at which drill string 12 may be unloaded from reel 11.

[0101] In an example embodiment the tensioner is mounted to be movable around the periphery of reel 11 and can be selectively coupled to move with reel 11 or uncoupled from reel 11 and coupled to a fixed structure such as base 50. Figure 1A shows an example embodiment wherein apparatus 10 comprises a coupling 63A operable to selectively lock tensioner 60 to drilling system 20, a coupling 63B selectively operable to lock tensioner 60 to a point on the periphery of reel 11 and a coupling 63C selectively operable to lock tensioner 60 to base 50.

[0102] In some embodiments, the tensioner is mounted to a fender structure that is mounted to reel 11 near the periphery of reel 11 and rotatable about axis 16 independently of reel 11. The fender structure may be temporarily secured to reel 11 while reel 11 turns the tail 12B of drill string 12 up to a position for presentation to drilling system 20.

[0103] A tensioner may have any of a wide variety of forms. A simple tensioner comprises a choker sling that may be manually placed on the tubular tail and connected to a winch fixed to either reel 11 or base 50. Two such winch/sling arrangements may be used to enable a leap-frog process for maintaining drill string 12 in tension on reel 11 while adding/removing single joints or stands of two or more joints.

[0104] In an alternative embodiment a latching elevator is employed to tension drill string 12. Dual, common-axis tilting elevators separately actuated along a tensioner beam mounted to be movable around the periphery of reel 11 (e.g. at the end of a fender) may be employed for example. Such elevators may be operated in a leapfrog manner to extend the tail of tubular 12, unspooling the tubular from reel 11, for presenting to drilling system 20. Once the tail has been connected to drill string 12 in the well, the tensioner is not needed and can remain idle.

[0105] Pivoting tensioning elevators or other pipe engaging elements may be passive or active. Passive pipe engaging elements may require no external energy (hydraulic, pneumatic or electric) to engage with drill string 12. In the alternative, active elevator devices could be used. A drag chain or recoil arrangement may be applied to manage hoses or cables that supply power to active elevator devices. Tensioning could also be accomplished with opposing tractive rollers or with a tractive chain drive similar to that provided in some coiled tubing injectors.

[0106] Figure 8 shows an example tensioner 60 configured to present drill string 12 to drilling apparatus 20. Tensioner 60 comprises a tensioner arm 61 that is pivotally mounted to a fender bar 40 at end 61A. Tensioner arm 61 may have an arcuate profile, as shown. Drill string 12 may be received by and guided by a trough on tensioner arm 61. Tensioner arm 61 may be mounted to allow movement of tensioner arm 61 axially relative to reel 11. Tensioner arm 61 may be positioned axially so that its end connected to reel 11 is aligned with the axial location of the portion of drill string 12 that is passing onto tensioner 60. Some embodiments provide one or more actuators controlled to position tensioner arm 61 at the appropriate axial position and to move tensioner arm axially as drill string 12 is wound onto or unwound from reel 11.

[0107] Extendible actuator 45 is mounted to fender bars 40 and can be extended or retracted to maintain suitable alignment of drill string 12 with drilling system 20. Extendible actuator 45 may also be used to draw tensioner arm 61 closer to reel 11 to facilitate using tensioner 60 in a loading/unloading location in which there is reduced clearance between reel 11 and adjacent structures (e.g. the loading/unloading position may be between reel 11 and the ground).

[0108] Figure 8A is a more detailed view of a non-limiting example tensioner 60. In this embodiment, tensioner 60 comprises carriages 62A and 62B (collectively and generally carriages 62) that are each mounted to travel along tensioner arm 61. Carriages 62 may be actuated by any suitable actuators. In some embodiments carriages 62 are positioned using chain drives.

[0109] Carriages 62A and 62B each carry a pivotal elevator plate 63. Each elevator plate 63 comprises a slot 64 dimensioned to receive the main body of a tubular. Slots 64 are dimensioned to be smaller than tool joints at either end of the tubular. Elevator plates 63 are automatically folded out of the way when carriages 62 are fully retracted as shown in the position of carriages 62 illustrated in solid-lines in Figure 8A. Figure 8B illustrates an example embodiment in which cam surfaces 65 are located in the paths of elevator plates 63. When a carriage 62 is drawn toward its fully-retracted position the corresponding cam surface 65 contacts the corresponding elevator plate 63 and causes the elevator plate 63 to pivot to a position out of the way of drill string 12.

[0110] When one carriage 62 is being retracted the elevator plate 63 carried by the retracting carriage 62 deflects to allow the retracting carriage 62 to pass by the other carriage 62. This is shown in the dotted-line depiction of carriages 62 that is lowermost in Figure 8A.

[0111] Drill string 12 may be kept under tension while adding tubulars to the tail end of drill string 12 by engaging elevator plate 63 of one of carriages 62 with a tool joint near the tail end of drill string 12, attaching a new tubular to the tail end of drill string 12 (e.g. using a make/brake machine), extending the other one of carriages 62 to engage a tool joint toward the (now extended) tail end of drill string 12 and rotating reel 11 relative to tensioner 60 while retracting carriages 62. The process may be repeated to add another tubular to the tail end of drill string 12. This may be continued until reel 11 is full. The process may be reversed to remove tubulars from drill string 12.

[0112] Tensioner 60 may be adapted for tensioning a drill string that does not have enlarged tool joints (e.g. a drill string made up of tubulars welded-together at joints that do not project radially or do not project radially very much) by replacing elevator plates 63 with pipe engagement elements such as slips or grippers that can be passively or actively actuated to grip the tubulars.

[0113] Drilling fluid may be supplied to the uphole end 12A of drill string 12. In the illustrated embodiment, a drilling fluid supply system 18 comprises a standpipe 18A which delivers drilling fluid from pumps to a swivel joint 18B (which may comprise, for example, a commercially-available swivel joint such as a FMC Technologies TripleStep™ swivel joint) that is at center of rotation 16. Swivel joint 18B allows drilling fluid to continue to be delivered while reel 11 rotates. Swivel joint 18B couples standpipe 18A to a mudline 18C that extends to a further swivel joint 18D coupled to the end of drill string 12. Mudline 18C may optionally extend along a spoke 15 or replace a spoke 15. Swivel joint 18D allows drilling fluid to be delivered into a bore of drill string 12 while drill string 12 rotates about is longitudinal axis. Swivel joint 18D may, for example, comprise a washpipe packing system, a mechanical seal system, a commercially-available swivel joint such as a an oilfield swivel available from King Oil Tools of Enid, Oklahoma, USA or FMC Technologies TripleStep™ swivel joint. System 18 may supply drilling fluid continuously to drill string 12 as drilling progresses.

[0114] Figure 1E is a detail view showing an example rotary assembly 43 for coupling an uphole end of a drill string 12 to reel 11. This example arrangement includes a rotary head 30, a drilling fluid delivery line 18C that carries drilling fluid to pass through a bore of rotary head 30 by way of a rotary coupling 18D a manual valve 43A, a remotely-operated valve 43B and a wireline module 43C. Wireline module 43C provides an interface to an umbilical cable. Wireline module 43C may comprise wireless data transmitter configured to transmit data received from downhole locations on umbilical cable to surface equipment and/or to receive data and/or control signals from surface equipment and to apply corresponding signals to signal conductors in the umbilical cable.

[0115] A system as described herein may be used to maintain continuous circulation of drilling mud. It is not necessary to interrupt circulation of drilling mud every time drilling has progressed by the length of a section of drill string. This is advantageous for several reasons. These include the delta (change in) effective circulating density (ECD) associated with breaking circulation can be avoided. This allows tighter pressure control between the pore pressure constraint and the fracture pressure constraint. This can enable more efficient well design, especially in deep water, with fewer intermediate casing strings required.

[0116] Apparatus as described herein may optionally include one or more Please find attached drawings for discussion today. mechanisms or structures operative to hold drill string 12 in its coiled configuration around peripheral support deck 14 (e.g. in the unlikely event that the tensioner fails or drill string 12 breaks).

[0117] A range of possible safety features for holding drill string 12 in place wrapped in a coil-like fashion around reel 11 while allowing drill string 12 to be unwound from or wound back onto reel 11 include:

- Passive fender surfaces 41 extending around most of the circumference of reel 11. The fender surfaces 41 may be arranged to leave an opening at the point at which drill string 12 leaves reel 11 in order to reach drilling system 20. Sufficient clearance between the fender surfaces and the surfaces of peripheral support platform 14 may be provided to accommodate the largest size of tubular to be used for drill string 12, including any tool joints and couplings. Such fender surfaces may be mounted to a base, an axle of reel 11, or slidably mounted on the periphery of reel 11. The fender surfaces 41 may be continuous surfaces or discrete horizontal members such as fender bars 40 spaced circumferentially around reel 11.

- Active retention members may be provided which can be moved between a position in which they hold drill string 12 in place and a position in which drill string 12 can leave reel 11. For example, retention bars may be mounted on a rim of reel 11 parallel to and radially adjacent to some or all of a number of support roller cross bars. The retention bars may be selectably translatable in a direction parallel to the axis of reel 11 so that they can progressively capture each wrap of drill string 12 as it is wrapped around reel 11. In some embodiments, the retention bars may have limited radial clearance such that tool joints of drill string 12 are captured (i.e. the radial gap between the retention bars and the corresponding support roller crossbars may exceed the pipe body diameter but be less than the tool joint diameter of drill string 12).
- Active retainers may be provided for each wrap of drill string 12 around reel 11. The active retainer may comprise a movable member which can be manually, or remotely or automatically actuated to either retain a wrap of drill string 12 in position or to allow that portion of drill string 12 to be free to leave reel 11. In such embodiments, the operation of the active retainers may be synchronized to the rotation of reel 11 during drilling such that drill string 12 is retained all along its length by active retainers except for those near the point at which drill string 12 leaves reel 11. Examples of active retainers are elements 38 shown in Figure 3.

[0118] Figure 3 shows an example embodiment in which retaining members 38 hold each wrap of drill string 12 in contact with the rollers 35 which support it. In the illustrated embodiment, members 38 are mounted to rotate and include shafts 37 and arms 38A which may be rotated into one position in which drill string section 12 is held against rollers 35 and a second position in which member 38 does not block drill string section 12 from leaving rollers 35. Any of a wide range of mechanisms for keeping drill string 12 in its coiled configuration until it is time to spool drill string 12 off of apparatus 10 may be provided.

[0119] Figure 6 shows another example embodiment in which a fender bar 40 is slidable between tracks 42A and 42B that extend around reel 11. Adjacent wraps of drill string 12 are separated by dividers 44.

[0120] An umbilical cable containing conductors for carrying power and/or electrical control signals and/or optical control signals and/or electrical data signals and/or optical data signals may optionally be provided. The umbilical may include various types and combinations of conductors including conductors selected from electrical power cables, electrical data wires, optical fibers, hydraulic conduits, pneumatic conduits and the like. In some embodiments, an umbilical cable extends inside drill string 12. The umbilical cable may extend the full length of drill string 12 or along a portion of drill string 12. An umbilical cable may extend continuously along drill string 12. Sensors of suitable types may optionally be spaced apart along and/or located at one or more desired positions along the umbilical cable. The umbilical cable may be connected to supply electrical power to downhole apparatus such as downhole motors, tractors or actuators that may be incorporated into or attached to drill string 12.

[0121] In some embodiments, the umbilical cable carries power conductors (e.g. conductors of electrical or hydraulic or pneumatic power) of sufficient gauge to drive downhole devices such as one or a combination of a powered downhole motor that may be used for drilling, a steering device, a tractor device or the like. In some embodiments, the umbilical cable carries power conductors (e.g. conductors of electrical or hydraulic or pneumatic power) of sufficient gauge to drive a downhole tractor used to axially advance drill string 12 along a borehole. Such a configuration may have particular applications in horizontal wells. In some embodiments the umbilical cable carries signal conductors that supply a communication bus that extends the full length of drill string 12. The umbilical cable may provide bidirectional data communication along all or a portion of drill string 12.

[0122] The umbilical cable may, for example, comprise a number of electrical wires sheathed in a durable cladding that is resistant to downhole conditions. Since the umbilical cable may be provided in a continuous length (with few or no couplings), the umbilical cable may be relatively immune to connection problems. The umbilical cable may be applied to provide high bandwidth control and data connections in both directions and/or to supply power to downhole equipment. In some embodiments drill string 12 provides a return path for electrical power and/or electrical signals.

[0123] In some embodiments, the umbilical cable is continuously present within drill string 12. Other embodiments provide a mechanism by which the umbilical may be fed into or removed from drill string 12 either prior to or during drilling. In an example embodiment, an axial port and packing is provided in rotary head 30. The umbilical cable may be introduced into the interior of the drill string by way of this axial port. The packing may seal around the umbilical cable to prevent drilling fluid from escaping through the axial port. With an end of the umbilical inside the drill string, the umbilical cable may be carried into the drill string by the flow of drilling mud through the drill string.

[0124] In some embodiments, it may be desired to introduce a downhole probe or other downhole tool into the bore of the drill string. The umbilical cable may, for example, terminate at the downhole probe or tool. In such embodiments, two packing sets arranged in a lubricator arrangement may be optionally provided on the axial port. In other embodiments, an access lock having a structure like that of an airlock is provided. The access lock may comprise a section of conduit sized to accept the downhole probe with a valve at both ends. The downhole probe may be introduced into the conduit and then a packing may be sealed around the umbilical. After this has been done, the downhole probe may be introduced into the drill string by opening the other valve and pushing the downhole probe inwardly until the flow of drilling fluid begins to carry the downhole probe and the trailing umbilical cable down through drill string 12. Optionally, the umbilical cable is attached to a tractor (that may be powered by way of the umbilical cable) that can operate to pull the umbilical cable along drill string 12.

