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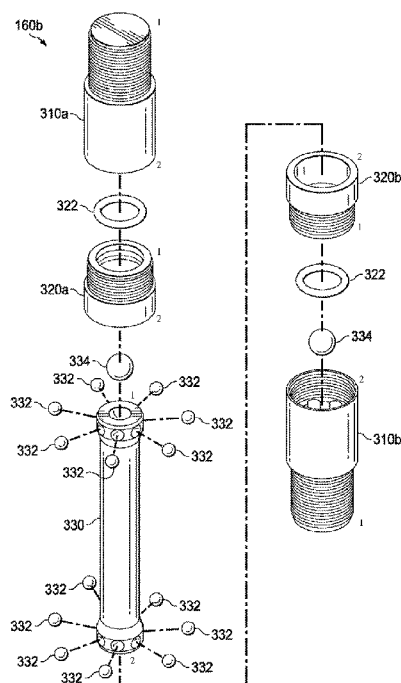


FIG. 4B

(57) Abstract: A drive shaft assembly includes a drive shaft that includes a first cylindrical end having a first diameter, a cylindrical portion having a second diameter, and a second cylindrical end having the first diameter. A first distal end of the drive shaft includes a first distal spherical indentation. A first adapter cap includes a first tapered inner aperture and a first seal disposed within a first groove formed in a circumference of the first tapered inner aperture. The first tapered inner aperture is configured to receive the first cylindrical end of the drive shaft and the first seal forms a seal with the cylindrical portion of the drive shaft having the second diameter. A first adapter includes a first distal spherical indentation. A first distal spherical ball is removably attached to the first distal spherical indentation.



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## DRIVE SHAFT ASSEMBLY

### BACKGROUND OF THE INVENTION

[0001] Hydrocarbon exploration includes drilling operations that seek to recover hydrocarbon deposits from below the Earth's surface. Typically, a drilling rig is used to drill a wellbore (straight and/or directional) that provides access to a subsurface formation. In addition, a drilling rig may be used to stimulate an existing well and gain access to more remote subsurface formations. Hydraulic fracturing is an example of an effective well-stimulation technique in which a geologic formation is hydraulically fractured by a high-pressure fluid to extract the hydrocarbon deposits disposed therein.

[0002] Conventional drilling methods include the use of a top drive, or rotary table, drilling system that is configured to rotate a drill string and a drill bit from the surface or the use of a hydraulic drilling system that is configured to rotate a drill bit downhole using hydrostatic pressure. In certain applications, more than one drilling method may be used at different times during the course of drilling operations. For example, a top drive drilling system may be used to establish a substantially vertical wellbore and a hydraulic drilling system may be used as part of slide drilling operations to drill in a directional manner. Because of advances in directional drilling and well-stimulation techniques, more remote subsurface formations are now accessible for hydrocarbon recovery.

[0003] A conventional hydraulic drilling system includes a hydraulic power section, sometimes referred to as a mud motor, which is disposed downhole to convert hydraulic energy from drilling fluid and/or drilling mud into mechanical energy that rotates a drill bit. A conventional mud motor uses a Moineau progressive cavity positive displacement pump system that typically includes a helical rotor inserted into a double helix stator. The interference fit between the rotor and the stator forms a number of sealed cavities. As fluid enters a cavity formed at an inlet, hydrostatic pressure forces the fluid through the cavities toward an outlet and rotates the rotor eccentrically within the stator. The eccentric rotation of the rotor is transferred to the drill bit by a drive shaft assembly that seeks to reduce or eliminate eccentricity while transferring torque to the drill bit.

### BRIEF SUMMARY OF THE INVENTION

- [0004] According to one aspect of one or more embodiments of the present invention, a drive shaft assembly includes a drive shaft comprising a first cylindrical end having a first diameter, a cylindrical portion having a second diameter, and a second cylindrical end having the first diameter. A first distal end of the drive shaft includes a first distal spherical indentation and a second distal end of the drive shaft includes a second distal spherical indentation. A first adapter cap includes a first tapered inner aperture and a first seal disposed within a first groove formed in a circumference of the first tapered inner aperture. The first tapered inner aperture is configured to receive the first cylindrical end of the drive shaft and the first seal forms a seal with the cylindrical portion of the drive shaft having the second diameter. A first adapter includes a first distal spherical indentation. A first distal spherical ball is removably attached to the first distal spherical indentation of the first adapter. A second adapter cap includes a second tapered inner aperture and a second seal disposed within a second groove formed in a circumference of the second tapered inner aperture. The second tapered inner aperture is configured to receive the second cylindrical end of the drive shaft and the second seal forms a seal with the cylindrical portion of the drive shaft having the second diameter. A second adapter includes a second distal spherical indentation. A second distal spherical ball is removably attached to the second distal spherical indentation of the second adapter.
- [0005] Other aspects of the present invention will be apparent from the following description and claims.

### BRIEF DESCRIPTION OF THE DRAWINGS

- [0006] Figure 1 shows a schematic view of a hydraulic drilling system in accordance with one or more embodiments of the present invention.
- [0007] Figure 2A shows an assembled view of a conventional drive shaft assembly.
- [0008] Figure 2B shows an exploded view of the conventional drive shaft assembly.
- [0009] Figure 3A shows a first step of a method of assembling a conventional drive shaft assembly.
- [0010] Figure 3B shows a second step of a method of assembling a conventional drive shaft assembly.

- [0011] Figure **3C** shows a third step of a method of assembling a conventional drive shaft assembly.
- [0012] Figure **3D** shows a fourth step of a method of assembling a conventional drive shaft assembly.
- [0013] Figure **3E** shows a fifth step of a method of assembling a conventional drive shaft assembly.
- [0014] Figure **3F** shows a sixth step of a method of assembling a conventional drive shaft assembly.
- [0015] Figure **3G** shows a seventh step of a method of assembling a conventional drive shaft assembly.
- [0016] Figure **3H** shows an eighth step of a method of assembling a conventional drive shaft assembly.
- [0017] Figure **3I** shows a ninth step of a method of assembling a conventional drive shaft assembly.
- [0018] Figure **4A** shows an assembled view of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0019] Figure **4B** shows an exploded view of the drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0020] Figure **5A** shows a bottom perspective view of an adapter of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0021] Figure **5B** shows a top perspective view of the adapter of the drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0022] Figure **5C** shows a side view of the adapter of the drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0023] Figure **5D** shows a top view of the adapter of the drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0024] Figure **6A** shows a bottom perspective view of an adapter cap of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0025] Figure **6B** shows a top perspective view of the adapter cap of the drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0026] Figure **6C** shows a side view of the adapter cap of the drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0027] Figure **6D** shows a cross-section side view of the adapter cap of the drive shaft assembly in accordance with one or more embodiments of the present invention.

- [0028] Figure 7A shows a perspective view of a drive shaft of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0029] Figure 7B shows a side view of a drive shaft of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0030] Figure 7C shows a top view of a drive shaft of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0031] Figure 7D shows a bottom view of a drive shaft of a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0032] Figure 8A shows a first step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0033] Figure 8B shows a second step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0034] Figure 8C shows a third step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0035] Figure 8D shows a fourth step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0036] Figure 8E shows a fifth step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0037] Figure 8F shows a sixth step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0038] Figure 8G shows a seventh step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0039] Figure 8H shows a eighth step of a method of assembling a drive shaft assembly in accordance with one or more embodiments of the present invention.
- [0040] Figure 9 shows a portion of a bottom hole assembly in accordance with one or more embodiments of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

- [0041] One or more embodiments of the present invention are described in detail with reference to the accompanying figures. For consistency, like elements in the various figures are denoted by like reference numerals. In the following detailed description of the present invention, specific details are set forth in order to provide a thorough understanding of the present invention. In other instances, well-known

features to one of ordinary skill in the art are not described to avoid obscuring the description of the present invention.

[0042] Figure 1 shows a schematic view of a hydraulic drilling system, or rig, **100** in accordance with one or more embodiments of the present invention. For purposes of illustration only, a coiled tubing rig **100** is depicted in Figure 1. Coiled tubing rig **100** may be used in various applications including, for example, drilling operations, well stimulation including hydraulic fracturing, well intervention, and repair and remediation work. One of ordinary skill in the art will recognize that other types of hydraulic drilling systems (not shown) may be used in accordance with one or more embodiments of the present invention.

[0043] Coiled tubing rig **100** includes a sufficient length of tubing **130** spooled on a coiled tubing reel **110** that is disposed above the surface **103**. A first end (not shown) of tubing **130** remains disposed above the surface **103** and is in fluid communication with a fluid source (not shown) that provides drilling fluid and/or drilling mud (not shown) under pressure. A second end (not shown) of tubing **130** is disposed downhole **105** and is in fluid communication with a bottom hole assembly (“BHA”) **195** that receives the drilling fluid and/or drilling mud (not shown) provided from the surface **103**. An injector head **120** may be used to push and/or pull the tubing **130** into or out of wellbore **105** to position the BHA **195** in a desired location.

[0044] BHA **195** typically includes top sub **140**, hydraulic power section **150**, drive shaft assembly **160**, flow diverter **170**, bearing assembly **180**, and drill bit **190**. Top sub **140** is a tubular connector that provides a fluid connection between tubing **130** and hydraulic power section **150**. Hydraulic power section, or mud motor, **150** uses the hydrostatic pressure of the drilling fluid and/or drilling mud (not shown) to provide eccentric rotation to drive shaft assembly **160**. One of ordinary skill in the art will recognize that a given hydraulic power section **150** may vary based on one or more design characteristics such as, for example, the number of stages (not shown), the lobe ratio (not shown), the external diameter (not shown), the design of the rotor, and the design of the stator. In addition, one of ordinary skill in the art will also recognize that a given hydraulic power section **150** may vary in the rotational speed, torque, or amount of eccentricity it produces. Drive shaft assembly **160** reduces or eliminates the eccentricity of the hydraulic power section **150** and provides substantially concentric rotation to drill bit **190** via bearing assembly **180**

and flow diverter **170**. In this way, drive shaft assembly **160** transfers torque from the hydraulic power section **150** to the mandrel (not shown) of the bearing assembly **180** and, ultimately, the drill bit **190**. Flow diverter **170** is disposed between drive shaft assembly **160** and bearing assembly **180** and provides an inlet for drilling fluid and/or drilling mud (not shown) to lubricate and cool the bearings (not shown) and the mandrel (not shown) of bearing assembly **180** during drilling operations.

[0045] Figure **2A** shows an assembled view of a conventional drive shaft assembly **160a**. Conventional drive shaft assembly **160a** includes, in part, first adapter **210a**, first adapter cap **220a**, drive shaft **230**, second adapter cap **220b**, and second adapter **210b**. First adapter **210a** is mechanically connected to a hydraulic power section (e.g., **150** of Figure **1**) and receives eccentric rotation from the hydraulic power section (e.g., **150** of Figure **1**). The rotation of first adapter **210a** rotates drive shaft **230**. The rotation of drive shaft **230** rotates second adapter **210b**. The rotation of second adapter **210b** rotates a flow diverter (e.g., **170** of Figure **1**) that rotates a mandrel (not shown) of a bearing assembly (e.g., **180** of Figure **1**) that in turn rotates a drill bit (e.g., **190** of Figure **1**). Because of the freedom of movement between first adapter **210a** and drive shaft **230** and the freedom of movement between drive shaft **230** and second adapter **210b**, the eccentric rotation of first adapter **210a** is converted into substantially concentric rotation at second adapter **210b**.

[0046] Continuing in Figure **2B**, an exploded view of the conventional drive shaft assembly **160a** is shown. As noted above, conventional drive shaft assembly **160a** includes first adapter **210a**, first adapter cap **220a**, drive shaft **230**, second adapter cap **220b**, and second adapter **210b**. Conventional drive shaft assembly **160a** also includes first beryllium copper cap **240a**, first boot **250a**, first split ring clamp **260a**, a first plurality of spherical balls **232**, a second plurality of spherical balls **232**, second split ring clamp **260b**, second boot **250b**, and second beryllium copper cap **240b**.

