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(12) **United States Patent**
Clausen et al.

(10) **Patent No.: US 12,385,337 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **DEPTH ACTIVATED DOWNHOLE ADJUSTABLE BEND ASSEMBLIES**

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(72) Inventors: **Jeffery Ronald Clausen**, Tulsa, OK (US); **Nicholas Ryan Marchand**, Edmonton (CA)

(73) Assignee: **National Oilwell Varco, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/719,338**

(22) PCT Filed: **Dec. 16, 2022**

(86) PCT No.: **PCT/US2022/053199**

§ 371 (c)(1),
(2) Date: **Jun. 13, 2024**

(87) PCT Pub. No.: **WO2023/114488**

PCT Pub. Date: **Jun. 22, 2023**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Provisional application No. 63/290,426, filed on Dec. 16, 2021.

(51) **Int. Cl.**
E21B 4/02 (2006.01)
E21B 7/06 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***E21B 21/08*** (2013.01); ***E21B 34/063*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 4/02; E21B 7/067; E21B 7/068
See application file for complete search history.

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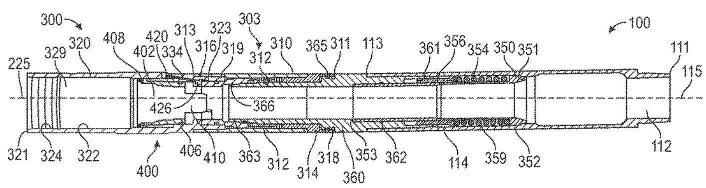
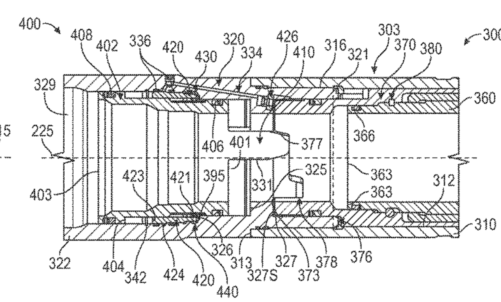
Primary Examiner — Kenneth L Thompson
(74) *Attorney, Agent, or Firm* — Conley Rose, P.C.

(57) **ABSTRACT**

A downhole mud motor includes a driveshaft rotatably disposed in a driveshaft housing, a bearing mandrel coupled to the driveshaft, wherein the bend adjustment assembly includes a first configuration that provides a first deflection angle between the driveshaft housing and the bearing mandrel, wherein the bend adjustment assembly includes a second configuration that provides a second deflection angle between the driveshaft housing and the bearing mandrel, and a locking assembly including a locked configuration configured to lock the bend adjustment assembly into one of the first configuration and the second configuration until the downhole mud motor has at least one of reached a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth, in response to which the locking assembly is configured to actuate from the locked configuration to an unlocked configuration.

34 Claims, 22 Drawing Sheets





(51) **Int. Cl.**
E21B 21/08 (2006.01)
E21B 34/06 (2006.01)

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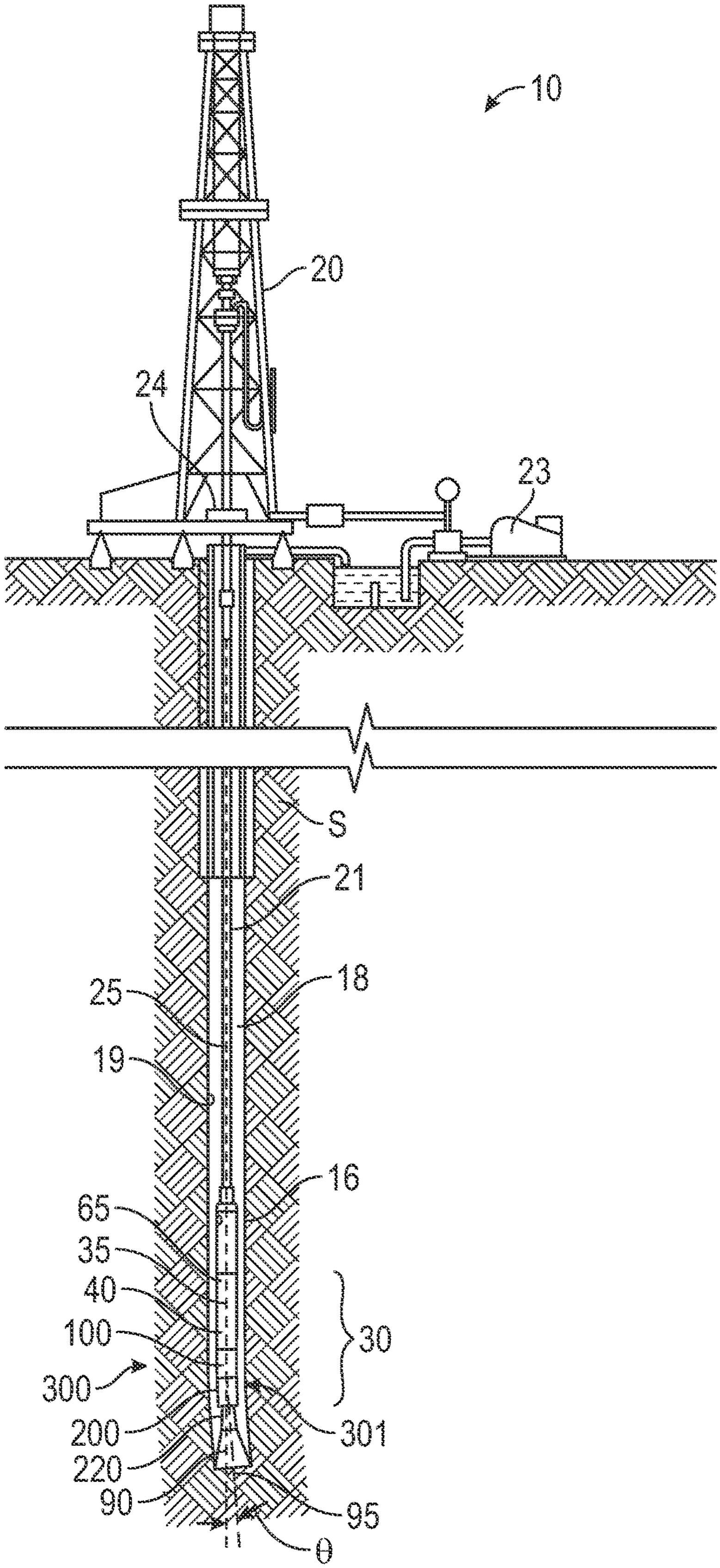
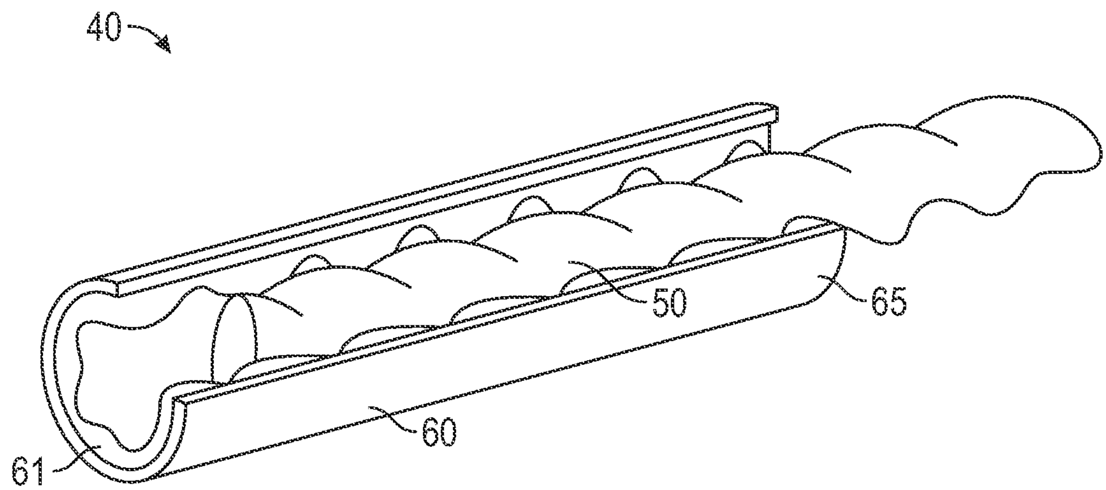


FIG. 1



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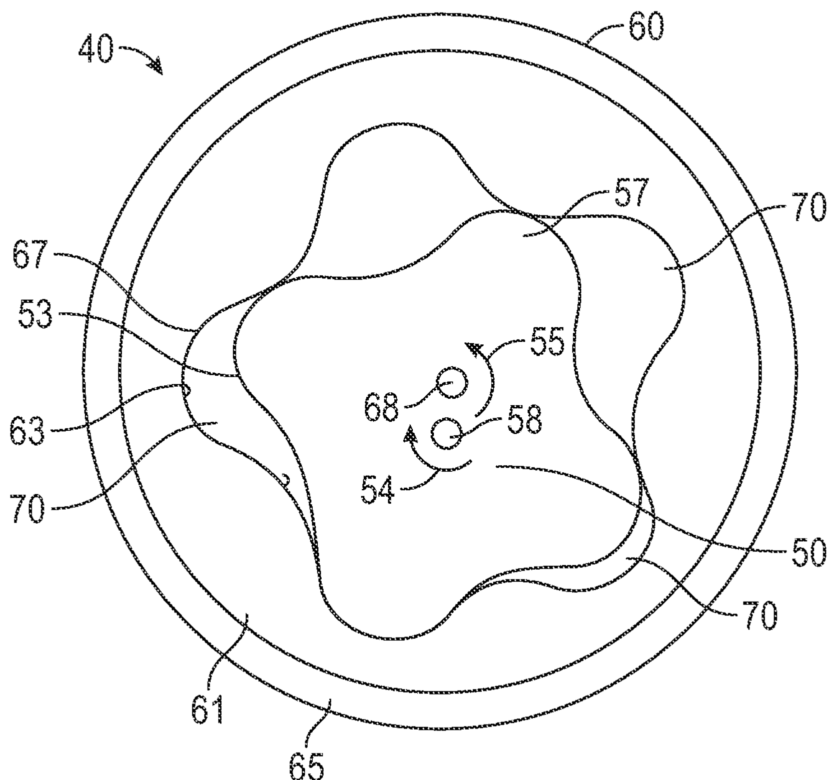

FIG. 3

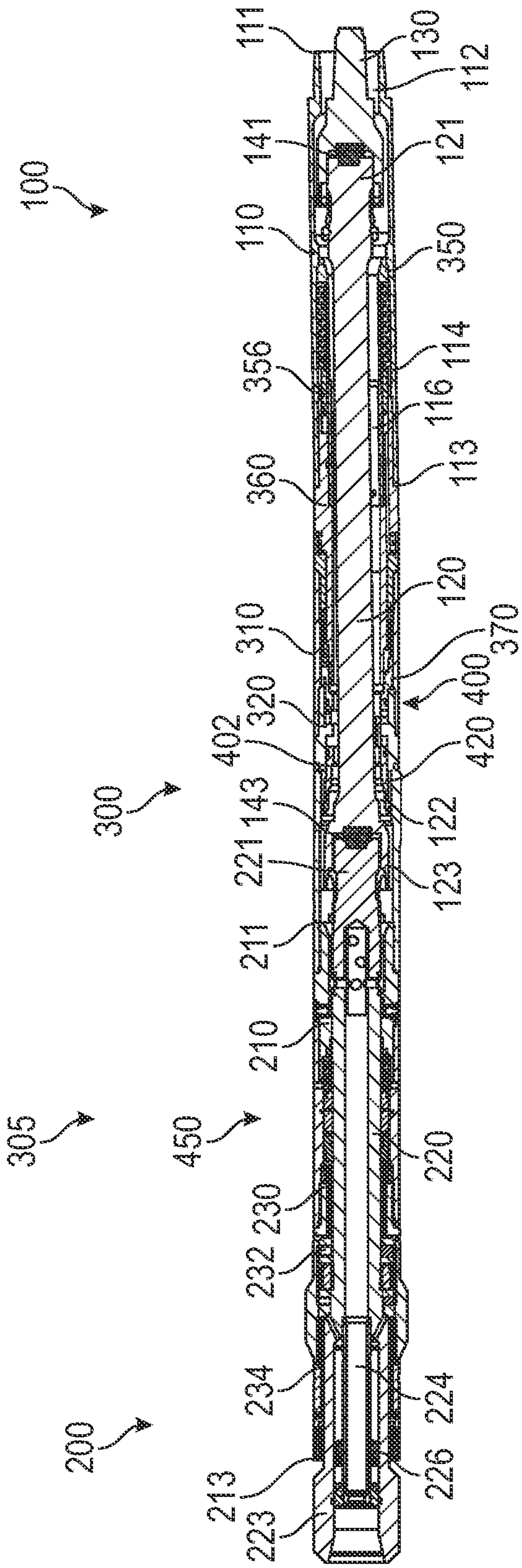

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FIG. 4

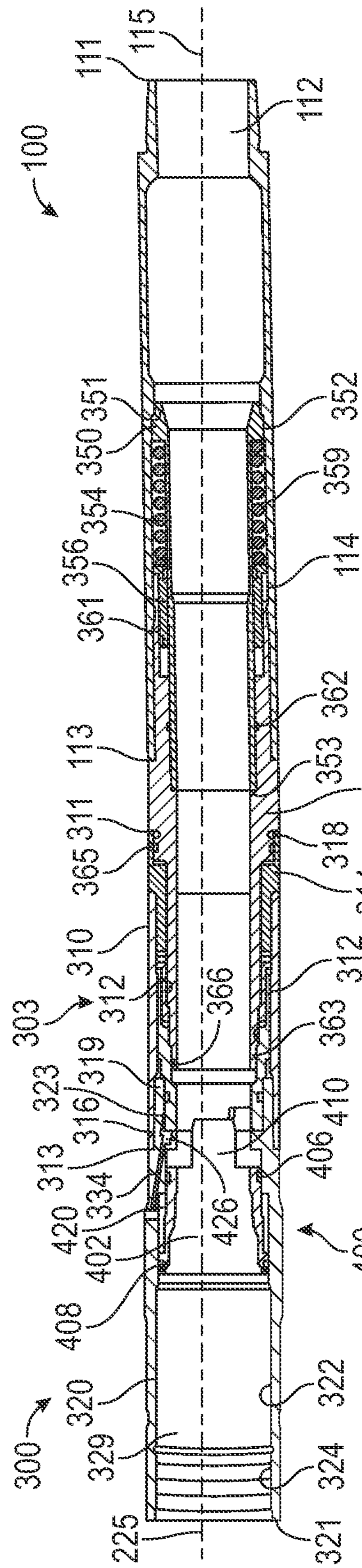
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FIG. 5

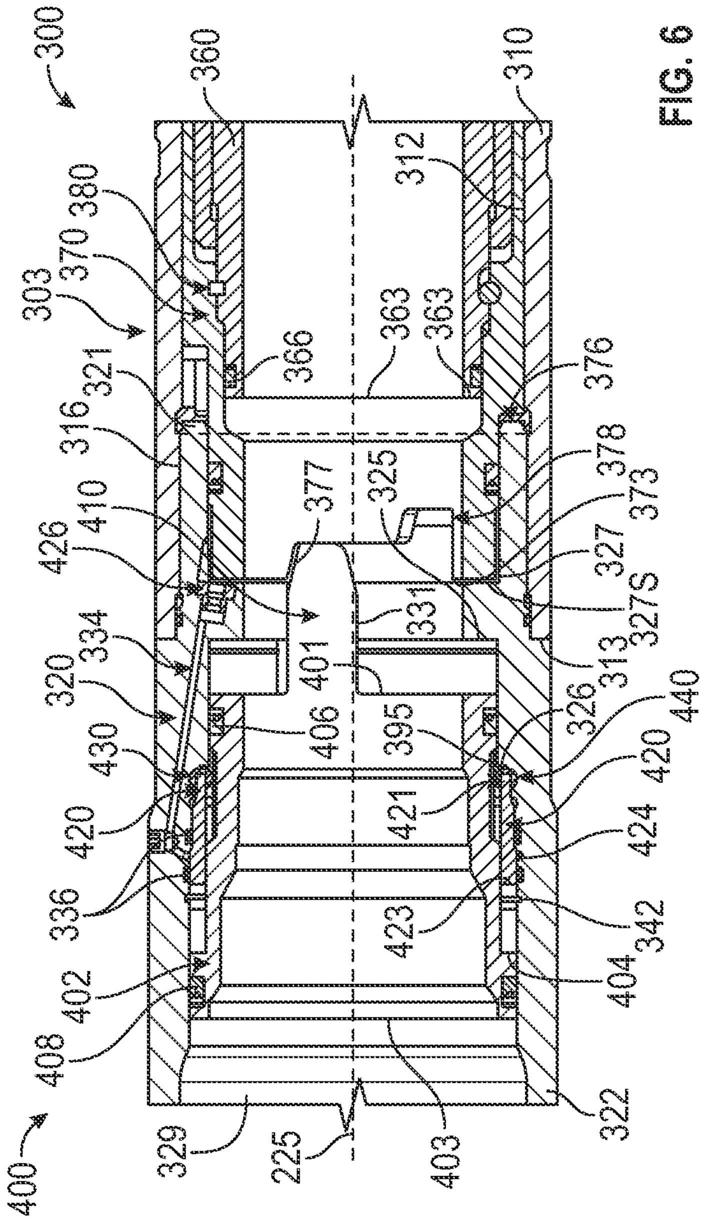
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FIG. 6

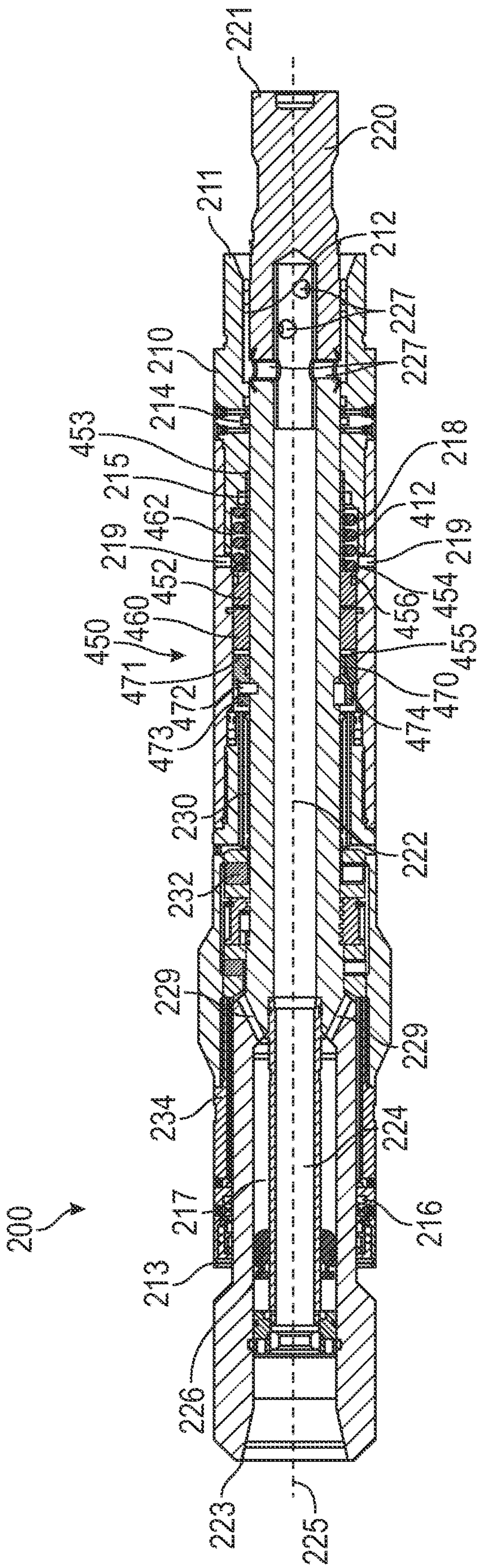
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FIG. 7

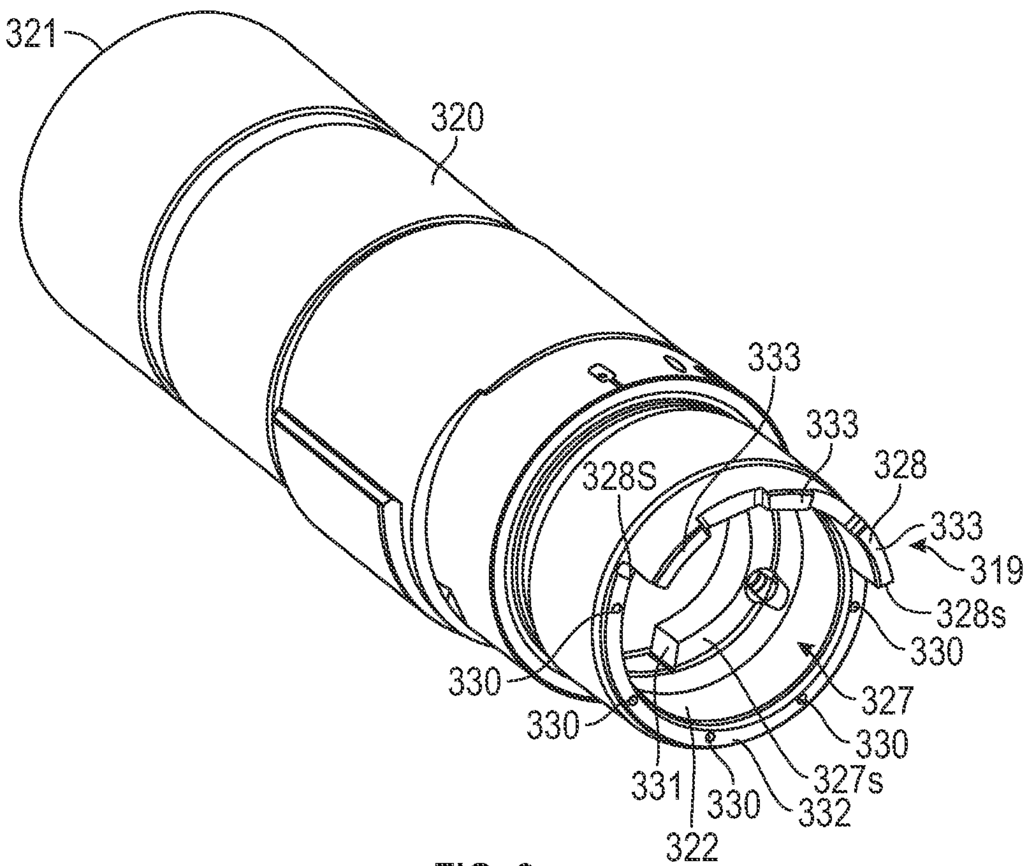
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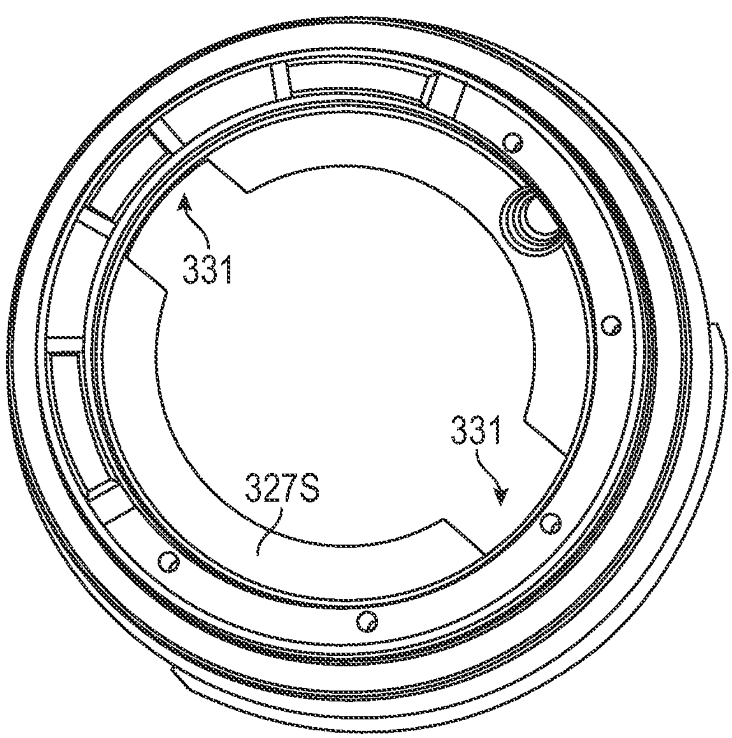
FIG. 8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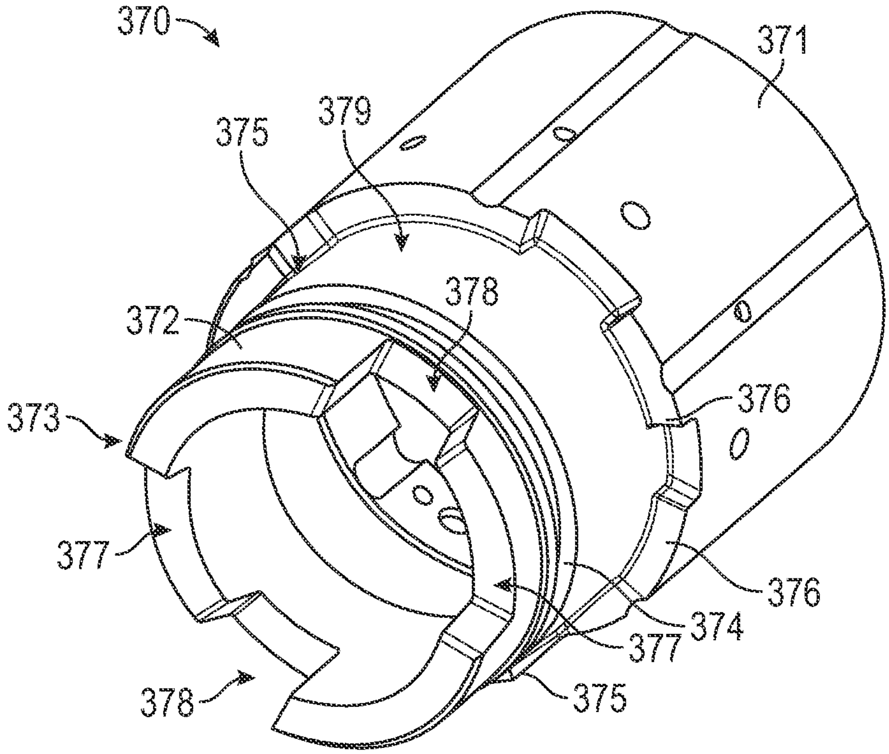
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FIG. 10