[0125] In some embodiments, the umbilical comprises a connector on its downstream end that is latched onto an associated electrical connection on a downhole tool which is part of a bottom hole assembly (BHA). In an example application the BHA is lowered into the borehole by drilling system 20 and then drill string 12 is coupled to an uphole end of the BHA.

[0126] In some embodiments, where no substantial rotation of drill string 12 is desired, the umbilical cable may extend out of the axial port at rotary head 30 and continue to an electric wireline reel. The wireline reel may, for example, be located at the base of reel 11. The umbilical cable may be paid out from or drawn into the wireline reel as necessary as drill string 12 is fed into the well and reel 11 turns.

[0127] Some embodiments provide two or more reels 11. In embodiments having multiple reels 11, wireline connectors may be provided such that umbilical cable lengths may correspond approximately to the tubular length wrapped on each reel 11. In this way, an umbilical may remain within a tubular, whether that tubular is being used in drill string 12 or not, thereby simplifying addition or removal of the tubular to drill string 12.

[0128] As noted above, in operation, drill string 12 may rotate about its longitudinal axis relative to reel 11 as drilling progresses. Additionally, reel 11 rotates as drill string 12 is fed into the borehole. Electrical connections with the umbilical may be maintained by providing rotary electrical couplings such as slip rings at rotary head 30 (or other rotatable coupling at the uphole end of drill string 12). For example, a cable may extend from a cable termination at or near the ground to the axis of rotation 16 of reel 11. A set of slip rings may transfer power and/or signals to conductors of a cable that extends from axis of rotation 16 to a set of slip rings at rotary head 30 which carry the power and/or signals to conductors of the umbilical cable.

[0129] In some embodiments, wireless communications may be used to communicate directly between a transmitter coupled to the up-hole end of the umbilical and other surface equipment. In some embodiments, the umbilical cable may comprise a connector at an uphole end thereof for terminating at a wireline sub above or below rotary head 30.

[0130] In some embodiments, pressure at the bottom hole assembly is monitored in real time via instrumentation that communicates to surface by way of an umbilical cable as described above. Hoist speed and/or mud pump pressure may be controlled automatically based at least in part on such real time pressure readings to minimize changes in equivalent circulating density (‘ECD’). In such embodiments, fluid flow through drill string 12 may be maintained while tripping drill string 12 out of a borehole. Pump pressure and/or flow rate may be controlled to reduce changes in ECD.

[0131] The ‘swab effect’ offsets the static gel strength effect of the drilling fluid. The swab effect results in a reduction in the downhole hydrostatic pressure due to fluid dynamic effects of drillstring upward movement through the fluid in the annulus. A similar ECD control process may be used to counteract the swab effect when tripping out of the well. Faster trip speed may be accomplished by avoiding the usual hoisting speed constraint due to swab effects. In some embodiments hoisting speed while tripping out of a borehole may be 3 feet/second or more.

[0132] In some alternative embodiments, the drill string 12 may be made of non-traditional materials. For example, drill string 12 may comprise a composite drill pipe (for example, a carbon fiber pipe body) for increased flexibility. In such embodiments, it may be possible to use a smaller diameter reel 11 while still avoiding non-elastic deformation of the drill string.

[0133] Although apparatus 10 may be large, apparatus 10 may be constructed in a manner that facilitates transportation from place-to-place as well as erection. For example, reel 11 may comprise multiple connected rim segments and pre-tensioned spokes. This construction may provide portability, a high capacity per weight ratio, and low wind loaded area. In some embodiments, reel 11 is made in a way that facilitates tilting the reel up, for example using two portable cranes for erection. In general, reel 11 and apparatus 10 may be erected using similar techniques as are used to erect other large structures such as wind power generators.

[0134] Some embodiments may provide multiple reels either mounted on a common axle or mounted side-by-side on separate axles. For example, Figure 11 shows apparatus 10A which includes reels 11A and 11B each of which may be constructed as described herein and each of which may support a coiled drill string. Such embodiments may permit one reel to be loaded with drill string while drilling using another reel. In some embodiments a single standpipe provides a supply of drilling fluid at the level of an axis of rotation of reels 11A and 11B that can be delivered to a drill string on either one of the reels by way of suitable valving. the common standpipe may, for example, be between reels 11A and 11B.

[0135] Providing plural or multiple reels at a drilling site, all of which can supply a drill string to a drilling system as described herein, may be advantageous by permitting plural or multiple drill string sizes or types to be prepared for drilling different parts of the well and/or to stage casing while drilling the well. Further, two or more reels may be arranged so that a longer section of drill string 12 may be wrapped as a single coil extending around a plurality of reels. This arrangement may minimize tail handling for deep trips. In such embodiments, sustained drill string rotation might be practical only for the last reel in some cases.

[0136] For example, in some embodiments a first length of drill string is wrapped around a first reel (e.g. a tensioner is placed into loading position, transitioned into a working position and tubulars are loaded on to the first reel). Once the first length of drill string is wrapped on the first reel, drilling may begin (as described herein and/or in any conventional manner). A second length of drill string may be wrapped around a second reel either contemporaneously, before or after the wrapping of the first length of drill string around the first reel. The second reel may then be aligned with the drilling apparatus such that drilling can continue with the second length of drill string. While drilling with the second length of drill string, the first reel can be re-loaded with a third length of drill string. In this manner, the first and second reels can be loaded, switched, and unloaded, as desired. A similar process could be employed for tripping out.

[0137] Alternatively or additionally, one of the first and second reels could be loaded up with casing and, once casing depth is reached or at another desired time, casing may be installed into the wellbore. Optionally, one or more lengths of drill string may be tripped out prior to installing casing into the wellbore.

[0138] In some embodiments a system as described herein may have more than two reels (e.g. three or four reels). In any embodiment with two or more reels a drill string may be loaded or unloaded on one reel concurrent with well operations with another reel. Some embodiments provide two or more reels holding drill strings and another casing staging reel. Casing may be loaded onto the casing staging reel while drilling progreses using one or more other reels.

[0139] Drilling system 20 may be any of a wide variety of drilling systems capable of supporting the weight of drill string 12 as drilling progresses. A drilling system may optionally have the capacity to drive rotation of drill string 12 as drilling progresses.

Drilling apparatus 20 that does not drive rotation of drill string 12 may optionally be used in cases where rotation of drill string 12 is driven by rotary head 30 or drilling is performed using a mud motor or electrical motor without rotating drill string 12. One example of apparatus capable of being used as drilling system 20 is described in PCT international application publication WO 2016/197255 which is hereby incorporated herein by reference. This drilling system 20 provides elevators for supporting drill string 12 and for allowing rotation (continuous or not) of drill string 12 while supporting drill string 12. Another example of drilling apparatus that may be used for drilling system 20 is apparatus like that described in US Patent No. 8844616.

[0140] In some embodiments, drilling system 20 comprises plural elevators that can individually bear the weight of a portion of drill string 12 that is downhole and hoists operable to transfer the weight of the drill string from one of the elevators to another (e.g. by raising one elevator relative to another). The elevators may engage drill string 12 at spaced apart locations. In some embodiments motions of the elevators are coordinated to provide continuous or substantially continuous raising or lowering of drill string 12 into a borehole.

[0141] In some embodiments, drilling system 20 comprises a tower, a pair of parallel chain loops supported for circulation on the tower, a drive connected to circulate the chain loops, a plurality of crossheads connected pivotally between the chain loops at spaced-apart locations along the chain loops, each of the crossheads supporting an elevator for a tubular string and one or more actuators coupled to adjust an elevation of each elevator relative to the chain loops. A tubular string may be tripped by moving the chain loops to cause the elevators to circulate along a closed path and while moving the chain loops, engaging a first location on the tubular string with a first one of the elevators, supporting a weight of the tubular string on the first one of the elevators, supporting a second location of the tubular string with a second one of the elevators, and transferring the weight of the tubular string to the second one of the elevators.

[0142] To allow drill string 12 to extend upward from the well bore toward reel 11, drilling system 20 may comprise an unimpeded well center area above the hoist elevator (or equivalent). This can be accomplished, for example, with split traveling blocks, a rack and pinion hoist or a hydraulic hoist. If drilling system 20 is equipped with a top drive, the top drive may be laterally shiftable to clear well center for the tubular. Alternately, the quill of some traditional top drive models (e.g. The Warrior™ model 500E) could be extracted and its drilling fluid delivery system (i.e. the washpipe, glands, and gooseneck) removed to leave a center bore passage through the spindle through which drill string 12 may be passed.

[0143] Drilling system 20 may also comprise a traveling, rotatable hoisting support for the drill string. Such support could take the form of conventional shoulder elevators supporting upset tool joints, or slips supporting the pipe body. In the case of an open-bore top drive, an elevator or bowl plus slips resting on top of the spindle may support the tubular. If the top drive is one equipped with an ICD (integrated casing drive) system as described, for example in US patent application publication US 2014/0131052 AI which is hereby incorporated herein by reference for all purposes. Such a system may include a pipe handler elevator that can support drill string 12 and allow rotation of drill string 12. The ICD system may also be used to grip a tool joint and rotate the drill string.

[0144] In some embodiments, a casing string is pre-built on an offline reel 11 by welding sections of casing together. The casing string may comprise regular or expandable casing. In this way, the process of expanding the casing once downhole may be made easier as compared to the difficulties associated with expanding casing of the type that includes threaded couplings. This may improve the expandability of the casing and allow for a reduction of the diameter of the casing string thereby requiring less casing material and smaller initial boreholes.

[0145] Apparatus 10 may optionally provide a means to keep the portion of drill string 12 that is coiled around reel 11 above a threshold temperature (e.g. to prevent freezing of fluid contained within drill string 12). In an example embodiment, warm air is introduced into an annular chamber defined by an inner fender surface and the periphery of reel 11 at one or more points along its circumference, typically at or near ground level. The heated annular chamber surrounding the coiled tubular may prevent freezing of the tubular and its contained drilling fluid in cold weather operations. In this and other embodiments an umbilical may optionally contain a heating element that may be energized to help to keep fluid inside drill string 12 from freezing.

[0146] Advantageously, embodiments may permit interaction with drill string 12 virtually anywhere along its length. For example, a joint partway along drill string 12 may be unmade by drilling system 20 and a downhole tool or other sub may be inserted. Furthermore, drill string 12 may be broken at any point and drilling operations may continue by adding tubulars or stands of tubulars one by one to the uphole end of that part of the drill string that is in the borehole. Other devices such as subs of any types, stablilzers, reamers or the like may also be added into drill string 12 in this manner. At any point the disconnected end of the portion of drill string 12 may be reconnected to the portion of drill string 12 that extends into the borehole and continuous drilling or tripping may be resumed. In another example embodiment, a drilling system may be used to drill a first portion of a borehole by adding individual tubulars or stands of tubulars to the drill string. This drilling may be performed at relatively high RPM. At a selected depth drill string 12 from reel 11 may be connected into the drill string that is in the borehole and drilling may resume, this time by rotating the entre drill string 12 including the portion that is coiled around reel 11.

[0147] Figure 13 shows an example control system 110 for an example apparatus as described herein. Control system 110 includes a controller 112 (which may, for example, comprise a programmed computer, one or more PLCs, a distributed control system, hard wired logic circuits, configurable logic circuits or the like). Controller 112 controls operation of reel drive motor(s) 114. Drive motors 114 may be controlled to drive rotation of reel 11 and/or to apply torque to reel 11 to maintain a desired tension in the portion of drill string 12 coiled onto reel 11. A sensor 115 provides a signal to controller 112 indicative of tension in the portion of drill string 12 on reel 11. Sensor 115 may, for example, comprise one or more load cells, strain gauges or the like connected to monitor a force applied by drill string 12 to rotary head 30 or another device to which drill string 12 is connected.

[0148] In the embodiment shown in Figure 13, control system 110 includes rotary head 30 and a motor 116 of drilling system 20 that is operable to rotate drill string 12. controller 112 may control rotary head 30 and/or motor 116 to rotate drill string 12 about its longitudinal axis and/or to maintain a desired torque on the portion of drill string 12 coiled onto reel 11 such that connections between tubulars of drill string 12 do not become undone.

[0149] In the embodiment shown in Figure 13, controller 112 controls mud pump(s) 118 and remotely-operated valve 43B. In the illustrated embodiment, controller 112 is connected to receive readings from one or more downhole pressure sensors 119 by way of umbilical cable 120. Controller 112 may, in addition or in the alternative receive pressure readings by another telemetry system such as a mud pulse, electromagnetic, ultrasonic or wired drillpipe data telemetry system. In some modes of operation, controller 112 may control mud pumps 118 and/or valve 43B and/or based on signals from pressure sensor(s) 119.

[0150] Apparatus as described herein is particularly well adapted to mud-pulse telemetry because a continuous flow of drilling fluid may be maintained. A pressure sensor for receiving mud pulse telemetry signals from a pressure sensor or other downhole equipment

[0151] In the embodiment shown in Figure 13, controller 112 controls the hoisting system 122 of drilling system 20 to adjust the rate at which drilling system 10 raises or lowers drill string 12 into a borehole. Controller 112 may optionally set this rate based in part on pressure readings from pressure sensor(s) 119 and may control drive motor 114 in coordination with hoisting system 122 to maintain desired tension on the coiled portion of drill string 12.

[0152] In other embodiments control system 110 may provide more or less automation and/or control of additional elements and/or control of fewer elements than the embodiment depicted in Figure 13.