[0047] First beryllium copper cap **240a** is a consumable component typically made of beryllium copper. First beryllium copper cap **240a** is a substantially cylindrical member that has diameter and a height that allows first beryllium copper cap **240a** to be inserted into a corresponding cavity of first adapter **210a** that is configured to receive it. A first side of first beryllium copper cap **240a** includes a flat surface that is in moveable contact with a flat surface (not shown) of the corresponding cavity of

first adapter **210a**. A second side of first beryllium copper cap **240a** includes a spherical indentation (not shown) configured to receive a portion of a first spherical end of drive shaft **230**. A spherical indentation is a portion of a spherical shape that lies above or below a given plane. In operation, first beryllium copper cap **240a** tends to wear out over time giving rise to a variety of failure modes. As such, first beryllium copper cap **240a** must be removed and replaced at regular intervals requiring the cessation of drilling operations, removal of the BHA from the wellbore, disassembly of the drive shaft assembly **160a**, replacement of the first beryllium copper cap **240a**, reassembly of the drive shaft assembly **160a**, and redeployment of the BHA.

[0048] First boot **250a** is another consumable component that is typically made of synthetic rubber or fluoropolymer elastomer. First boot **250a** includes a first end having a flared aperture of a first diameter and a second end having an aperture of a second diameter. A portion of drive shaft **230** extends through the second aperture of first boot **250a** and the first end of first boot **250a** covers a portion of a first universal joint formed by the first adapter cap **220a**, the first spherical end of drive shaft **230**, the first plurality of spherical balls **232**, the first beryllium copper cap **240a**, and the first adapter **210a** protecting the first joint from drilling fluid and/or drilling mud and other particulate matter. In this way, first boot **250a** functions as a temporary seal that protects the first joint from contamination and retains the lubrication necessary for the functionality of the first joint. In operation, first boot **250a** tends to deform and ultimately disintegrate allowing the first joint to become contaminated, lose lubrication, and ultimately fail. As such, first boot **250a** must be removed and/or replaced at regular intervals requiring the cessation of drilling operations, removal of the BHA from the wellbore, disassembly of the drive shaft assembly **160a**, replacement of the first boot **250a**, reassembly of the drive shaft assembly **160a**, and redeployment of the BHA.

[0049] First split ring clamp **260a** is a retention member that is typically made out of a metal. First split ring clamp **260a** includes a first end having a flared aperture of a first diameter and a second end having an aperture of a second diameter. The first end of first split ring clamp **260a** wraps around the first end of first boot **250a** within an inner diameter of first adapter cap **210a**. The second end of first split ring clamp **260a** is flush with an inner diameter of first adapter cap **220a** and closes the clamp **260a** when first adapter cap **220a** is removably attached to first adapter **210a**.

First adapter cap **220a** includes a first end (male threaded) configured to mate with a second end (female threaded) of first adapter **210a**. The first end (male threaded) of first adapter **210a** is connected to a hydraulic power section (e.g., **150** of Figure 1).

[0050] Drive shaft **230** includes the first spherical end and a second spherical end. Around the circumference of the first spherical end, a first plurality of spherical indentations is formed that are configured to receive the first plurality of spherical balls **232**. Around the circumference of the second spherical end, a second plurality of spherical indentations is formed that are configured to receive the second plurality of spherical balls **232**.

[0051] Second beryllium copper cap **240b** is a consumable component typically made of beryllium copper. Second beryllium copper cap **240b** is a substantially cylindrical member that has diameter and a height that allows second beryllium copper cap **240b** to be inserted into a corresponding cavity of second adapter **210b** that is configured to receive it. A first side of second beryllium copper cap **240b** includes a flat surface (not shown) that is in moveable contact with a flat surface of the corresponding cavity of second adapter **210b**. A second side of second beryllium copper cap **240b** includes a spherical indentation configured to receive a portion of a second spherical end of drive shaft **230**. In operation, second beryllium copper cap **240b** tends to wear out over time giving rise to a variety of failure modes. As such, second beryllium copper cap **240b** must be removed and replaced at regular intervals requiring the cessation of drilling operations, removal of the BHA from the wellbore, disassembly of the drive shaft assembly **160a**, replacement of the second beryllium copper cap **240b**, reassembly of the drive shaft assembly **160a**, and redeployment of the BHA.

[0052] Second boot **250b** is another consumable component that is typically made of synthetic rubber or fluoropolymer elastomer. Second boot **250b** includes a first end having a flared aperture of a first diameter and a second end having an aperture of a second diameter. A portion of drive shaft **230** extends through the second aperture of second boot **250b** and the first end of second boot **250b** covers a portion of a second universal joint formed by the second adapter cap **220b**, the second spherical end of drive shaft **230**, the second plurality of spherical balls **232**, the second beryllium copper cap **240b**, and the second adapter **210b** protecting the second joint from drilling fluid and/or drilling mud and other particulate matter. In this way, second boot **250b** functions as a temporary seal that protects the second joint from

contamination and retains the lubrication necessary for the functionality of the second joint. In operation, second boot **250b** tends to deform and ultimately disintegrate allowing the second joint to become contaminated, lose lubrication, and ultimately fail. As such, second boot **250b** must be removed and/or replaced at regular intervals requiring the cessation of drilling operations, removal of the BHA from the wellbore, disassembly of the drive shaft assembly **160a**, replacement of the second boot **250b**, reassembly of the drive shaft assembly **160a**, and redeployment of the BHA.

[0053] Second split ring clamp **260b** is a retention member that is typically made out of metal. Second split ring clamp **260b** includes a first end having a flared aperture of a first diameter and a second end having an aperture of a second diameter. The first end of second split ring clamp **260b** wraps around the first end of second boot **250b** within an interior diameter of second adapter **210b**. The second end of second split ring clamp **260b** is flush with second adapter cap **220b** and closes the clamp **260b** when second adapter cap **220b** is removably attached to second adapter **210b**. Second adapter cap **220b** includes a first end (male threaded) configured to mate with a second end (female threaded) of second adapter **210b**. The first end (male threaded) of second adapter **210b** is connected to a bearing assembly (*e.g.*, **180** of Figure 1) by way of a flow diverter (*e.g.*, **170** of Figure 1).

[0054] Figures 3A through 3I shows a method of assembling a conventional drive shaft assembly **160a**. In Figure 3A, conventional drive shaft **230** includes a first spherical end and a second spherical end. Around the circumference of the first spherical end, a first plurality of spherical indentations is formed that are configured to receive a first plurality of spherical balls (**232** of Figure 2B). Around the circumference of the second spherical end, a second plurality of spherical indentations is formed that are configured to receive a second plurality of spherical balls (**232** of Figure 2B). The first and the second plurality of spherical indentations may be greased to help hold the first and the second plurality of spherical balls (**232** of Figure 2B) in place at a later time. Continuing in Figure 3B, a first adapter cap **220a** is disposed around a first end of drive shaft **230** and a second adapter cap **220b** is disposed around a second end of drive shaft **230**. The first adapter cap **220a** and the second adapter cap **220b** are positioned such that their male threaded ends are directed outward as shown in the figure. Continuing in Figure 3C, a first boot **250a** is pulled over the first spherical end of drive shaft **230** and a second boot **250b** is

pulled over the second spherical end of drive shaft **230**. The first boot **250a** and the second boot **250b** are positioned such that their first flared apertures are directed outward towards the respective spherical ends of drive shaft **230** as shown in the figure. Pulling the first boot **250a** and the second boot **250b** over their respective spherical ends of drive shaft **230** is exceptionally difficult because the second ends of first boot **250a** and second boot **250b** have a diameter smaller than that of the spherical ends of drive shaft **230**. In many instances, the boots are torn or otherwise damaged in attempting to pull them over their respective spherical ends of drive shaft **230**.

[0055] Continuing in Figure **3D**, a first plurality of spherical balls **232** are removably attached to the first plurality of spherical indentations formed in the first spherical end of drive shaft **230** and a second plurality of spherical balls **232** are removably attached to the second plurality of spherical indentations formed in the second spherical end of drive shaft **230**. A second beryllium copper cap **240b** is disposed in a corresponding cavity of second adapter **210b** as shown in the figure. The second spherical end of drive shaft **230** and the second plurality of spherical balls **232** removably disposed thereon are removably attached to second adapter **210b**. The second spherical end of drive shaft **230** is oriented such that the second plurality of spherical balls **232** removably slides into position in the corresponding sidewall of second adapter **210b**. Continuing in Figure **3E**, a second split ring clamp **260b** is placed around the second boot **250b** such that a first end having a flared aperture of a first diameter of second split ring clamp **260b** is wrapped around the first end of second boot **250b** within second adapter **210b**. Continuing in Figure **3F**, a second adapter cap **220b** is removably attached to second adapter **210b**. As second adapter cap **220b** is secured to second adapter **210b**, second adapter cap **220b** is flush with a second end of second split ring clamp **260b** such that second split ring clamp **260b** closes as second adapter cap **220b** is removably attached to second adapter **210b**.

[0056] Continuing in Figure **3G**, a first beryllium copper cap **240a** is disposed in a corresponding cavity of first adapter **210a** as shown in the figure. The first spherical end of drive shaft **230** and the first plurality of spherical balls **232** removably disposed thereon are removably attached to first adapter **210a**. The first spherical end of drive shaft **230** is oriented such that the first plurality of spherical balls **232** removably slides into position in the corresponding sidewall of first

adapter **210a**. Continuing in Figure **3H**, a first split ring clamp **260a** is placed around the first boot **250a** such that a first end having a flared aperture of a first diameter of first split ring clamp **260a** is wrapped around the first end of first boot **250a** within first adapter **210a**. Continuing in Figure **3I**, a first adapter cap **220a** is removably attached to first adapter **210a**. As first adapter cap **220a** is secured to first adapter **210a**, first adapter cap **220a** is flush with a second end of first split ring clamp **260a** such that first split ring clamp **260a** closes as first adapter cap **220a** is removably attached to first adapter **210a**.

[0057] As noted above, in operation, the conventional drive shaft assembly is prone to failure. The first boot and the second boot tend to wear out with use, deform, and, in many instances, disintegrate. When the boots fail, the joints lose lubrication, become contaminated by the drilling fluid and/or drilling mud or other particulate matter, and tend to fail rather quickly. Failures relating to the drive shaft assembly can manifest themselves in a variety of ways negatively impacting its functionality as well as, for example, the functionality of the mandrel of the bearing assembly, the bearings of the bearing assembly, the radial bearing, and the drill bit itself. When there is a failure with any component of the BHA arising out of the failure of the conventional drive shaft assembly, the drilling operations must be stopped, the BHA must be removed from the wellbore, the various components of the BHA must be disassembled to determine the source of the failure, then the failed components must be repaired and/or replaced prior to redeploying the BHA and continuing drilling operations.

[0058] Accordingly, in one or more embodiments of the present invention an improved drive shaft assembly provides substantially similar functionality to that of a conventional drive shaft assembly in a manner that is more robust, less prone to failure, and capable of functioning for extended periods of time free from maintenance and/or service.

[0059] Figure **4A** shows an assembled view of a drive shaft assembly **160b** in accordance with one or more embodiments of the present invention. Drive shaft assembly **160b** may be used in place of, for example, a conventional drive shaft assembly **160a**, thereby providing a number of advantages as noted herein by mere substitution. Drive shaft assembly **160b** includes, in part, first adapter **310a**, first adapter cap **320a**, drive shaft **330**, second adapter cap **320b**, and second adapter **310b**. First adapter **310a**, first adapter cap **320a**, drive shaft **330**, second adapter

cap **320b**, and second adapter **310b** are unibody components made out of a metal or a metal alloy. In certain embodiments, they are made out of 8620 alloy steel. In other embodiments, they may be made out of 9310 alloy steel. In still other embodiments, they may be made out of 4140 alloy steel with EN30B shafting. One of ordinary skill in the art will recognize that other metals or metal alloys may be used in accordance with one or more embodiments of the present invention. One of ordinary skill in the art will also recognize that the material composition may vary based on an application or design in accordance with one or more embodiments of the present invention. In certain embodiments, first adapter cap **320a** may include threading configured for right hand tightening while second adapter cap **320b** may include threading configured for left hand tightening. In this way, when the spherical rotates in a right hand direction, the components of the drive shaft assembly **160b** tighten rather than loosen.