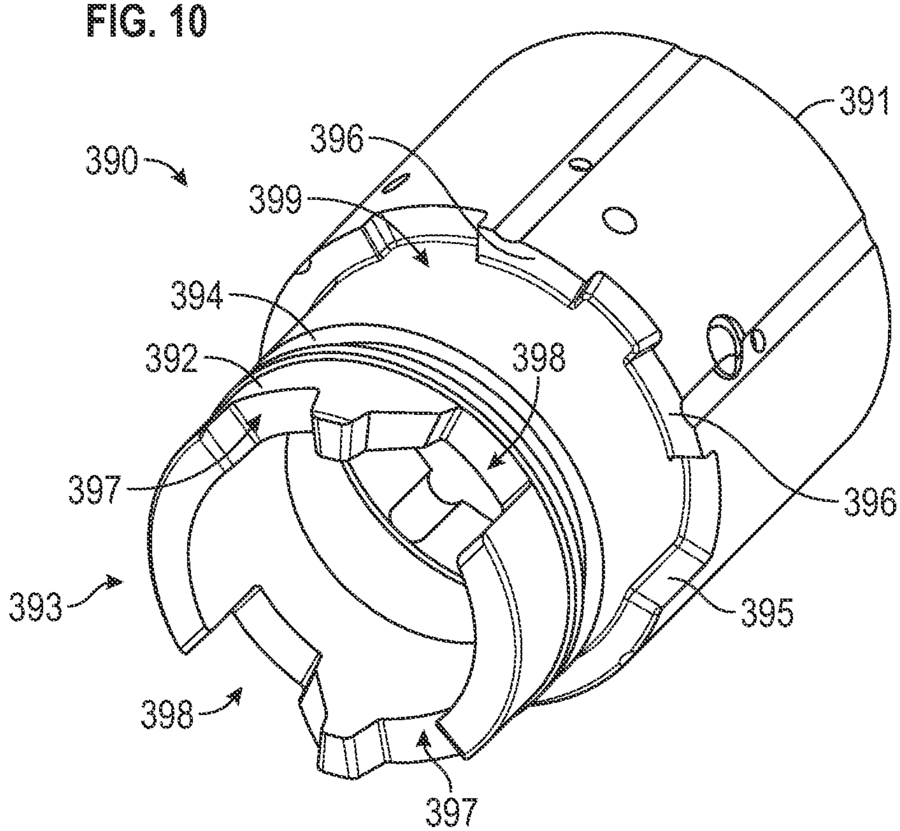
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FIG. 11

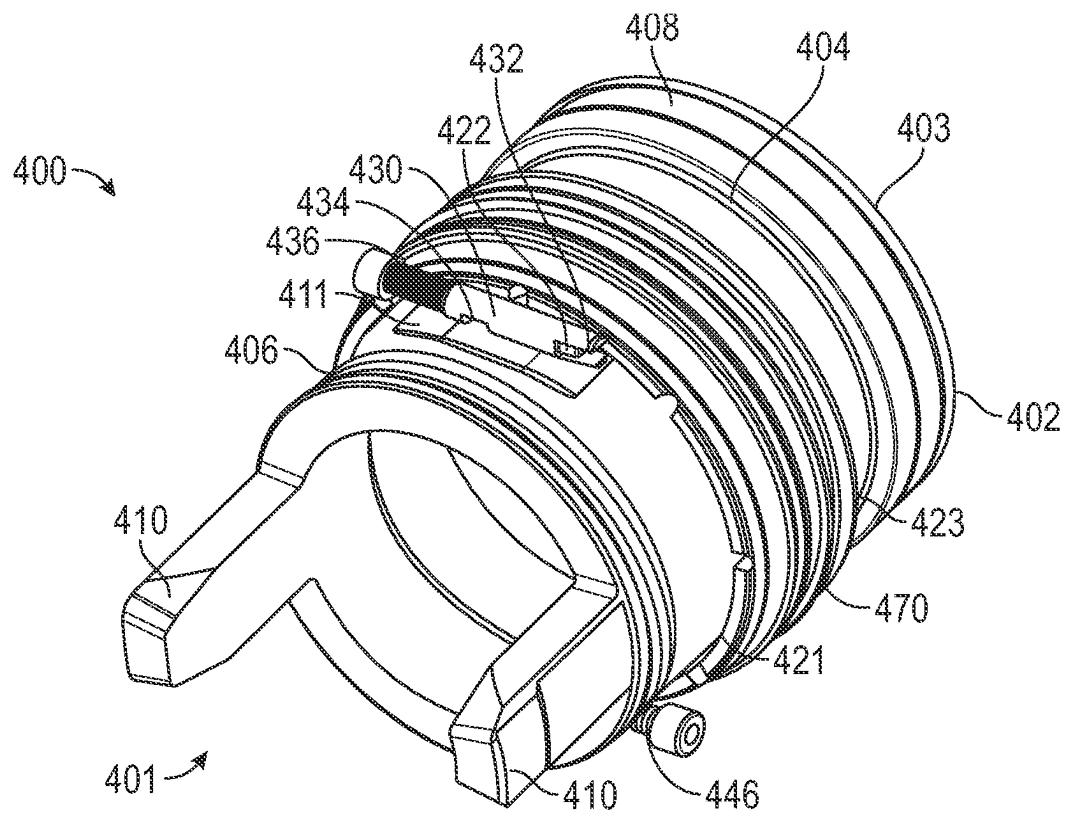

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FIG. 12

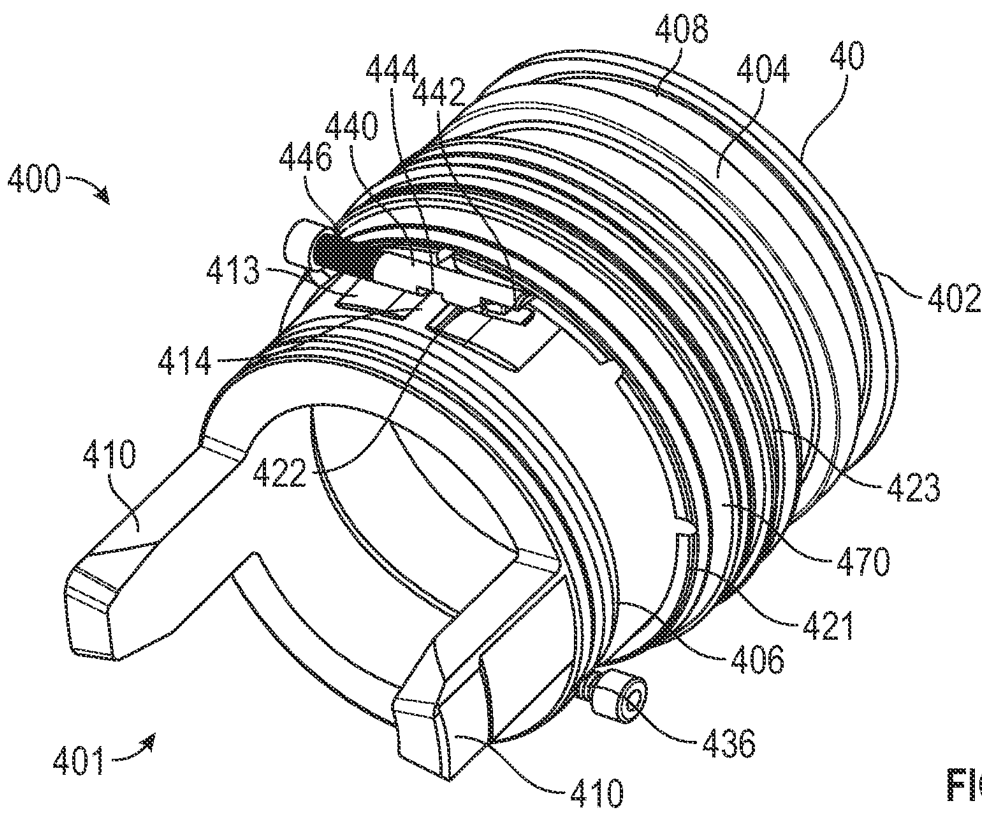

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FIG. 13

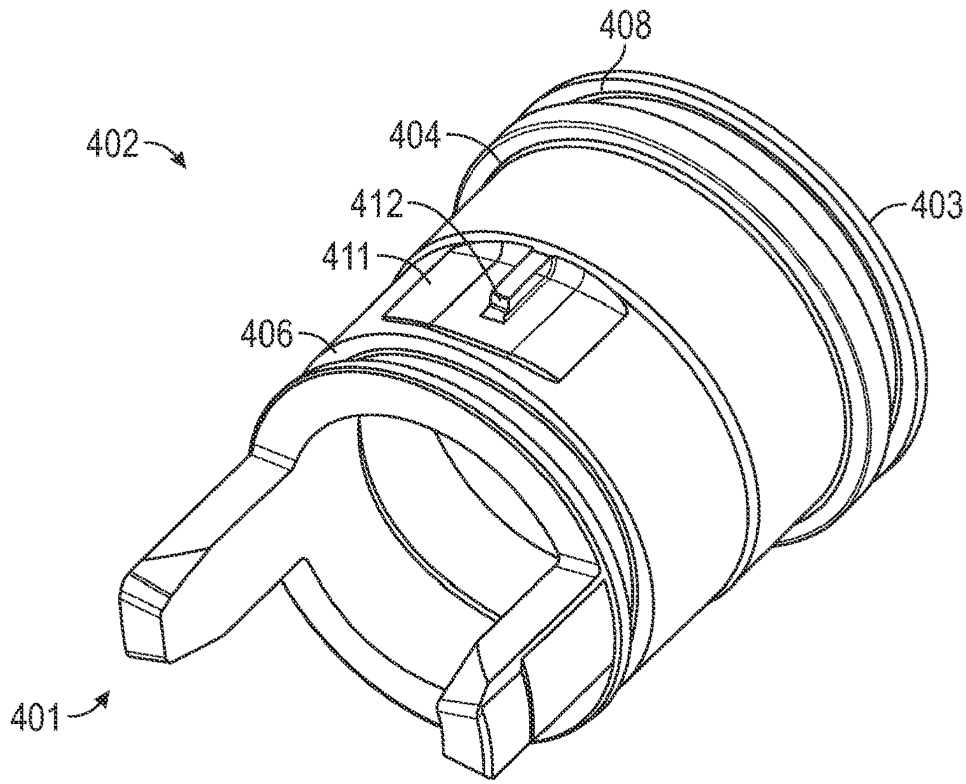
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FIG. 14

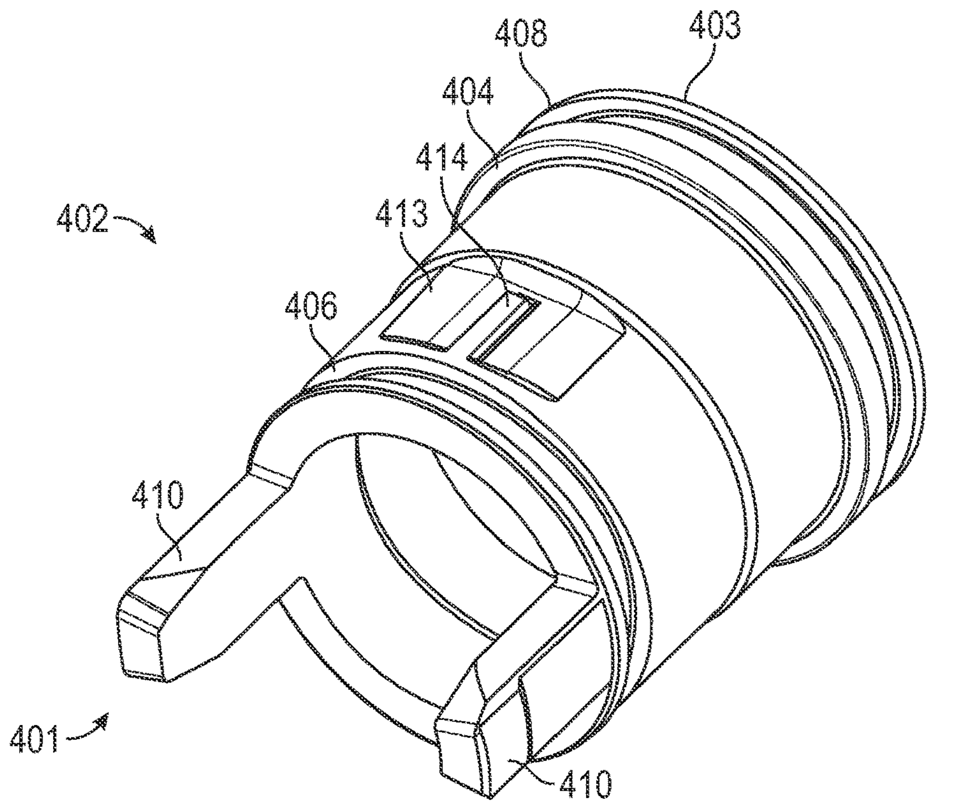
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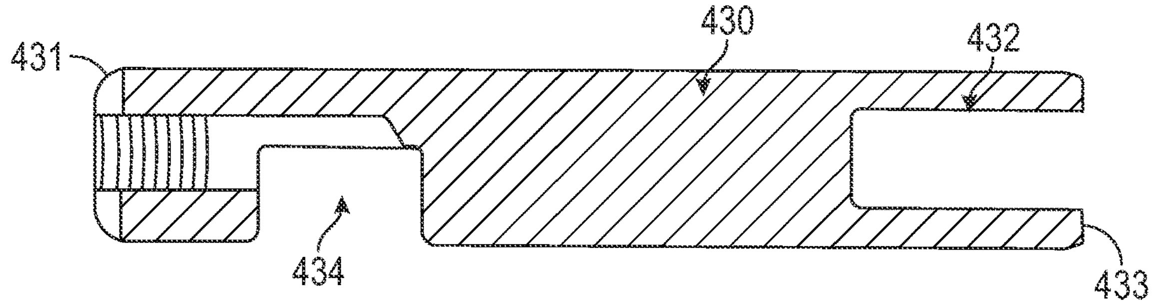
FIG. 15



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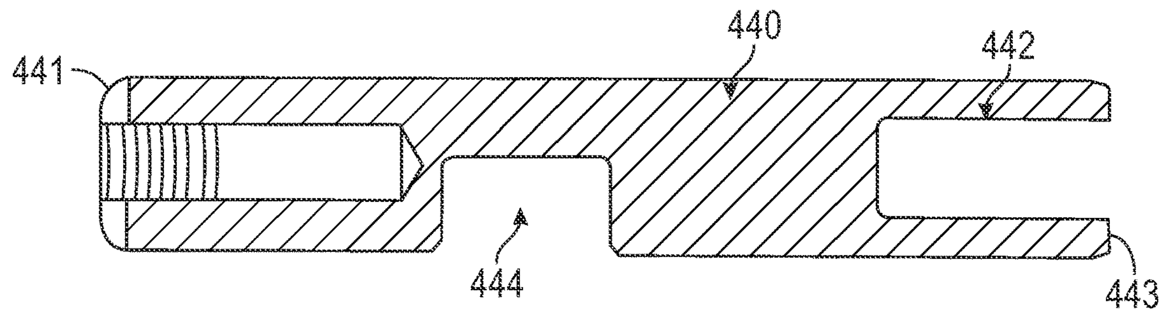

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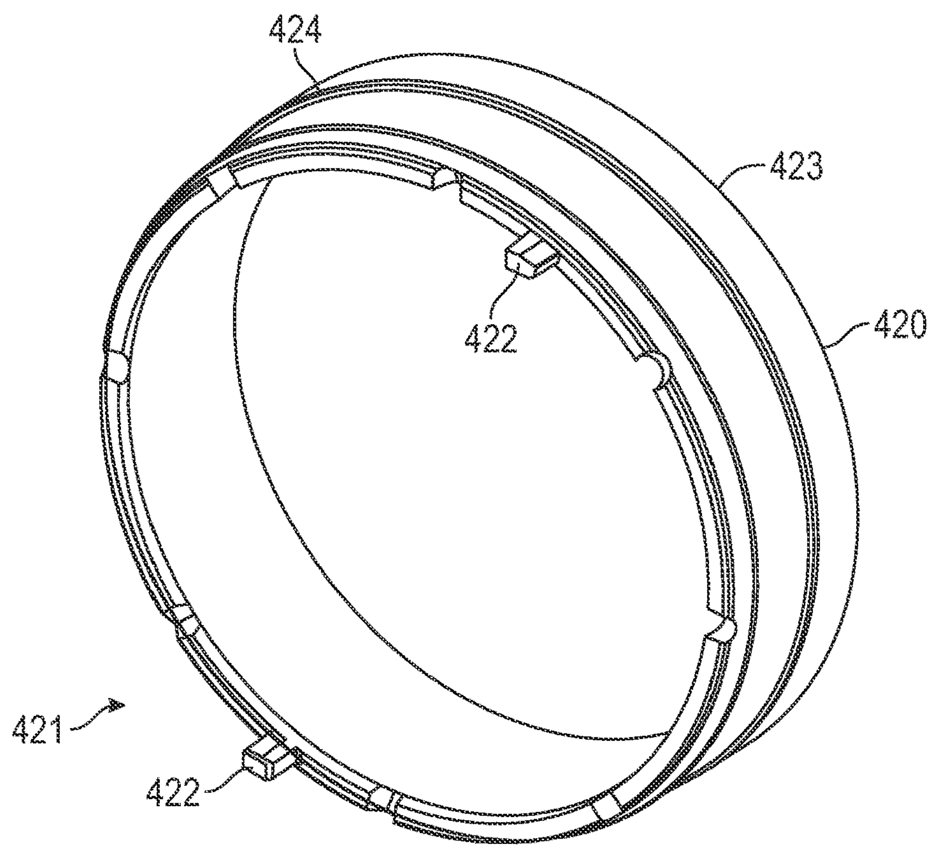

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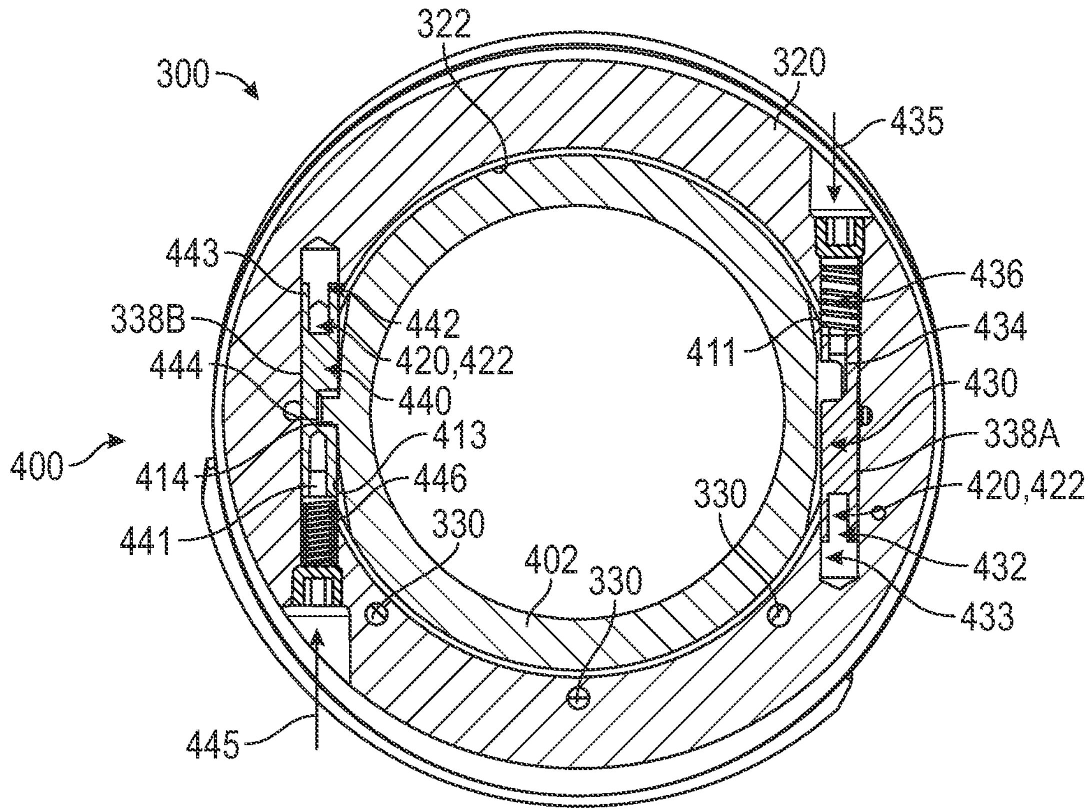
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FIG. 19