<u>Interpretation of Terms</u>

[0153] Unless the context clearly requires otherwise, throughout the description and the claims:

- “comprise”, “comprising”, and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”;

- “connected”, “coupled”, or any variant thereof, means any connection or coupling, either direct or indirect, between two or more elements; the coupling or connection between the elements can be physical, logical, or a combination thereof;
- “herein”, “above”, “below”, and words of similar import, when used to describe this specification, shall refer to this specification as a whole, and not to any particular portions of this specification;
- “or”, in reference to a list of two or more items, covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list;
- the singular forms “a”, “an”, and “the” also include the meaning of any appropriate plural forms.

[0154] Words that indicate directions such as “vertical”, “transverse”, “horizontal”, “upward”, “downward”, “forward”, “backward”, “inward”, “outward”, “vertical”, “transverse”, “left”, “right”, “front”, “back”, “top”, “bottom”, “below”, “above”, “under”, and the like, used in this description and any accompanying claims (where present), depend on the specific orientation of the apparatus described and illustrated. The subject matter described herein may assume various alternative orientations. Accordingly, these directional terms are not strictly defined and should not be interpreted narrowly.

[0155] While processes or blocks are presented in a given order, alternative examples may perform routines having steps, or employ systems having blocks, in a different order, and some processes or blocks may be deleted, moved, added, subdivided, combined, and/or modified to provide alternative or subcombinations. Each of these processes or blocks may be implemented in a variety of different ways. Also, while processes or blocks are at times shown as being performed in series, these processes or blocks may instead be performed in parallel, or may be performed at different times.

[0156] In addition, while elements are at times shown as being performed sequentially, they may instead be performed simultaneously or in different sequences. It is therefore intended that the following claims are interpreted to include all such variations as are within their intended scope.

[0157] Where a component (e.g. a roller, support, motor, assembly, device, elevator, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a “means”) should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0158] Specific examples of systems, methods and apparatus have been described herein for purposes of illustration. These are only examples. The technology provided herein can be applied to systems other than the example systems described above. Many alterations, modifications, additions, omissions, and permutations are possible within the practice of this invention. This invention includes variations on described embodiments that would be apparent to the skilled addressee, including variations obtained by: replacing features, elements and/or acts with equivalent features, elements and/or acts; mixing and matching of features, elements and/or acts from different embodiments; combining features, elements and/or acts from embodiments as described herein with features, elements and/or acts of other technology; and/or omitting combining features, elements and/or acts from described embodiments.

[0159] It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions, omissions, and sub-combinations as may reasonably be inferred. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

WHAT IS CLAIMED IS:

1. Apparatus for drilling, the apparatus comprising:

a reel mounted for rotation about an axis;

a coupling mounted on the reel, the coupling configured for attachment to an uphole end of a drill string and rotatable relative to the reel to allow rotation of the attached drill string around a longitudinal axis of the drill string while the drill string is coiled around the reel.

2. Apparatus according to claim 1 wherein a material of the drill string has a yield point and a minimum radius of curvature of the reel is sufficiently large that a maximum stress of the drill string is less than the yield point.

3. Apparatus according to claim 2 wherein the maximum stress of the drill string is less than the yield point by a safety factor of 2 or more.

4. Apparatus according to any one of claims 1 to 3 wherein the coupling comprises a rotary drive.

5. Apparatus according to claim 1 to 4 comprising a drilling fluid supply system connected to supply drilling fluid to the uphole end of the drill string.

6. Apparatus according to claim 5 wherein the drilling fluid supply system comprises a first standpipe extending to a first rotary coupling, a radially-extending conduit extending from the first rotary coupling to a peripheral portion of the reel, the radially extending conduit in fluid communication with a bore of the drill string by way of a second rotary coupling.

7. Apparatus according to any one of claims 1 to 6 comprising a tensioner operable to apply tension to a tail end of the drill string.

8. Apparatus according to claim 7 wherein the tensioner is mounted to the reel

and is movable circumferentially relative to the reel.

9. Apparatus according to claim 7 or 8 wherein the tensioner comprises a tensioner arm extending at an angle to a radius of the reel such that the tensioner arm extends generally tangentially to the reel.

10. Apparatus according to claim 7 comprising a an extendible actuator coupled between the tensioner arm and the reel, the extendible actuator operable to alter the angle by moving a distal end of the tensioner arm radially toward or away from the reel.

11. Apparatus according to claim 10 wherein the tensioner arm is curved.

12. Apparatus according to any one of claims 8 to 11 wherein the tensioner comprises first and second carriages mounted to travel along the tensioner arm, each of the first and second carriages comprising a pipe engaging element, and actuators coupled to move the first and second carriages along the tensioner arm.

13. Apparatus according to claim 12 wherein the pipe engaging elements comprise elevator plates pivotally mounted to the carriages, the elevator plates comprising cutouts having edge contours dimensioned to receive portions of the drill string between joints of the drill string.

14. Apparatus according to claim 12 or 13 wherein the actuators comprise first and second chain drives respectively connected to position the first and second carriages.

15. Apparatus according to any one of claims 1 to 14 comprising a sensor configured to provide a signal to a controller, the signal indicative of a tension in at least a portion of the drill string and wherein the controller is configured to control the tensioner based at least in part on the signal.

16. Apparatus according to any one of claims 1 to 15 comprising an umbilical cable extending along at least part of the drill string, the umbilical cable comprising a

plurality of conductors, the conductors of the umbilical cable connected to corresponding conductors mounted to the reel by way of a rotary connection.

17. Apparatus according to claim 16 wherein the umbilical cable extends along substantially all of the drill string.

18. Apparatus according to claim 16 wherein the umbilical cable extends along less than an entire length of the drill string.

19. Apparatus according to any one of claims 16 to 18 wherein the umbilical cable carries electrical power.

20. Apparatus according to claim 19 wherein the umbilical cable carries electrical power via a hydraulic conduit.

21. Apparatus according to claim 19 wherein the umbilical cable carries electrical power via a pneumatic conduit.

22. Apparatus according to any one of claims 19 to 21 wherein the umbilical cable carries electrical power to a downhole tractor for axially advancing the drill string.

23. Apparatus according to any one of claims 16 and 22 wherein the umbilical cable carries optical control signals.

24. Apparatus according to any one of claims 16 to 23 wherein the umbilical cable carries electrical control signals.

25. Apparatus according to any one of claims 16 to 24 comprising a pressure sensor connected to deliver downhole pressure readings to surface equipment by way of one or more of the conductors of the umbilical cable.

26. Apparatus according to any one of claims 1 to 25 wherein the drill string comprises a plurality of tubulars coupled together.

27. Apparatus according to claim 26 wherein the plurality of tubulars are coupled together by welding.

28. Apparatus according to claim 26 wherein the plurality of tubulars are coupled together by threaded joints.

29. Apparatus according to claim 26 wherein the plurality of tubulars are coupled together by shrink fit connections.

30. Apparatus according to any one of claims 1 to 29 wherein the drill string has an outside diameter of 4 inches or more.

31. Apparatus according to any one of claims 1 to 30 wherein the reel comprises rollers that support the drill string and the rollers are oriented to rotate when the drill string is rotated about the longitudinal axis of the drill string.

32. Apparatus according to claim 31 wherein the rollers are arranged in sets of rollers spaced circumferentially around the reel and different sets of the rollers are offset relative to one another in an axial direction relative to the reel so as to follow helical wraps of the drill string on the reel.

33. Apparatus according to any one of claims 1 to 32 wherein the reel comprises a peripheral support surface and the peripheral support surface comprises one or more dry-sliding bearing supports to support and allow rotation of the drill string on the reel.

34. Apparatus according to any one of claims 1 to 33 wherein the reel has a width sufficient to accommodate at least 6 wraps of the drill string.

35. Apparatus according to any one of claims 1 to 34 wherein the reel comprises a support deck rotatable about the axis relative to at least a portion of the reel.

36. Apparatus according to any one of claims 1 to 35 wherein the reel has a

diameter of at least 30 meters.

37. Apparatus according to claim 36 wherein the reel has a diameter of at least 50 meters.

38. Apparatus according to claim 37 wherein the reel has a diameter in the range of about 30 to 125 meters.

39. Apparatus according to any one of claims 1 to 38 comprising a fender structure extending around a periphery of the reel, the fender structure rotatable about the axis of the reel independently of the reel.

40. Apparatus according to claim 39 wherein the fender structure comprises circumferentially spaced-apart bars spaced radially outwardly from the support deck.

41. Apparatus according to claim 39 wherein the fender structure comprises a wall spaced radially outwardly from the support deck.

42. Apparatus according to claim 41 wherein the wall covers one side of an annular enclosure around the support deck wherein the apparatus comprises a heater arranged to heat an interior of the annular enclosure.

43. Apparatus according to claim 42 wherein the wall is thermally insulated.

44. Apparatus according to any one of claims 1 to 38 wherein the reel comprises one or more active retention members, each active retention member operable between a first configuration in engagement with the drill string to prevent the drill string from moving away from the reel and a second configuration in which the drill string is free to move away from the reel.

45. Apparatus according to any one of claims 1 to 44 wherein the drill string comprises 100 or more tubulars coupled end to end.

46. Apparatus according to any one of claims 1 to 45, the apparatus comprising a drilling system comprising plural elevators arranged to carry the weight of a portion of the drill string that is downhole and hoists operable to transfer the weight of the drill string from one of the elevators to another.

47. Apparatus according to any one of claims 1 to 45, the apparatus comprising a drilling system comprising:

a tower;

a pair of parallel chain loops supported for circulation on the tower;

a drive connected to circulate the chain loops;

a plurality of crossheads connected pivotally between the chain loops at spaced-apart locations along the chain loops, each of the crossheads supporting an elevator for a tubular string; and

one or more actuators coupled to adjust an elevation of each elevator relative to the chain loops.

48. Apparatus according to claim 46 or 47 wherein the elevators are rotatable.

49. Apparatus according to any one of claims 1 to 48 comprising:

a second reel mounted for rotation about a second axis;

a second coupling mounted on the second reel, the second coupling configured for attachment to an uphole end of a second drill string and rotatable relative to the second reel to allow rotation of the attached second drill string around a longitudinal axis of the second drill string while the second drill string is coiled around the second reel.

50. Apparatus according to claim 49 comprising a second tensioner operable to apply tension to a tail end of the second drill string.

51. A method for deploying a drill string into a borehole, the method comprising:

providing a drill string arranged to lie along a curving path outside of and adjacent to a borehole, extending a tail end portion of the drill string into the borehole, each point of the curving path having a radius of curvature greater than a threshold radius such that the drill string is elastically bent to follow the curving path; and

rotating the drill string about a longitudinal axis of the drill string while the drill string lies along the curving path.

52. A method according to claim 51, comprising rotating the drill string about the longitudinal axis while tripping the drill string into or out of the borehole.

53. A method according to claim 51 or 52 comprising providing a drill bit coupled to the tail end of the drill string, and rotating the drill string about the longitudinal axis while allowing the drill bit to extend into the borehole.

54. A method according to claim 53 comprising flowing a drilling fluid through the drill string.

55. A method according to claim 54 wherein flowing the drilling fluid through the drill string is performed while rotating the drill string about the longitudinal axis.

56. A method according to claim 54 wherein flowing the drilling fluid through the drill string is performed while tripping the drill string into or out of the borehole.

57. A method according to claim 54 comprising monitoring a pressure of the drilling fluid in real time at a location proximate the tail end of the drill string and controlling a flow of the drilling fluid based at least in part on the monitored pressure.

58. A method according to any one of claims 51 to 57 wherein arranging the drill string to follow the curved path comprises wrapping the drill string around a first reel to form a coil around the reel.

59. A method according to claim 58 wherein the first reel has a diameter of at least 30 meters.

60. A method according to claim 58 wherein the first reel has a diameter of at least

50 meters.

61. A method according to claim 58 wherein the first reel has a diameter in the range of about 30 to 125 meters.

62. A method according to any one of claims 58 to 61 wherein wrapping the drill string around the first reel comprises making at least 4 wraps of the drill string around the first reel.

63. A method according to any one of claims 58 to 62 comprising supporting a weight of a portion of the drill string that is in the borehole by an elevator of a drilling system adjacent to the first reel.

64. A method according to claim 63 wherein rotating the drill string about the longitudinal axis comprises applying a first torque to a portion of the drill string passing through the drilling system.

65. A method according to claim 64 comprising, while rotating the drill string about the longitudinal axis applying a second torque to an uphole end of the drill string on the first reel.

66. A method according to claim 63 wherein rotating the drill string about the longitudinal axis comprises applying a torque to an uphole end of the drill string.

67. A method according to any one of claims 58 to 66 further comprising removing the tail end portion of the drill string from the borehole and rotating the first reel to wrap the tail end portion of the drill string onto the first reel and operating a tensioner on the first reel to maintain the drill string under tension.

68. A method according to any one of claims 51 to 67 wherein the drill string has a diameter of about 4 inches (about 10 cm) or more.

69. A method according to any one of claims 51 to 68 wherein the drill string

comprises 100 or more tubulars coupled end to end.

70. A method according to claim 69 wherein the one or more tubulars are coupled end to end by shrink fit connections.

71. A method according to claim 69 wherein the one or more tubulars are coupled end to end by threaded joints.

72. A method according to claim 69 wherein the one or more tubulars are coupled end to end by welding.

73. A method according to claim 54 comprising feeding an umbilical cable into an interior of the drill string and carrying the cable into the drill string by flowing the drilling fluid.

74. A method according to any one of claims 51 to 73 comprising aligning a support deck of the first reel with a well center of the borehole.