[0060] First adapter **310a** is mechanically connected to a hydraulic power section (e.g., **150** of Figure **1**) and receives eccentric rotation from the hydraulic power section (e.g., **150** of Figure **1**). The rotation of first adapter **310a** rotates drive shaft **330**. The rotation of drive shaft **330** rotates second adapter **310b**. The rotation of second adapter **310b** rotates a flow diverter (e.g., **170** of Figure **1**) that rotates a mandrel (not shown) of a bearing assembly (e.g., **180** of Figure **1**) that in turn rotates a drill bit (e.g., **190** of Figure **1**). Because of the freedom of movement between first adapter **310a** and drive shaft **330** and the freedom of movement between drive shaft **330** and second adapter **310b**, the eccentric rotation of first adapter **310a** is converted into substantially concentric rotation at second adapter **310b**.

[0061] Figure **4B** shows an exploded view of the drive shaft assembly **160b** in accordance with one or more embodiments of the present invention. As noted above, drive shaft assembly **160b** includes first adapter **310a**, first adapter cap **320a**, drive shaft **330**, second adapter cap **320b**, and second adapter **310a**. Drive shaft assembly **160b** also includes first seal **322**, first distal spherical ball **334**, a first plurality of spherical balls **332**, a second plurality of spherical balls **332**, second distal spherical ball **334**, and second seal **322**.

[0062] Figures **5A** through **5D** show an adapter **310** of a drive shaft assembly (**160b** of Figure **4A** and **4B**) in accordance with one or more embodiments of the present invention. Adapter **310** is representative of first adapter **310a** or second adapter

**310b** of Figures **4A** and **4B**. Figure **5A** shows a bottom perspective view of adapter **310**. A first end of adapter **310** includes male threading formed around a portion of an outer circumference that is configured for removably attaching adapter **310** to, for example, a hydraulic power section (e.g., **150** of Figure **1**) or a flow diverter (e.g., **170** of Figure **1**) that includes a corresponding female threaded end.

[0063] Continuing in Figure **5B**, a top perspective view of adapter **310** is shown. A second distal end of adapter **310** includes a cavity (partially shown) that includes a patterned bottom (not shown), patterned inner sidewall (partially shown), and a female threading (partially shown) formed within an inner circumference near the top of the second end of adapter **310**. The threading formed within the inner circumference near the top of the second end of adapter **310** may be used to removably attach an adapter cap (e.g., **320** of Figures **4A** and **4B**) that includes a male threaded end.

[0064] Continuing in Figure **5C**, a side view of the adapter **310** is shown. Continuing in Figure **5D**, a top view of the adapter **310** is shown. The interior of the cavity of adapter **310** (accessible via the second distal end), includes a ball cage formed by a plurality of cylindrical segments **311** formed in a sidewall of an inner circumference of the cavity. In certain embodiments, the ball cage may include seven cylindrical segments **311**. In other embodiments, the ball cage may include six cylindrical segments **311**. In still other embodiments, the ball cage may include five cylindrical segments **311**. In still other embodiments, the ball cage may include a number of cylindrical segments **311** in a range between five and eight cylindrical segments **311**. One of ordinary skill in the art will recognize that the number of cylindrical segments **311** used may vary based on an application or design.

[0065] In operation, the drive shaft (**330** of Figure **4B**) includes a plurality of spherical indentations in which a plurality of spherical balls **332** are removably attached. When the drive shaft **330** and the plurality of spherical balls (**332** of Figure **4B**) are inserted into the cavity of adapter **310**, the balls (**332** of Figure **4B**) are secured in place by the plurality of spherical indentations of drive shaft (**330** of Figure **4B**) and the ball cage formed by the plurality of cylindrical segments **311**. As such, the plurality of spherical balls (**332** of Figure **4B**) provide the driving contact between the drive shaft (**330** of Figure **4B**) and the adapter **310**. Adapter **310** also includes a distal spherical indentation **312** formed in a distal bottom of the cavity of adapter **310**. Distal spherical indentation **312** is configured to receive a

spherical ball (334 of Figure 4B) that may be secured in place by a corresponding spherical indentation formed in a distal end of the drive shaft (330 of Figure 4B). Advantageously, the drive shaft (330 of Figure 4B) may move more freely and without damage to, for example, a beryllium copper cap of a conventional drive shaft assembly. For example, as the drive shaft (330 of Figure 4B) moves, it pivots around the spherical ball (334 of Figure 4B) whereas in a conventional drive shaft assembly the movement of the spherical end of the conventional drive shaft imparts force on the beryllium cap causing it to deform.

[0066] Figures 6A through 6D show an adapter cap 320 of a drive shaft assembly (160b of Figure 4A and 4B) in accordance with one or more embodiments of the present invention. Adapter cap 320 is representative of first adapter cap 320a or second adapter cap 320b of Figures 4A and 4B. However, in certain embodiments, adapter cap 320a may include threading configured for right hand tightening and adapter cap 320b may include threading configured for left hand tightening (not independently illustrated) to promote tightening as the downhole spherical rotates in a right hand direction.

[0067] Figure 6A shows a bottom perspective view of adapter cap 320. A first end of adapter cap 320 includes male threading formed around a portion of an outer circumference that is configured for removably attaching adapter cap 320 to an adapter (310 of Figures 4A through 5D). A groove (not independent illustrated) is formed on an interior circumference of the first end of adapter cap 320 and is configured to receive a seal 322. A first distal end of adapter cap 320 includes a first aperture of a first diameter. Continuing in Figure 6B, a top perspective view of adapter cap 320 is shown. A second distal end of adapter cap 320 includes a second aperture of a second diameter that is larger than the first diameter of the first aperture. Continuing in Figure 6C, a side perspective view of adapter 320 is shown. Continuing in Figure 6D, a cross-sectional side view of adapter 320 is shown. As shown in the cross-section, the second diameter of the second aperture is larger than the first diameter of the first aperture, forming a tapered inner aperture. Seal 322 may be disposed in a groove (not shown) formed in a circumference of the inner aperture of the first end of adapter cap 320. In certain embodiments, seal 322 may be an o-ring comprised of a fluoropolymer. In other embodiments, seal 322 may be a cup seal. One of ordinary skill in the art will recognize that seal 322 may vary in accordance with one or more embodiments of the present invention.

[0068] Figures 7A through 7D show a drive shaft 330 of a drive shaft assembly (160b of Figure 4A and 4B) in accordance with one or more embodiments of the present invention. Figure 7A shows a perspective view of drive shaft 330. Drive shaft 330 includes a first cylindrical end having a first diameter, a cylindrical portion having a second diameter smaller than the first diameter, and a second cylindrical end having the first diameter. The first cylindrical end of drive shaft 330 includes a first plurality of spherical indentations 331 formed in an outer circumference of the first end of drive shaft 330. The second cylindrical end of drive shaft 330 includes a second plurality of spherical indentations 331 formed in an outer circumference of the second end of drive shaft 330. In certain embodiments, each cylindrical end of drive shaft 330 may include seven spherical indentations 331. In other embodiments, each cylindrical end of drive shaft 330 may include six spherical indentations 331. In still other embodiments, each cylindrical end of drive shaft 330 may include five spherical indentations 331. In still other embodiments, each cylindrical end of drive shaft 330 may include a number of spherical indentations 331 in a range between five and eight spherical indentations 331. One of ordinary skill in the art will recognize that the number of spherical indentations 331 used may vary based on an application or design. Continuing in Figure 7B, a side view of drive shaft 330 is shown. Drive shaft 330 may have a length and diameters that may vary based on an application or design. Continuing in Figure 7C, a top view of a first distal end of drive shaft 330 is shown. The first distal end of drive shaft 330 includes a first distal spherical indentation 333. Continuing in Figure 7D, a bottom view of a second distal end of drive shaft 330 is shown. The second distal end of drive shaft 330 includes a second distal spherical indentation 333.

[0069] Figures 8A through 8H shows a method of assembling a drive shaft assembly 160b in accordance with one or more embodiments of the present invention. In Figure 8A, drive shaft 330 includes a first cylindrical end and a second cylindrical end that are substantially identical to one another. Around an outer circumference of the first cylindrical end, a first plurality of spherical indentations 331 is formed that are configured to receive a first plurality of spherical balls (332 of Figure 4b). Around an outer circumference of the second cylindrical end, a second plurality of spherical indentations 331 is formed that are configured to receive a second plurality of spherical balls (332 of Figure 4b). The first and the second plurality of

spherical indentations **331** may be greased to help hold the first and the second plurality of spherical balls (**332** of Figure **4b**) in place at a later time.

[0070] Continuing in Figure **8B**, a first adapter cap **320a** may be disposed around a first end of drive shaft **330** and a second adapter cap **320b** may be disposed around a second end of drive shaft **330**. The first cylindrical end of drive shaft **330** extends through the tapered inner aperture of the first adapter cap **320a**. The second cylindrical end of drive shaft **330** extends through the tapered inner aperture of the second adapter cap **320b**. The first adapter cap **320a** and the second adapter cap **320b** are positioned such that their male threaded ends are directed outward as shown in the figure. Continuing in Figure **8C**, a first seal **322** may be disposed around the first end of drive shaft **330** and a second seal **322** may be disposed around the second end of drive shaft **330**. In certain embodiments, the first and the second seals **322** may be formed by a cylindrical rubber member whose distal ends are glued together in place forming o-rings. In other embodiments, the first and the second seals **322** may be unibody members formed in the shape of o-rings. In still other embodiments, the first and the second seals **322** may be other type of seal. Continuing in Figure **8D**, the first and the second seals **322** may be pushed into their corresponding grooves in the first adapter cap **320a** and the second adapter cap **320b** respectively. In certain embodiments, the first and the second seals **322** may be pushed into place from the first aperture of the first ends of adapter caps **320a** and **320b**. In other embodiments, the first and the second seals **322** may be pushed into place from the second aperture of the second ends of adapter caps **320a** and **320b**. A first plurality of spherical balls **332** may be removably attached to the first plurality of spherical indentations **331** formed in the first end of drive shaft **330**. A second plurality of spherical balls **332** may be removably attached to the second plurality of spherical indentations **331** formed in the second end of drive shaft **330**. In certain embodiments, grease may be used to hold the spherical balls **332** in place during assembly and provide lubrication for the spherical balls **332** during use.

[0071] Continuing in Figure **8E**, a second distal spherical ball **334** may be removably attached to a second distal spherical indentation (**312** of Figure **5D**) formed in second adapter **310b**. The second end of drive shaft **330** and the second plurality of spherical balls **332** removably disposed thereon are removably attached to second adapter **310b** such that a second distal spherical indentation **333** of drive shaft **330** is in movable contact with second distal spherical ball **334** and the second plurality of

spherical balls 332 removably slide into position in the corresponding sidewall of second adapter 310b. When the drive shaft 330 and the second plurality of spherical balls 332 are inserted into the cavity of second adapter 310b, the second distal spherical ball 333 is secured in place by the second distal spherical indentation 333 of drive shaft 330 and the second distal spherical indentation 312 of second adapter 310b. In addition, the plurality of spherical balls 332 are secured in place by the plurality of spherical indentations 331 of drive shaft 330 and the ball cage formed by the plurality of cylindrical segments 311. As such, the plurality of spherical balls 332 provides the driving contact between the drive shaft 330 and the second adapter 310b. Continuing in Figure 8F, second adapter cap 320b may be removably attached to second adapter 310b. When second adapter cap 320b is secured to second adapter 310b, second seal 332 forms a seal around the second diameter of the drive shaft 330 such that the second end of drive shaft 330, the second plurality of spherical balls 332, the second distal spherical ball 334, and the cavity of adapter 310b is sealed, retains any lubrication disposed therein, and prevents drilling fluid and/or drilling mud from entering the sealed cavity.