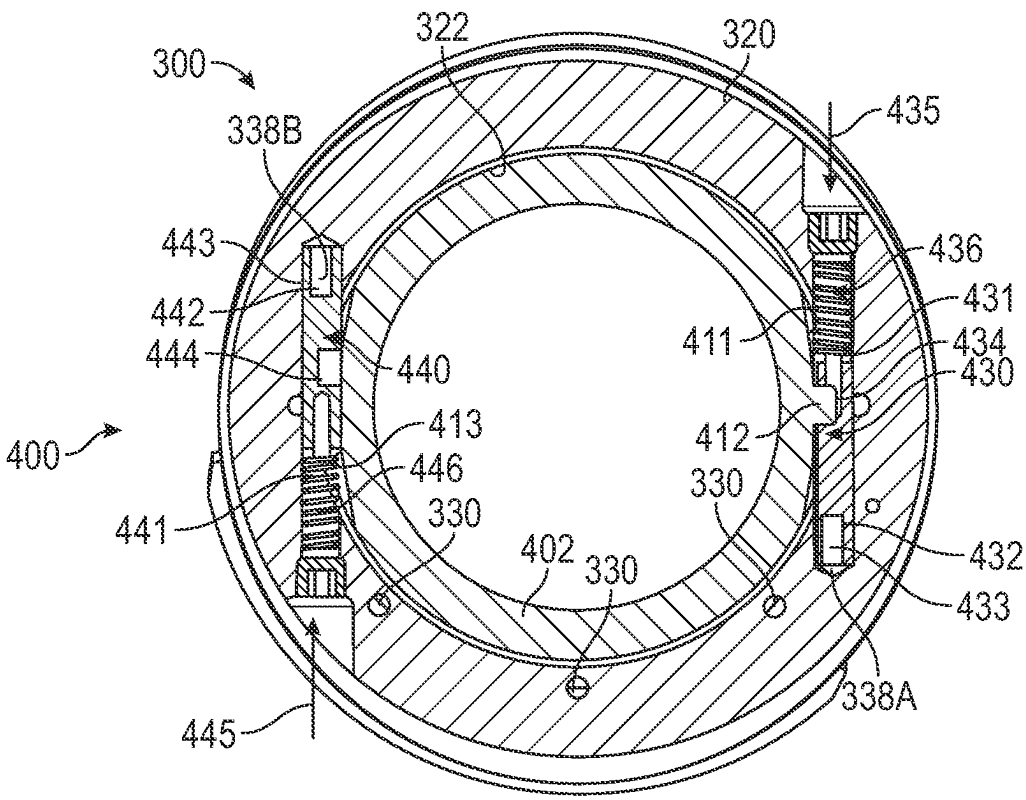
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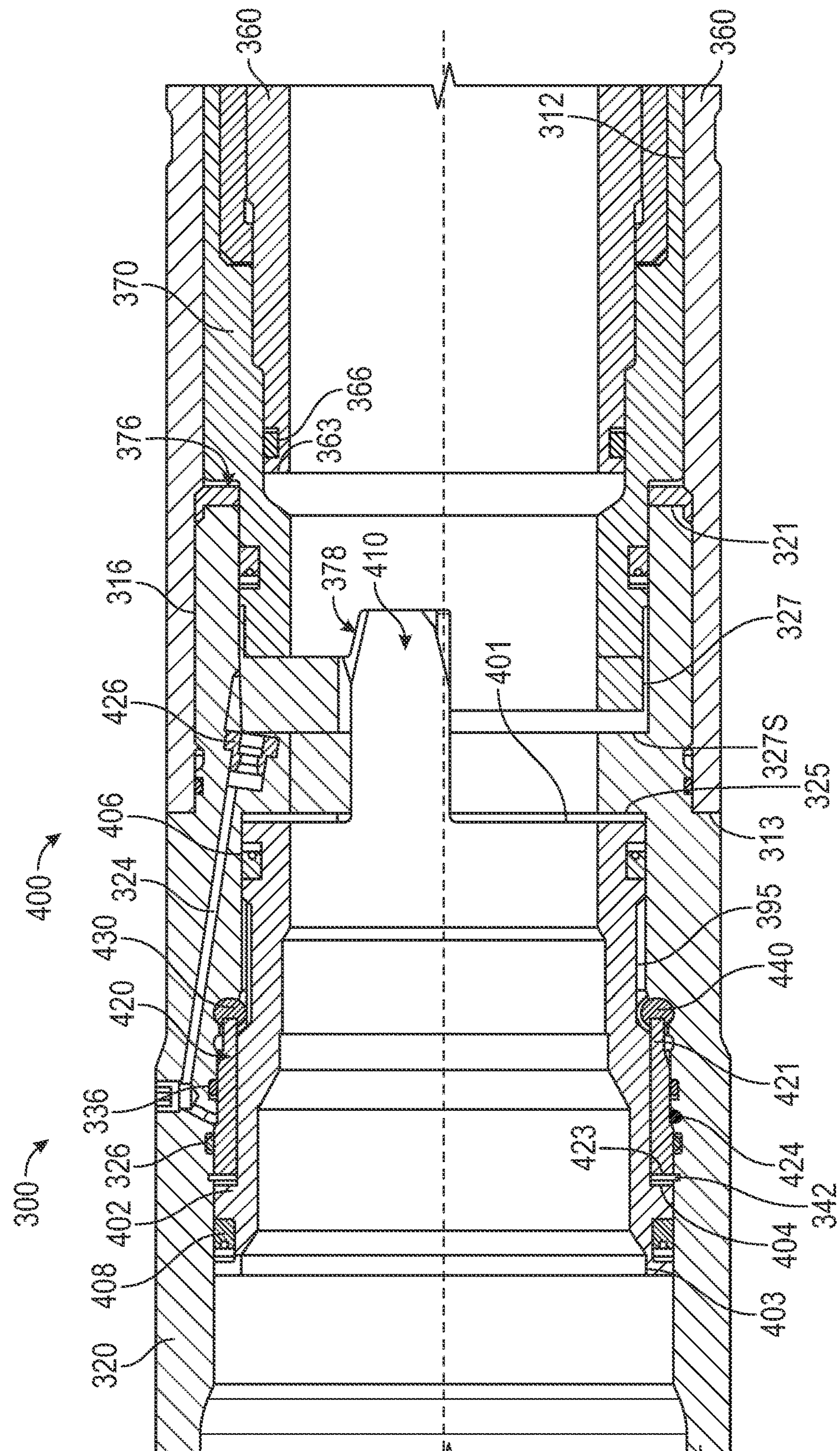
FIG. 20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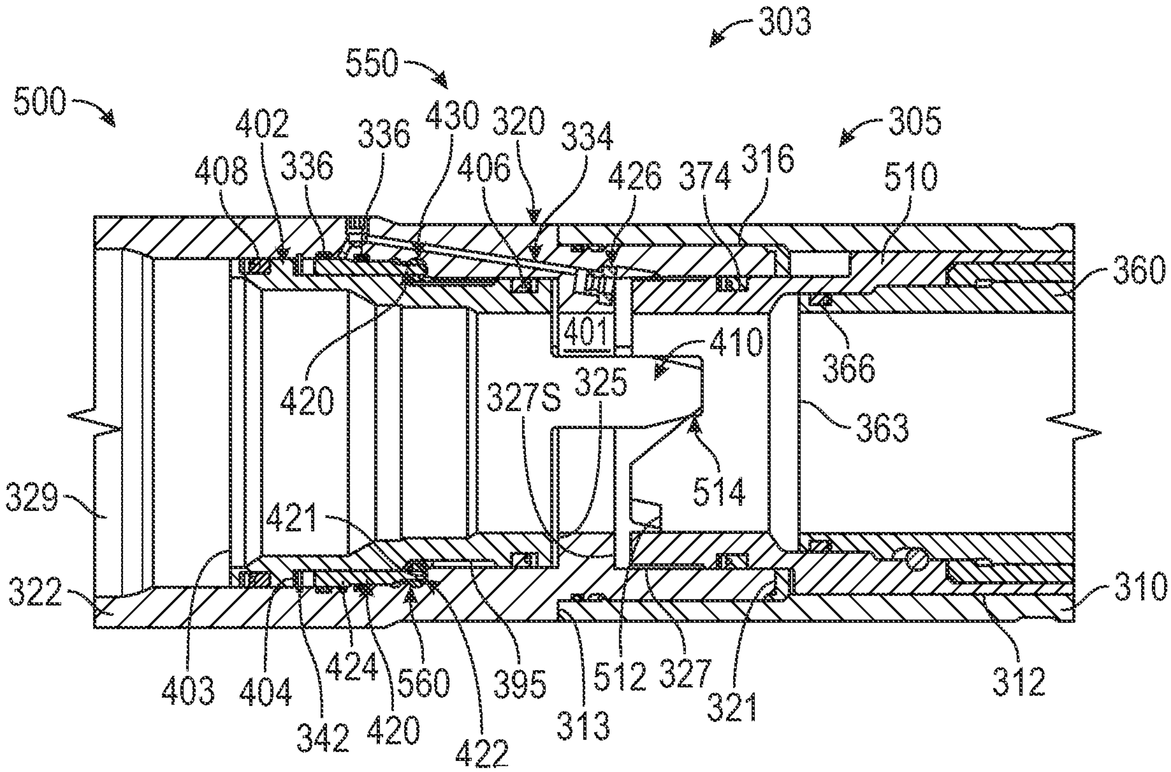
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FIG. 22

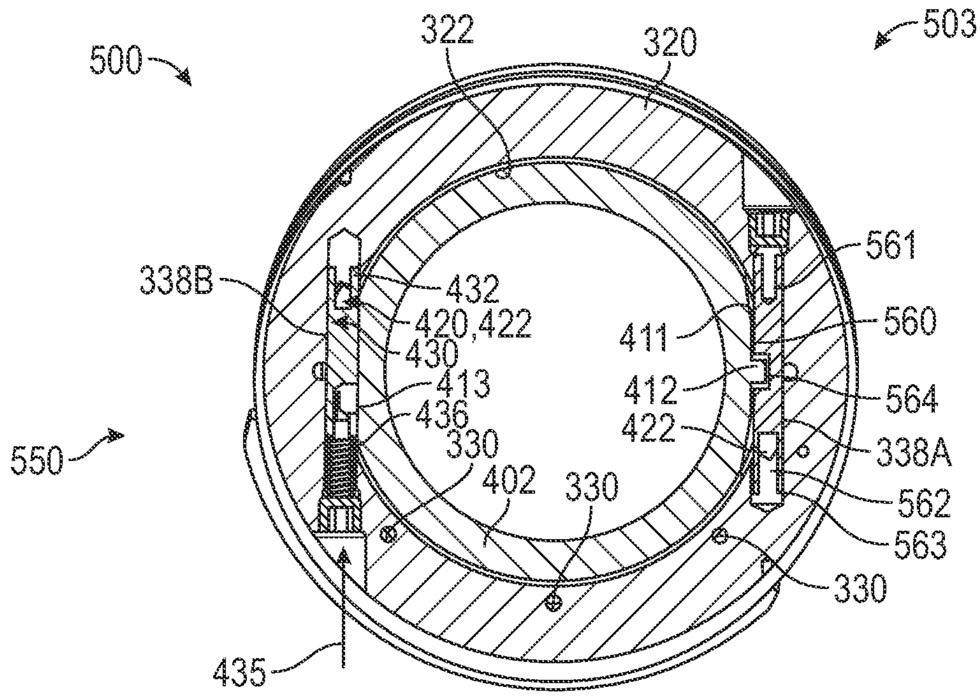
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FIG. 23

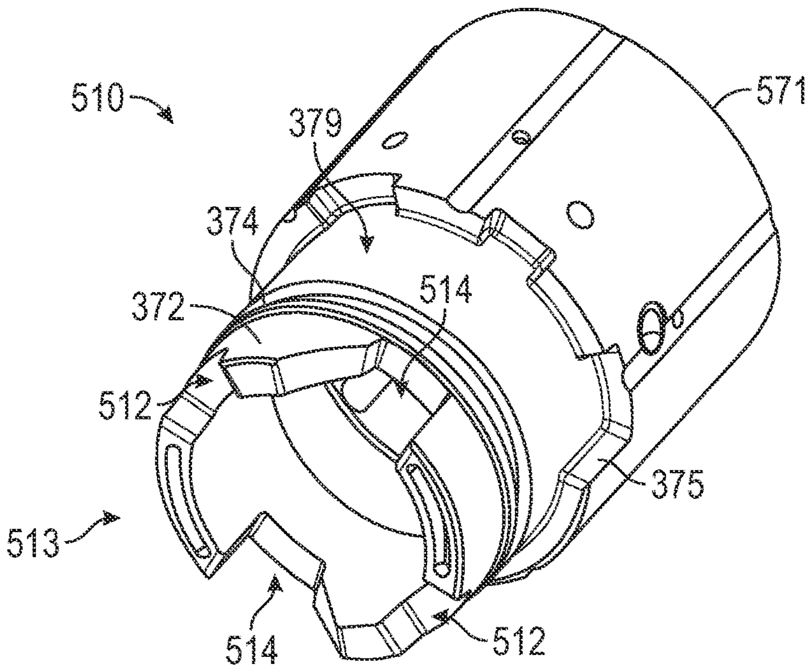
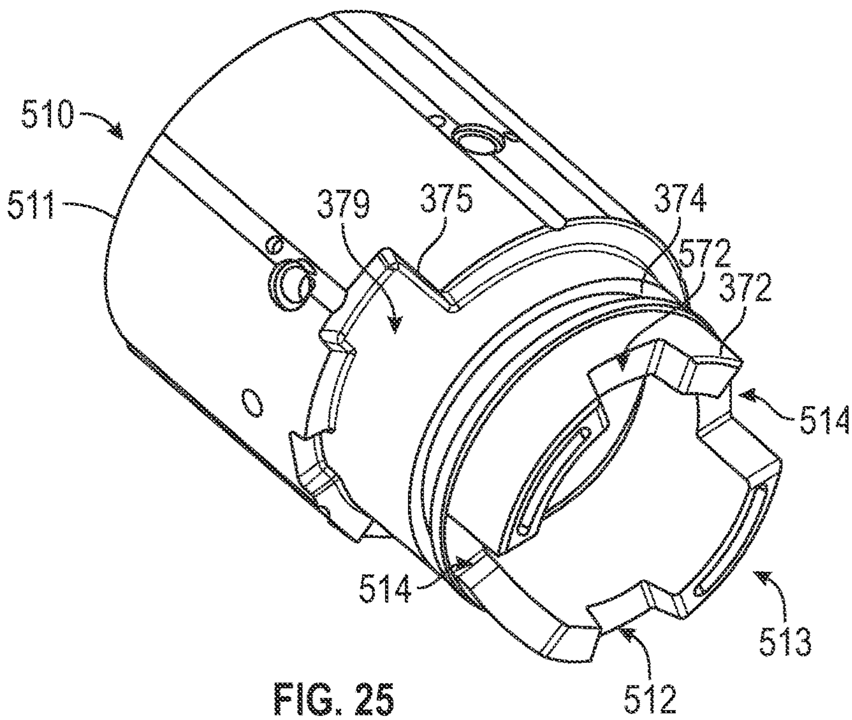


FIG. 24



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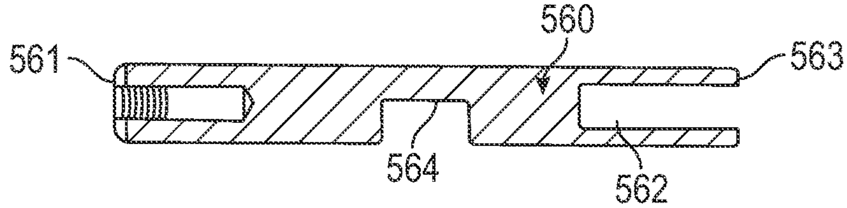

FIG. 26

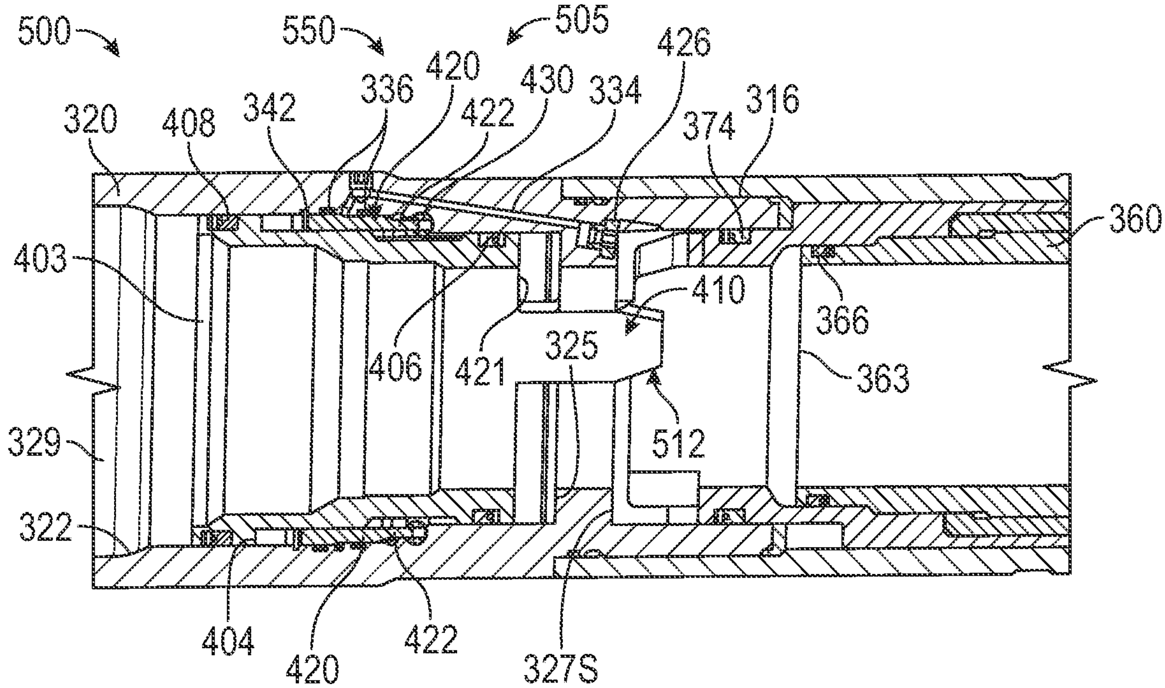
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FIG. 27

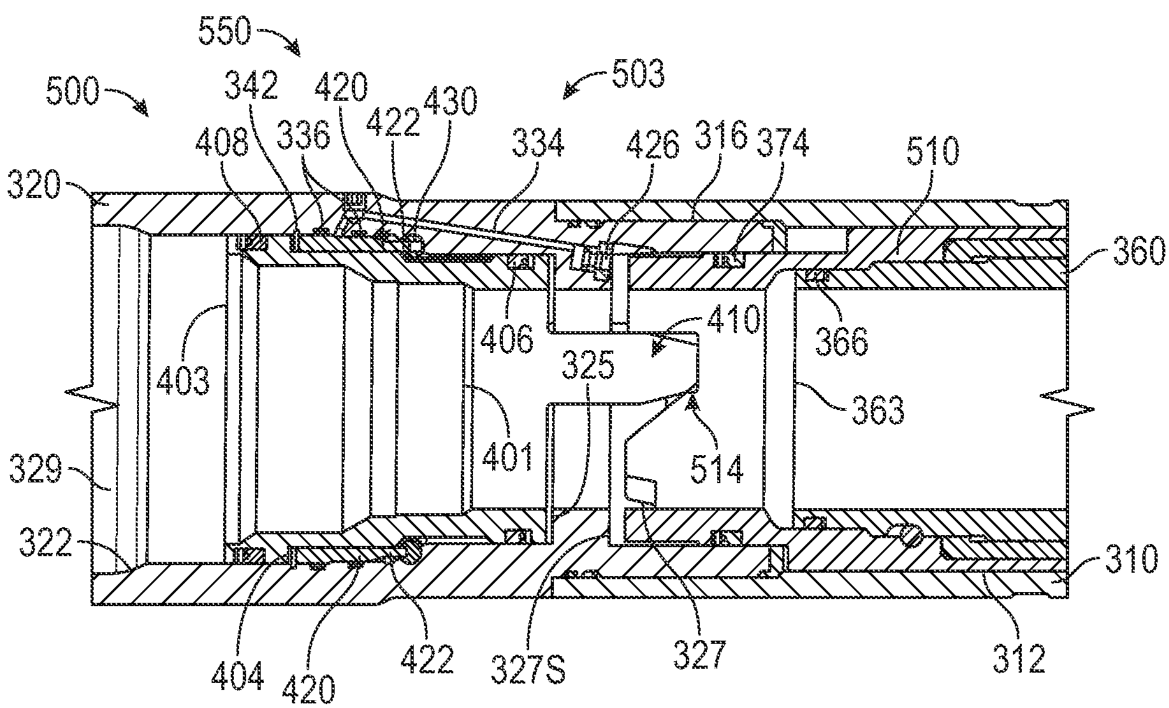
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FIG. 28

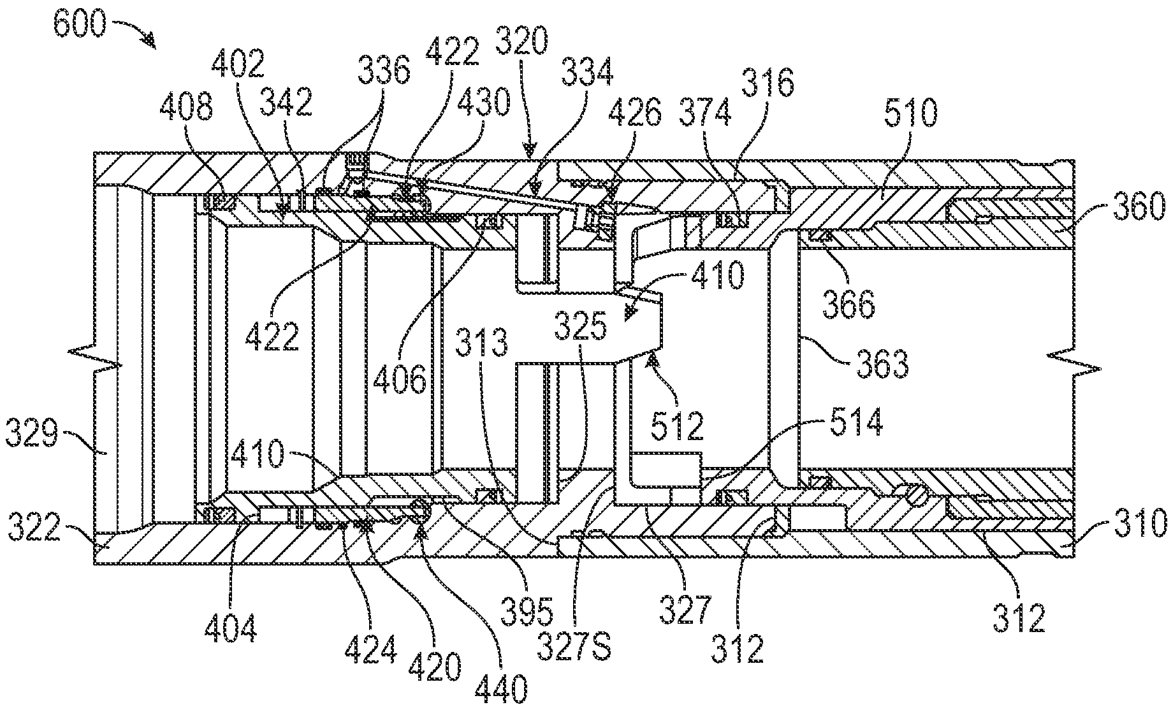
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FIG. 29

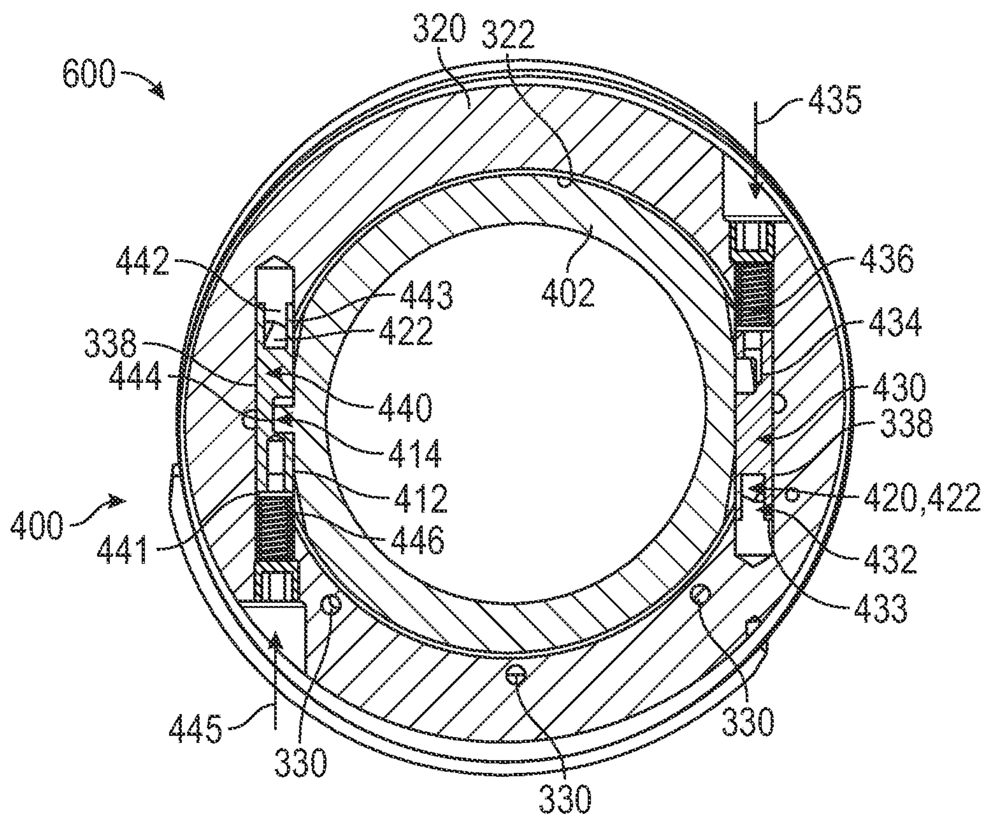
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FIG. 30