75. A method according to any one of claims 51 to 73 comprising wrapping a second drill string around a second reel to form a second coil around the second reel.

76. A method according to claim 75 comprising moving the first reel away from a well center of the borehole and aligning a support deck of the second reel with the well center of the borehole.

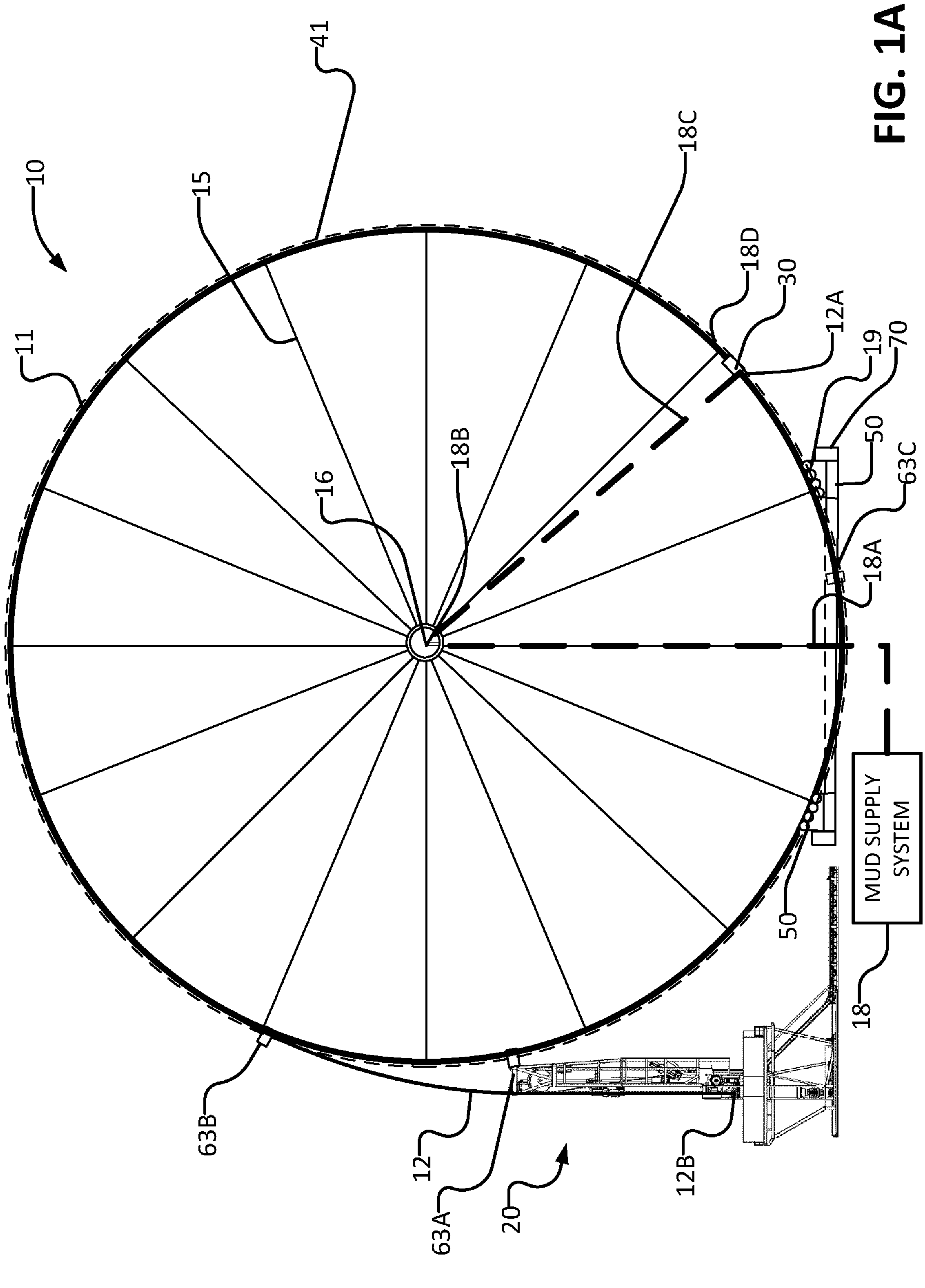
77. A method according to claim 76 comprising extending a tail portion of the second drill string into the borehole and rotating the second drill string about a longitudinal axis of the second drill string while the second drill string forms the second coil around the second reel.

78. A method according to any one of claims 75 to 77 comprising wrapping a casing around one or both of the first and second reels and installing the casing in the borehole.

79. A method according to any one of claims 51 to 66 and 69 to 78 comprising:
stopping rotation of the first reel;
operating a tensioner on the first reel to maintain the drill string under tension;
uncoupling first and second tubulars of the drill string;
installing a stabilizer on the first tubular;
re-coupling the first and second tubulars; and
disengaging the tensioner and restarting rotation of the first reel.

80. Apparatus having any new and inventive feature, combination of features, or sub-combination of features as described herein.

81. Methods having any new and inventive steps, acts, combination of steps and/or acts or sub-combination of steps and/or acts as described herein.


10
11
15
41
16
18B
18C
18D
30
12A
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70
50
63C
18A
50
MUD SUPPLY SYSTEM
18
63B
12
63A
20
12B