[0072] Continuing in Figure 8G, a first distal spherical ball 334 may be removably attached to a first distal spherical indentation (312 of Figure 5D) formed in first adapter 310a. The first end of drive shaft 330 and the first plurality of spherical balls 332 removably disposed thereon may be removably attached to first adapter 310a such that a first distal spherical indentation 333 of drive shaft 330 is in movable contact with first distal spherical ball 334 and the first plurality of spherical balls 332 removably slide into position in the corresponding sidewall of first adapter 310a. When the drive shaft 330 and the first plurality of spherical balls 332 are inserted into the cavity of first adapter 310a, the first distal spherical ball 334 is secured in place by the first distal spherical indentation 333 of drive shaft 330 and the first distal spherical indentation 312 of first adapter 310a. In addition, the plurality of spherical balls 332 are secured in place by the first plurality of spherical indentations 331 of drive shaft 330 and the ball cage formed by the plurality of cylindrical segments 311. As such, the first plurality of spherical balls 332 provides the driving contact between the drive shaft 330 and the first adapter 310a. Continuing in Figure 8H, first adapter cap 320a may be removably attached to first adapter 310a. When first adapter cap 320a is secured to first adapter 310a, first seal 332 forms a seal around the second diameter of the drive shaft 330 such that the first

end of drive shaft **330**, the first plurality of spherical balls **332**, the first distal spherical ball **334**, and the cavity of adapter **310a** is sealed, retains any lubrication disposed therein, and prevents drilling fluid and/or drilling mud from entering the sealed cavity.

[0073] Figure 9 shows a portion of a bottom hole assembly in accordance with one or more embodiments of the present invention. A portion of bottom hole assembly (*e.g.*, **195** of Figure 1) may include a drive shaft assembly **160b**, a flow diverter **170**, a bearing assembly **180**, and a drill bit **190**. A housing that covers the drive shaft assembly **160b** and flow diverter **170** is not shown to illustrate how the drive shaft assembly **160b** has freedom of movement that reduces or eliminates eccentricity.

[0074] Advantages of one or more embodiments of the present invention may include one or more of the following:

[0075] In one or more embodiments of the present invention, a drive shaft assembly may be used in place of a conventional drive shaft assembly.

[0076] In one or more embodiments of the present invention, a drive shaft assembly provides at least the same level of performance as that of a conventional drive shaft assembly and in many instances improved performance.

[0077] In one or more embodiments of the present invention, a drive shaft assembly includes a unique design for an adapter that includes a cavity that includes a distal spherical indentation. A distal spherical ball disposed in the distal spherical indentation provides a pivot point around which a drive shaft may move. Because of the freedom of movement and the lack of a beryllium copper cap, there is no consumable part in the adapter cap.

[0078] In one or more embodiments of the present invention, a drive shaft assembly includes a unique design for a drive shaft having a first diameter along a substantial length and a first end and a second end that each have a second diameter that is larger than the first diameter. A first and a second distal end of the drive shaft includes a substantially flat surface that includes a first and a second distal spherical indentation. Because the drive shaft does not include a spherical end and instead relies on the drive shaft pivoting around distal spherical ball, the drive shaft does not damage, for example, a beryllium copper cap.

[0079] In one or more embodiments of the present invention, a drive shaft assembly includes a unique design for an adapter cap that includes a tapered inner aperture that includes a groove for a seal. The seal is sized such that it forms a seal with the

second diameter of the drive shaft. The adapter cap with seal forms a tight seal with the drive shaft that retains any lubrication disposed therein and prevents drilling fluid and/or drilling mud from entering the sealed cavity. Advantageously, this design does not require the use of a consumable boot and allows for prolonged periods of use without maintenance or service.

[0080] In one or more embodiments of the present invention, a drive shaft assembly reduces the operating cost of a hydraulic drilling system. Conventional drive shaft assemblies are prone to failure. When a conventional drive shaft assembly fails, drilling operations must cease, the BHA must be removed from the wellbore, the drive shaft assembly must be disassembled and consumable parts must be repaired or replaced before it is reassembled and the BHA is redeployed. Because the drive shaft assembly of the claimed invention includes fewer parts overall and no consumable parts, the drive shaft assembly may be used for prolonged periods of time without maintenance or service.

[0081] In one or more embodiments of the present invention, a drive shaft assembly provides improved reliability over a conventional drive shaft assembly. The design of the drive shaft, adapter, and adapter cap of the drive shaft assembly forms a sealed cavity that retains any lubrication disposed therein and prevents drilling fluid and/or drilling mud from entering the sealed cavity. The tapered inner aperture of the adapter cap includes a seal disposed therein that forms a seal around a second diameter of the drive shaft. Unlike a boot of a conventional drive shaft assembly, the o-ring is not prone to failure and does not disintegrate. As such, the sealed cavity of the drive shaft assembly retains lubrication and prevents contamination by drilling fluid and/or drilling mud for substantially longer amounts of time allowing for prolonged use of drive shaft assembly in a way that a conventional drive shaft assembly cannot achieve.

[0082] In one or more embodiments of the present invention, a drive shaft assembly is easier to assemble than a conventional drive shaft assembly.

[0083] In one or more embodiments of the present invention, a drive shaft assembly is at or near cost parity with a conventional drive shaft assembly.

[0084] In one or more embodiments of the present invention, a size of the various components of a drive shaft assembly may vary based on an application or design.

[0085] In one or more embodiments of the present invention, a drive shaft assembly may be compatible with hydraulic drilling systems including, for example, a coiled tubing rig.

[0086] In one or more embodiments of the present invention, a drive shaft assembly may be compatible with top drive drilling systems.

[0087] While the present invention has been described with respect to the above-noted embodiments, those skilled in the art, having the benefit of this disclosure, will recognize that other embodiments may be devised that are within the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the appended claims.

CLAIMS

What is claimed is:

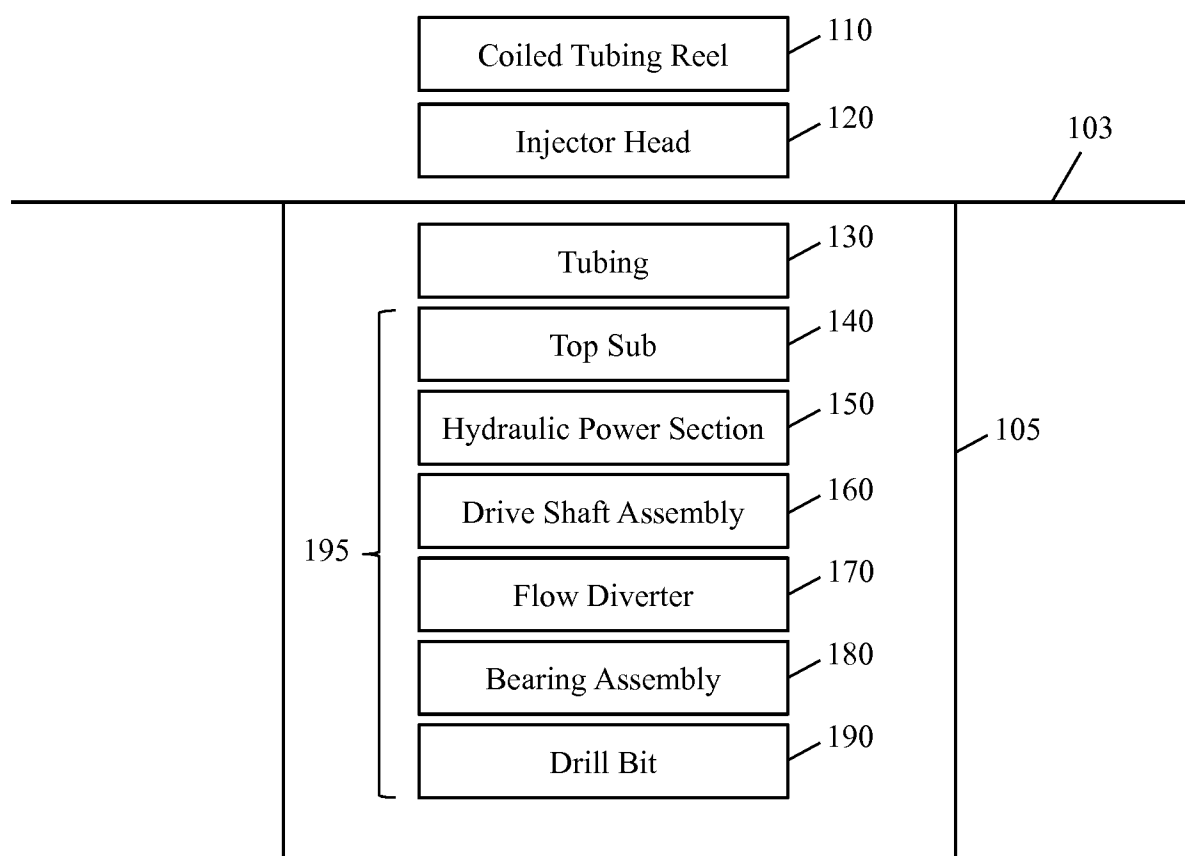
1. A drive shaft assembly comprising:

- a drive shaft comprising a first cylindrical end having a first diameter, a cylindrical portion having a second diameter, and a second cylindrical end having the first diameter, wherein a first distal end of the drive shaft includes a first distal spherical indentation and wherein a second distal end of the drive shaft includes a second distal spherical indentation;
- a first adapter cap comprising a first tapered inner aperture and a first seal disposed within a first groove formed in a circumference of the first tapered inner aperture, wherein the first tapered inner aperture is configured to receive the first cylindrical end of the drive shaft and the first seal forms a seal with the cylindrical portion of the drive shaft having the second diameter;
- a first adapter comprising a first distal spherical indentation;
- a first distal spherical ball removably attached to the first distal spherical indentation of the first adapter;
- a second adapter cap comprising a second tapered inner aperture and a second seal disposed within a second groove formed in a circumference of the second tapered inner aperture, wherein the second tapered inner aperture is configured to receive the second cylindrical end of the drive shaft and the second seal forms a seal with the cylindrical portion of the drive shaft having the second diameter;
- a second adapter comprising a second distal spherical indentation; and
- a second distal spherical ball removably attached to the second distal spherical indentation of the second adapter.

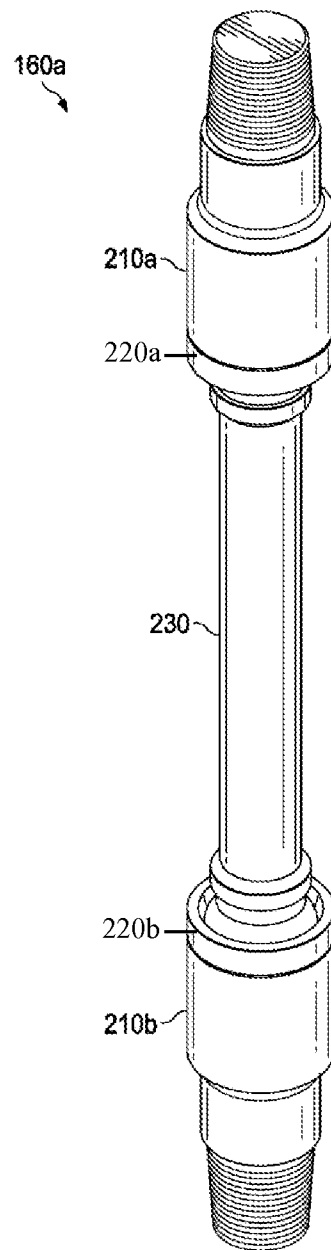
2. The drive shaft assembly of claim 1, wherein the first cylindrical end of the drive shaft comprises a first plurality of spherical indentations formed in an outer circumference of the first cylindrical end.
3. The drive shaft assembly of claim 2, wherein the first plurality of spherical indentations comprises seven spherical indentations.
4. The drive shaft assembly of claim 2, wherein the first adapter comprises a first plurality of cylindrical segments formed in a sidewall of an inner circumference of a cavity of the first adapter.
5. The drive shaft assembly of claim 4, wherein the first cylindrical end of the drive shaft extends through the tapered inner aperture of the first adapter cap.
6. The drive shaft assembly of claim 5, wherein a first plurality of spherical balls are removably attached to the first plurality of spherical indentations.
7. The drive shaft assembly of claim 6, wherein the first cylindrical end of the drive shaft and the removably attached first plurality of spherical balls are inserted into the first adapter.
8. The drive shaft assembly of claim 7, wherein the first distal spherical indentation of the drive shaft movably contacts the first distal spherical ball removably attached to the first distal spherical indentation of the first adapter.
9. The drive shaft assembly of claim 8, wherein the first adapter cap removably attaches to the first adapter and secures the first cylindrical end of the drive shaft to the first adapter.