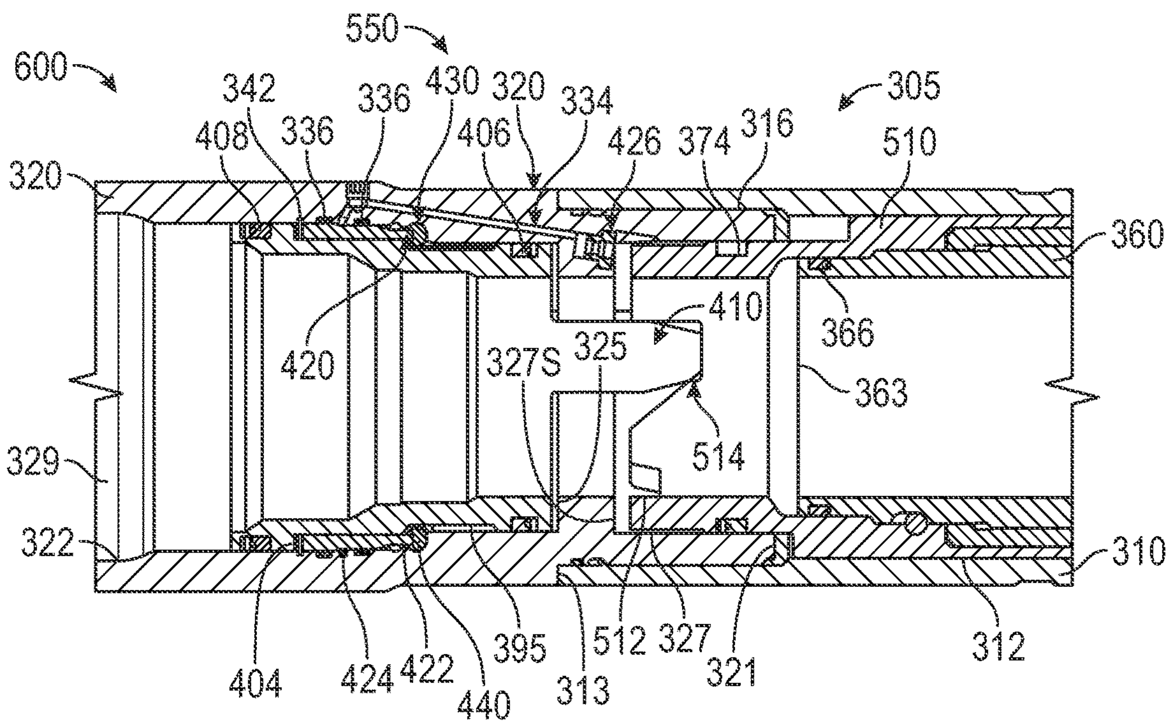
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FIG. 31

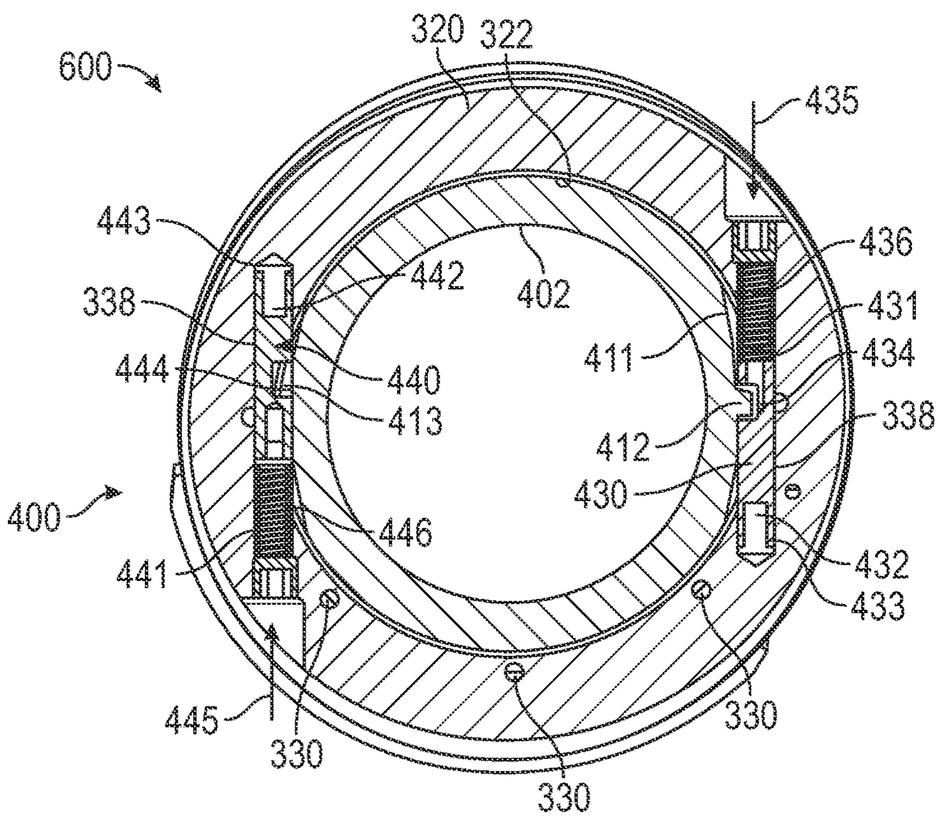
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FIG. 32

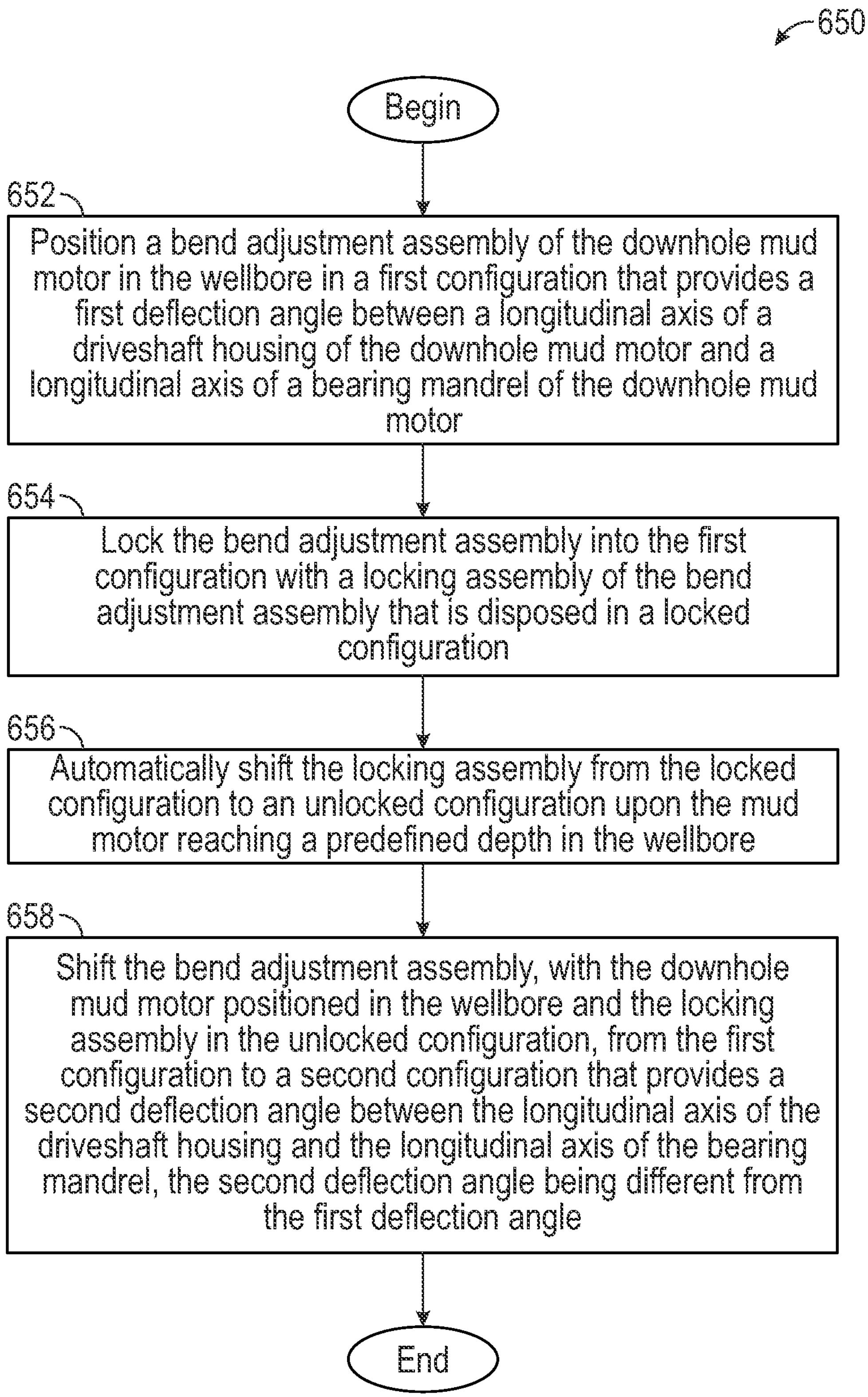
650
Begin
652
Position a bend adjustment assembly of the downhole mud motor in the wellbore in a first configuration that provides a first deflection angle between a longitudinal axis of a driveshaft housing of the downhole mud motor and a longitudinal axis of a bearing mandrel of the downhole mud motor
654
Lock the bend adjustment assembly into the first configuration with a locking assembly of the bend adjustment assembly that is disposed in a locked configuration
656
Automatically shift the locking assembly from the locked configuration to an unlocked configuration upon the mud motor reaching a predefined depth in the wellbore
658
Shift the bend adjustment assembly, with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, from the first configuration to a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel, the second deflection angle being different from the first deflection angle
End

FIG. 33

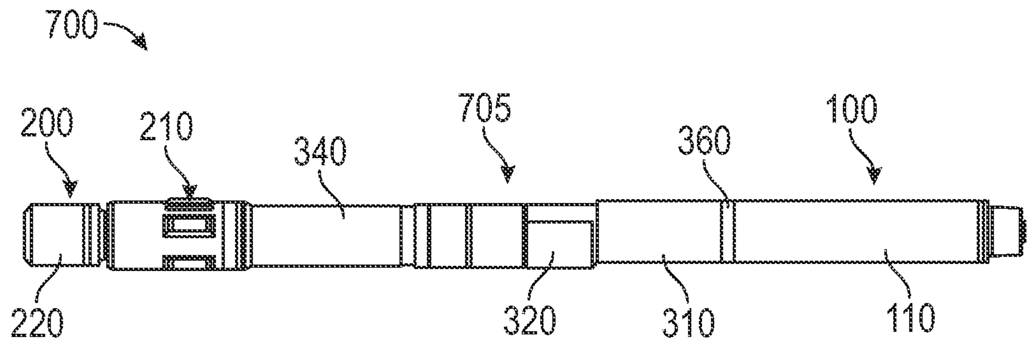
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FIG. 34

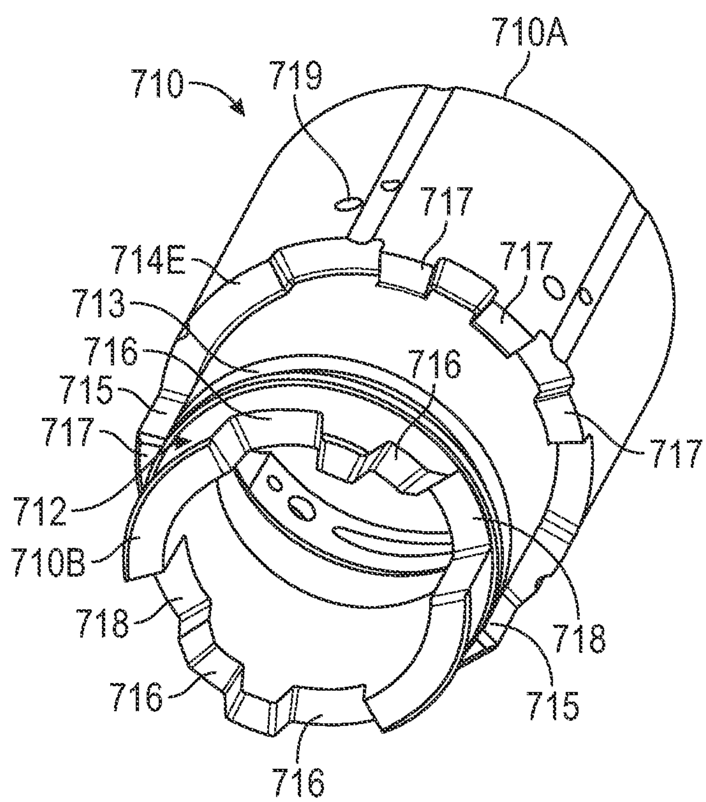
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FIG. 35

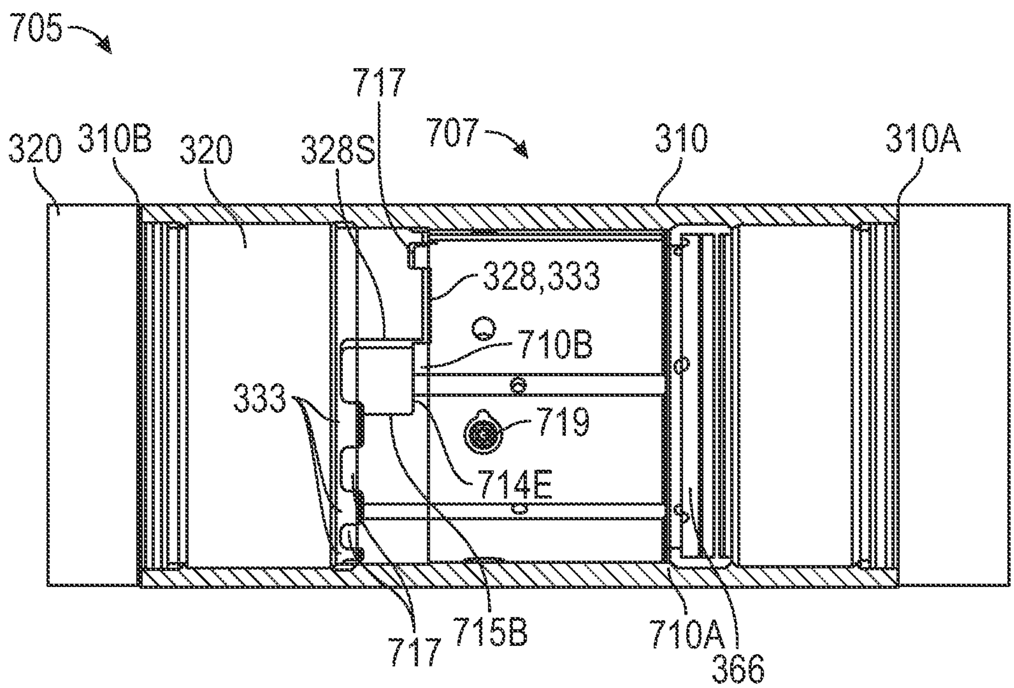
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FIG. 36

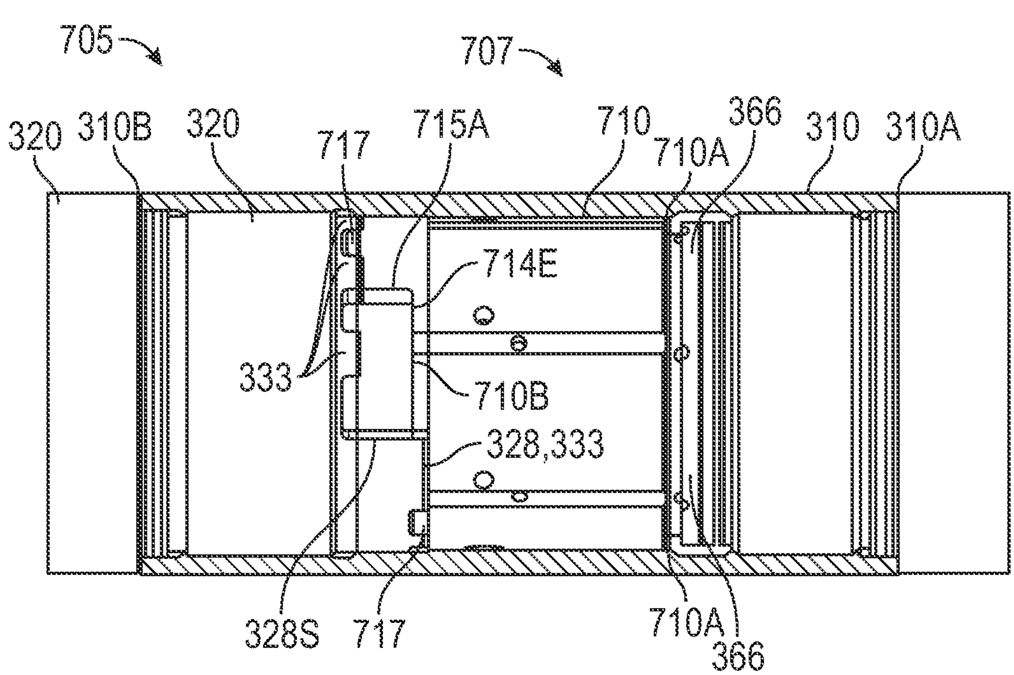
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FIG. 37

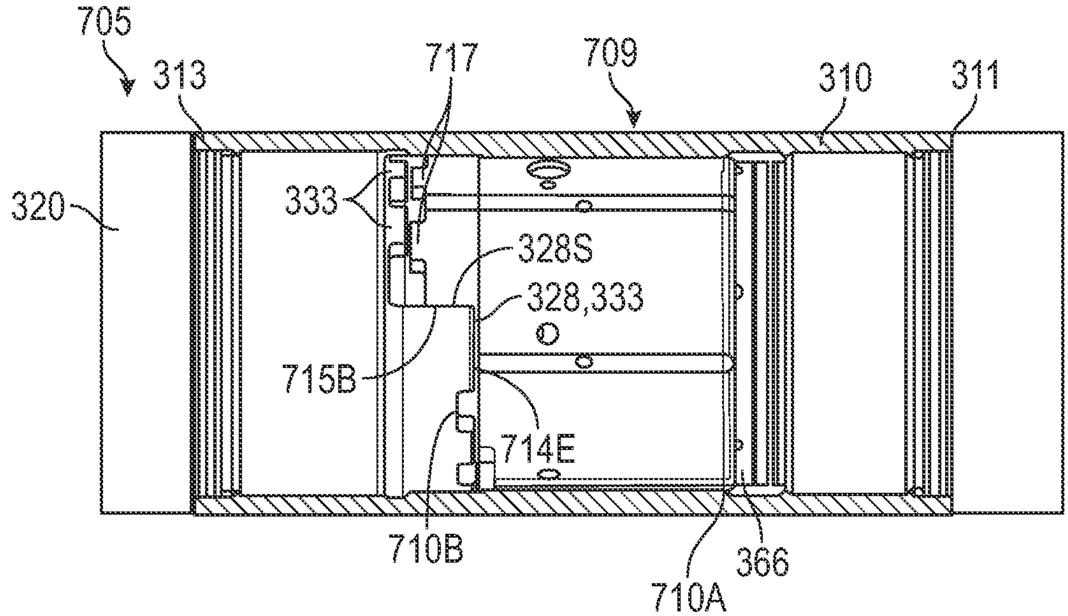
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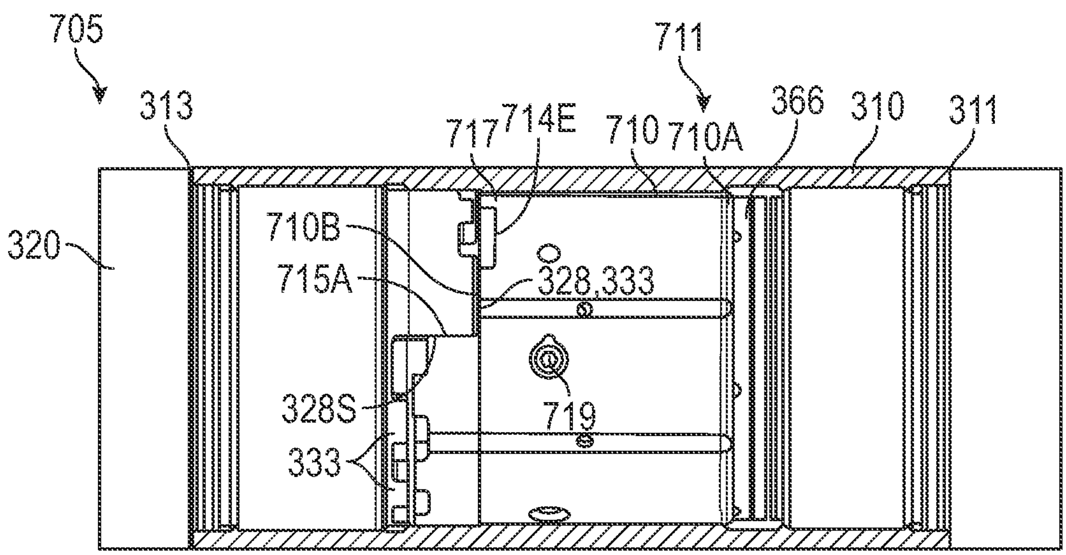
FIG. 38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311
320
710B
715A
328,333
719
328S
333

FIG. 39

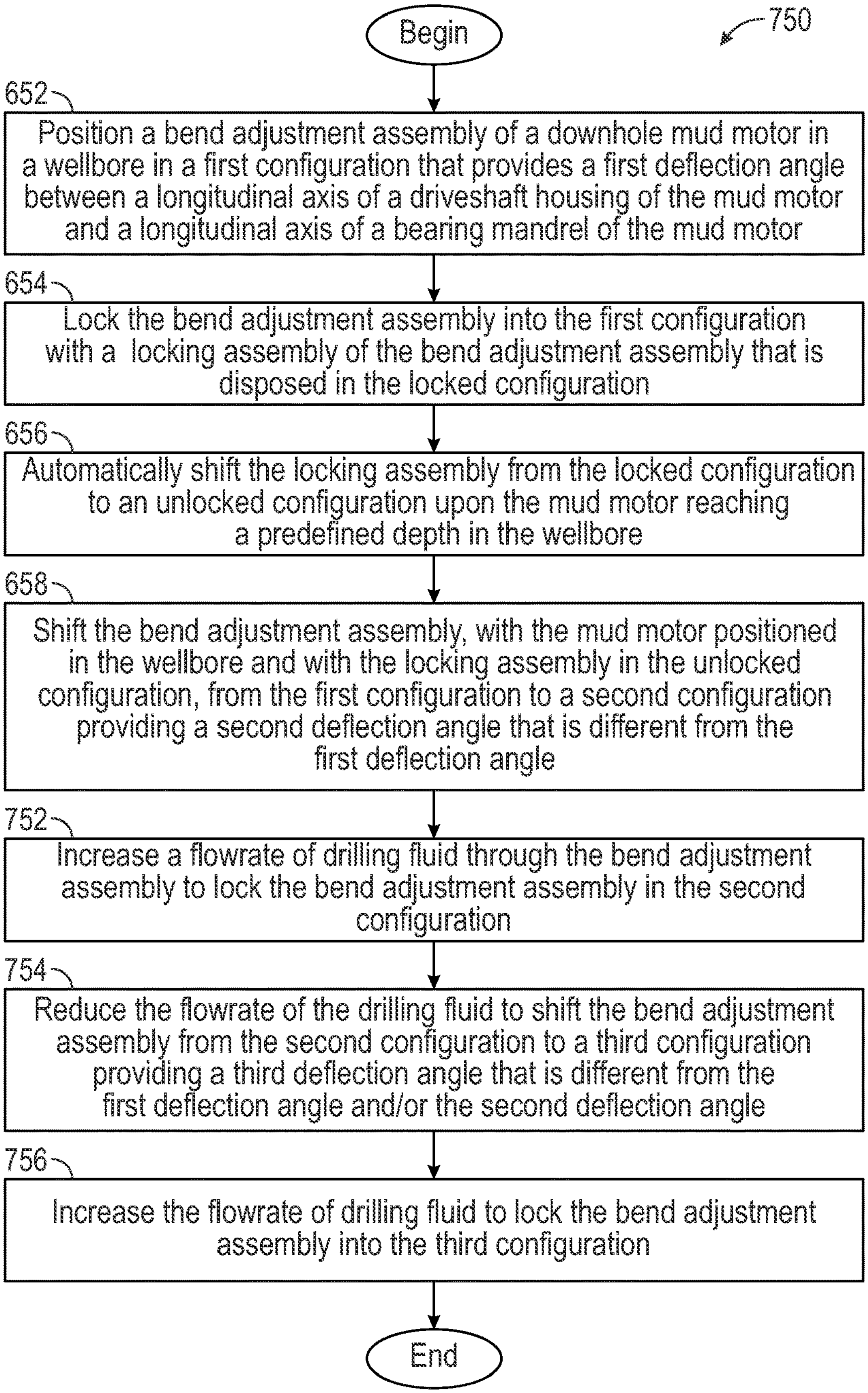
750
Begin
652
Position a bend adjustment assembly of a downhole mud motor in a wellbore in a first configuration that provides a first deflection angle between a longitudinal axis of a driveshaft housing of the mud motor and a longitudinal axis of a bearing mandrel of the mud motor
654
Lock the bend adjustment assembly into the first configuration with a locking assembly of the bend adjustment assembly that is disposed in the locked configuration
656
Automatically shift the locking assembly from the locked configuration to an unlocked configuration upon the mud motor reaching a predefined depth in the wellbore
658
Shift the bend adjustment assembly, with the mud motor positioned in the wellbore and with the locking assembly in the unlocked configuration, from the first configuration to a second configuration providing a second deflection angle that is different from the first deflection angle
752
Increase a flowrate of drilling fluid through the bend adjustment assembly to lock the bend adjustment assembly in the second configuration
754
Reduce the flowrate of the drilling fluid to shift the bend adjustment assembly from the second configuration to a third configuration providing a third deflection angle that is different from the first deflection angle and/or the second deflection angle
756
Increase the flowrate of drilling fluid to lock the bend adjustment assembly into the third configuration
End

FIG. 40

DEPTH ACTIVATED DOWNHOLE ADJUSTABLE BEND ASSEMBLIES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a 35 U.S.C. § 371 national stage application of PCT/US2022/053199 filed Dec. 16, 2022, entitled "Depth Activated Downhole Adjustable Bend Assemblies" which claims benefit of U.S. provisional patent application Ser. No. 63/290,426 filed Dec. 16, 2022, entitled "Depth Activated Downhole Adjustable Bend Assemblies," both of which are hereby incorporated herein by reference in their entirety for all purposes.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

BACKGROUND

In drilling a wellbore into an earthen formation, such as for the recovery of hydrocarbons or minerals from a subsurface formation, it is typical practice to connect a drill bit onto the lower end of a drillstring formed from a plurality of pipe joints connected together end-to-end, and then rotate the drillstring so that the drill bit progresses downward into the earth to create a wellbore along a predetermined trajectory. In addition to pipe joints, the drillstring typically includes heavier tubular members known as drill collars positioned between the pipe joints and the drill bit. The drill collars increase the weight applied to the drill bit to enhance its operational effectiveness. Other accessories commonly incorporated into drillstrings include stabilizers to assist in maintaining the desired direction of the drilled wellbore, and reamers to ensure that the drilled wellbore is maintained at a desired gauge (i.e., diameter).