FIG. 1A

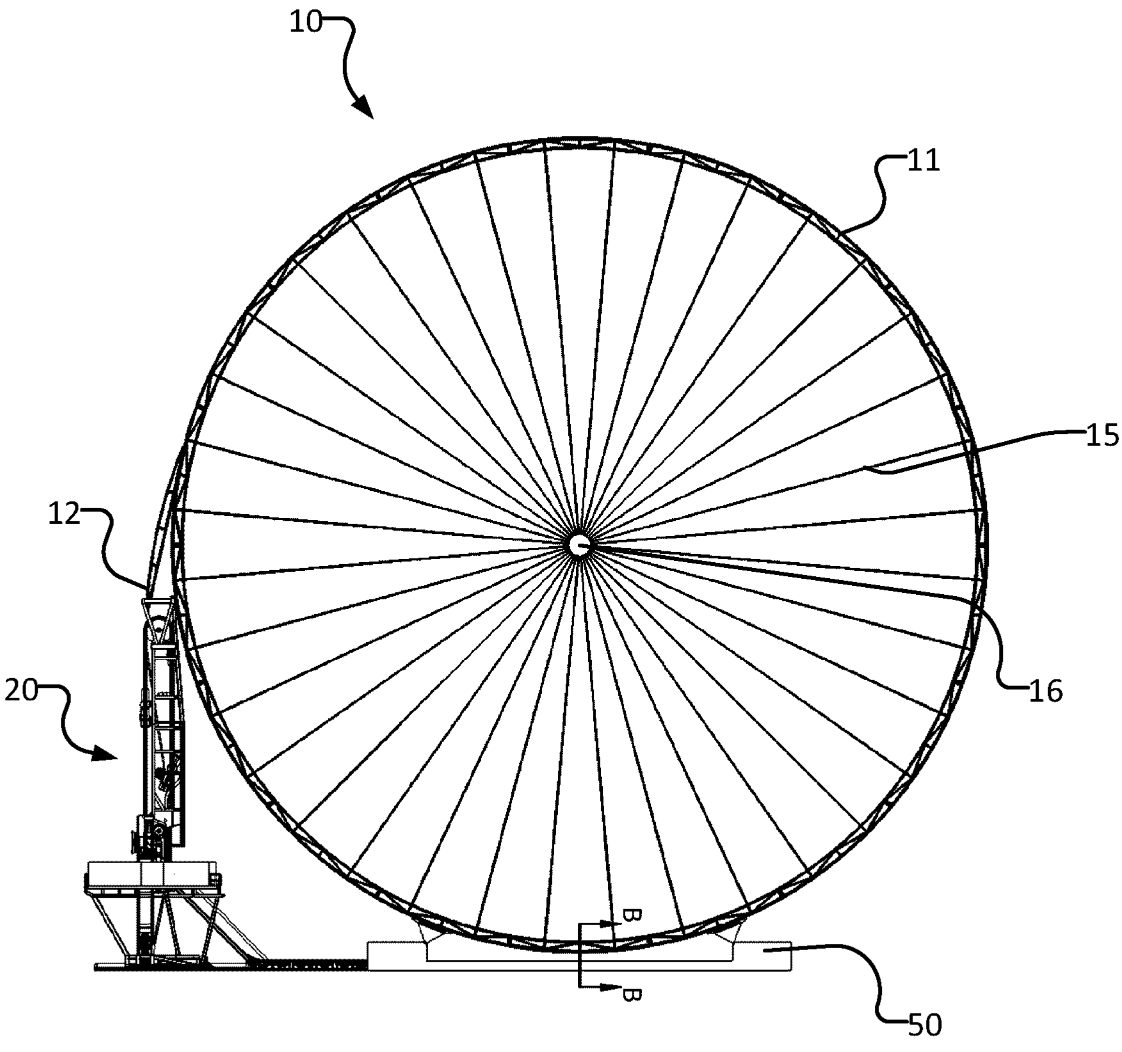

FIG. 1B

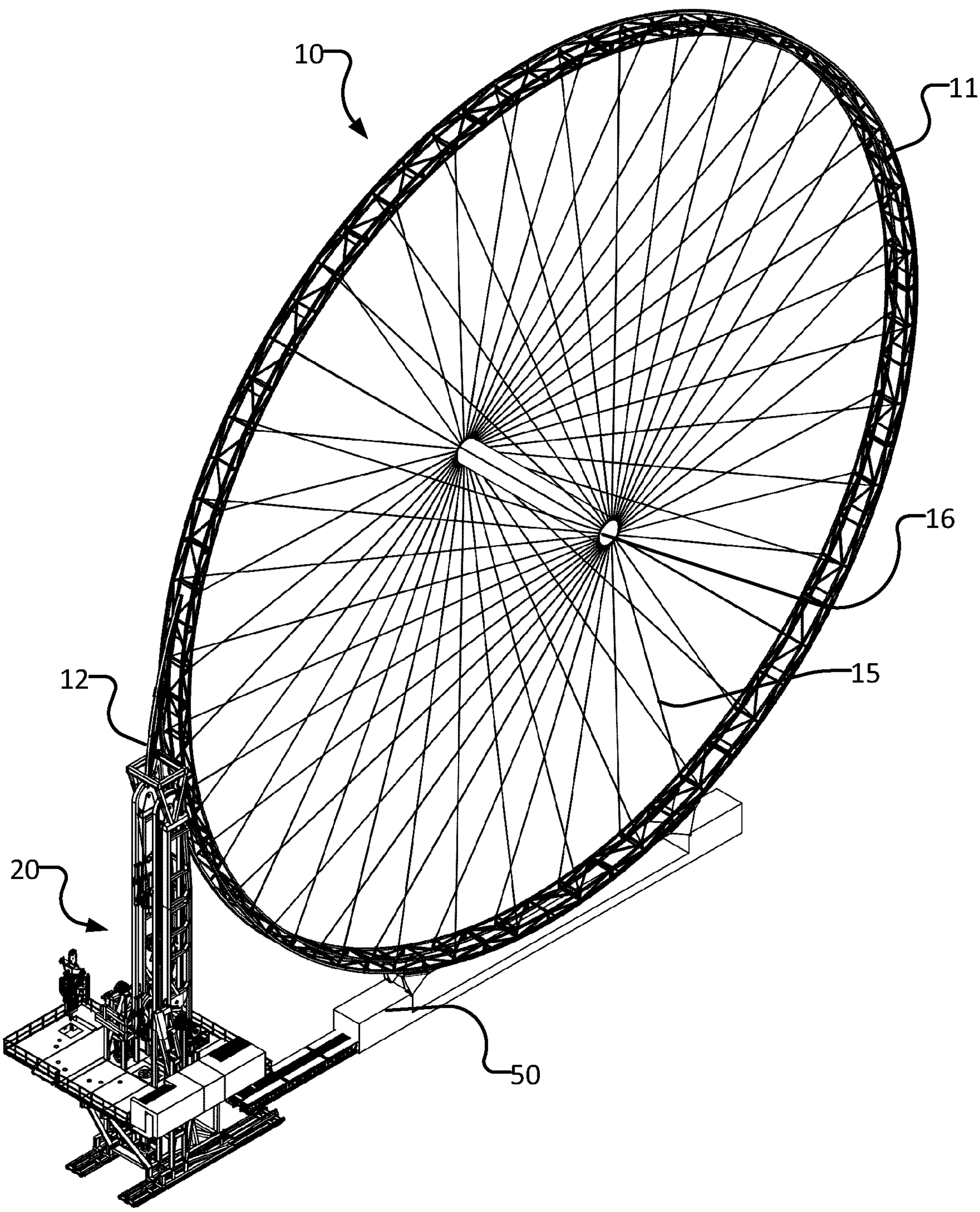

FIG. 1C

SECTION B-B

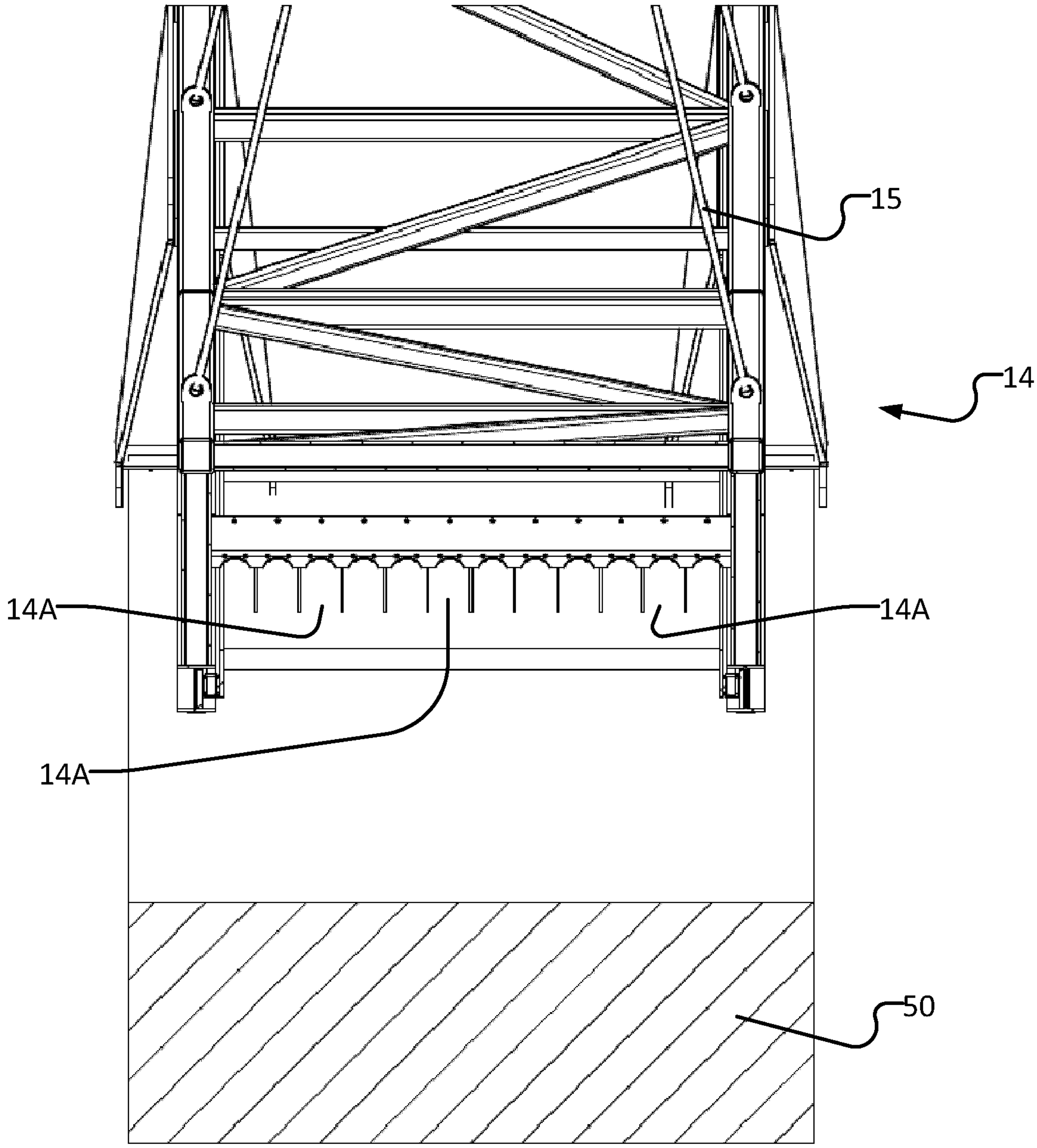

FIG. 1D

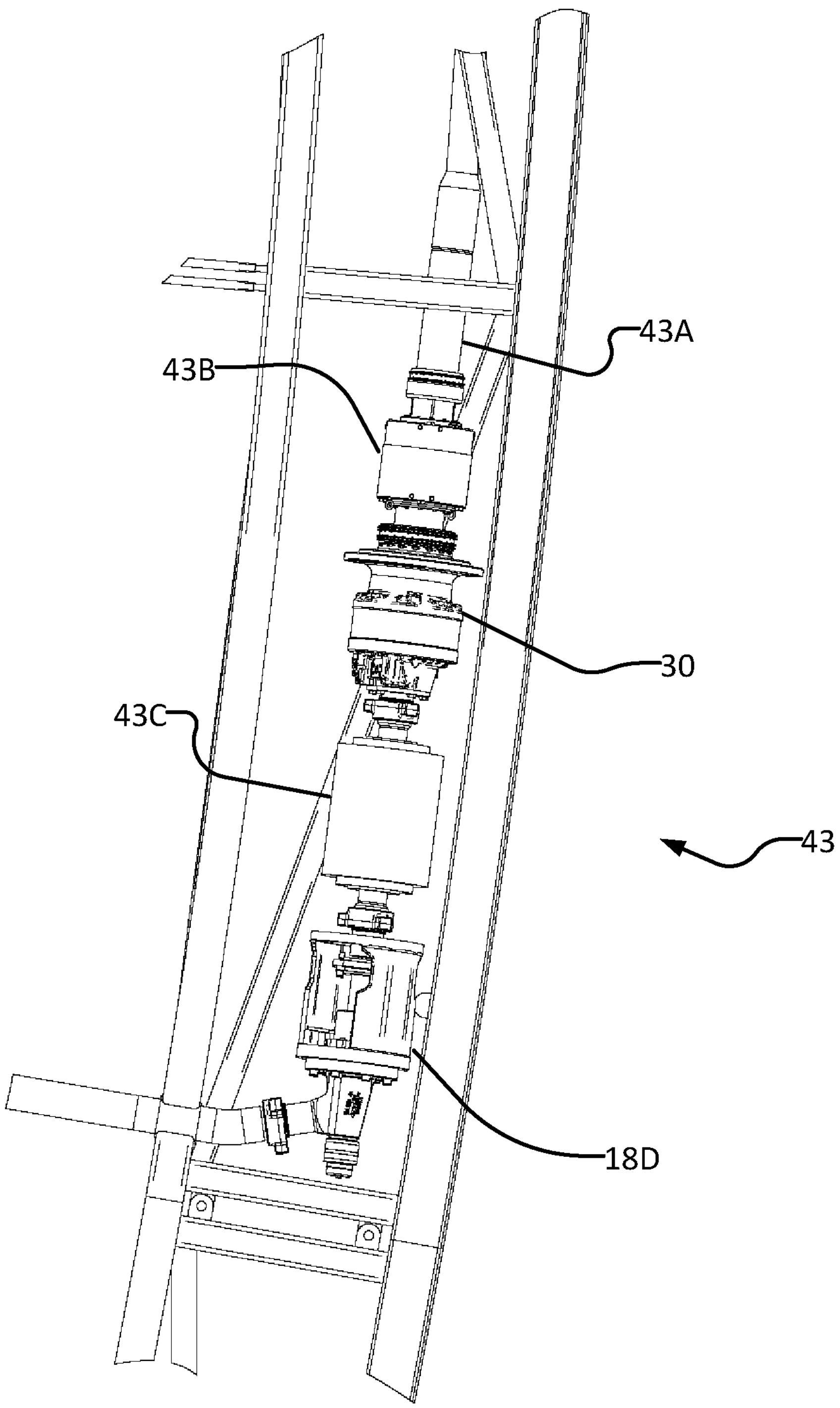

FIG. 1E

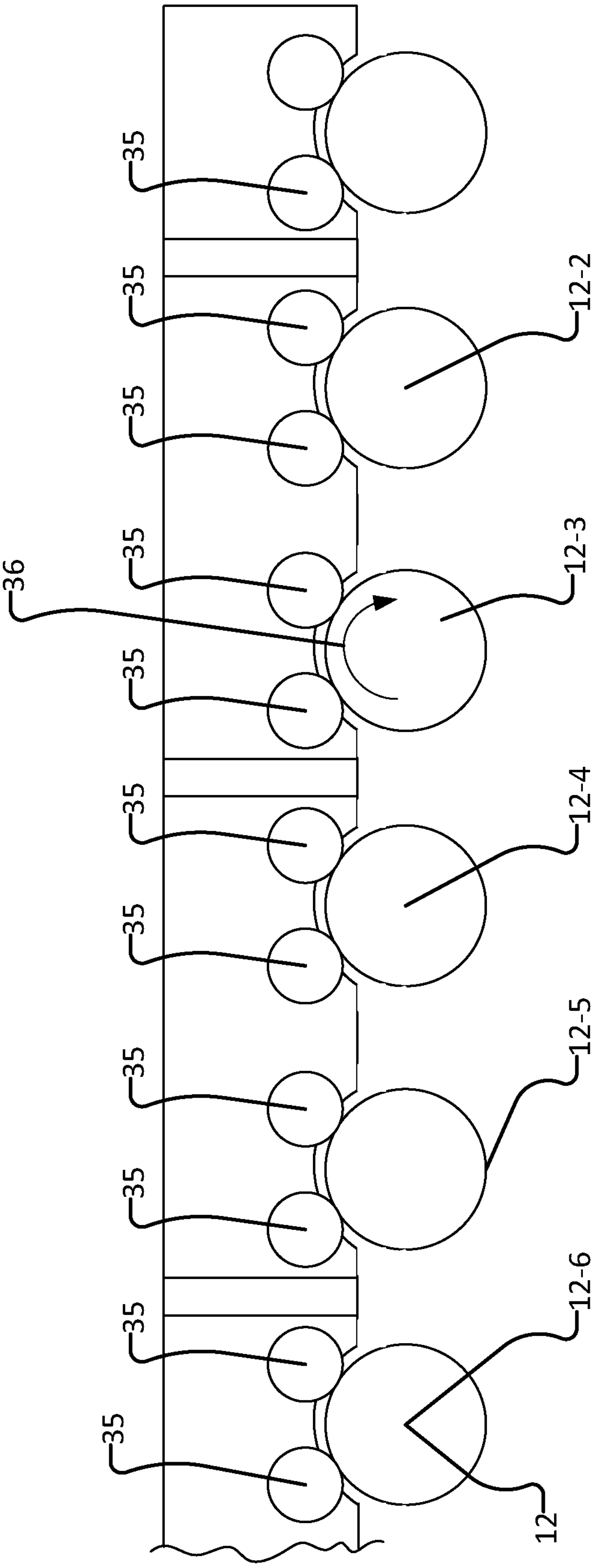

FIG. 2

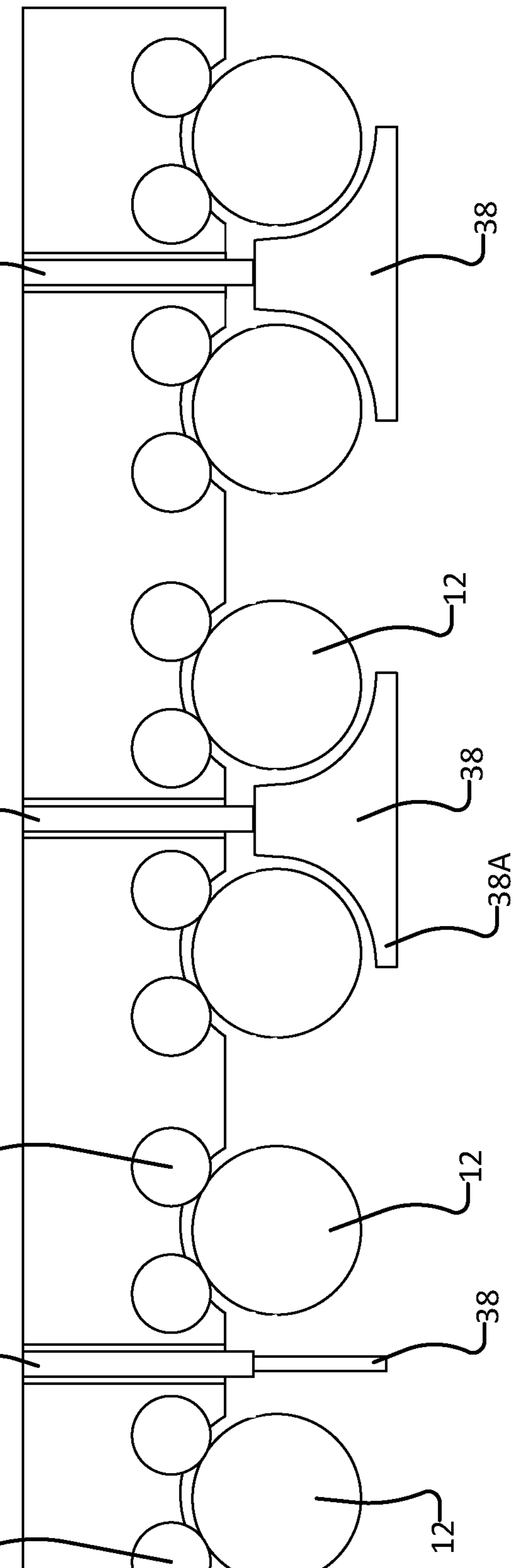

FIG. 3

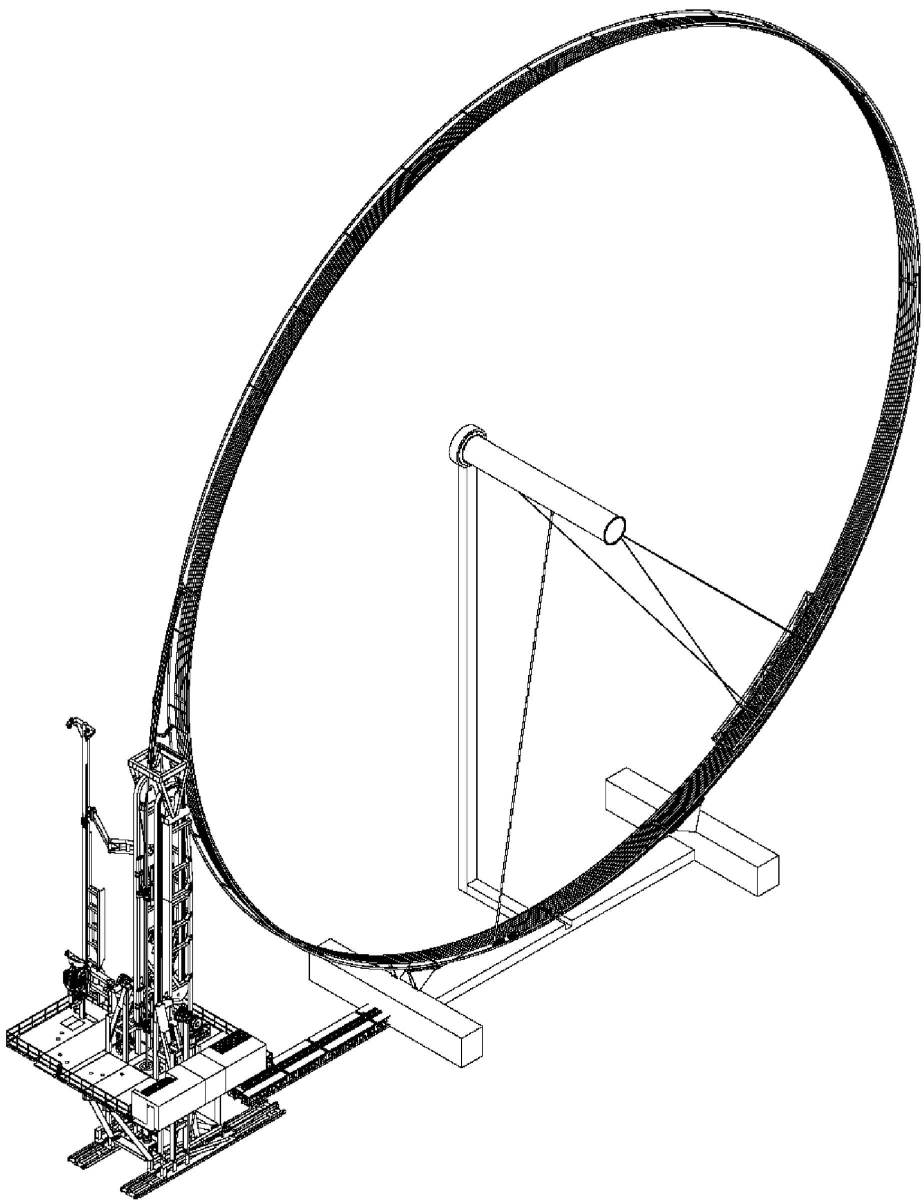

FIG. 4

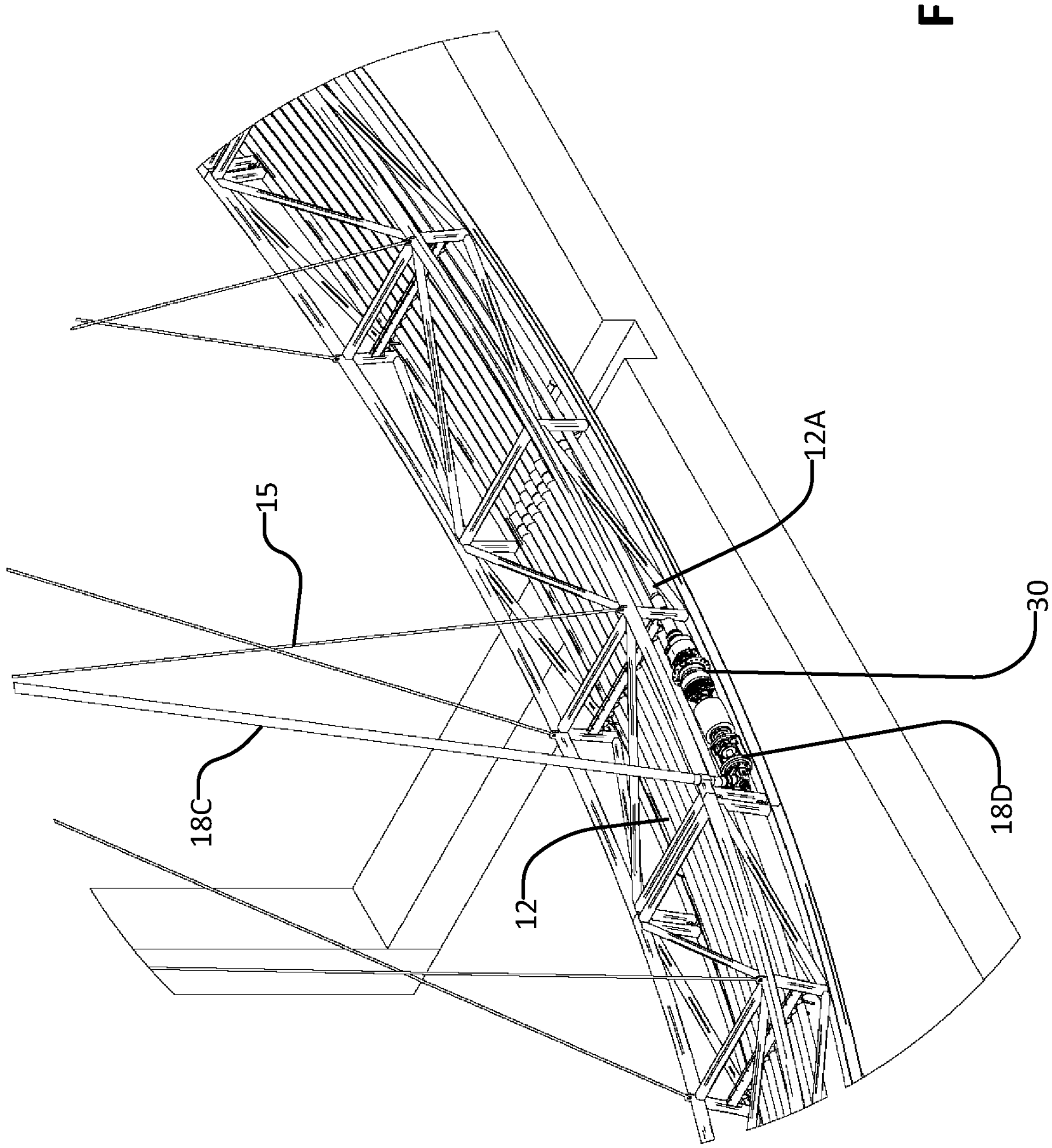

FIG. 5

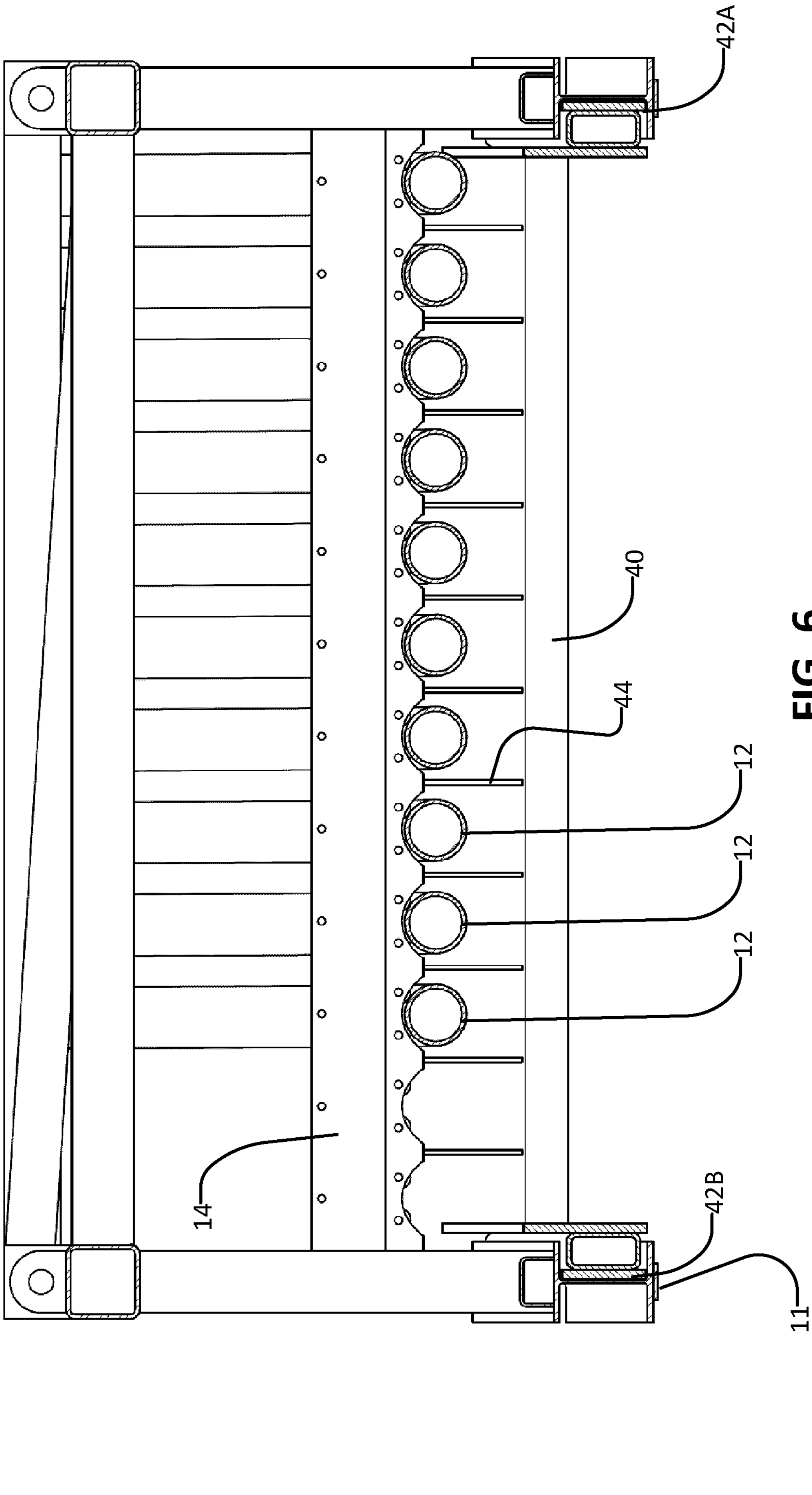

FIG. 6

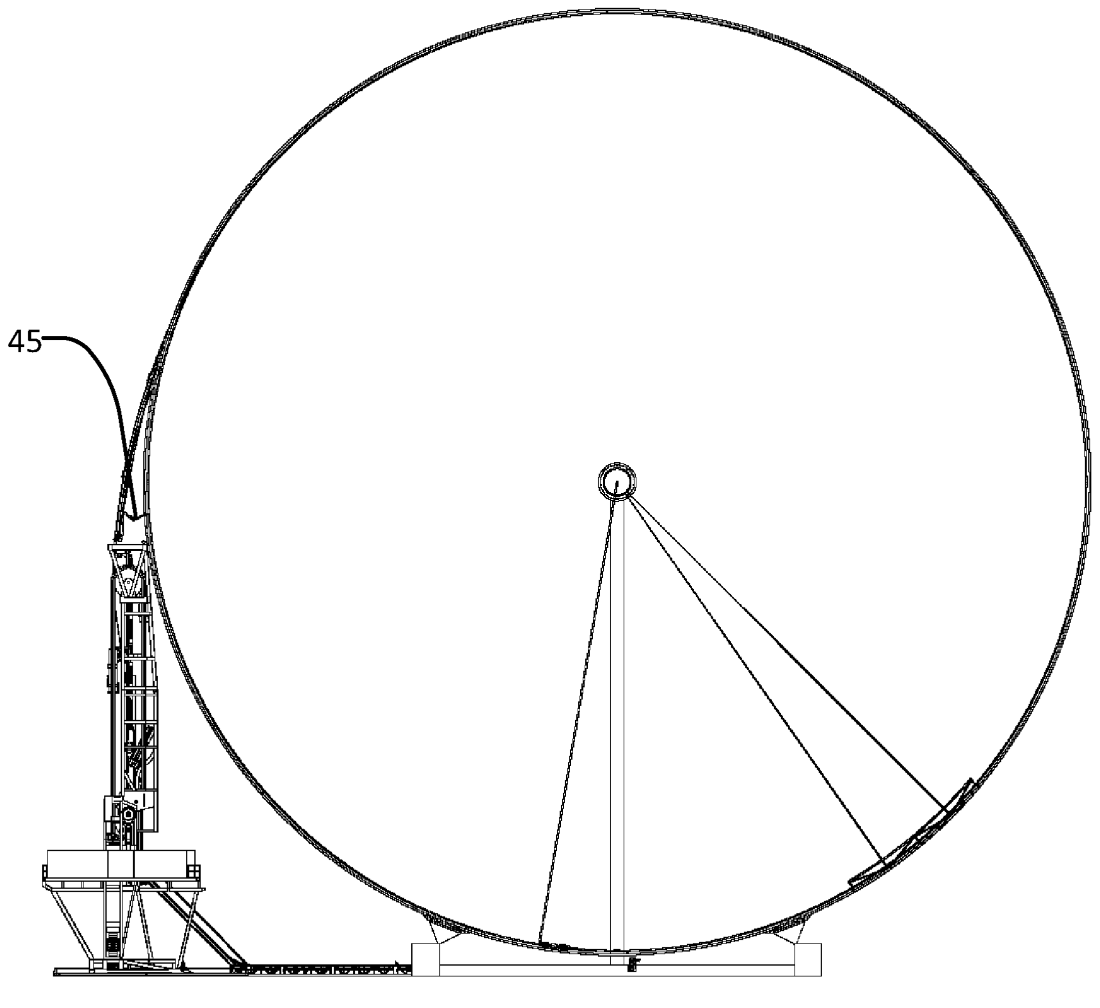

FIG. 7

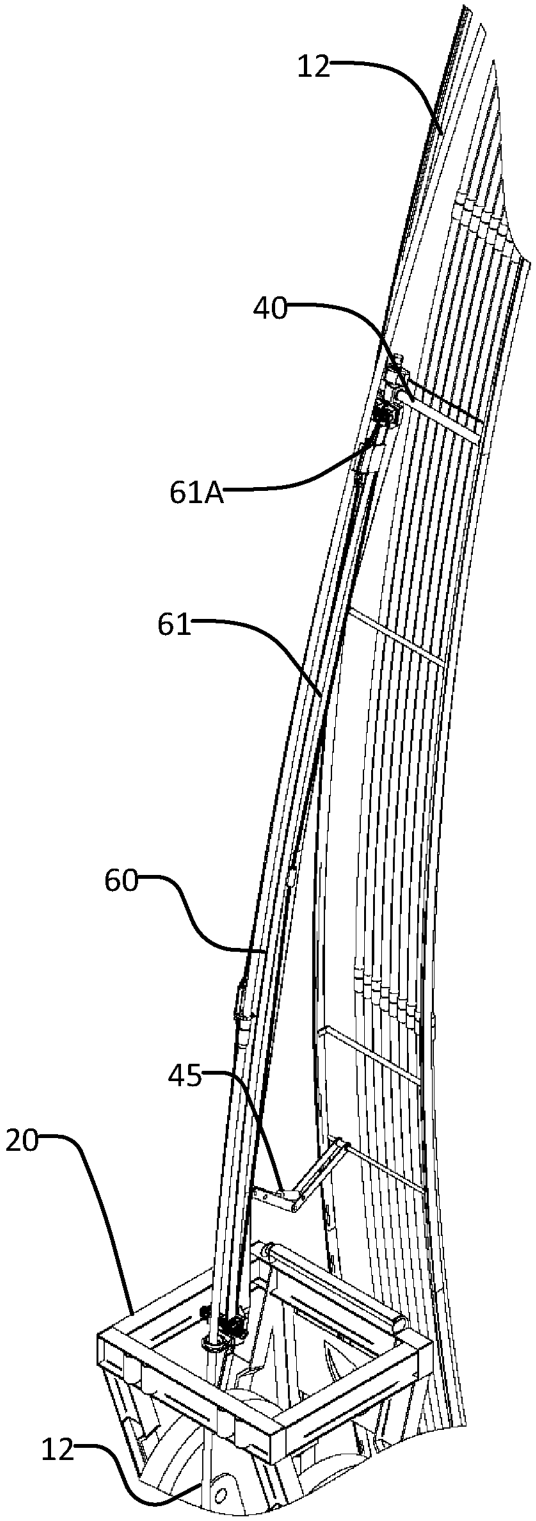

FIG. 8

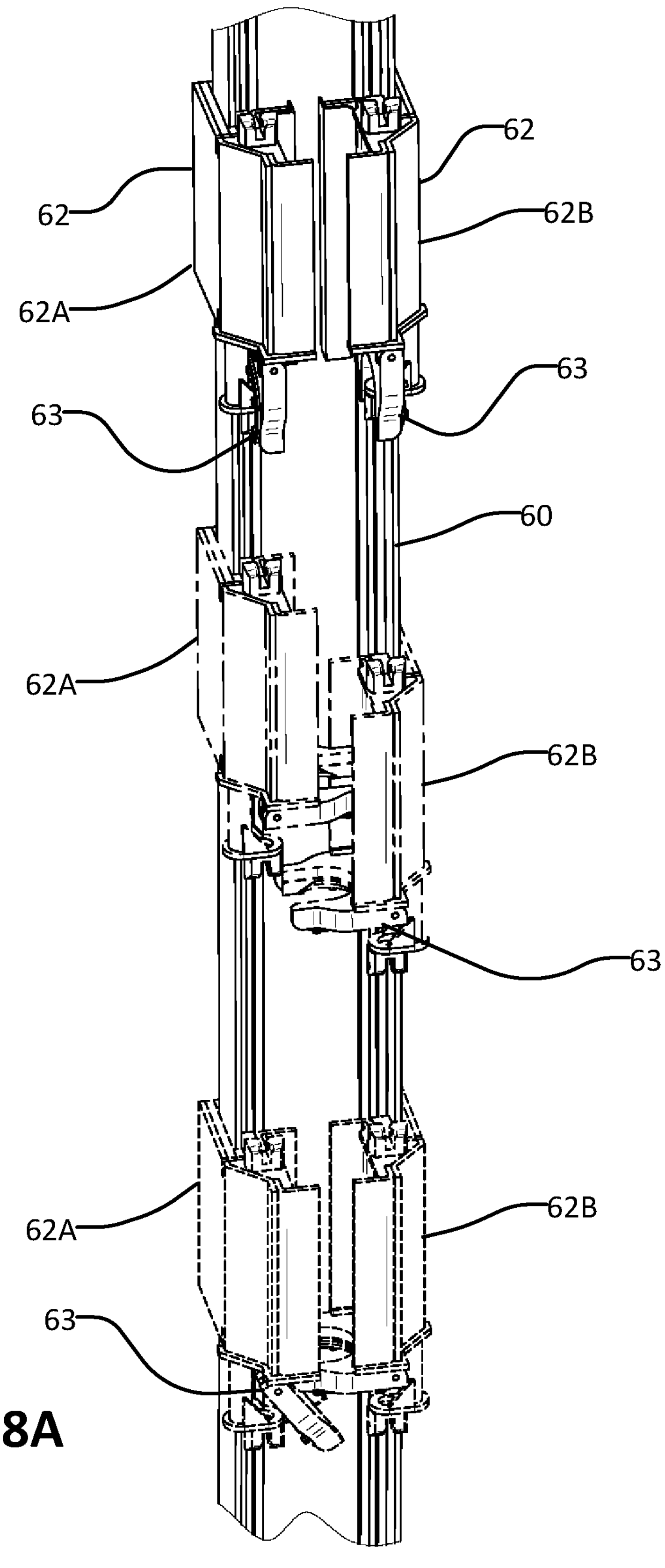

FIG. 8A

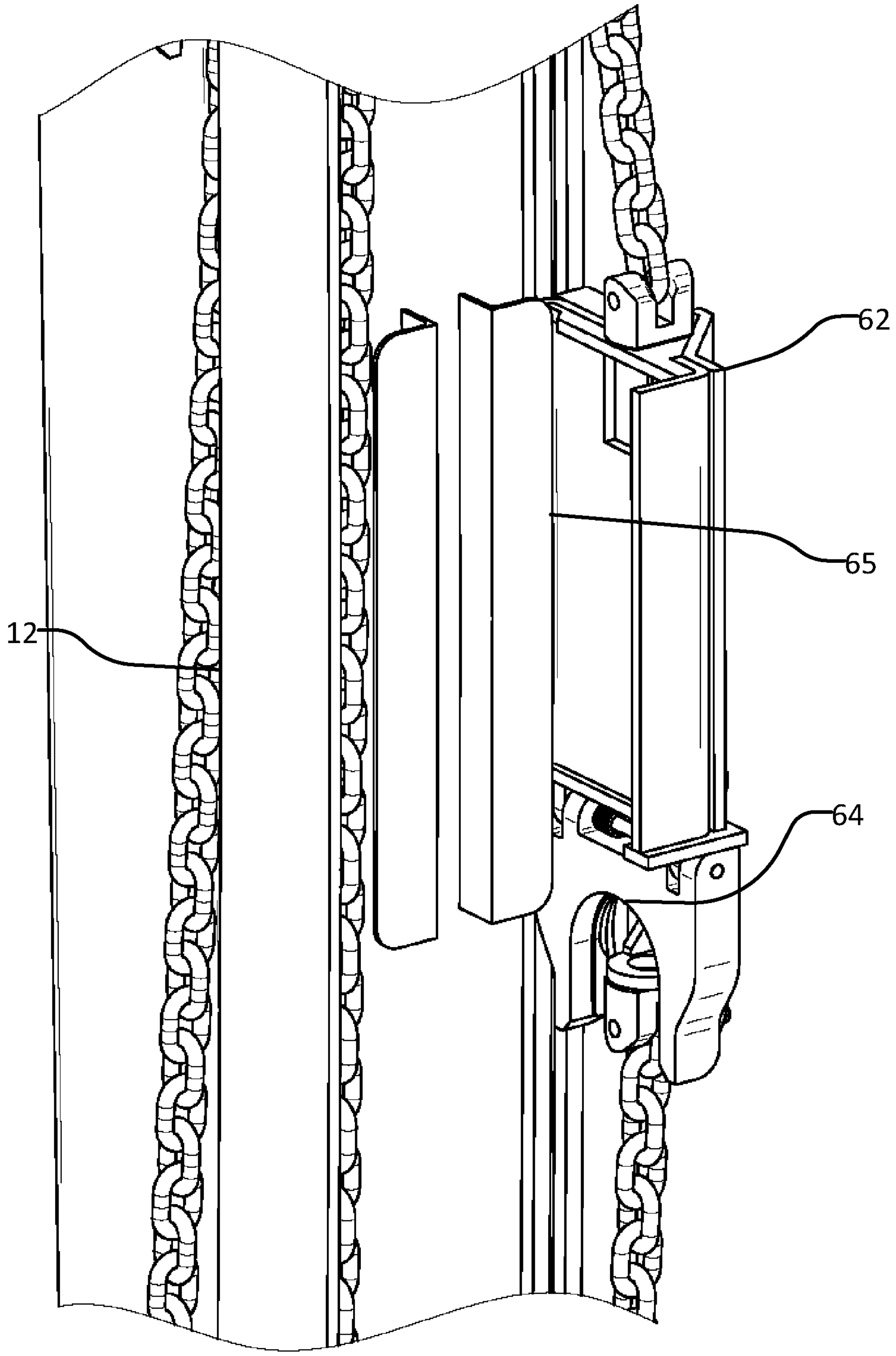

FIG. 8B

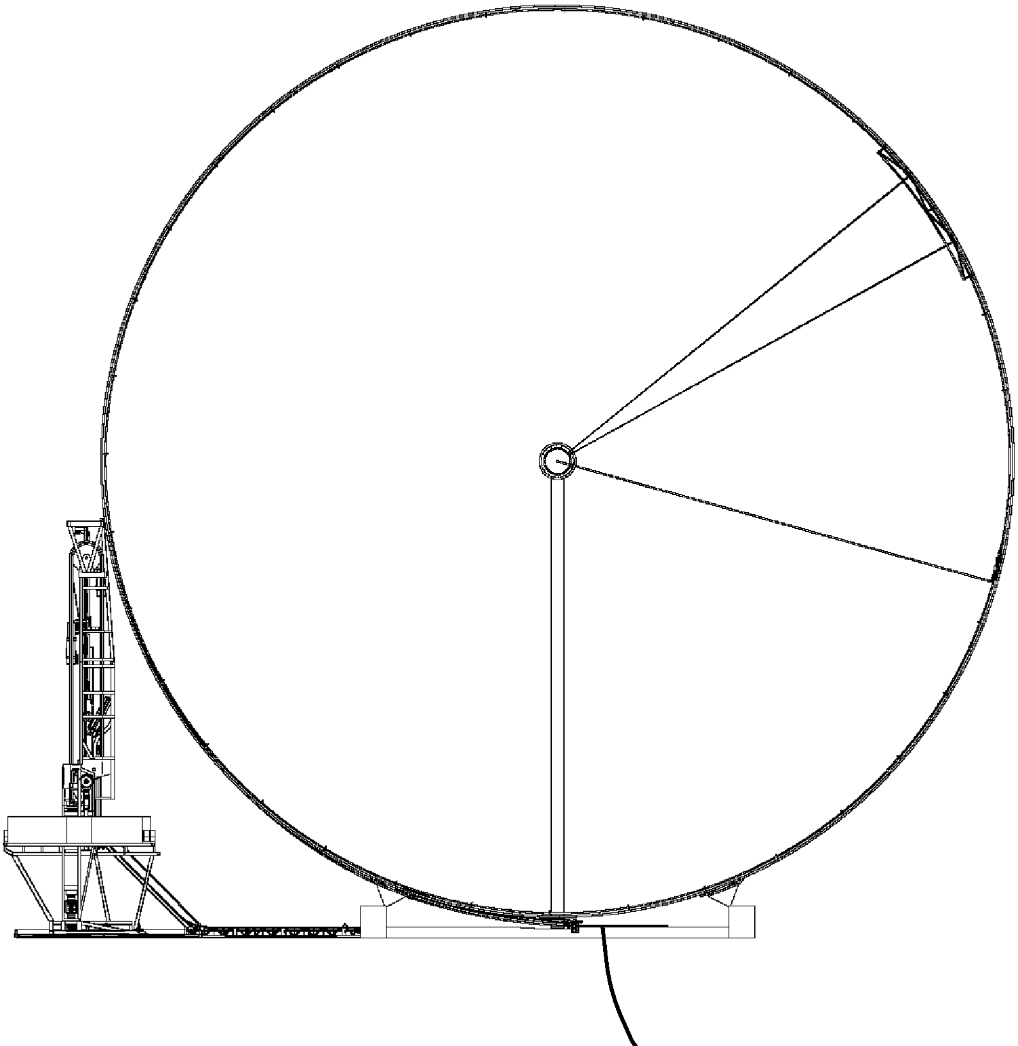

FIG. 9

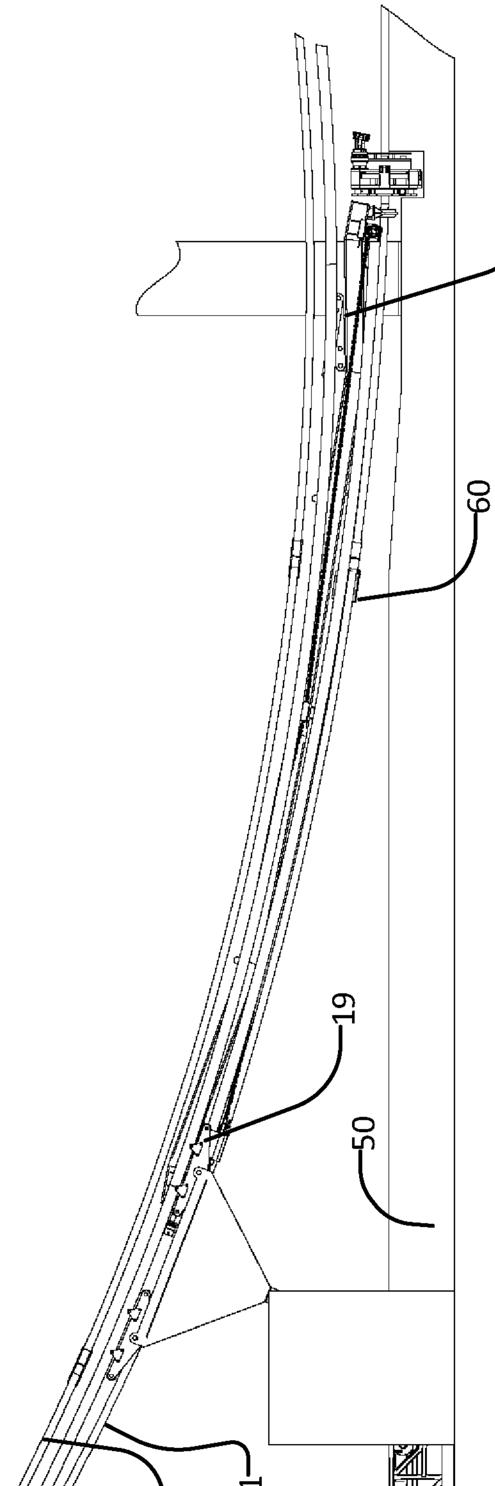

FIG. 10

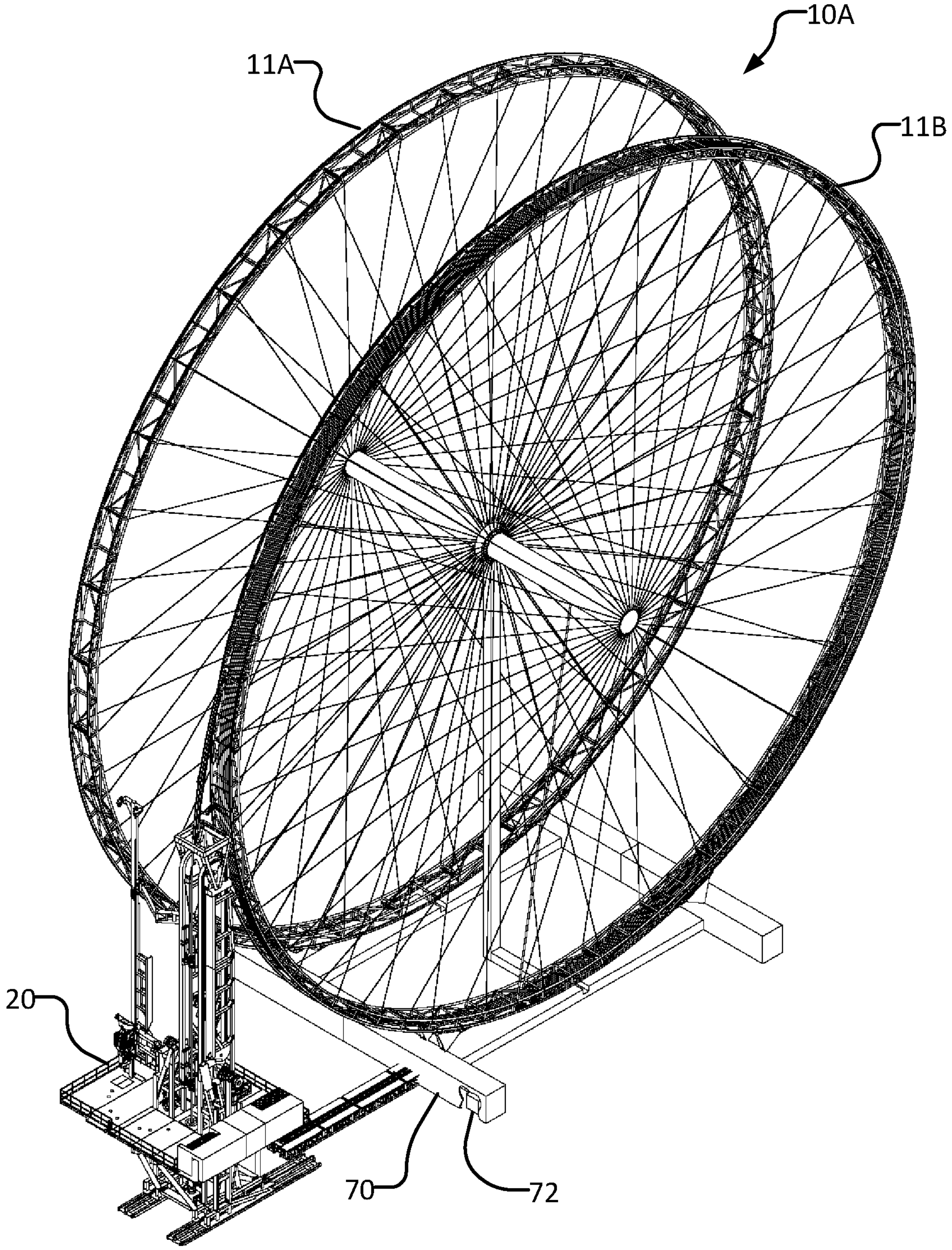

FIG. 11

Pipe Stress on Reel

Effective Reel Diameter	Pipe OD	Pipe Nominal Wt/ft	Pipe ID	Pressure	Outside Surface			Inside Surface				Min Safety Factor on Yield			