10. The drive shaft assembly of claim 1, wherein the second cylindrical end of the drive shaft comprises a second plurality of spherical indentations formed in an outer circumference of the second cylindrical end.
11. The drive shaft assembly of claim 10, wherein the second plurality of spherical indentations comprises seven spherical indentations.
12. The drive shaft assembly of claim 10, wherein the second adapter comprises a second plurality of cylindrical segments formed in a sidewall of an inner circumference of a cavity of the second adapter.
13. The drive shaft assembly of claim 12, wherein the second cylindrical end of the drive shaft extends through the tapered inner aperture of the second adapter cap.
14. The drive shaft assembly of claim 13, wherein a second plurality of spherical balls are removably attached to the second plurality of spherical indentations.
15. The drive shaft assembly of claim 14, wherein the second cylindrical end of the drive shaft and the removably attached second plurality of spherical balls are inserted into the second adapter.
16. The drive shaft assembly of claim 15, wherein the second distal spherical indentation of the drive shaft movably contacts the second distal spherical ball removably attached to the second distal spherical indentation of the second adapter.

17. The drive shaft assembly of claim 16, wherein the second adapter cap removably attaches to the second adapter and secures the second cylindrical end of the drive shaft to the second adapter.
18. The drive shaft assembly of claim 1, wherein the first and the second seal comprise an o-ring composed of fluoropolymer.

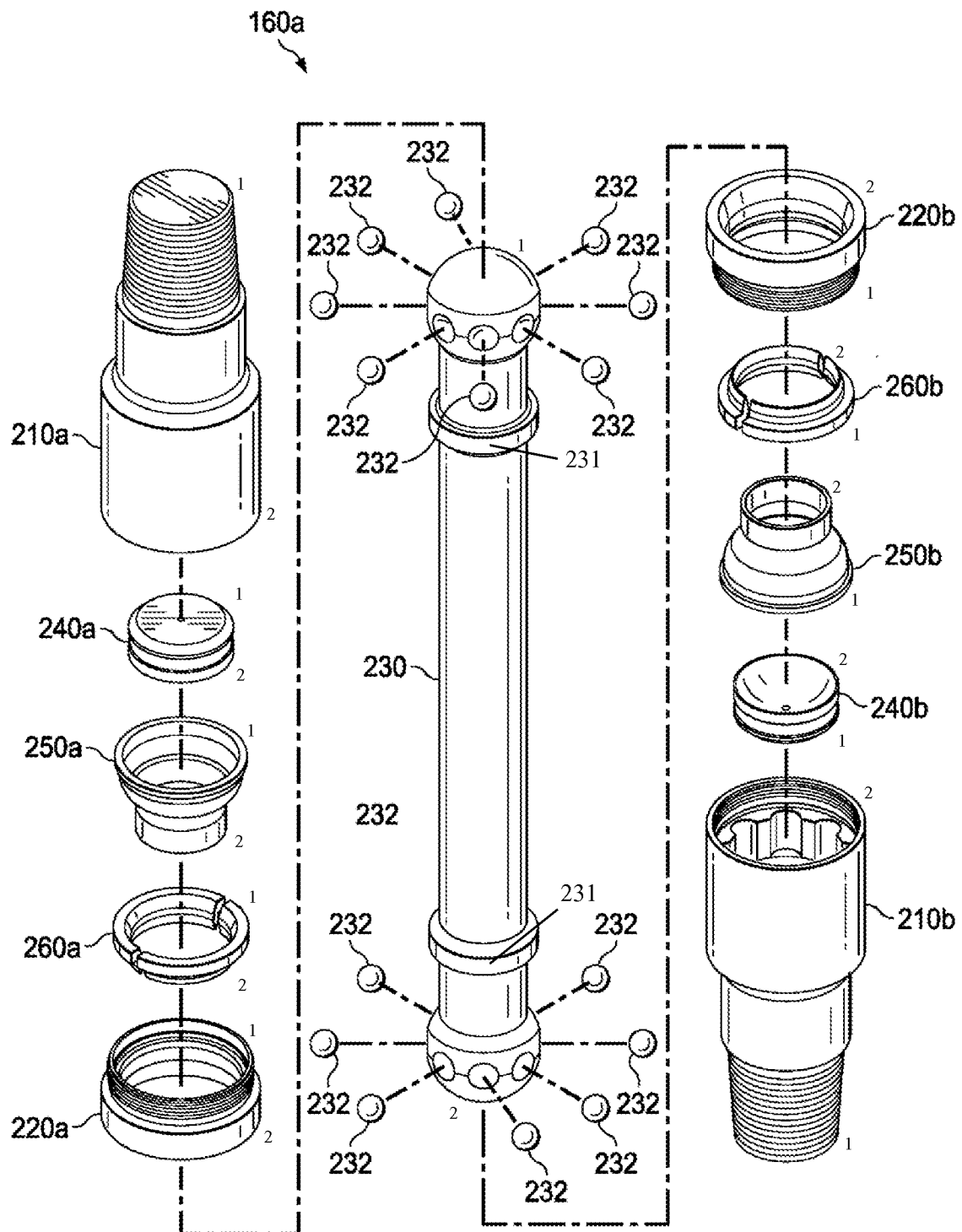
**1/16**100**PRIOR ART****FIG. 1**

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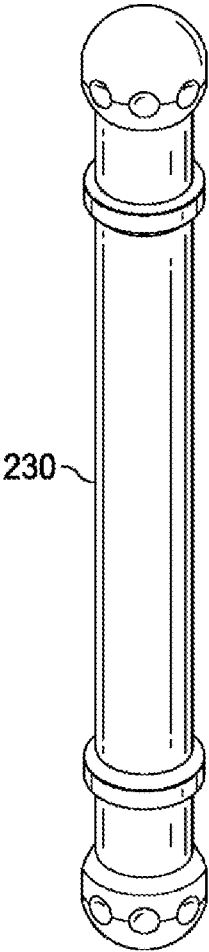


PRIOR ART  
FIG. 2A

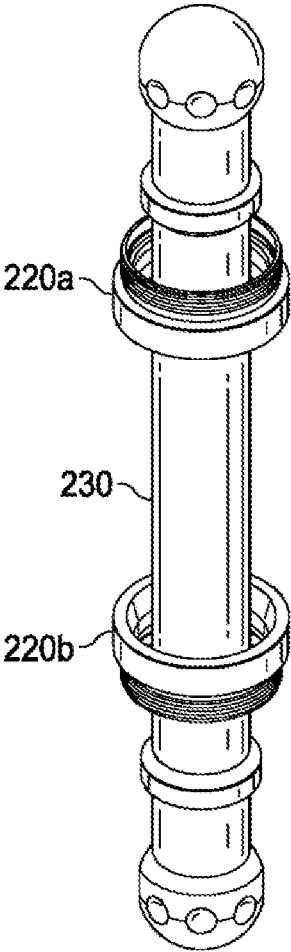
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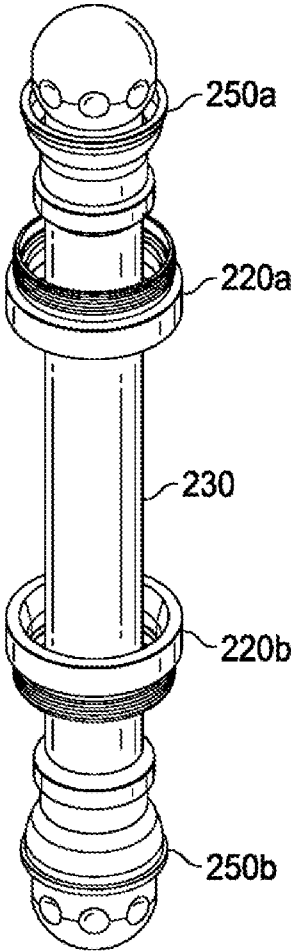
PRIOR ART  
FIG. 2B