In some applications, horizontal and other non-vertical or deviated wellbores are drilled (i.e., "directional drilling") to facilitate greater exposure to and production from larger regions of subsurface hydrocarbon-bearing formations than would be possible using only vertical wellbores. In directional drilling, specialized drillstring components and "bottomhole assemblies" (BHAs) may be used to induce, monitor, and control deviations in the path of the drill bit, so as to produce a wellbore of the desired deviated configuration. Directional drilling may be carried out using a downhole or mud motor provided in the BHA at the lower end of the drillstring immediately above the drill bit. Downhole mud motors may include several components, such as, for example (in order, starting from the top of the motor): (1) a power section including a stator and a rotor rotatably disposed in the stator; (2) a driveshaft assembly including a driveshaft disposed within a housing, with the upper end of the driveshaft being coupled to the lower end of the rotor; and (3) a bearing assembly positioned between the driveshaft assembly and the drill bit for supporting radial and thrust loads. For directional drilling, the motor may include a bent housing to provide an angle of deflection between the drill bit and the BHA.

SUMMARY

An embodiment of a downhole mud motor positionable in a wellbore comprises a driveshaft housing, a driveshaft rotatably disposed in the driveshaft housing, a bearing

mandrel coupled to the driveshaft, wherein the bend adjustment assembly includes a first configuration that provides a first deflection angle between a longitudinal axis of the driveshaft housing and a longitudinal axis of the bearing mandrel, wherein the bend adjustment assembly includes a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from the first deflection angle, and wherein the bend adjustment assembly is configured to shift between the first configuration and the second configuration when positioned in the wellbore, and a locking assembly comprising a locked configuration configured to lock the bend adjustment assembly into one of the first configuration and the second configuration until the downhole mud motor has at least one of reached a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth, in response to which the locking assembly is configured to actuate from the locked configuration to an unlocked configuration. In some embodiments, the locking assembly comprises a rupture disk configured to burst at a predefined pressure. In some embodiments, the locking assembly comprises a locking sleeve including a locked position and an unlocked position longitudinally spaced from the locked position, and wherein the locking sleeve is configured to shift from the locked position to the unlocked position in response to bursting of the rupture disk. In certain embodiments, the bend adjustment assembly comprises an offset housing and an adjustment mandrel having a first relative angular orientation associated with the first configuration and a second relative angular orientation associated with the second configuration. In certain embodiment, the locking assembly comprises a locking piston configured to lock the offset housing and the adjustment mandrel in the first relative angular orientation when in a first position. In some embodiments, the locking assembly comprises a first locking pin configured to lock the locking piston in the first position. In some embodiments, the locking assembly comprises a second locking pin configured to lock the locking piston in a second position configured to lock the offset housing and the adjustment mandrel in the second relative angular orientation. In certain embodiments, the adjustment mandrel and offset housing comprise interlocking castellations configured to lock the offset housing and adjustment mandrel in the first relative angular orientation. In certain embodiments, the adjustment mandrel has a first axial position wherein the interlocking castellations between the adjustment mandrel and offset housing are matingly engaged, and a second axial position wherein the interlocking castellations between the adjustment mandrel and offset housing are disengaged, and the adjustment mandrel shifts from the first axial position to the second axial position in response to the locking sleeve shifting from the locked to the unlocked position. In some embodiments, the adjustment mandrel is held in the first axial position by a shear pin, the locking assembly comprises a first locking pin configured to hold the locking piston axially separated from the adjustment mandrel when the locking sleeve is in the locked position, the locking pin is configured to release the locking piston into contact with the adjustment mandrel when the locking sleeve is in the unlocked position, and the locking piston is configured to apply force to the adjustment mandrel to fracture the shear pin and permit the adjustment mandrel to shift from the first axial position to the second axial position. In certain embodiments, the bend adjustment assembly can shift between the first relative angular orientation and second relative angular orientation when the adjustment mandrel has shifted into the second axial position. In certain embodiments, the locking assembly comprises a second locking pin configured to lock the locking piston in a second position configured to lock the offset housing and the adjustment mandrel in the second relative angular orientation.

In some embodiments, the offset housing and the adjustment mandrel can shift between the first relative angular orientation and the second relative angular orientation up to an unlimited number of times. In some embodiments, the offset housing and the adjustment mandrel can shift between the second relative angular orientation and a third relative angular orientation up to an unlimited number of times. In some embodiments, the offset housing and adjustment mandrel have a third relative angular orientation associated with a third configuration. In certain embodiments, the second deflection angle is larger than the first deflection angle. In certain embodiments, the second deflection angle is less than the first deflection angle. In some embodiments, the actuator assembly is configured to shift the bend adjustment assembly between the first configuration and the second configuration in response to a change in at least one of flowrate of a drilling fluid supplied to the downhole mud motor, pressure of the drilling fluid supplied to the downhole mud motor, and relative rotation between the driveshaft housing and the bearing mandrel. In some embodiments, the bend adjustment assembly includes a third configuration providing a third deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from at least one of the first deflection angle and the second deflection angle.

An embodiment of a downhole mud motor positionable in a wellbore comprises a driveshaft housing, a driveshaft rotatably disposed in the driveshaft housing, a bearing mandrel coupled to the driveshaft, wherein the bend adjustment assembly includes a first configuration that provides a first deflection angle between a longitudinal axis of the driveshaft housing and a longitudinal axis of the bearing mandrel, wherein the bend adjustment assembly includes a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from the first deflection angle, an actuator assembly configured to shift the bend adjustment assembly between the first configuration and the second configuration when the mud motor is disposed in the wellbore, and a locking assembly configured to prevent the actuator assembly from shifting the bend adjustment assembly between the first configuration and the second configuration until the mud motor has at least one of reached a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth. In some embodiments, the locking assembly comprises a rupture disk configured to burst at a predefined pressure. In some embodiments, the locking assembly comprises a locking sleeve including a locked position and an unlocked position longitudinally spaced from the locked position, and wherein the locking sleeve is configured to shift from the locked position to the unlocked position in response to bursting of the rupture disk. In certain embodiments, the bend adjustment assembly comprises an offset housing and an adjustment mandrel having a first relative angular orientation associated with the first configuration and a second relative angular orientation associated with the second configuration, and the locking assembly comprises a locking piston configured to lock the offset housing and the adjustment mandrel in the first relative angular orientation when in a first position. In certain embodiments, the locking assembly comprises a first locking pin configured to lock the locking piston in the first position. In some embodiments, the locking assembly comprises a second locking pin configured to lock the locking piston in a second position configured to lock the offset housing and the adjustment mandrel in the second relative angular orientation. In some embodiments, the actuator assembly is configured to shift the bend adjustment assembly between the first configuration and the second configuration in response to a change in at least one of flowrate of a drilling fluid supplied to the downhole mud motor, pressure of the drilling fluid supplied to the downhole mud motor, and relative rotation between the driveshaft housing and the bearing mandrel. In certain embodiments, the bend adjustment assembly includes a third configuration providing a third deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from at least one of the first deflection angle and the second deflection angle.

An embodiment of a method for forming a deviated wellbore using a downhole mud motor comprises (a) positioning a bend adjustment assembly of the downhole mud motor in the wellbore in a first configuration that provides a first deflection angle between a longitudinal axis of a driveshaft housing of the downhole mud motor and a longitudinal axis of a bearing mandrel of the downhole mud motor, (b) locking the bend adjustment assembly into the first configuration with a locking assembly of the bend adjustment assembly that is disposed in a locked configuration, (c) automatically shifting the locking assembly from the locked configuration to an unlocked configuration upon at least one of the mud motor reaching a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth, and (d) with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, shifting the bend adjustment assembly from the first configuration to a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel, the second deflection angle being different from the first deflection angle. In some embodiments, (c) comprises (c1) bursting a rupture disk of the locking assembly, and (c2) longitudinally shifting a locking sleeve of the locking assembly from a locked position to an unlocked position. In some embodiments, (c) comprises (c3) laterally shifting a locking pin from a first lateral position to a second lateral position in response to longitudinally shifting the locking sleeve to the unlocked position. In certain embodiments, (c) comprises (c4) shifting a locking piston of the locking assembly from a locked position to an unlocked position in response to laterally shifting the locking pin to the unlocked position. In certain embodiments, (d) comprises (d1) pumping drilling fluid into the wellbore from the surface pump at a reduced flowrate that is less than the drilling flowrate for a first time period, and (d2) following the first time period, pumping drilling fluid in the wellbore from the surface pump at an increased flowrate that is different than the reduced flowrate for a second time period. In some embodiments, the method comprises (e) with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, shifting the bend adjustment assembly from the second configuration to the first configuration. In some embodiments, the method comprises (e) with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, shifting the bend adjustment assembly from the second configuration to a third configuration that provides a third deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel, the third deflection angle being different from at least one of the first deflection angle and the second deflection angle.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of disclosed embodiments, reference will now be made to the accompanying drawings in which:

FIG. **1** is a schematic partial cross-sectional view of a drilling system including an embodiment of a downhole mud motor in accordance with principles disclosed herein;

FIG. **2** is a perspective, partial cut-away view of the power section of FIG. **1**;

FIG. **3** is a cross-sectional end view of the power section of FIG. **1**;

FIG. **4** is a cross-sectional side view of an embodiment of the mud motor of FIG. **1**;

FIG. **5** is a cross-sectional side view of an embodiment of a bend adjustment assembly of the downhole mud motor of FIG. **4**;

FIG. **6** is a zoomed-in cross-sectional side view of the bend adjustment assembly of FIG. **5**;

FIG. **7** is a cross-sectional side view of an embodiment of a bearing assembly of the downhole mud motor of FIG. **4**;

FIG. **8** is a perspective view of an embodiment of an offset housing of the bend adjustment assembly of FIG. **5**;

FIG. **9** is a front view of the offset housing of FIG. **8**;

FIG. **10** is a perspective views of an embodiment of an adjustment mandrel of the bend adjustment assembly of FIG. **5**;

FIG. **11** is a perspective view of another embodiment of an adjustment mandrel;

FIGS. **12**, **13** are perspective views of an embodiment of a locking assembly of the bend adjustment assembly of FIG. **5**;

FIGS. **14**, **15** are perspective views of an embodiment of a locking piston of the locking assembly of FIGS. **12**, **13**;

FIG. **16** is a cross-sectional side view of an embodiment of a locking pin of the locking assembly of FIGS. **12**, **13**;

FIG. **17** is a cross-sectional side view of an embodiment of another locking pin of the locking assembly of FIGS. **12**, **13**;

FIG. **18** is a perspective view of an embodiment of a locking sleeve of the locking assembly of FIGS. **12**, **13**;

FIGS. **19**, **20** are cross-sectional end views of the bend adjustment assembly of FIG. **5**;

FIG. **21** is another zoomed-in cross-sectional side view of the bend adjustment assembly of FIG. **5**;

FIG. **22** is a cross-sectional side view of another embodiment of a bend adjustment assembly;

FIG. **23** is a cross-sectional end view of the bend adjustment assembly of FIG. **22**;

FIGS. **24**, **25** are perspective views of an embodiment of an adjustment mandrel of the bend adjustment assembly of FIG. **22**;

FIG. **26** is a side view of an embodiment of a locking pin of a locking assembly of the bend adjustment assembly of FIG. **22**;

FIGS. **27**, **28** are additional cross-sectional side views of the bend adjustment assembly of FIG. **22**;

FIG. **29** is a cross-sectional side views of an embodiment of another bend adjustment assembly;

FIG. **30** is a cross-sectional end view of the bend adjustment assembly of FIG. **29**;

FIG. **31** is another cross-sectional side view of the bend adjustment assembly of FIG. **29**;

FIG. **32** is another cross-sectional end view of the bend adjustment assembly of FIG. **29**;

FIG. **33** is a flowchart of an embodiment of a method for forming a deviated wellbore using a downhole mud motor;

FIG. **34** is a side view of another embodiment of a downhole mud motor including a bend adjustment assembly in a first configuration in accordance with principles disclosed herein;

FIG. **35** is a perspective view of an embodiment of a lower adjustment mandrel of the bend adjustment assembly of FIG. **34** in accordance with principles disclosed herein;

FIGS. **36** and **37** are opposing side views of the bend adjustment assembly of FIG. **34** in a first configuration;

FIG. **38** is a side view of the bend adjustment assembly of FIG. **34** in a second configuration;

FIG. **39** is a side view of the bend adjustment assembly of FIG. **34** in a third configuration; and

FIG. **40** is a flowchart of another embodiment of a method for forming a deviated wellbore using a downhole mud motor in accordance with principles disclosed herein.

DETAILED DESCRIPTION

The following discussion is directed to various embodiments. However, one skilled in the art will understand that the examples disclosed herein have broad application, and that the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to suggest that the scope of the disclosure, including the claims, is limited to that embodiment. The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to . . . ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection as accomplished via other devices, components, and connections. In addition, as used herein, the terms "axial" and "axially" generally mean along or parallel to a central axis (e.g., central axis of a body or a port), while the terms "radial" and "radially" generally mean perpendicular to the central axis. For instance, an axial distance refers to a distance measured along or parallel to the central axis, and a radial distance means a distance measured perpendicular to the central axis. Any reference to up or down in the description and the claims is made for purposes of clarity, with "up", "upper", "upwardly", "uphole", or "upstream" meaning toward the surface of the wellbore and with "down", "lower", "downwardly", "downhole", or "downstream" meaning toward the terminal end of the wellbore, regardless of the wellbore orientation.

As described above, downhole mud motors may include a bent housing for providing a deflection angle between the drill bit and the BHA. Conventionally, bent housings either provide a fixed deflection angle or an adjustable deflection angle that may only be adjustable at the surface. However, it may be desirable to adjust a deflection angle of the bent housing without needing to go through the lengthy process of pulling the BHA out of the wellbore so that the deflection angle may be adjusted.

Accordingly, embodiments of downhole-adjustable bend adjustment assemblies of downhole mud motors are described herein which may be adjusted in situ within the wellbore without needing to retrieve the downhole mud motor to the surface. Additionally, bend adjustment assemblies described herein include a locking assembly which only permits the bend adjustment assembly to adjust the deflection angle provided by the bend adjustment assembly once the downhole mud motor had reached a predefined depth in the wellbore. In this manner, the mud motor may be operated as desired (e.g., at different fluid flowrates, while providing rotation to the mud motor from the surface, etc.) without inadvertently actuating the bend adjustment assembly when it is not desired to do so. Additionally, locking assemblies of the bend adjustment assemblies described herein are configured to actuate automatically in response to reaching the predefined depth in the wellbore from a locked configuration locking the bend adjustment assembly into a given configuration and an unlocked configuration in which the bend adjustment assembly is permitted to actuate between a plurality of configurations providing a plurality of different deflection angles.

Referring to FIG. **1**, an embodiment of a well system **10** is shown. Well system **10** is generally configured for drilling a wellbore **16** in an earthen formation **5**. In this exemplary embodiment, well system **10** includes a drilling rig **20** disposed at the surface, a drillstring **21** extending downhole from rig **20**, a bottomhole assembly (BHA) **30** coupled to the lower end of drillstring **21**, and a drill bit **90** attached to the lower end of BHA **30**. A surface or mud pump **23** is positioned at the surface and pumps drilling fluid or mud through drillstring **21**. Additionally, rig **20** includes a rotary system **24** for imparting torque to an upper end of drillstring **21** to thereby rotate drillstring **21** in wellbore **16**. In this exemplary embodiment, rotary system **24** comprises a rotary table located at a rig floor of rig **20**; however, in other embodiments, rotary system **24** may comprise other systems for imparting rotary motion to drillstring **21**, such as a top drive. A downhole mud motor **35** is provided in BHA **30** for facilitating the drilling of deviated portions of wellbore **16**. Moving downward along BHA **30**, motor **35** includes a hydraulic drive or power section **40**, a driveshaft assembly **100**, and a bearing assembly **200**. In some embodiments, the portion of BHA **30** disposed between drillstring **21** and motor **35** can include other components, such as drill collars, measurement-while-drilling (MWD) tools, reamers, stabilizers and the like.

Power section **40** of BHA **30** converts the fluid pressure of the drilling fluid pumped downward through drillstring **21** into rotational torque for driving the rotation of drill bit **90**. Driveshaft assembly **100** and bearing assembly **200** transfer the torque generated in power section **40** to bit **90**. With force or weight applied to the drill bit **90**, also referred to as weight-on-bit ("WOB"), the rotating drill bit **90** engages the earthen formation and proceeds to form wellbore **16** along a predetermined path toward a target zone. The drilling fluid or mud pumped down the drillstring **21** and through BHA **30** passes out of the face of drill bit **90** and back up the annulus **18** formed between drillstring **21** and the wall **19** of wellbore **16**. The drilling fluid cools the bit **90**, and flushes the cuttings away from the face of bit **90** and carries the cuttings to the surface.

Referring to FIGS. **1-3**, an embodiment of the power section **40** of BHA **30** is shown schematically in FIGS. **2** and **3**. In this exemplary embodiment, power section **40** comprises a helical-shaped rotor **50** disposed within a stator **60** comprising a cylindrical stator housing **65** lined with a helical-shaped elastomeric insert **61**. Helical-shaped rotor **50** defines a set of rotor lobes **57** that intermesh with a set of stator lobes **67** defined by the helical-shaped insert **61**. As best shown in FIG. **3**, the rotor **50** has one fewer lobe **57** than the stator **60**. When the rotor **50** and the stator **60** are assembled, a series of cavities **70** are formed between the outer surface **53** of the rotor **50** and the inner surface **63** of the stator **60**. Each cavity **70** is sealed from adjacent cavities **70** by seals formed along the contact lines between the rotor **50** and the stator **60**. The central axis **58** of the rotor **50** is radially offset from the central axis **68** of the stator **60** by a fixed value known as the "eccentricity" of the rotor-stator assembly. Consequently, rotor **50** may be described as rotating eccentrically within stator **60**.

During operation of the power section **40**, fluid is pumped under pressure into one end of the power section **40** where it fills a first set of open cavities **70**. A pressure differential across the adjacent cavities **70** forces the rotor **50** to rotate relative to the stator **60**. As the rotor **50** rotates inside the stator **60**, adjacent cavities **70** are opened and filled with fluid. As this rotation and filling process repeats in a continuous manner, the fluid flows progressively down the length of power section **40** and continues to drive the rotation of the rotor **50**. Driveshaft assembly **100** shown in FIG. **1** includes a driveshaft discussed in more detail below that has an upper end coupled to the lower end of rotor **50**. In this arrangement, the rotational motion and torque of rotor **50** is transferred to drill bit **90** via driveshaft assembly **100** and bearing assembly **200**.

In this exemplary embodiment, driveshaft assembly **100** is coupled to bearing assembly **200** via a bend adjustment assembly **300** of BHA **30** that provides an adjustable bend **301** along motor **35**. Due to bend **301**, a deflection angle θ is formed between a central or longitudinal axis **95** (shown in FIG. **1**) of drill bit **90** and the longitudinal axis **25** of drillstring **21**. To drill a straight section of wellbore **16**, drillstring **21** is rotated from rig **20** with a rotary table or top drive to rotate BHA **30** and drill bit **90** coupled thereto. Drillstring **21** and BHA **30** rotate about the longitudinal axis of drillstring **21**, and thus, drill bit **90** is also forced to rotate about the longitudinal axis of drillstring **21**. With bit **90** disposed at deflection angle θ, the lower end of drill bit **90** distal BHA **30** seeks to move in an arc about longitudinal axis **25** of drillstring **21** as it rotates, but is restricted by the sidewall **19** of wellbore **16**, thereby imposing bending moments and associated stress on BHA **30** and mud motor **35**.

In general, driveshaft assembly **100** functions to transfer torque from the eccentrically-rotating rotor **50** of power section **40** to a concentrically-rotating bearing mandrel **220** of bearing assembly **200** and drill bit **90**. As best shown in FIG. **3**, rotor **50** rotates about rotor axis **58** in the direction of arrow **54**, and rotor axis **58** rotates about stator axis **68** in the direction of arrow **55**. However, drill bit **90** and bearing mandrel **220** are coaxially aligned and rotate about a common axis that is offset and/or oriented at an acute angle relative to rotor axis **58**. Thus, driveshaft assembly **100** converts the eccentric rotation of rotor **50** to the concentric rotation of bearing mandrel **220** and drill bit **90**, which are radially offset and/or angularly skewed relative to rotor axis **58**.

Referring to FIGS. **4-7**, embodiments of driveshaft assembly **100**, bearing assembly **200**, and bend adjustment assembly **300** are shown. In this exemplary embodiment, driveshaft assembly **100** includes an outer or driveshaft housing **110** and a one-piece (i.e., unitary) driveshaft **120** rotatably disposed within housing **110**. Housing **110** has a linear central or longitudinal axis **115**, a first or upper end **111**, a second or lower end **113** coupled to an outer or bearing housing **210** of bearing assembly **200** via bend adjustment assembly **300**, and a central bore or passage **112** extending between ends **111** and **113**. Particularly, an externally threaded connector or pin end of driveshaft housing **110** located at upper end **111** threadably engages a mating internally threaded connector or box end disposed at the lower end of stator housing **65**, and an internally threaded connector or box end of driveshaft housing **110** located at lower end **113** threadably engages a mating externally threaded connector of bend adjustment assembly **300**. Additionally, in this exemplary embodiment, driveshaft housing includes ports **114** that extend radially between the inner and outer surfaces of driveshaft housing **110**.

In this exemplary embodiment, driveshaft housing **110** is coaxially aligned with stator housing **65**. As will be discussed further herein, bend adjustment assembly **300** is configured to actuate between a first configuration **303** (shown in FIGS. **4**, **5**), and a second configuration **305** (shown in FIG. **21**). In this exemplary embodiment, when bend adjustment assembly **300** is in the first configuration **303**, driveshaft housing **110** is not disposed at an angle relative to bearing assembly **200** and drill bit **90**. However, when bend adjustment assembly is disposed in the second configuration **305**, bend **301** is formed between driveshaft assembly **100** and bearing assembly **200**, orienting driveshaft housing **110** at deflection angle θ relative to bearing assembly **200** and drill bit **90**. Additionally, as will be discussed further herein, bend adjustment assembly **300** is configured to actuate between the first and second configurations **303** and **305** in-situ with BHA **30** disposed in wellbore **16**.

Driveshaft **120** of driveshaft assembly **100** has a linear central or longitudinal axis, a first or upper end **121**, and a second or lower end **123** opposite end **121**. Upper end **121** is pivotally coupled to the lower end of rotor **50** with a driveshaft adapter **130** and a first or upper universal joint **141**, and lower end **123** is pivotally coupled to an upper end **221** of bearing mandrel **220** with a second or lower universal joint **143**. In this exemplary embodiment, upper end **121** of driveshaft **120** and upper universal joint **141** are disposed within driveshaft adapter **130**, whereas lower end **123** of driveshaft **120** comprises an axially extending counterbore or receptacle that receives upper end **221** of bearing mandrel **220** and lower universal joint **143**. In this exemplary embodiment, driveshaft **120** includes a radially outwards extending shoulder **122** located proximal lower end **123**.