					Bending Stress	Hoop Stress	Combined Stress	Bending Stress	Hoop Stress	Radial Stress	Combined Stress	X-95	G-105	S-135	V-150
in	in	lb/ft	in	psi	lb/in²	lb/in²	lb/in²	lb/in²	lb/in²	lb/in²	lb/in²				
3,438	4.00	14.00	3.34	6,000	34,322	27,633	44,064	28,659	33,633	6,000	44,593	2.13	2.35	3.03	3.36
3,438	4.00	15.70	3.24	6,000	34,322	22,894	41,257	27,801	28,894	6,000	40,543	2.30	2.55	3.27	3.64
3,438	4.50	16.60	3.83	6,000	38,613	31,302	49,707	32,829	37,302	6,000	50,052	1.90	2.10	2.70	3.00
3,438	4.50	20.00	3.64	6,000	38,613	22,712	44,797	31,233	28,712	6,000	42,848	2.12	2.34	3.01	3.35
3,438	5.00	19.50	4.28	6,000	42,903	32,671	53,926	36,691	38,671	6,000	53,643	1.76	1.95	2.50	2.78
3,438	5.00	25.60	4.00	6,000	42,903	21,333	47,914	34,322	27,333	6,000	44,285	1.98	2.19	2.82	3.13
3,438	5.50	21.90	4.78	6,000	47,193	36,917	59,917	40,998	42,917	6,000	59,655	1.59	1.75	2.25	2.50
3,438	5.50	24.70	4.67	6,000	47,193	31,004	56,466	40,071	37,004	6,000	54,873	1.68	1.86	2.39	2.66

FIG. 12