PRIOR ART  
FIG. 3A

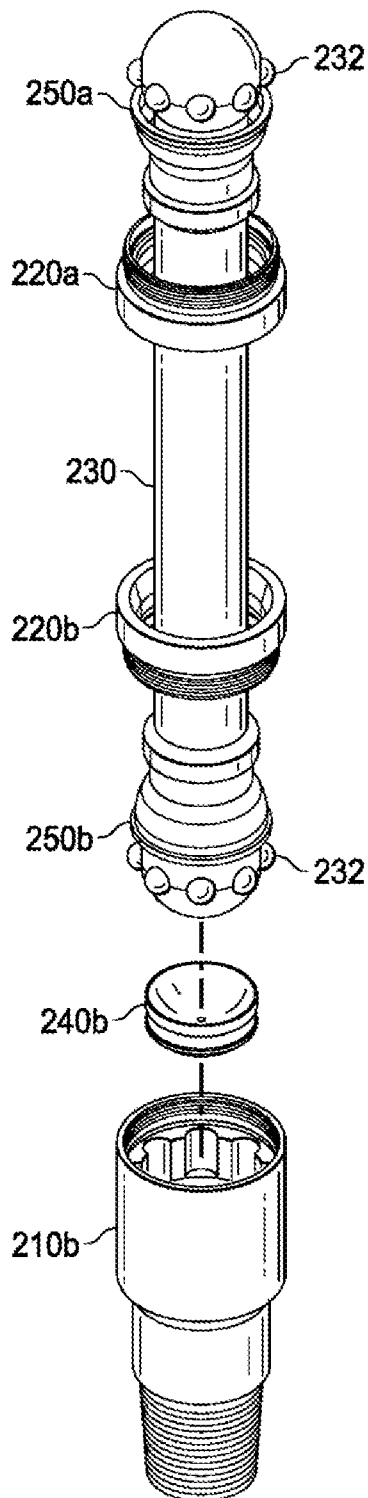


PRIOR ART  
FIG. 3B

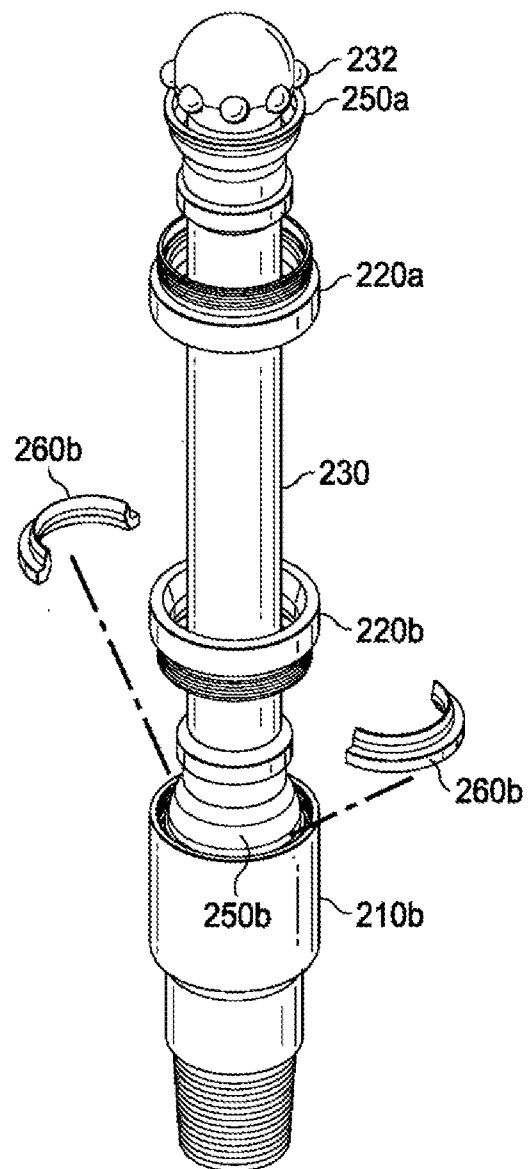


PRIOR ART  
FIG. 3C

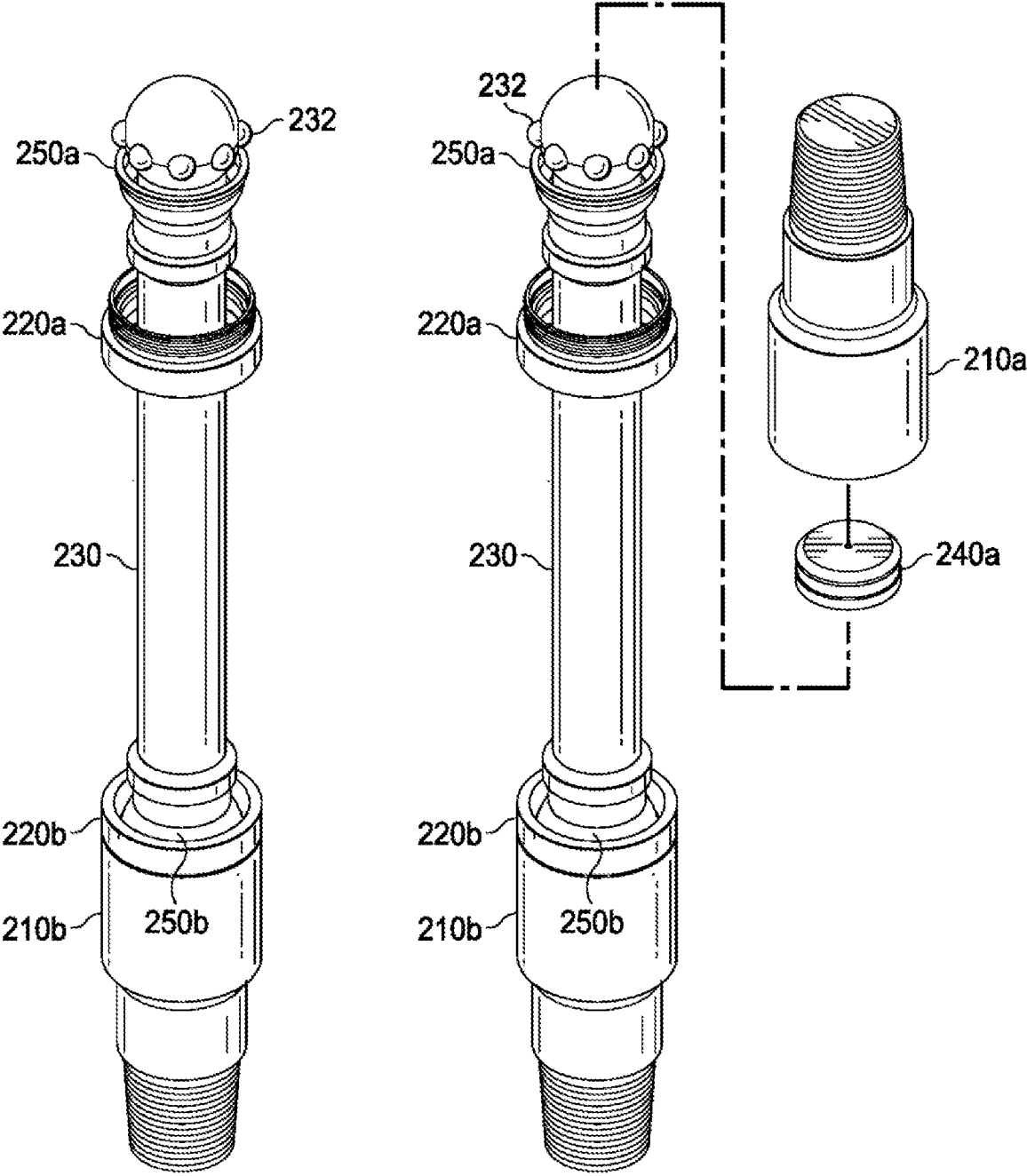
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PRIOR ART  
FIG. 3D



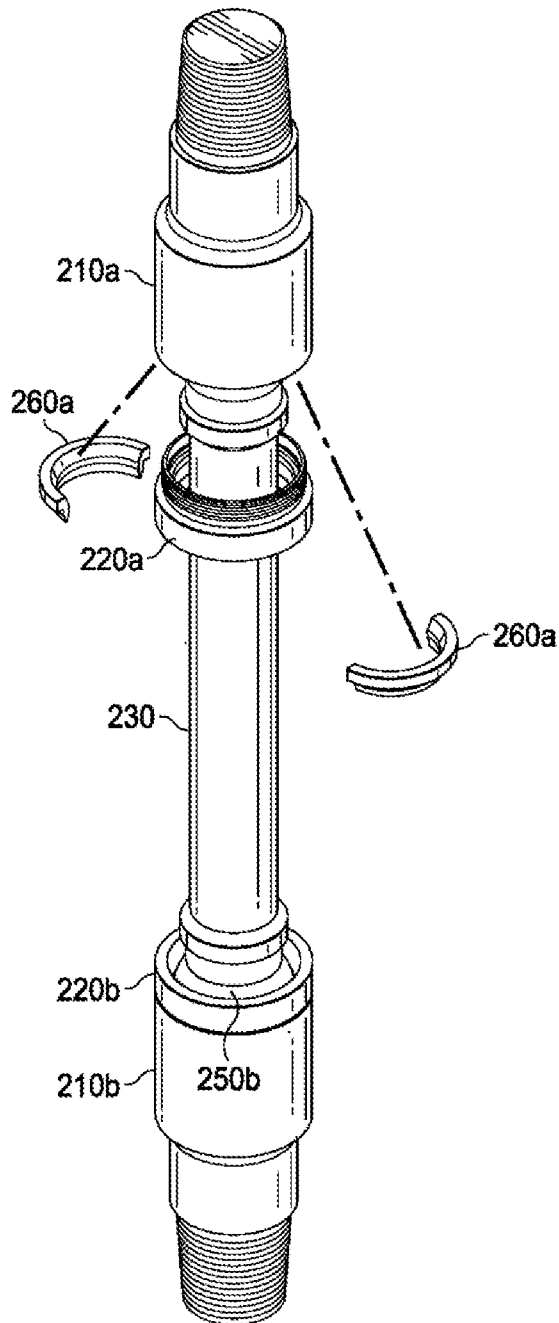
PRIOR ART  
FIG. 3E



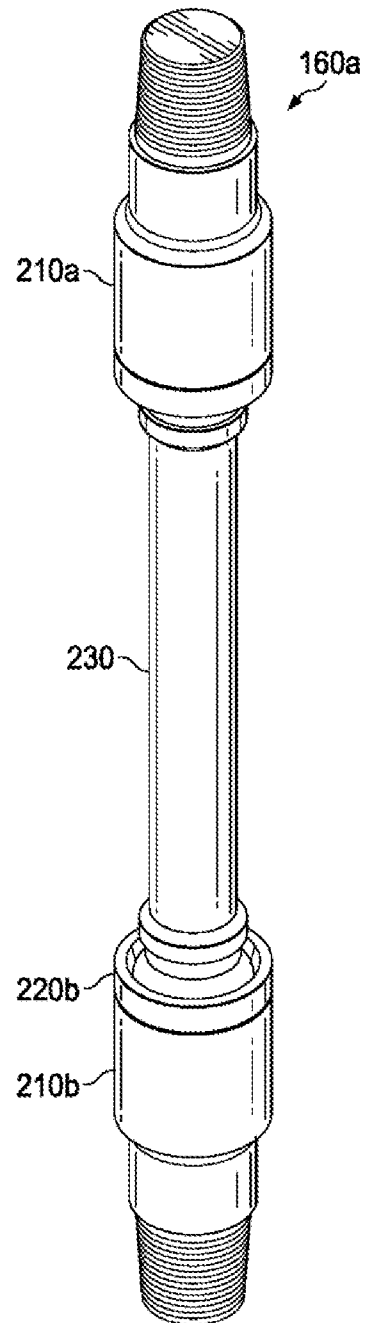
PRIOR ART  
FIG. 3F

PRIOR ART  
FIG. 3G

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PRIOR ART  
FIG. 3H



PRIOR ART  
FIG. 3I

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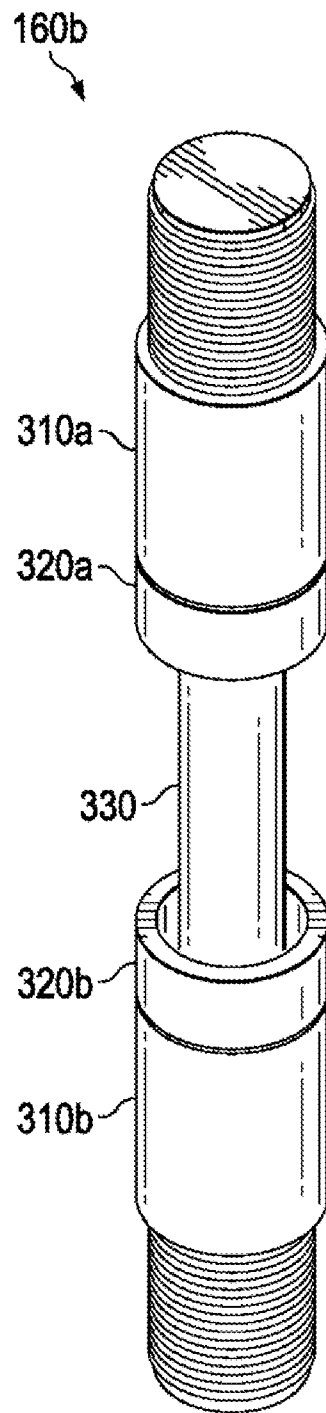