In this exemplary embodiment, driveshaft adapter **130** extends along a central or longitudinal axis **135** between a first or upper end coupled to rotor **50**, and a second or lower end coupled to the upper end **121** of driveshaft **120**. In this exemplary embodiment, the upper end of driveshaft adapter **130** comprises an externally threaded male pin or pin end that threadably engages a mating female box or box end at the lower end of rotor **50**. A receptacle or counterbore extends axially (relative to axis **135**) from the lower end of adapter **130**. The upper end **121** of driveshaft **120** is disposed within the counterbore of driveshaft adapter **130** and pivotally couples to adapter **130** via the upper universal joint **141** disposed within the counterbore of driveshaft adapter **130**.

Universal joints **141** and **143** allow ends **121** and **123** of driveshaft **120** to pivot relative to adapter **130** and bearing mandrel **220**, respectively, while transmitting rotational torque between rotor **50** and bearing mandrel **220**. Driveshaft adapter **130** is coaxially aligned with rotor **50**. Since rotor axis **58** is radially offset and/or oriented at an acute angle relative to the central axis of bearing mandrel **220**, the central axis of driveshaft **120** is skewed or oriented at an acute angle relative to axis **115** of housing **110**, axis **58** of rotor **50**, and a central or longitudinal axis **225** of bearing mandrel **220**. However, universal joints **141** and **143** accommodate for the angularly skewed driveshaft **120**, while simultaneously permitting rotation of the driveshaft **120** within driveshaft housing **110**.

In general, each universal joint (e.g., each universal joint **141** and **143**) may comprise any joint or coupling that allows two parts that are coupled together and not coaxially aligned with each other (e.g., driveshaft **120** and adapter **130** oriented at an acute angle relative to each other) limited freedom of movement in any direction while transmitting rotary motion and torque including, without limitation, universal joints (Cardan joints, Hardy-Spicer joints, Hooke joints, etc.), constant velocity joints, or any other custom designed joint. In other embodiments, driveshaft assembly **100** may include a flexible shaft comprising a flexible material (e.g., Titanium, etc.) that is directly coupled (e.g., threadably coupled) to rotor **50** of power section **40** in lieu of driveshaft **120**, where physical deflection of the flexible shaft (the flexible shaft may have a greater length relative driveshaft **120**) accommodates axial misalignment between driveshaft assembly **100** and bearing assembly **200** while allowing for the transfer of torque therebetween.

As previously described, adapter **130** couples driveshaft **120** to the lower end of rotor **50**. During drilling operations, high pressure drilling fluid or mud is pumped under pressure down drillstring **21** and through cavities **70** between rotor **50** and stator **60**, causing rotor **50** to rotate relative to stator **60**. Rotation of rotor **50** drives the rotation of driveshaft adapter **130**, driveshaft **120**, bearing assembly mandrel **220**, and drill bit **90**. The drilling fluid flowing down drillstring **21** through power section **40** also flows through driveshaft assembly **100** and bearing assembly **200** to drill bit **90**, where the drilling fluid flows through nozzles in the face of bit **90** into annulus **18**. Within driveshaft assembly **100** and the upper portion of bearing assembly **200**, the drilling fluid flows through an annulus **116** formed between driveshaft housing **110** and driveshaft **120**.

Still referring to FIGS. **4-7**, bearing assembly **200** includes bearing housing **210** and one-piece (i.e., unitary) bearing mandrel **220** rotatably disposed within housing **210**. Bearing housing **210** has a linear central or longitudinal axis disposed coaxial with central axis **225** of mandrel **220**, a first or upper end **211** coupled to lower end **113** of driveshaft housing **110** via bend adjustment assembly **300**, a second or lower end **213**, and a central through bore or passage extending axially between ends **211** and **213**. Particularly, the upper end **211** comprises an externally threaded connector or pin end coupled with bend adjustment assembly **300**. Bearing housing **210** is coaxially aligned with bit **90**, however, due to bend **301** between driveshaft assembly **100** and bearing assembly **200**, bearing housing **210** is oriented at deflection angle θ relative to driveshaft housing **110**. In this exemplary embodiment, bearing housing **210** comprises a plurality of separate tubular housings connected end-to-end; however, it may be understood that in other embodiments, bearing housing **210** may comprise a single, integrally or monolithically formed housing.

In this exemplary embodiment, bearing mandrel **220** of bearing assembly **200** has a first or upper end **221**, a second or lower end **223**, and a central through passage **222** extending axially from lower end **223** and terminating axially below upper end **221**. The upper end **221** of bearing mandrel **220** is directly coupled to the lower end **123** of driveshaft **120** via lower universal joint **143**. In particular, upper end **221** is disposed within a receptacle formed in the lower end **123** of driveshaft **120** and pivotally coupled thereto with lower universal joint **143**. Additionally, the lower end **223** of mandrel **220** is coupled to drill bit **90**.

In this exemplary embodiment, bearing mandrel **220** includes a plurality of drilling fluid ports **227** extending radially from passage **222** to the outer surface of mandrel **220**, and a plurality of lubrication ports **229** also extending radially to the outer surface of mandrel **220**, where drilling fluid ports **227** are disposed proximal an upper end of passage **222** and lubrication ports **229** are axially spaced from drilling fluid ports **227**. In this arrangement, lubrication ports **229** are separated or sealed from passage **222** of bearing mandrel **220** and the drilling fluid flowing through passage **222**. Drilling fluid ports **227** provide fluid communication between annulus **116** and passage **222**. During drilling operations, mandrel **220** is rotated about axis **225** relative to housing **210**. In particular, high pressure drilling fluid is pumped through power section **40** to drive the rotation of rotor **50**, which in turn drives the rotation of driveshaft **120**, mandrel **220**, and drill bit **90**. The drilling mud flowing through power section **40** flows through annulus **116**, drilling fluid ports **227** and passage **222** of mandrel **220** in route to drill bit **90**.

In this exemplary embodiment, the upper end **121** of driveshaft **120** is coupled to rotor **50** with a driveshaft adapter **130** and upper universal joint **141**, and the lower end **123** of driveshaft **120** is coupled to the upper end **221** of bearing mandrel **220** with lower universal joint **143**. As shown particularly in FIG. **7**, bearing housing **210** has a central bore or passage defined by a radially inner surface **212** that extends between ends **211** and **213**. One or more upper annular seals **214** are disposed in the inner surface **212** of housing **210** proximal upper end **211** while a second or lower annular seal **216** is disposed in the inner surface **212** proximal lower end **213**. In this arrangement, an annular chamber **217** is formed radially between inner surface **212** and an outer surface of bearing mandrel **220**, where annular chamber **217** extends axially between upper seals **214** and lower seal **216**. In this exemplary embodiment, the inner surface **212** of bearing housing **210** additionally includes an annular seal **215** located proximal an annular shoulder **218** of the inner surface **212**. Bearing housing **210** further includes one or more radial ports **219** in this exemplary embodiment.

Additionally, in this exemplary embodiment, bearing mandrel **220** includes a central sleeve **224** disposed in passage **222** and coupled to an inner surface of mandrel **220** defining passage **222**. An annular piston **226** is slidably disposed in passage **222** radially between the inner surface of mandrel **220** and an outer surface of sleeve **224**, where piston **226** includes a first or outer annular seal that seals against the inner surface of mandrel **220** and a second or inner annular seal that seals against the outer surface of sleeve **224**. In this arrangement, chamber **217** extends into the annular space (via lubrication ports **229**) formed between the inner surface of mandrel **220** and the outer surface of sleeve **224** that is sealed from the flow of drilling fluid through passage **222** via the annular seals of piston **226**.

In this exemplary embodiment, a first or upper radial bearing **230**, a thrust bearing assembly **232**, and a second or lower radial bearing **234** are each disposed in chamber **217**. Upper radial bearing **230** is disposed about mandrel **220** and axially positioned above thrust bearing assembly **232**, and lower radial bearing **234** is disposed about mandrel **220** and axially positioned below thrust bearing assembly **232**. In general, radial bearings **230**, **234** permit rotation of mandrel **220** relative to housing **210** while simultaneously supporting radial forces therebetween. In this exemplary embodiment, upper radial bearing **230** and lower radial bearing **234** are both sleeve type bearings that slidingly engage the outer surface of mandrel **220**. However, in general, any suitable type of radial bearing(s) may be employed including, without limitation, needle-type roller bearings, radial ball bearings, PDC Diamond tiled bearings, and/or combinations thereof.

Annular thrust bearing assembly **232** is disposed about mandrel **220** and permits rotation of mandrel **220** relative to housing **210** while simultaneously supporting axial loads in both directions (e.g., off-bottom and on-bottom axial loads). In this exemplary embodiment, thrust bearing assembly **232** generally comprises a pair of caged roller bearings and corresponding races, with the central race coupled to bearing mandrel **220**. In other embodiments, one or more other types of thrust bearings may be included in bearing assembly **200**, including ball bearings, planar bearings, PDC Diamond insert bearings etc. In still other embodiments, the thrust bearing assemblies of bearing assembly **200** may be disposed in the same or different thrust bearing chambers (e.g., two-shoulder or four-shoulder thrust bearing chambers). In this exemplary embodiment, radial bearings **230**, **234** and thrust bearing assembly **232** are oil-sealed bearings. Particularly, chamber **217** comprises an oil or lubricant filled chamber that is pressure compensated via piston **226**. In other words, piston **226** equalizes the fluid pressure within chamber **217** with the pressure of drilling fluid flowing through passage **222** of mandrel **220** towards drill bit **90**. As previously described, in this exemplary embodiment, bearings **230**, **232**, **234** are oil-sealed. However, in other embodiments, the bearings of the bearing assembly (e.g., bearing assembly **200**) are mud lubricated.

Referring still to FIGS. **4-7**, as previously described, bend adjustment assembly **300** couples driveshaft housing **110** to bearing housing **210**, and introduces bend **301** and deflection angle θ along motor **35**. Central axis **115** of driveshaft housing **110** is coaxially aligned with axis **25**, and central axis **225** of bearing mandrel **220** is coaxially aligned with axis **95**, thus, deflection angle θ also represents the angle between axes **115**, **225** when mud motor **35** is in an undeflected state (e.g., outside wellbore **16**). Bend adjustment assembly **300** is configured to adjust the deflection angle θ between a first predetermined deflection angle θ_1 and a second predetermined deflection angle θ_2, different from the first deflection angle θ_1, with drillstring **21** and BHA **30** in-situ disposed in wellbore **16**. In other words, bend adjustment assembly **300** is configured to adjust the amount of bend **301** without needing to pull drillstring **21** from wellbore **16** to adjust bend adjustment assembly **300** at the surface, thereby reducing the amount of time required to drill wellbore **16**. In this exemplary embodiment, first predetermined deflection angle θ_1 is substantially equal to 0° while second deflection angle θ_2 is an angle greater than 0°, such as an angle between 0°-5°; however, in other embodiments, first deflection angle θ_1 may be greater than 0°, as will be discussed further herein.

In this exemplary embodiment, bend adjustment assembly **300** generally includes a first or upper housing **310**, a second or lower housing **320**, a piston mandrel **350**, a first or upper adjustment mandrel **360**, a second or lower adjustment mandrel **370**, and a locking assembly **400**. Additionally, in this exemplary embodiment, bend adjustment assembly **300** includes an actuator assembly **450** housed in bearing housing **210**, where actuator assembly **450** is generally configured to control the actuation of bend adjustment assembly between the first deflection angle θ_1 and the second deflection angle θ_2 with BHA **30** disposed in wellbore **16**. Upper housing **310** and lower housing **320** may be referred to at times as offset housings **310**, **320**. Additionally, in this exemplary embodiment, upper housing **310** comprises a plurality of tubular housings connected end-to-end; however, it may be understood that in other embodiments, upper housing **310** may comprise a singular integrally or monolithically formed housing.

Referring now to FIGS. **5**, **6**, and **8-11**, components of the bend adjustment assembly **300** are shown. As shown particularly in FIG. **6**, upper housing **310** is generally tubular and has a first or upper end **311**, a second or lower end **313**, and a central bore or passage defined by a generally cylindrical inner surface **312** extending between ends **311** and **313**. The inner surface **312** of upper housing **310** includes an engagement surface **314** extending from upper end **311** and a threaded connector **316** extending from lower end **313**. An annular seal **318** is disposed radially between engagement surface **314** of upper housing **310** and an outer surface of upper adjustment mandrel to seal the annular interface formed therebetween.

Lower housing **320** of bend adjustment assembly **300** is generally tubular and has a first or upper end **319**, a second or lower end **321**, and a generally cylindrical inner surface **322** extending between ends **319** and **321**. A generally cylindrical outer surface of lower housing **320** includes a threaded connector coupled to the threaded connector **316** of upper housing **310**. The inner surface **322** of lower housing **320** includes an offset engagement surface **323** extending from upper end **319** to an internal shoulder **327**S, and a threaded connector **324** extending from lower end **321**. In this exemplary embodiment, offset engagement surface **323** defines an offset bore or passage **327** that extends between upper end **319** and internal shoulder **327**S of lower housing **320**.

Additionally, lower housing **320** includes a central bore or passage **329** extending between lower end **321** and internal shoulder **327**S, where central bore **329** has a central axis disposed at an angle relative to a central axis of offset bore **327**. In other words, offset engagement surface **323** has a central or longitudinal axis that is offset or disposed at an angle relative to a central or longitudinal axis of lower housing **320**. Thus, in this exemplary embodiment, the offset or angle formed between central bore **329** and offset bore **327** of lower housing **320** facilitates the formation of bend **301** described above. In this exemplary embodiment, the inner surface **322** of lower housing **320** additionally includes a first or upper annular shoulder **325**, and a second or lower annular shoulder **326**. Additionally, inner surface **322** of lower housing **320** includes a pair of circumferentially spaced slots **331**, where slots **331** extend axially into lower housing **320** from upper shoulder **325**.

In this exemplary embodiment, lower housing **320** of bend adjustment assembly **300** includes an arcuate lip or extension **328** at upper end **319**. Particularly, extension **328** extends arcuately between a pair of axially extending shoulders **328**S. In this exemplary embodiment, extension **328** extends less than 180° about the central axis of lower housing **320**; however, in other embodiments, the arcuate length or extension of extension **328** may vary. Additionally, in this exemplary embodiment, a plurality of circumferentially spaced teeth or castellations **333** are formed on the extension **328**. Further, in this exemplary embodiment, lower housing **320** includes a plurality of circumferentially spaced and axially extending ports **330**. Particularly, ports **330** extend axially between lower shoulder **326** and an arcuate shoulder **332** from which extension **328** extends. As will be discussed further herein, ports **330** of lower housing **320** provide fluid communication through a generally annular compensation or locking chamber **395** of bend adjustment assembly **300**.

As shown particularly in FIG. **5**, piston mandrel **350** of bend adjustment assembly **300** is generally tubular and has a first or upper end **351**, a second or lower end **353**, and a central bore or passage extending between ends **351** and **353**. Additionally, in this exemplary embodiment, piston mandrel **350** includes a generally an annular seal **352** positioned on an outer surface thereof proximal upper end **351** and which sealingly engages the inner surface of driveshaft housing **110**. Further, piston mandrel **350** includes an annular shoulder located proximal upper end **351** that physically engages or contacts an annular biasing member **354** extending about the outer surface of piston mandrel **350**. In this exemplary embodiment, an annular compensating piston **356** is slidably disposed about the outer surface of piston mandrel **350**. In some embodiments, compensating piston **356** may include a pair of annular seals which sealingly engage the inner surface of driveshaft housing **110** and the outer surface of piston mandrel **350**.

The upper adjustment mandrel **360** of bend adjustment assembly **300** is generally tubular and has a first or upper end **361**, a second or lower end **363**, and a central bore or passage defined by a generally cylindrical inner surface extending between ends **361** and **363**. In this exemplary embodiment, the inner surface of upper adjustment mandrel **360** includes an annular recess extending axially into mandrel **360** from upper end **361**, and an annular seal **362** axially spaced from recess **361** and which sealingly engages the outer surface of piston mandrel **350**. Adjustment mandrel **360** is connected with piston mandrel **350** to restrict relative movement therebetween. In this exemplary embodiment, an outer seal of compensating piston **356** sealingly engages the inner surface of upper adjustment mandrel **360**, restricting fluid communication between locking chamber **395** and a generally annular compensating chamber **359** formed about piston mandrel **350** and extending axially between seal **352** of piston mandrel **350** and outer seal of compensating piston **356**. In this configuration, compensating chamber **359** is in fluid communication with the surrounding environment (e.g., wellbore **16**) via ports **114** in driveshaft housing **110**.

In this exemplary embodiment, upper adjustment mandrel **360** includes a generally cylindrical outer surface comprising a first or upper threaded connector, an offset engagement surface **365**, and a second or lower threaded connector. The upper threaded connector of upper adjustment mandrel **360** extends from upper end **361** and couples to a threaded connector disposed on the inner surface of driveshaft housing **110** at lower end **113**. Offset engagement surface **365** has a central or longitudinal axis that is offset from or disposed at an angle relative to a central or longitudinal axis of upper adjustment mandrel **360**. Offset engagement surface **365** matingly engages the engagement surface **314** of upper housing **310**, as will be described further herein. In this exemplary embodiment, relative rotation is permitted between upper housing **310** and upper adjustment mandrel **360** while relative axial movement is restricted between housing **310** and mandrel **360**. Adjustment mandrel **360** is connected with lower adjustment mandrel **370** to restrict relative movement therebetween. Further, the outer surface of upper offset mandrel **360** proximal the lower end **363** thereof includes an annular seal **366** located proximal lower end **363** that sealingly engages lower adjustment mandrel **370**.

Referring still to FIGS. **5**, **6**, and **8-10**, lower adjustment mandrel **370** of bend adjustment assembly **300** is generally tubular and has a first or upper end **371**, a second or lower end **373**, and a central bore or passage extending therebetween that is defined by a generally cylindrical inner surface. In this exemplary embodiment, the inner surface of lower adjustment mandrel **370** includes axial slots which engage axial splines of upper adjustment mandrel **360**. Additionally, in this exemplary embodiment, lower adjustment mandrel **370** includes a generally cylindrical outer surface comprising an offset engagement surface **372**. Offset engagement surface **372** has a central or longitudinal axis that is offset or disposed at an angle relative to a central or longitudinal axis of the upper end **361** of upper adjustment mandrel **360** and the lower end **321** of lower housing **320**, where offset engagement surface **372** is disposed directly adjacent or overlaps the offset engagement surface **323** of lower housing **320**. When bend adjustment assembly **300** is disposed in the first configuration **303**, a first deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360**, and when bend adjustment assembly **300** is disposed in the second configuration **305**, a second deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360** that is different from the first deflection angle.

In this exemplary embodiment, an annular seal **374** is disposed in the outer surface of lower adjustment mandrel **370** to sealingly engage the inner surface of lower housing **320**. In this exemplary embodiment, a recess **379** is formed on the outer surface of lower adjustment mandrel **370** which extends arcuately between a pair of circumferentially spaced shoulders **375**. Additionally, a plurality of circumferentially spaced teeth or castellations **376** are formed in the arcuate recess **379** between shoulders **375**. In this exemplary embodiment, lower adjustment mandrel **370** further includes a pair of circumferentially spaced first or short slots **377** and a pair of circumferentially spaced second or long slots **378**. Both the short slots **377** and long slots **378** of lower adjustment mandrel **370** extend axially into lower adjustment mandrel **370** from the lower end **373** thereof. In this exemplary embodiment, each short slot **377** is circumferentially spaced approximately 180° apart. Similarly, in this exemplary embodiment, each long slot **378** is circumferentially spaced approximately 180° apart.

FIG. **10** illustrates the short slots **377** and long slots **378** directly adjacent each with no rib of material or other obstruction interposed therebetween thereby permitting a single shift from the first configuration **303** to the second configuration **305** of bend adjustment assembly **300**. However, it may be understood that other applications may require multiple shifts during the run, as will be described further herein with respect to FIG. **11**, which permits the use of a lower adjustment mandrel **390** with slots **377** and **378** circumferentially spaced such that a rib of material is present between the adjacent slots of the lower adjustment mandrel.

In this exemplary embodiment, lower adjustment mandrel **370** is initially coupled to upper adjustment mandrel **360** by a shear member or pin **380** positioned radially therebetween which restricts relative axial movement between adjustment mandrels **360**, **370**. As will be described further herein, shear pin **380** may be sheared during the operation of bend adjustment assembly **300** to permit relative axial movement between adjustment mandrels **360**, **370**. Additionally, one or more splines or keys are positioned radially between adjustment mandrels **360**, **370** to restrict relative rotation therebetween.

Referring now to FIG. **11**, another embodiment of a lower adjustment mandrel **390** is shown. It may be understood that in some embodiments lower adjustment mandrel **390** may be used in the bend adjustment assembly **300** (and other bend adjustment assemblies which vary in configuration from bend adjustment assembly **300**) in lieu of the lower adjustment mandrel **370** shown in FIG. **10**.

In this exemplary embodiment, lower adjustment mandrel **390** has a first or upper end **391**, a second or lower end **393**, and a central bore or passage extending therebetween that is defined by a generally cylindrical inner surface. Additionally, in this exemplary embodiment, lower adjustment mandrel **390** includes a generally cylindrical outer surface comprising an offset engagement surface **392** which has a central or longitudinal axis that is offset or disposed at an angle relative to a central or longitudinal axis of the upper end **361** of upper adjustment mandrel **360** and the lower end **321** of lower housing **320**.

In this exemplary embodiment, an annular seal **394** is disposed in the outer surface of lower adjustment mandrel **390** to sealingly engage the inner surface of lower housing **320**. Additionally, a recess **399** is formed on the outer surface of lower adjustment mandrel **390** which extends arcuately between a pair of circumferentially spaced shoulders **395**. A plurality of circumferentially spaced teeth or castellations **396** are formed in the arcuate recess **399** between shoulders **395**. Lower adjustment mandrel **390** further includes a pair of circumferentially spaced first or short slots **397** and a pair of circumferentially spaced second or long slots **398**. Both the short slots **397** and long slots **398** of lower adjustment mandrel **390** extend axially into lower adjustment mandrel **390** from the lower end **393** thereof. In this exemplary embodiment, each short slot **397** is circumferentially spaced approximately 180° apart. Similarly, each long slot **398** is circumferentially spaced approximately 180° apart.

Referring now to FIGS. **5**, **6**, and **12-19**, as will be described further herein, locking assembly **400** prevents bend adjustment assembly from shifting from the first configuration **303** to the second configuration **305** until mud motor **35** has reached a predefined depth within wellbore **16**. In other words, prior to reaching the predefined depth, mud motor **35** may be operated in any manner desired by an operator of well system **10** without inadvertently triggering the actuation of bend adjustment assembly **300** from the first configuration **303** to the second configuration **305**. For example, the pumping of drilling fluid through drillstring **21** may be ceased without inadvertently unlocking bend adjustment assembly **300** from the first configuration **303** until the predefined depth has been achieved. Similarly, drilling fluid may be pumped through drillstring **21** at a maximum drilling pressure without inadvertently unlocking bend adjustment assembly **300** from the first configuration **303** until the predefined depth has been achieved. The maximum drilling pressure may correspond to a maximum discharge pressure of mud pump **23** that may be safely and practically delivered by mud pump **23**. To state in other words, locking assembly **400** allows mud motor **35** to be operated as if bend adjustment assembly **300** were not present therein until the predefined depth has been achieved.

In this exemplary embodiment, locking assembly **400** generally includes a locking piston **402**, a locking sleeve **420**, a rupture disk **426**, a first locking pin **430**, and a second locking pin **440** circumferentially spaced from the first locking pin **430**. Locking piston **402** is generally tubular and has a first or upper end **401**, a second or lower end **403**, and a central bore or passage extending therebetween. Locking piston **402** includes a generally cylindrical outer surface comprising an annular shoulder **404** positioned axially between a pair of annular seals **406**, **408** positioned on the outer surface of locking piston **402**.

Locking piston **402** additionally includes a pair of circumferentially spaced keys **410** that extend axially from upper end **401**, where each key **410** extends through one of the circumferentially spaced slots **331** of lower housing **320**. In this arrangement, relative rotation between locking piston **402** and lower housing **320** is restricted while relative axial movement is permitted therebetween. As will be discussed further herein, each key **410** is receivable in either one of the short slots **377** or long slots **378** of lower adjustment mandrel **370** depending on the relative angular position between locking piston **402** and lower adjustment mandrel **370**.