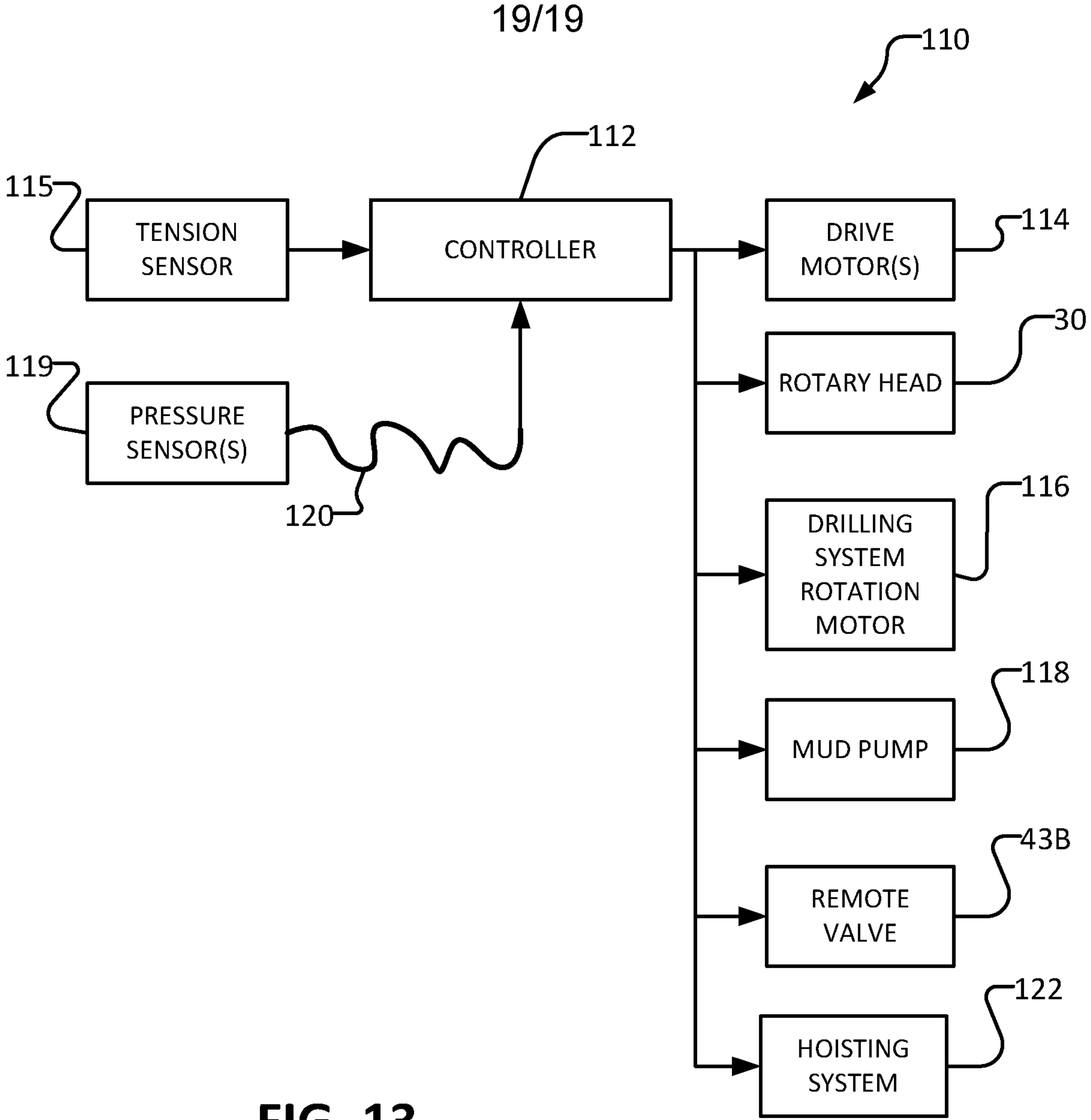
110
112
115
TENSION SENSOR
CONTROLLER
DRIVE MOTOR(S)
114
ROTARY HEAD
30
119
PRESSURE SENSOR(S)
120
DRILLING SYSTEM ROTATION MOTOR
116
MUD PUMP
118
REMOTE VALVE
43B
HOISTING SYSTEM
122

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2017/050569

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***E21B 19/22*** (2006.01) , ***E21B 19/06*** (2006.01) , ***E21B 19/08*** (2006.01)

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 19/22 (2006.01) , E21B 19/06 (2006.01) , E21B 19/08 (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Google patents (reel of jointed tubulars)

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel Orbit (fampat); Keywords (tripping, wheel, reel, ferris, carousel, string, torq+ or tight+)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US6508311; (TORRES) 21 January 2003 (2003-01-21) *whole document*	1-81
A	US3677345; (SIZER) 18 July 1972 (1972-07-18) *whole document*	1-81
A	US3559905; (PALYNCHUK) 02 February 1971 (1971-02-02) *whole document*	1-81
A	US5975207; (SMITHERMAN) 02 November 1999 (1999-11-02) *whole document*	1-81

☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

*	Special categories of cited documents:	"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
"A"	document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"&"	document member of the same patent family
"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		

Date of the actual completion of the international search
21 August 2017 (21-08-2017)

Date of mailing of the international search report
25 August 2017 (25-08-2017)

Name and mailing address of the ISA/CA
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US6089489; (CRUICKSHANK) 18 July 2000 (2000-07-18) *whole document*	1-81
A	US4917540; (RECALDE) 17 April 1990 (1990-04-17) *whole document*	1-81
A	US3965713; (HORTON) 29 June 1976 (1976-06-29) *whole document*	1-81

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