FIG. 4A

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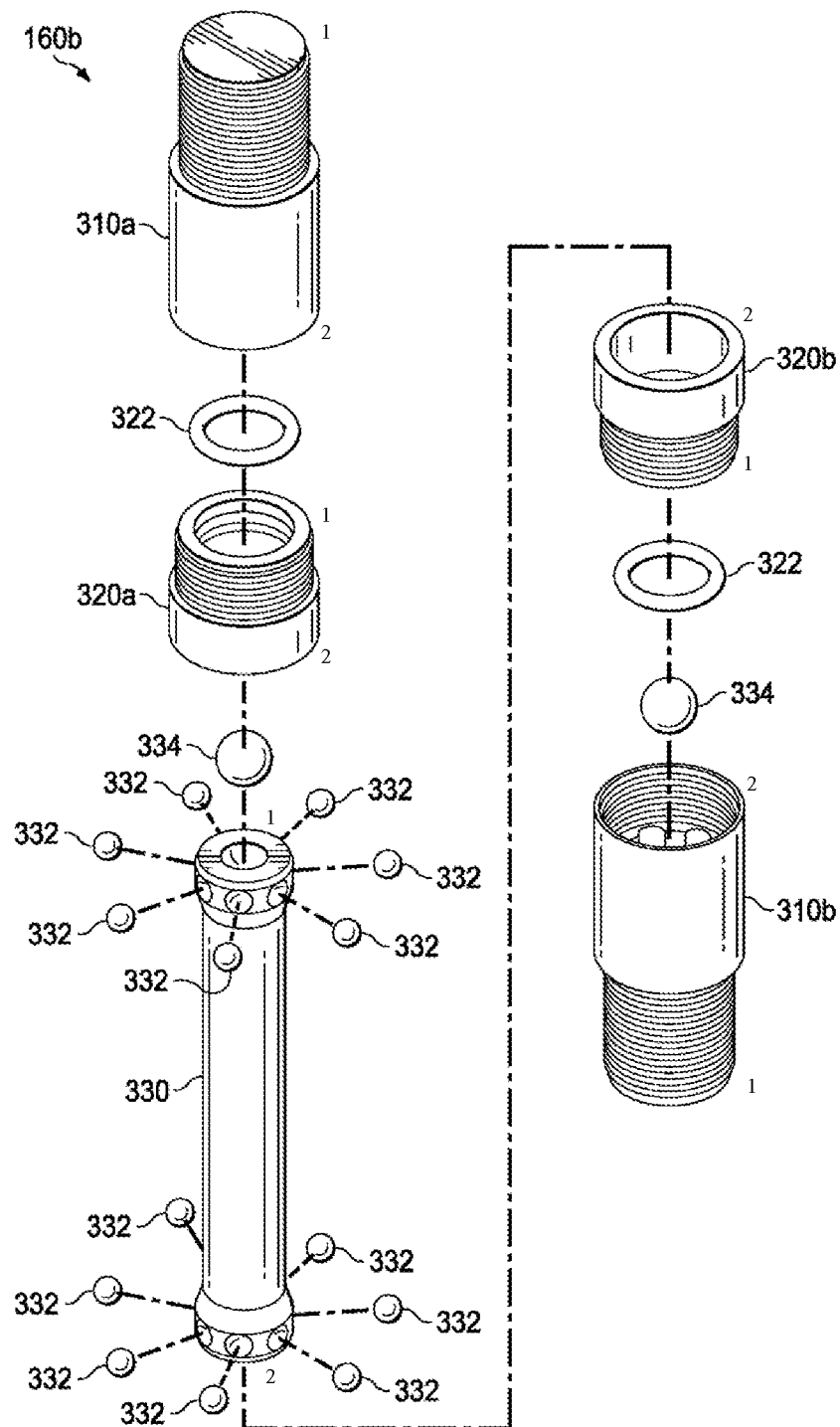


FIG. 4B

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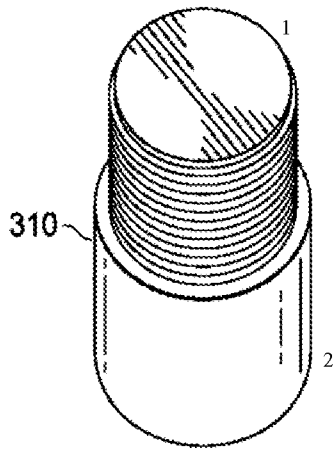


FIG. 5A

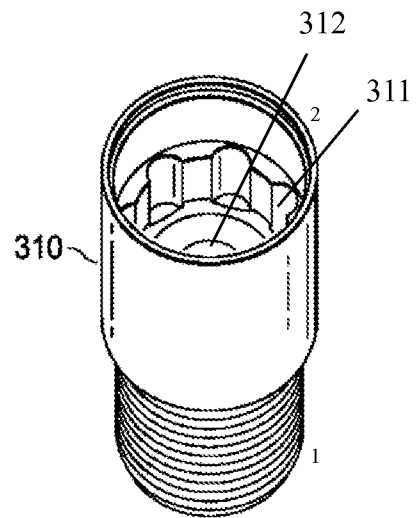


FIG. 5B

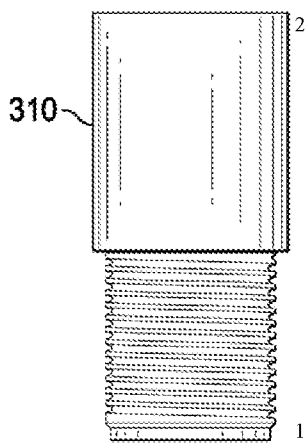


FIG. 5C

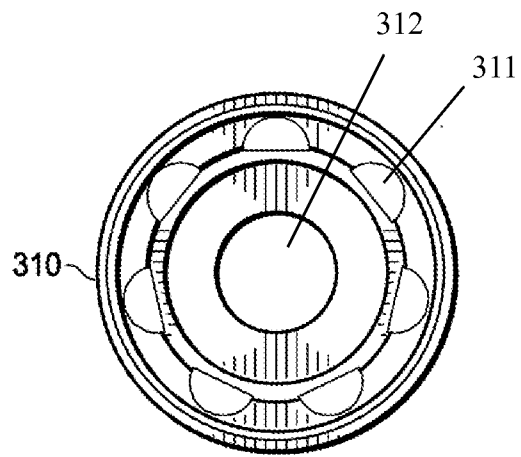


FIG. 5D

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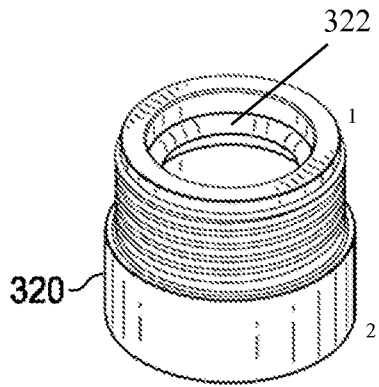


FIG. 6A

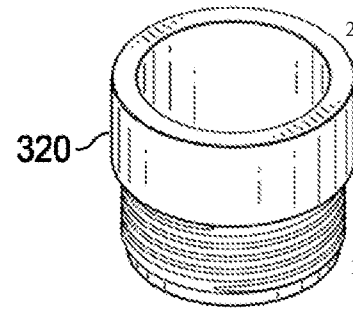


FIG. 6B

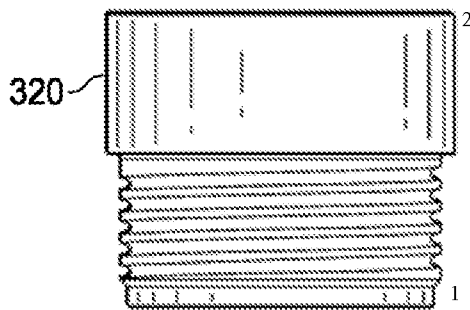


FIG. 6C

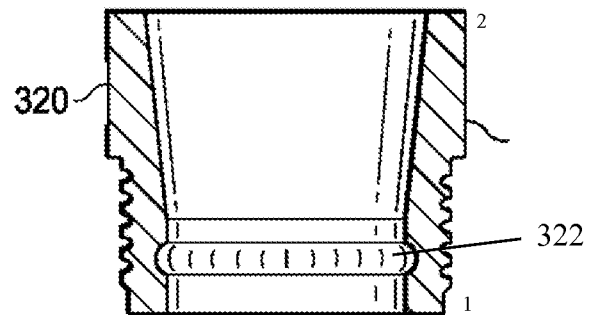


FIG. 6D

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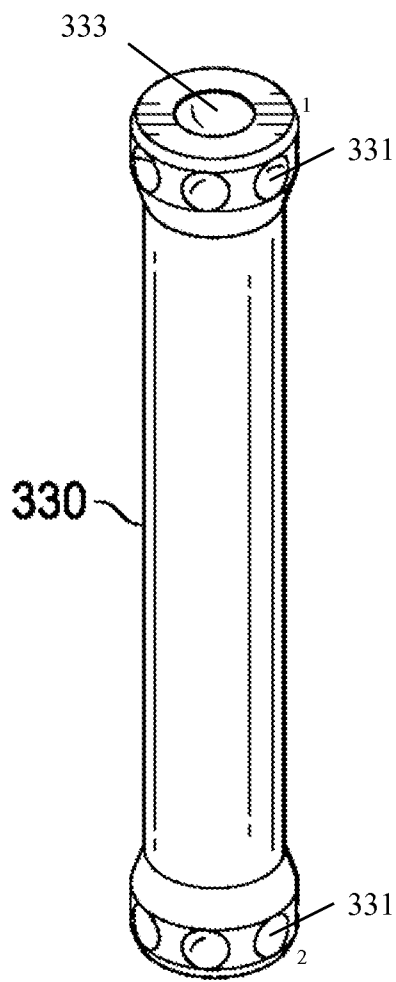


FIG. 7A

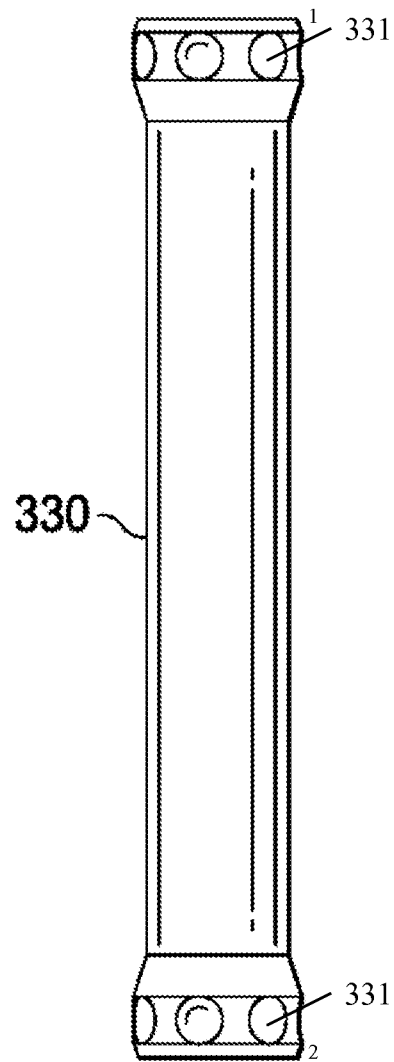


FIG. 7B

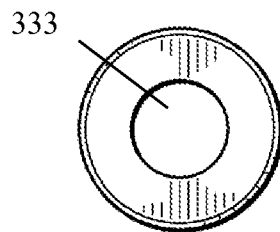


FIG. 7C

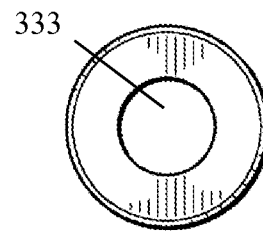


FIG. 7D

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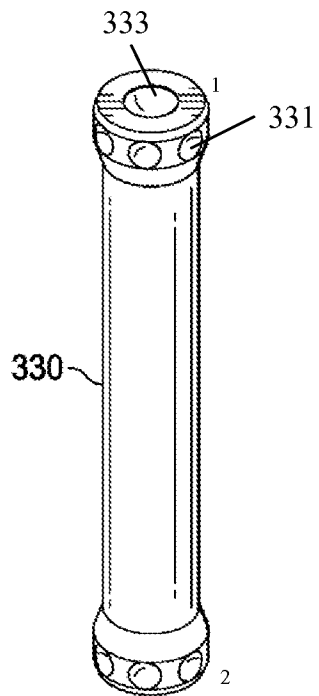