In this exemplary embodiment, the outer surface of locking piston **402** additionally includes a pair of circumferentially opposed recesses **411**, **413** formed therein. First recess **411** is circumferentially aligned with the first locking pin **430** and a first ledge **412** of locking piston **402** formed on the first recess **411** engages the first locking pin **430** as will be described further herein. Similarly, second recess **413** is circumferentially aligned with the second locking pin **440** and a second ledge **414** of locking piston **402** formed on the second recess **413** engages the second locking pin **440** as will be described further herein.

The combination of sealing engagement between seals **406**, **408** of locking piston **402** and the inner surface **322** of lower housing **320** defines a lower axial end of locking chamber **395**. Locking chamber **395** extends longitudinally from the lower axial end thereof to an upper axial end defined by the combination of sealing engagement between the outer seal of compensating piston **356** and the inner seal of piston **356**. Particularly, lower adjustment mandrel **370** and upper adjustment mandrel **360** each include axially extending ports similar in configuration to the ports **330** of lower housing **320** such that fluid communication is provided between the annular space directly adjacent shoulder **404** of locking piston **402** and the annular space directly adjacent a lower end of compensating piston **356**. Locking chamber **395** is sealed from annulus **116** such that drilling fluid flowing into annulus **116** is not permitted to communicate with fluid disposed in locking chamber **395**, where locking chamber **395** is filled with lubricant.

The locking sleeve **420** of locking assembly **400** is positioned about locking piston **402** radially between the outer surface of locking piston **402** and the inner surface **322** of lower housing **320**. In this exemplary embodiment, locking sleeve **420** includes a first or upper end **421**, a second or lower end **423** opposite upper end **421**, and a pair of circumferentially opposed fingers **422** extending from the upper end **421**. Fingers **422** are circumferentially aligned with the locking pins **430**, **440** of locking assembly **400** as will be described further herein. Additionally, a generally cylindrical outer surface of locking sleeve **420** includes an annular shoulder **424** formed thereon.

In this exemplary embodiment, the rupture disk **426** of locking assembly **400** is positioned in an internal fluid passage **334** of lower housing **320** which extends from a first opening formed in the internal shoulder **327S** to a second opening formed in the inner surface **322** of lower housing **320**. Additionally, lower housing **320** includes a pair of annular seals **336** positioned on the inner surface **322** of lower housing **320** and flanking the second opening of fluid passage **334**. Each of the seals **336** sealingly engages the outer surface of locking sleeve **420** such that while fluid communication between fluid passage **334** and the shoulder **424** of locking sleeve **420** is permitted, fluid communication between the ends **421**, **423** of locking sleeve **420** is restricted.

Fluid passage **334** may initially comprise or form an ambient chamber filled with air at ambient pressure. Rupture disk **426** is configured to burst or rupture in response to the mud motor **35** reaching the predefined depth within wellbore **16**, causing fluid pressure within fluid passage **334** to increase and equalize with the fluid pressure in the central passage of lower housing **320**. The increase in pressure within fluid passage **334** is applied to the shoulder **424** of locking sleeve **420** as will be described further herein.

In some embodiments, the rupture disk **426** is configured to burst in response to fluid pressure within bend adjustment assembly **300** reaching a pressure corresponding to the predefined depth. A static or head pressure of the drilling fluid flowing through bend adjustment assembly **300** increases as the depth of mud motor **35** within wellbore **16** increases. In addition to the head pressure dependent on the depth of mud motor **35** within wellbore **16**, a dynamic pressure is added to the drilling fluid by mud pump **23**, where the pressure of the drilling fluid flowing through bend adjustment assembly **300** at a given time is equal to the combined head pressure (dependent on the depth of the mud motor **35**) and dynamic pressure (dependent on the operation of mud pump **23**) of the drilling fluid. In some embodiments, the rupture disk **426** is configured to burst when the head pressure of the drilling fluid within bend adjustment assembly **300** corresponds to the predefined depth and the dynamic pressure of the drilling fluid is equal to the maximum drilling pressure delivered by mud pump **23**.

First locking pin **430** initially holds or restrains locking piston **402** in a first or initial axial position before mud motor **35** achieves the predefined depth within wellbore **16**. First locking pin **430** has a longitudinal first end **431**, a longitudinal second end **433** opposite first end **431**, an outer receptacle **432** extending longitudinally into second end **433**, and a slotted opening **434** located between ends **431**, **433**. A first biasing member **436** of locking assembly **400** biases first locking pin **430** in a first lateral direction **435** (shown in FIG. **19**) that extends orthogonal the central axis of lower housing **320**. The first locking pin **430** and first biasing member **436** are each positioned in a first lateral slot **338**A formed in the lower housing **320** of bend adjustment assembly **300** where both the outer receptacle **432** and slotted opening **434** of first locking pin **430** are positioned within the central passage of lower housing **320**.

Second locking pin **440** locks the locking piston **402** in a second or set axial position that is spaced from the initial axial position of locking piston **402**. As will be described further herein, locking piston **402** travels from the initial axial position to the set axial position during the actuation of bend adjustment assembly **300** from the first configuration **303** to the second configuration **305** once mud motor **35** achieves the predefined depth within wellbore **16**.

Similar to first locking pin **430** described above, second locking pin **440** has a longitudinal first end **441**, a longitudinal second end **443** opposite first end **441**, an outer receptacle **442** extending longitudinally into second end **443**, and a slotted opening **444** located between ends **441**, **443**. A second biasing member **446** of locking assembly **400** biases second locking pin **440** in a second lateral direction **445** (shown in FIG. **19**) that extends orthogonal the central axis of lower housing **320** and is opposite the first lateral direction **435**. Additionally, the second locking pin **440** and second biasing member **446** are each positioned in a second lateral slot **338**B formed in lower housing **320** where both the outer receptacle **442** and slotted opening **444** of second locking pin **440** are positioned within the central passage of lower housing **320**. In this exemplary embodiment, the location of slotted opening **444** is shifted closer to the second end **443** of second locking pin **440** compared to the location of slotted opening **434** of first locking pin **430**. However, in other embodiments, the configuration of locking pins **430**, **440** may vary.

In this exemplary embodiment, the first locking pin **430** is received in the first recess **411** of locking piston **402** while the second locking pin **440** is received in the second recess **413** of locking piston **402**. Particularly, when bend adjustment assembly **300** is in the first configuration **303**, the first ledge **412** of locking piston **402** is laterally offset from the slotted opening **434** of first locking pin **430** and contacts a side of the first locking pin **430**. Contact between the first ledge **412** and first locking pin **402** prevents locking piston **402** from travelling upwards from the initial axial position to the set axial position. Additionally, when bend adjustment assembly **300** is in the first configuration **303**, one of the fingers **422** of locking sleeve **420** is received in the outer receptacle **432** of first locking pin **430**, preventing first locking pin **430** from travelling in the first lateral direction **435** from a first or initial lateral position (corresponding to the first configuration **303** of bend adjustment assembly **300**) to a second or set lateral position that is spaced in the first lateral direction **435** from the initial lateral position.

Further, when bend adjustment assembly **300** is in the first configuration **303**, the second ledge **414** of locking piston **402** is laterally aligned with and received in the slotted opening **444** of second locking pin **440**. Additionally, when bend adjustment assembly **300** is in the first configuration **303**, the other of the fingers **422** of locking sleeve **420** is received in the outer receptacle **442** of second locking pin **440**, preventing second locking pin **440** from travelling in the second lateral direction **445** from a first or initial lateral position (corresponding to the first configuration **303** of bend adjustment assembly **300**) to a second or set lateral position that is spaced in the second lateral direction **445** from the initial lateral position.

Referring now to FIG. **7**, actuator assembly **450** of bend adjustment assembly **300** forces or causes bend adjustment assembly **300** to actuate from the first configuration **303** to the second configuration **305** after mud motor **35** has achieved the predefined depth within wellbore **16**. In this exemplary embodiment, actuator assembly **450** generally includes an actuator piston **452** and a torque transmitter or teeth ring **470**. Actuator piston **452** of actuator assembly **450** is slidably disposed about bearing mandrel **220** and has a first or upper end **453**, a second or lower end **455**, and a central bore or passage extending therebetween. In this exemplary embodiment, actuator piston **452** has a generally cylindrical outer surface including an annular shoulder **454** and an annular seal **456** located axially between shoulder **454** and lower end **455**. The outer surface of actuator piston **452** includes a plurality of radially outwards extending and circumferentially spaced keys received in slots of the bearing housing **210** to restrict relative rotation between actuator piston **452** and bearing housing **210** while permitting actuator piston **452** to slide axially relative bearing housing **210**. Additionally, in this exemplary embodiment, actuator piston **452** includes a plurality of circumferentially spaced locking teeth **460** extending axially from lower end **455**.

In this exemplary embodiment, seal **456** of actuator piston **452** sealingly engages the inner surface **212** of bearing housing **210** and the seal **215** of bearing housing **210** sealingly engages the outer surface of actuator piston **452** to form an annular, sealed compensating chamber **412** extending therebetween. Fluid pressure within compensating chamber **412** is compensated or equalized with the surrounding environment (e.g., wellbore **16**) via ports **219** of bearing housing **210**. Additionally, an annular biasing member **462** is disposed within compensating chamber **412** and applies a biasing force against shoulder **454** of actuator piston **452** in the axial direction of teeth ring **470**.

Teeth ring **470** of actuator assembly **450** is generally tubular and comprises a first or upper end **471**, a second or lower end **473**, and a central bore or passage extending between ends **471** and **473**. Teeth ring **470** is coupled to bearing mandrel **220** via a plurality of circumferentially spaced splines or pins **472** disposed radially therebetween. In this arrangement, relative axial and rotational movement between bearing mandrel **220** and teeth ring **470** is restricted. In this exemplary embodiment, teeth ring **470** comprises a plurality of circumferentially spaced teeth **474** extending from upper end **471**. Teeth **474** of teeth ring **470** are configured to matingly engage or mesh with the teeth **460** of actuator piston **452** when biasing member **462** biases actuator piston **452** into contact with teeth ring **470**, as will be discussed further herein.

In this exemplary embodiment, actuator assembly **450** is both mechanically and hydraulically biased during operation of mud motor **35**. Additionally, the driveline of mud motor **35** is independent of the operation of actuator assembly **450** while drilling, thereby permitting 100% of the available torque provided by power section **40** to power drill bit **90** when actuator assembly **450** is disengaged. The disengagement of actuator assembly **450** may occur at high flowrates through mud motor **35**, and thus, when higher hydraulic pressures are acting against actuator piston **452**. Additionally, in some embodiments, actuator assembly **450** may be used to rotate something parallel to bearing mandrel **220** instead of being used like a clutch to interrupt the main torque carrying driveline of mud motor **35**. In this configuration, actuator assembly **450** comprises a selective auxiliary drive that is simultaneously both mechanically and hydraulically biased. Further, this configuration of actuator assembly **450** allows for various levels of torque to be applied as the hydraulic effect can be used to effectively reduce the preload force of biasing member **462** acting on mating teeth ring **470**. This type of angled tooth clutch may be governed by the angle of the teeth (e.g., teeth **474** of teeth ring **470**), the axial force applied to keep the teeth in contact, the friction of the teeth ramps, and the torque engaging the teeth to determine the slip torque that is required to have the teeth slide up and turn relative to each other.

In some embodiments, actuator assembly **450** permits rotation in mud motor **35** to rotate rotor **50** and bearing mandrel **220** until bend adjustment assembly **300** has fully actuated from the first configuration **303** to the second configuration **305**, and then, subsequently, ratchet or slip while transferring relatively large amounts of torque to bearing housing **210**. This reaction torque may be adjusted by increasing the hydraulic force or hydraulic pressure acting on actuator piston **452**, which may be accomplished by increasing flowrate through mud motor **35**. When additional torque is needed a lower flowrate or fluid pressure can be applied to actuator assembly **450** to modulate the torque and thereby rotate bend adjustment assembly **300**. The fluid pressure is transferred to actuator piston **452** by compensating piston **226**. In some embodiments, the pressure drop across drill bit **90** may be used to increase the pressure acting on actuator piston **452** as flowrate through mud motor **35** is increased.

Referring now to FIGS. **4-7**, **19-21**, having described the structure of the embodiment of driveshaft assembly **100**, bearing assembly **200**, and bend adjustment assembly **300**, an embodiment for operating assemblies **100**, **200**, and **300** will now be described. As described above, bend adjustment assembly **300** includes first configuration **303** shown in FIGS. **4**, **5** and second configuration **305** shown in FIGS. **20**, **21**. In this exemplary embodiment, first configuration **303** of assembly **300** corresponds to a low bend setting providing a first non-zero deflection angle θ_1 while second configuration **305** corresponds to a high bend setting providing a second deflection angle θ_2 that is greater than the first non-zero deflection angle θ_1. In other embodiments, the first configuration **303** or second configuration **305** may correspond to a straight setting providing a 0° deflection angle θ.

In this exemplary embodiment, mud motor **35** may be operated to drill wellbore **16** with bend adjustment assembly **300** locked into the first configuration **303** until mud motor **35** reaches the predefined depth at which point locking assembly **400** is configured to automatically unlock bend adjustment assembly **300** such that bend adjustment assembly **300** may be actuated from the first configuration **303** to the second configuration **305**. Locking assembly **400** includes a first or locked configuration which prevents actuator assembly **350** from shifting bend adjustment assembly **300** from the first configuration **303** to the second configuration **305** irrespective of the manner in which mud motor **35** is operated (e.g., irrespective of the flowrate of drilling fluid through mud motor **35** and/or the amount of rotational torque applied to mud motor **35** from the rotary system **24**). Locking assembly **400** is configured to automatically actuate from the locked configuration to an unlocked configuration upon the mud motor **35** reaching the predefined depth in wellbore **16**. In the unlocked configuration, locking assembly **400** permits actuator assembly **450** to actuate the bend adjustment assembly **300** from the first configuration **303** to the second configuration **305**, as will be described further herein.

Particularly, in the locked configuration of locking assembly **400**, first locking pin **430** restrains or locks locking piston **402** into the initial axial position within lower housing **320**. Additionally, the fingers **422** of locking sleeve **420** are received in the outer receptacles **432**, **442** of locking pins **430**, **440**, respectively, preventing locking pins **430**, **440** from travelling from their respective first lateral positions to their respective second lateral positions. Additionally, with locking assembly **400** in the locked configuration, lower adjustment mandrel **370** is axially locked in a first or initial axial position relative to upper adjustment mandrel **360** by shear pin **380**. In the initial axial position of lower adjustment mandrel **370**, castellations **333** of lower housing **320** interlock with the castellations **376** of lower adjustment mandrel **370**, preventing relative rotation between lower adjustment mandrel **370** and lower housing **320**. The prevention of relative rotation between housing **320** and mandrel **370** in-turn prevents bend adjustment assembly **300** from shifting from first configuration **303** to second configuration **305**.

Upon reaching the predefined depth in wellbore **16**, pressure within the central passage of lower housing **320** reaches a predefined burst pressure causing the rupture disk **426** to burst, exposing fluid passage **334** of lower housing **320** to the pressure of the drilling fluid flowing through bend adjustment assembly **300**. This increase in fluid pressure is applied to the shoulder **424** of locking sleeve **420**, forcing the locking sleeve **420** to travel axially through lower housing **320** until the lower end **423** of locking sleeve **420** contacts an annular ring or stop **342** positioned in lower housing **320**.

As locking sleeve **420** travels towards annular stop **342**, the fingers **422** of locking sleeve **420** release from the outer receptacles **432**, **442** of locking pins **430**, **440**, respectively, allowing biasing members **436**, **446** to shift locking pins **430**, **440**, respectively, from their respective first lateral positions to their respective second lateral positions, as shown particularly in FIG. **20**.

With first locking pin **430** in the second lateral position, the slotted opening **434** of first locking **430** aligns with the first ledge **412** of locking piston **402**. In this arrangement, the net pressure force applied to locking piston **402** by the pressure of the drilling fluid flowing through bend adjustment assembly forces locking piston **402** from the initial axial position to the set axial position. Additionally, keys **410** of locking piston **402** press against the lower adjustment mandrel **370** as the locking piston **402** is shifted to the set axial position, thereby shearing the shear pin **380** connecting lower adjustment mandrel **370** with upper adjustment mandrel **360**, and forcing lower adjustment mandrel **370** upwards from the initial axial position of mandrel **370** into a second or set axial position of lower adjustment mandrel **370**. In the set axial position of lower adjustment mandrel **370**, the castellations **333** of lower housing **320** are no longer interlocked with the castellations **376** of lower adjustment mandrel **370**, thereby permitting relative rotation between lower housing **320** and lower adjustment mandrel **370**.

With locking assembly **400** in the unlocked configuration and with lower adjustment mandrel **370** in the set axial position, bend adjustment assembly **300** may be actuated from the first configuration **303** to the second configuration **305** by rotating offset housings **310** and **320** relative adjustment mandrels **360** and **370** in response to varying a flowrate of drilling fluid through annulus **116** and/or varying the degree of rotation of drillstring **21** at the surface. As described above, offset bore **327** and offset engagement surface **323** of lower housing **320** are offset from central bore **329** and the central axis of housing **320** to form a lower offset angle, and offset engagement surface **365** of upper adjustment mandrel **360** is offset from the central axis of mandrel **360** to form an upper offset angle. Additionally, offset engagement surface **323** of lower housing **320** matingly engages the engagement surface **372** of lower adjustment mandrel **370** while the engagement surface **314** of upper housing **310** matingly engages the offset engagement surface **365** of upper adjustment mandrel **360**.

In this configuration, the relative angular position between lower housing **320** and lower adjustment mandrel **370** determines the total offset angle (ranging from 0° to a maximum angle greater than 0°) between the central axes of lower housing **320** and driveshaft housing **110**. The minimum angle occurs when the upper and lower offsets are in-plane and cancel out, while the maximum angle occurs when the upper and lower offsets are in-plane and additive. Therefore, by adjusting the relative angular positions between offset housings **310**, **320**, and adjustment mandrels **360**, **370**, the deflection angle θ and bend **301** of bend adjustment assembly **300** may be adjusted or manipulated.

The magnitudes of bend **301** in configurations **303** and **305** (e.g., the magnitudes of deflection angles θ_1 and θ_2) are controlled by the relative positioning of shoulders **328S** and shoulders **375**, which establish the extents of angular rotation in each direction. In this exemplary embodiment, lower housing **320** is provided with a fixed amount of spacing between shoulders **328S**, while adjustment mandrel **370** can be configured with an optional amount of spacing between shoulders **375**, allowing the motor to be set up with the desired bend setting options (θ_1 and θ_2) as dictated by a particular application simply by providing the appropriate configuration of lower adjustment mandrel **370**.

Actuator assembly **450** controls the actuation of bend adjustment assembly **300** between first configuration **303** and second configuration **305**. In this exemplary embodiment, actuator assembly **450** selectively or controllably transfers torque from bearing mandrel 220 (supplied by rotor **50**) to bearing housing **210** in response to changes in the flowrate of drilling fluid supplied to power section **40**. In this exemplary embodiment, to actuate bend adjustment assembly **300** from the first configuration **303** to the second configuration **305**, the pumping of drilling mud from surface pump **23** and the rotation of drillstring **21** by rotary system **24** is ceased and/or reduced by a predetermined percentage from the maximum drilling flowrate of well system **10**, where the maximum drilling flowrate of well system **10** is dependent on the application, including the size of drillstring **21** and BHA **30**.

For instance, the maximum drilling flowrate of well system **10** may comprise the maximum drilling flowrate that may be pumped through drillstring **21** and BHA **30** before components of drillstring **21** and/or BHA **30** are eroded or otherwise damaged by the mud flowing therethrough. In some embodiments, the reduced flowrate of drilling mud from surface pump **23** comprises approximately 1%-30% of the maximum drilling flowrate of well system **10**; however, in other embodiments, the reduced flowrate may vary. For instance, in some embodiments, the reduced flowrate may comprise zero or substantially zero fluid flow.

In this exemplary embodiment, as drilling fluid flows through BHA **30** from drillstring **21** at the reduced flowrate, rotational torque is transmitted to bearing mandrel **220** via rotor **50** of power section **40** and driveshaft **120**. Additionally, biasing member **462** applies a biasing force against shoulder **454** of actuator piston **452** to urge actuator piston **452** into contact with teeth ring **470**, with teeth **460** of piston **452** in meshing engagement with the teeth **474** of teeth ring **470**. In this arrangement, torque applied to bearing mandrel **220** is transmitted to bearing housing **210** via the meshing engagement between teeth **474** of teeth ring **470** (rotationally fixed to bearing mandrel **220**) and teeth **460** of actuator piston **452** (rotationally fixed to bearing housing **210**).

Rotational torque applied to bearing housing **210** via actuator assembly **450** is transmitted to offset housings **310**, **320**, which rotate (along with bearing housing **210**) in a first rotational direction relative adjustment mandrels **360**, **370**. Particularly, extension **328** of lower housing **320** rotates through arcuate recess **379** of lower adjustment mandrel **370** until a shoulder **328S** engages a corresponding shoulder **375** of recess **379**, restricting further relative rotation between offset housings **310**, **320**, and adjustment mandrels **360**, **370**. Following the rotation of lower housing **320**, bend adjustment assembly **300** forms second deflection angle θ_2 with bend adjustment assembly **300** now in the second configuration **305**.

With bend adjustment assembly **300** now in the second configuration **305**, the flowrate of drilling mud from surface pump **23** is increased from the reduced flowrate to an increased flowrate. In some embodiments, the increased flowrate of drilling mud from surface pump **23** comprises approximately 50%-100% of the maximum drilling flowrate of well system **10**; however, in other embodiments, the increased flowrate may vary. The increased flowrate applies a net pressure force sufficient to overcome the biasing force applied against the upper end **401** of locking piston **402** via biasing member **354** to force the locking piston upwards into a locked position whereby the keys **410** of locking piston **402** are received in long slots **378** as shown particularly in FIG. **21**.

Additionally, with drilling mud flowing through BHA **30** from drillstring **21** at the increased flowrate, fluid pressure applied against the lower end **455** of actuator piston **452** from the lubricant in chamber **217** is increased (due to the increased pressure of the drilling fluid which is transferred through piston **226**), overcoming the biasing force applied against shoulder **454** by biasing member **462** and thereby disengaging actuator piston **452** from teeth ring **470**. With actuator piston **452** disengaged from teeth ring **470**, torque is no longer transmitted from bearing mandrel **220** to bearing housing **210**. Further, in this exemplary embodiment, a flow restriction is formed between the inner surface of locking piston **402** and shoulder **122** of driveshaft **120** when locking piston **402** is in the locked position with keys **410** received in short slots **377** of lower adjustment mandrel **370**, corresponding to first bend configuration **303**. The flow restriction is deactivated when locking piston **402** is in the locked position with keys **410** received in long slots **377** of lower adjustment mandrel **370**, corresponding to second bend configuration **305**. The flow restriction may be registered or indicated by a pressure increase in the drilling fluid pumped into drillstring **21** by surface pump **23**, where the pressure increase results from the backpressure provided by the flow restriction. Thus, bend adjustment assembly **300** provides a surface indication of the assembly **300** shifting into the second configuration **305**.

Further, the second locking pin **440** retains locking piston **402** in the locked position with keys **410** received in long slots **378** such that relative rotation between lower adjustment mandrel **370** and lower housing **320** is restricted (keeping in mind relative rotation between locking piston **402** and lower housing **320** is restricted) and bend adjustment assembly **300** remains locked in the second configuration **305**. Particularly, with locking piston **402** in the locked position and second locking pin **440** in the second lateral position, the slotted opening **444** is laterally offset from the second ledge **414** of locking piston **402**. Instead, the second ledge **414** contacts or abuts a side of the second locking pin **440**, preventing locking piston **402** from travelling downwards through lower housing **320** away from the locked position. Thus, in this exemplary embodiment, second locking pin **440** automatically relocks the locking assembly **400** into the locked configuration following the actuation of bend adjustment assembly **300** into the second configuration **305** such that assembly **300** cannot depart the second configuration **305** irrespective of changes in drilling fluid flowrate and/or rotation of mud motor **35** by rotary system **24**.

In an alternative embodiment, the procedures for shifting bend adjustment assembly **300** between the first configuration **303** and the second configuration **305** may be reversed by reconfiguring lower adjustment mandrel **370** of bend adjustment assembly **300**. Particularly, in this alternative embodiment, the position of arcuate recess **379** is shifted 180° about the circumference of lower adjustment mandrel **370**. By shifting the angular position of arcuate recess **379** 180° about the circumference of lower adjustment mandrel **370**, the alternative embodiment of bend adjustment assembly **300** may be shifted from the first configuration **303** to the second configuration **305** by applying WOB to the mud motor **35** and activating rotary system **24** to rotate drillstring **21** to apply reactive torque to bearing housing **210** and rotate lower housing **320** relative to adjustment mandrel **370** in the second rotational direction, thereby shifting the alternative embodiment of bend adjustment assembly **300** into the second configuration **305**.