FIG. 8A

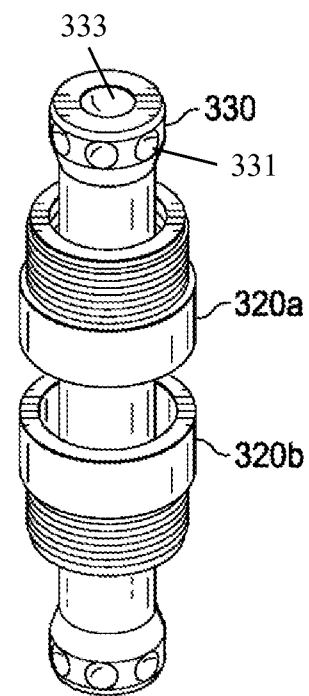


FIG. 8B

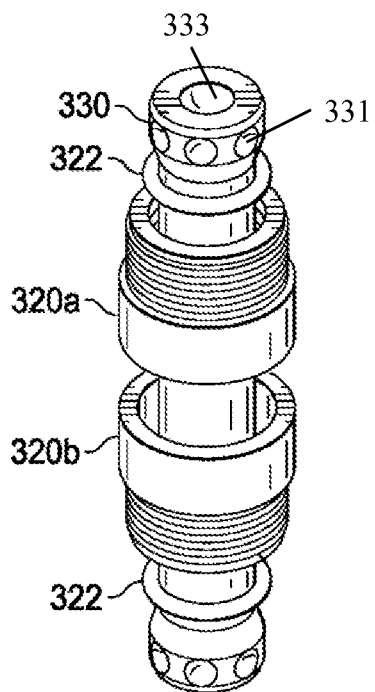


FIG. 8C

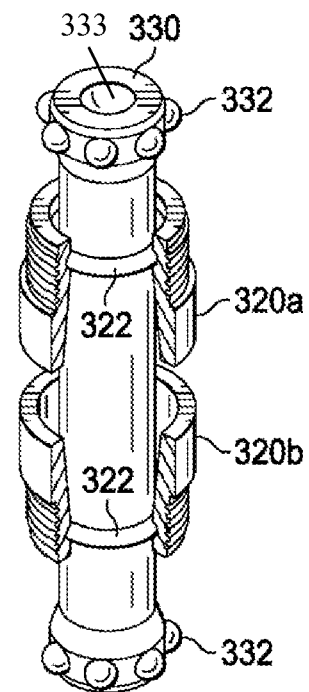


FIG. 8D

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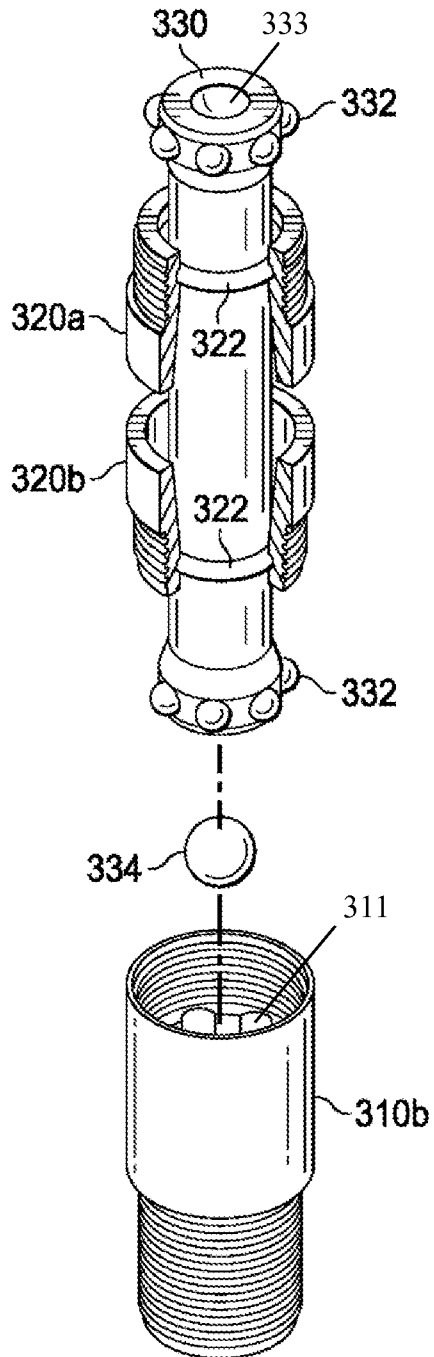


FIG. 8E

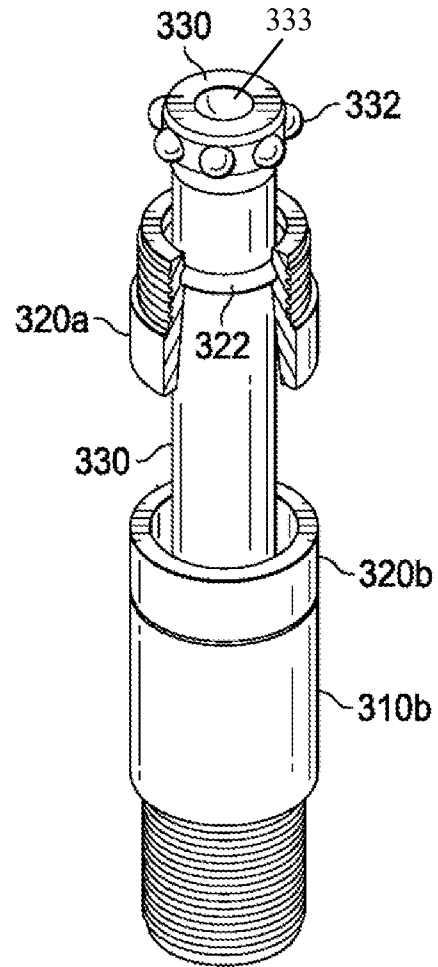


FIG. 8F

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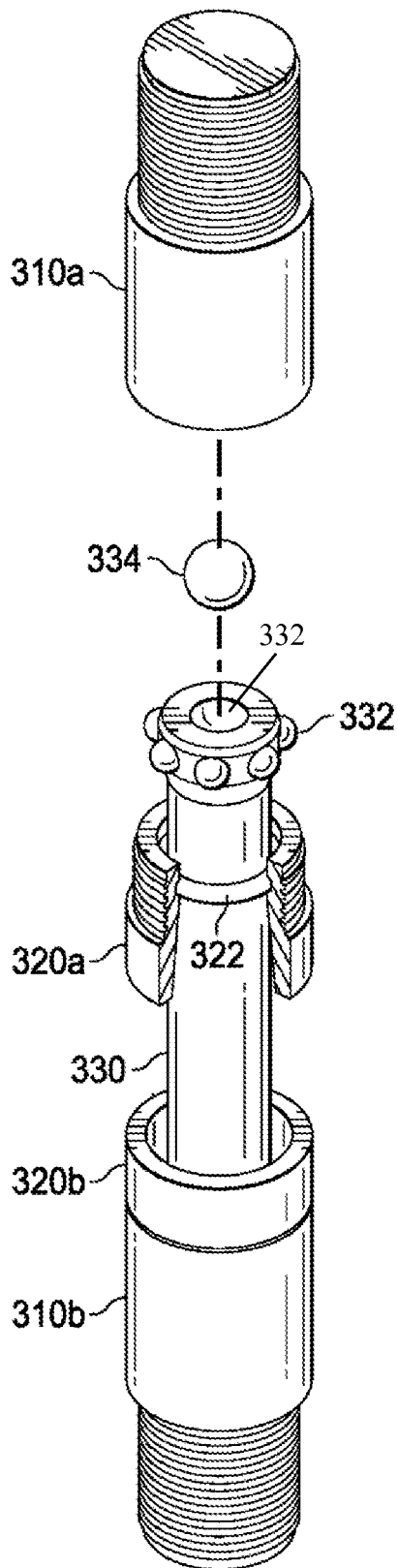


FIG. 8G

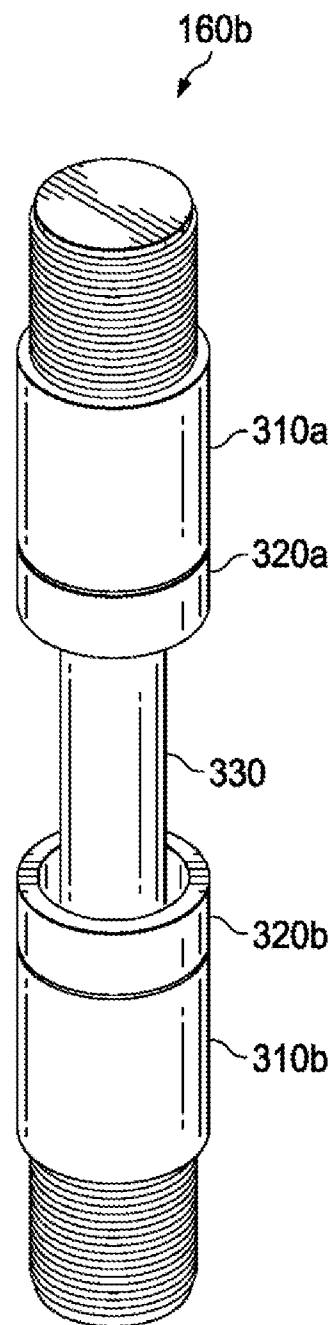


FIG. 8H

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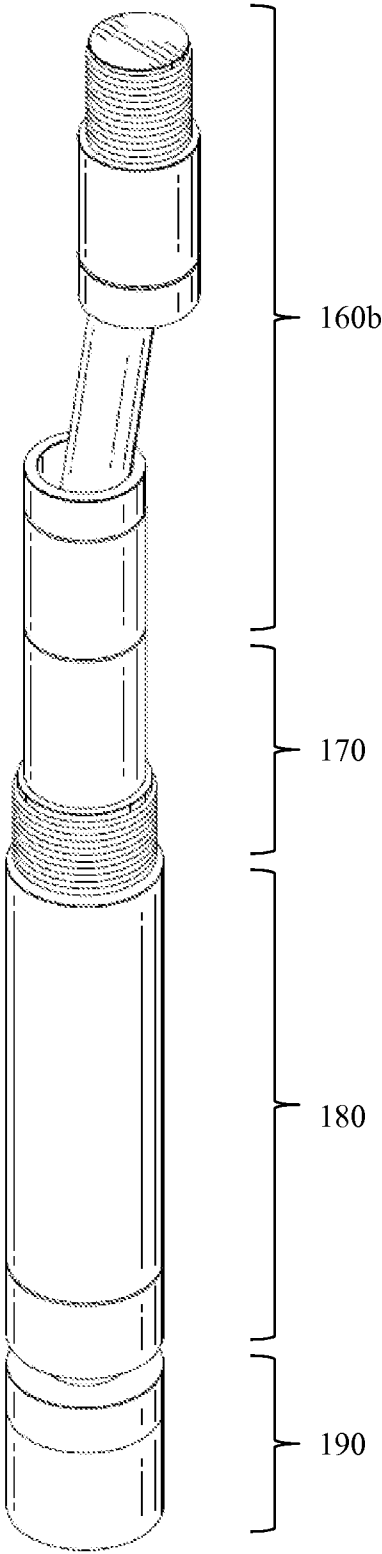


FIG. 9

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2015/030430

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F16D 3/22 (2015.01)

CPC - F16D 3/223 (2015.07)

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - E21B 4/02; F16C 1/04, 1/08, 11/06; F16D 3/22 (2015.01)

CPC - E21B 4/02; F16C 1/04, 1/08, 1/265, 11/06, 11/0623; F16D 3/22, 3/221, 3/223, 3/224 (2015.07)

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

USPC - 384/497; 464/139, 141, 142, 143, 145, 152, 155 (keyword delimited)

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

PatBase, Google Patents, Google Scholar, Google.

Search terms used: drive shaft, spherical ball, adapter, cap, indentation, groove, seal, tapered aperture, cylindrical

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages          | Relevant to claim No. |
|-----------|---------------------------------------------------------------------------------------------|-----------------------|
| X         | US 6,949,025 B1 (KRAUS et al) 27 September 2005 (27.09.2005) entire document                | 1-18                  |
| A         | US 5,000,723 A (LIVINGSTONE) 19 March 1991 (19.03.1991) entire document                     | 1-18                  |
| A         | US 2014/0224545 A1 (NATIONAL OILWELL VARCO, LP) 14 August 2014 (14.08.2014) entire document | 1-18                  |
| A         | US 2002/0092682 A1 (BLAIR et al) 18 July 2002 (18.07.2002) entire document                  | 1-18                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents:

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"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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

24 July 2015

Date of mailing of the international search report

11 AUG 2015

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