In an alternative embodiment, rather than having second locking pin **440** automatically relock the locking assembly **400** into the locked configuration following the actuation of bend adjustment assembly **300** into the second configuration **305**, a different configuration of locking pin may be used, as shown for example in FIG. **26**, that is not acted on by a biasing member and does not engage second ledge **414** at any point during operation. This allows for unlimited shifting between first configuration **303** and second configuration **305** upon reaching the predefined depth in wellbore **16** and causing rupture disk **426** to burst.

The bend adjustment assembly **300** described above comprises a single-shift bend adjustment assembly **300** which shifts automatically upon reaching the predefined depth in wellbore **16** from the first configuration **303** to the second configuration **305**. Prior to reaching the predefined depth the bend adjustment assembly **300** cannot be shifted from the first configuration **303** into a different configuration providing a different deflection angle θ by, for example, using a shear pin to hold the lower adjustment mandrel **370** in an axial position that keeps castellations **376** engaged with the castellations **333** of lower housing **320**. Additionally, after shifting into the second configuration **305** once the predefined depth has been reached, the bend adjustment assembly **300** cannot be shifted from the second configuration **305** into another configuration providing a different deflection angle θ.

In some applications, it may be desirable to shift a downhole-adjustable bend assembly an indefinite number of times between separate configurations providing separate deflection angles without needing to retrieve the bend adjustment assembly from the wellbore. Referring now to FIGS. **22-28**, another embodiment of a multi-shift bend adjustment assembly **500** is shown which may be locked in a first configuration **503** (shown in FIGS. **22-26**) providing a first deflection angle θ, then activated at a predefined depth to unlock and allow shifting between a first configuration **503** (shown in FIG. **28**) and a second configuration **505** (shown in FIG. **27**) an unlimited number of times without needing to retrieve the bend adjustment assembly **500** to the surface. In some embodiments, mud motor **35** may comprise bend adjustment assembly **500** in lieu of bend adjustment assembly **300**; however, in other embodiments, bend adjustment assembly **500** may comprise a component of mud motors which vary in configuration from mud motor **35**.

Bend adjustment assembly **500** includes features in common with mud motor **300**, and shared features are labeled similarly. Particularly, bend adjustment assembly **500** is similar to assembly **300** except that assembly **500** includes a lower adjustment mandrel **510** instead of lower adjustment mandrel **370** and a locking assembly **550** which includes an alternative second locking pin **560** instead of the second locking pin **440** of the locking assembly **400** described above. Second locking pin **560** has a longitudinal first end **561**, a longitudinal second end **563** opposite first end **561**, an outer receptacle **562** extending longitudinally into second end **563**, and a slotted opening **564** located between ends **561**, **563**.

As shown particularly in FIGS. **24**, **25**, lower adjustment mandrel **510** of bend adjustment assembly **300** is generally tubular and has a first or upper end **511**, a second or lower end **513**, and a central bore or passage extending therebetween that is defined by a generally cylindrical inner surface. In this exemplary embodiment, lower adjustment mandrel **510** is splined to the upper adjustment mandrel **360** such that relative movement therebetween is restricted. Similar to the operation of lower adjustment mandrel **370** described above, when bend adjustment assembly **500** is disposed in the first configuration **503**, a first deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360**, and when bend adjustment assembly **500** is disposed in the second configuration **505**, a second deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360** that is different from the first deflection angle.

In this exemplary embodiment, lower adjustment mandrel **510** additionally includes a pair of circumferentially spaced first or short slots **512** and a pair of circumferentially spaced second or long slots **514**. Both the short slots **512** and long slots **514** of lower adjustment mandrel **510** extend axially into lower adjustment mandrel **370** from the lower end **513** thereof. In this exemplary embodiment, each short slot **512** is circumferentially spaced approximately 180° apart. Similarly, in this exemplary embodiment, each long slot **514** is circumferentially spaced approximately 180° apart. Additionally, each of the slots **512**, **514** of lower adjustment mandrel **510** are configured to rotationally lock the lower housing **320** through the locking piston **402** to the lower adjustment mandrel **510** when the keys **410** of locking piston **402** are received in slots **512**, **514**. The locking between locking piston **402** and lower adjustment mandrel **510** via slots **512**, **514** eliminates the need for castellations **376**. Thus, although lower adjustment mandrel **510** is shown in FIGS. **24**, **25** as including castellations, it may be understood that in this exemplary embodiment, neither lower housing **320** nor lower adjustment mandrel **510** need include castellations.

Additionally, unlike lower adjustment mandrel **370** described above, lower adjustment mandrel **510** of bend adjustment assembly **500** is axially locked to upper adjustment mandrel **360** such that axial movement is prevented therebetween at all times. In other words, mandrels **360**, **510** are not connected by a shear pin in this embodiment intended to break during the operation of bend adjustment assembly **500**. Instead, lower adjustment mandrel **510** remains in the same axial position relative upper adjustment mandrel **360** in both the first configuration **503** and second configuration **505** of bend adjustment assembly **500**.

In the first configuration **503** of bend adjustment assembly **500**, locking piston **402** is disposed in a locked position with keys **410** received in the long slots **514** of lower adjustment mandrel **510**, preventing relative rotation between lower housing **320** and lower adjustment mandrel **370** (rotation being restricted between locking piston **402** and lower housing **320**). Additionally, locking piston **402** is prevented by first locking pin **430** (due to engagement between pin **430** and second ledge **414**) from shifting from the locked position to an unlocked position (axially spaced from the locked position) in which keys **410** are released from long slots **514**. Thus, similar to bend adjustment assembly **300** described above, locking assembly **550** prevents bend adjustment assembly **500** from shifting from the first configuration **503** to the second configuration **505** until bend adjustment assembly **500** has reached the predefined depth at which rupture disk **426** is configured to burst.

Similar to the operation of locking assembly **400** described above, upon reaching the predefined depth and bursting rupture disk **426** (which can be accomplished automatically by reaching a given depth at a given mud weight or by increasing mud weight at the given depth such that the mud weight reaches a predefined mud weight threshold to thereby increase the hydrostatic pressure beyond the burst disk threshold), the locking sleeve **420** of locking assembly **550** shifts from the locked position to the unlocked position, releasing finger **422** of locking sleeve **420** from the outer receptacle **432** of first locking pin **430**. First locking pin **430** is thus permitted to shift into the second lateral position via the biasing force applied by first biasing member **436**, thereby aligning slotted opening **434** of first locking pin **430** with the second ledge **414** of locking piston **402**.

In this configuration, the flowrate of drilling fluid through bend adjustment assembly **500** may be reduced and/or ceased to allow locking piston **402** to travel downwards into the unlocked position releasing keys **410** from long slots **514** of lower adjustment mandrel **510**. With locking piston **402** in the unlocked position, drilling fluid may be flowed through the bend adjustment assembly **500** at the reduced flowrate to activate actuator assembly **450** and thereby rotate lower housing **320** in the first rotational direction relative to lower adjustment mandrel **510** until bend adjustment assembly **500** is shifted into the second configuration **505**, as shown particularly in FIG. **24**. Drilling fluid may then be flowed through bend adjustment assembly **500** at a rate above the reduced flowrate (e.g., at the maximum drilling flowrate) to shift locking piston **402** upwards into a locked position with keys **410** received in the short slots **512** of lower adjustment mandrel **510**.

Unlike bend adjustment assembly **300** described above, second locking pin **560** does not lock bend adjustment assembly **500** into the second configuration **505**. Instead, bend adjustment assembly **500** is permitted to actuate back-and-forth between the second configuration **505** and first configuration **503** by reducing and/or ceasing the flow of drilling fluid through bend adjustment assembly **500** to shift locking piston **402** into the unlocked position, and rotating lower housing **320** relative lower adjustment mandrel **510** via the actuator assembly **450**. As an example, once in the second configuration **505**, bend adjustment assembly **500** may be returned to the first configuration **503** with or without applying WOB to the mud motor **35** and activating rotary system **24** to rotate drillstring **21** to apply reactive torque to bearing housing **210** and rotate lower housing **320** relative to adjustment mandrel **510** in a second rotational direction, thereby shifting bend adjustment assembly **500** from the second configuration **505** to the first configuration **503**.

Referring now to FIGS. **29-32**, another embodiment of a bend adjustment assembly **600** is shown. Bend adjustment assembly **600** includes features in common with the bend adjustment assemblies **300**, **500** described above, and shared features are labeled similarly. Particularly, bend adjustment assembly **600** comprises a single-shift bend adjustment assembly similar to bend adjustment assembly **300** except that, unlike bend adjustment assembly **300**, bend adjustment assembly **600** comprises the lower adjustment mandrel **510** of bend adjustment assembly **500**, which is axially locked to upper adjustment mandrel **360** such that axial movement is prevented therebetween at all times. As with bend adjustment assembly **500**, the locking between locking piston **402** and lower adjustment mandrel **510** via slots **512**, **514** eliminates the need for castellations **376**.

In this exemplary embodiment, bend adjustment assembly **600** is in the second configuration **505** when locking assembly **500** is in the locked configuration and may only shift from the second configuration **505** to the first configuration once locking assembly **500** has automatically shifted into the unlocked configuration upon mud motor **35**/bend adjustment assembly **600** reaching the predefined depth in the wellbore **16**. Thus, while both bend adjustment assembly **300** and bend adjustment assembly **600** each comprise single-shift bend adjustment assemblies shiftable between configurations **303**, **305**, bend adjustment assembly **300** shifts from the first configuration **303** to the second configuration **305** after reaching the predefined depth in wellbore **16** while bend adjustment assembly **600** shifts from the second configuration **505** to the first configuration **503** after reaching the predefined depth. In this exemplary embodiment, bend adjustment assembly **600** may shift from a high bend setting to a low bend setting after reaching the predefined depth.

Referring now to FIG. **33**, an embodiment of a method **650** for forming a deviated wellbore using a downhole mud motor is shown. Initially, at block **652** method **650** includes positioning a bend adjustment assembly of the downhole mud motor in the wellbore in a first configuration that provides a first deflection angle between a longitudinal axis of a driveshaft housing of the downhole mud motor and a longitudinal axis of a bearing mandrel of the downhole mud motor. In some embodiments, block **652** comprises positioning one of the bend adjustment assemblies **300**, **500**, and **600** of a downhole mud motor (e.g., mud motor **35**) in wellbore **16** in a first configuration (e.g., one of configurations **303**, **503**, and **505**) that provides a first deflection angle between the longitudinal axis **115** of driveshaft housing **110** and longitudinal axis **225** of bearing mandrel **220**.

At block **654**, method **650** comprises locking the bend adjustment assembly into the first configuration with a locking assembly of the bend adjustment assembly that is disposed in a locked configuration. In some embodiments, block **654** comprises locking one of the bend adjustment assemblies **300**, **500**, and **600** into the first configuration with one of the locking assemblies **400**, **550**. At block **656**, method **650** comprises automatically shifting the locking assembly from the locked configuration to an unlocked configuration upon the mud motor reaching a predefined depth (which can be accomplished automatically by reaching a given depth at a given mud weight or by increasing mud weight at the given depth such that the mud weight reaches a predefined mud weight threshold to thereby increase the hydrostatic pressure beyond the burst disk threshold), in the wellbore. In some embodiments, block **656** comprises automatically shifting the locking assembly **400**, **550** from the locked configuration to an unlocked configuration upon reaching the predefined depth in the wellbore **16**.

At block **658**, method **650** comprises shifting the bend adjustment assembly, with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, from the first configuration to a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel, the second deflection angle being different from the first deflection angle. In some embodiments, block **658** comprises shifting the bend adjustment assembly **300**, **500**, **600**, with the downhole mud motor positioned in the wellbore **16** and the locking assembly **400**, **550** in the unlocked configuration, from the first configuration to the second configuration **305**, **505**, and **503**, respectively.

Referring now to FIG. **34**, another embodiment of a downhole mud motor **700** is shown. Downhole mud motor **700** may replace the mud motor **40** described above in the BHA **30** shown in FIG. **1**. Additionally, mud motor **700** includes features in common with mud motor **40**, where shared features are labeled similarly. Mud motor **700** includes driveshaft assembly **100**, bearing assembly **200**, and a bend adjustment assembly **705**. Similar to bend adjustment assembly **300** described above, bend adjustment assembly **705** is configured to shift from a first configuration **707** (shown in FIGS. **36** and **37** as further described below) providing a first deflection angle θ_1 to a second configuration **709** (shown in FIG. **38** as further described below) providing a second deflection angle θ_2 upon achieving a predefined depth in a wellbore (e.g. wellbore **16** shown in FIG. **1**). In addition, after shifting from the first configuration **707** to the second configuration **709** upon achieving the predefined depth, bend adjustment assembly **705** is configured to shift from the second configuration **709** to a third configuration **711** (shown in FIG. **39** as further described below) providing a third deflection angle θ_1 that is different from the first deflection angle θ_1 and/or the second deflection angle θ_2.

Structurally, bend adjustment assembly **705** is similar in configuration to the bend adjustment assembly **300** described above except that bend adjustment assembly **705** includes a lower adjustment mandrel **710** in lieu of the lower adjustment mandrel **370** shown in FIG. **10**. Referring to FIG. **35**, lower adjustment mandrel **710** of bend adjustment assembly **705** is generally tubular and has a first or upper end **710**A, a second or lower end **710**B opposite upper end **710**A, and a central bore or passage extending therebetween that is defined by a generally cylindrical inner surface. In this exemplary embodiment, lower adjustment mandrel **710** includes a generally cylindrical outer surface comprising an offset engagement surface **712**, an annular seal **713**, and an arcuately extending recess **714**. Offset engagement surface **712** has a central or longitudinal axis that is offset or disposed at a non-zero angle relative to a central or longitudinal axis of the upper end **360**A of upper adjustment mandrel **360** and the lower end **320**B of lower housing **320**, where offset engagement surface **712** is disposed directly adjacent or overlaps the offset engagement surface **323** of lower housing **320**. Additionally, lower adjustment mandrel **710** includes a pair of circumferentially spaced stop shoulders **715**A and **715**B.

In this exemplary embodiment, when bend adjustment assembly **705** is disposed in the first configuration **707**, a first deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360**. When bend adjustment assembly **705** is in the first configuration **707** the bend adjustment assembly **705** cannot change its angular position and, unlike bend adjustment assembly **300** described above, all of the reactive torque loads (e.g., reactive torque applied to the drill bit **90** by the sidewall **19** of wellbore **16**) are passed through castellations **717** and **333**. Additionally, in this exemplary embodiment, the initial angular position of bend adjustment assembly **705** comprises a value in-between a maximum bend setting and a minimum bend setting of the bend adjustment assembly **705** without either of the large stop shoulders **715**A and **715**B being in contact with the **328**S shoulders of lower housing **320**.

When bend adjustment assembly **300** is disposed in the second configuration **709**, a second deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360** that is different from the first deflection angle (shoulder **328**S of lower housing **320** being in contact with shoulder **715**A of lower adjustment mandrel **710** when in the second configuration **709**), and when bend adjustment assembly **300** is disposed in the third configuration **711**, a third deflection angle is provided between the central axis of lower housing **320** and the central axis of upper adjustment mandrel **360** that is different from both the first deflection angle and the second deflection angle (shoulder **328**S of lower housing **320** being in contact with shoulder **715**B of lower adjustment mandrel **710** when in the third configuration **709**).

Annular seal **713** of lower adjustment mandrel **710** is disposed in the outer surface of lower adjustment mandrel **710** to sealingly engage the inner surface of lower housing **320**. Arcuate recess **714** of lower adjustment mandrel **710** is defined by an inner terminal end or arcuate shoulder **714**E and the pair of circumferentially spaced axially extending shoulders **715**A and **715**B. Lower adjustment mandrel **710** also includes a pair of circumferentially spaced first or short slots **716** and a pair of circumferentially spaced second or long slots **718**, where both short slots **716** and long slots **718** extend axially into lower adjustment mandrel **710** from lower end **710**B. In this embodiment, each short slot **716** is circumferentially spaced approximately 180° apart. Similarly, in this embodiment, each long slot **718** is circumferentially spaced approximately 180° apart; however, in other embodiments, the circumferential spacing of short slots **716** and long slots **718** may vary.

In this embodiment, the lower end **710**B of lower adjustment mandrel **710** further includes a plurality of circumferentially spaced protrusions or castellations **717** configured to matingly or interlockingly engage the castellations **333** formed at the upper end **320**A of lower housing **320**. Castellations **717** are spaced substantially about the circumference of lower adjustment mandrel **710**, and may be formed on the portion of the circumference of lower adjustment mandrel **710** comprising recess **714** as well as the portion of the circumference of lower adjustment mandrel **710** which is arcuately spaced from recess **714**. Castellations **717** may be circumferentially spaced uniformly about a circumference of lower adjustment mandrel **710**; alternatively, castellations **717** may only be positioned along a portion of the circumference of lower adjustment mandrel **710**.

In some embodiments, lower adjustment mandrel **710** comprises a first or lower axial position (shown in FIGS. **36** and **37**) relative lower housing **320** and upper adjustment mandrel **360**, and a second or upper axial position relative lower housing **320** and upper adjustment mandrel **360** which is axially spaced from the lower axial position. When lower adjustment mandrel **710** is in the lower axial position, castellations **717** of lower adjustment mandrel **710** may interlock with castellations **333** of lower housing **320**, restricting relative rotation therebetween. In this configuration, bend adjustment assembly **705** may be operated by an operator of well system **10** as a bend assembly that provides a fixed bend and thus may operate drillstring **21** and BHA **30** as desired without inadvertently actuating bend assembly **300** between configurations **705**, **707**, and **709**. For example, with lower adjustment mandrel **710** disposed in the lower axial position, rotation of drillstring **21** and/or the flow of drilling fluid at a drilling flowrate through bend adjustment assembly **705** will not unlock or otherwise actuate bend adjustment assembly **705** from the first configuration **707** to either the second configuration **709** or third configuration **711** given the interlocking engagement between castellations **333** of lower housing **320** with castellations **717** of lower adjustment mandrel **710**. However, when lower adjustment mandrel **710** is in the upper axial position (this movement of lower adjustment mandrel **710** occurs after achieving the predefined depth), castellations **717** of lower adjustment mandrel **710** are axially spaced and disengaged from castellations **333** of lower housing **320**, permitting relative rotation therebetween. As will be described further herein, in some embodiments, lower adjustment mandrel **710** is initially retained in the lower axial position via a shear pin or member **719** and lower adjustment mandrel **710** is actuatable while downhole or in-situ from the lower axial position to the upper axial position.

Referring now to FIGS. **34-39**, initially, it may be understood that upper housing **310** is shown as transparent in FIGS. **35-39** for the purpose of clarity. Similar to bend adjustment assembly **300** described above, the bend adjustment assembly **705** of mud motor **700** is configured to shift from the first configuration **707** (shown in FIGS. **36** and **37**) to the second configuration **709** (shown in FIG. **38**) automatically upon reaching the predefined depth in wellbore **16**. Particularly, mud motor **700** may be operated to drill wellbore **16** with bend adjustment assembly **705** locked into the first configuration **707** until mud motor **700** reaches the predefined depth at which point locking assembly **400** is configured to automatically unlock bend adjustment assembly **705** such that bend adjustment assembly **705** may be actuated automatically from the first configuration **707** to the second configuration **709**.

It may be understood that in the first configuration **707** the extension **328** of lower housing **320** is oriented angularly relative to lower adjustment mandrel **710** whereby both shoulders **328**S of extension **328** are circumferentially spaced from the corresponding shoulders **715**A and **715**B of mandrel **710**. Additionally, in the first configuration **707** relative rotation between lower housing **320** and lower adjustment mandrel **710** is restricted via interlocking engagement between castellations **333** of lower housing **320** and castellations **717** of lower adjustment mandrel **710** prior to mud motor **700** achieving the predefined depth. Once bend adjustment assembly **705** is unlocked from the first configuration **707** via the bursting of rupture disk **426** of locking assembly **400** as described in further detail above in relation to bend adjustment assembly **700** may be cycled or toggled indefinitely between the second configuration **709** and third configuration **711** (shown in FIGS. **38** and **39**) an unlimited number of times without needing to retrieve the mud motor **700** from the wellbore **16**.

In this exemplary embodiment, bend adjustment assembly **705** may be shifted from the second configuration **709** to the third configuration **711** by ceasing the pumping of drilling fluid from surface pump **23** for a first time period to shift the locking piston **380** of bend adjustment assembly **705** into the unlocked position. Either concurrent with the first time period or following the initiation of the first time period, rotary system **24** may be activated to rotate drillstring **21** at an actuation rotational speed (surface pump **23** is also activated to flow at a first actuation flowrate) for a second time period to apply reactive torque from the sidewall **19** of wellbore **16** to the bearing housing **210** of bearing assembly and thereby rotate lower offset housing **320** relative to the lower adjustment mandrel **710** in a first rotational direction, which thereby shifts bend adjustment assembly **705** into the third configuration **711**. With bend adjustment assembly **705** in the third configuration **711**, surface pump **23** may be operated either at a second actuation flowrate for a third time period or operated immediately at a maximum drilling flowrate of the well system comprising mud motor **700** to thereby shift locking piston **380** into the locked position, locking bend adjustment assembly **705** into the third configuration **711**. This exemplary embodiment allows for all three of the deflection angles θ_1-θ_3 to be non-zero in magnitude. For example, in some embodiments, the first deflection angle corresponding to the first configuration **707** of bend adjustment assembly **705** is approximately 1.5 degrees, the second deflection angle corresponding to the second configuration **709** of bend adjustment assembly **705** is approximately 2.12 degree, and the third deflection angle corresponding to the third configuration **711** of bend adjustment assembly **705** is approximately 1.15 degrees.

In this exemplary embodiment, bend adjustment assembly **705** may be shifted from the third configuration **711** to the second configuration **709** by ceasing the rotation of drillstring **21** by rotary system **24** while also ceasing the pumping of drilling fluid from surface pump **23** at a second flowrate to thereby shift locking piston **380** of the bend adjustment assembly **705** into the unlocked position. With locking piston **380** disposed in the unlocked position, surface pump **23** may resume pumping drilling fluid into drill string **21** while rotary system **24** remains inactive, thereby rotating lower adjustment mandrel **710** in a second rotational direction, opposite the first rotational direction, to shift bend adjustment assembly **705** into the second configuration **709**. With bend adjustment assembly **705** now disposed in second configuration **709**, the flowrate of drilling fluid from surface pump **23** is increased from the second flowrate to a third flowrate to shift locking piston **380** into the locked position, thus locking bend adjustment assembly **705** in the second configuration **709**. Additionally, a pressure signal provided by flow restrictor **123** may provide a surface indication of the actuation of bend adjustment assembly **705** switching from the third configuration **711** to the second configuration **709**.

In an alternative embodiment, bend adjustment assembly **705** may not include actuator assembly **400**. In this alternative embodiment, first deflection angle θ_1 is equal or substantially equal to the second deflection angle θ_2. For example, in this alternative embodiment, the first deflection angle θ_1 is approximately 2.1 degrees, the second deflection angle θ_2 is approximately 2.15 degrees, and the third deflection angle θ_3 is approximately 1.5 degrees. For applications that only require unlocking and two distinct deflection angles and no need to return to the first or second deflection angle the actuator assembly **400** in this alternative embodiment may be eliminated.

Referring to FIG. **40**, an embodiment of a method **750** for adjusting a deflection angle of a downhole mud motor disposed in a borehole is shown. It may be understood that in at least some embodiments method **750** may be performed using the mud motor **700** shown in FIG. **34**. Method **750** includes features in common with the method **600** shown in FIG. **33**. Particularly, in addition to previously described blocks **652-658**, method **750** includes block **752** where a flowrate of drilling fluid is increased through the bend adjustment assembly to lock the bend adjustment assembly in the second configuration. Block **752** may be performed when the BHA comprising the mud motor is "off-bottom" where WOB is not applied to the BHA. Alternatively, block **752** may be performed when the BHA comprising the mud motor is "on-bottom" with WOB being actively applied to the BHA.

At block **756**, method **750** includes reducing the flowrate of the drilling fluid to shift the bend adjustment assembly from the second configuration to a third configuration providing a third deflection angle that is different from the first deflection angle and/or the second deflection angle. In some embodiments, the first deflection angle is approximately 1.5 degrees, the second deflection angle is approximately 2.12 degree, and the third deflection angle is approximately 1.15 degrees. In other embodiments, the first deflection angle is approximately 2.1 degrees, the second deflection angle is approximately 2.15 degree, and the third deflection angle is approximately 1.5 degrees. However, it may be understood the magnitude of each deflection angle may vary in other embodiments. At block **758**, method **750** includes increasing the flowrate of drilling fluid to lock the bend adjustment assembly in the third configuration. In some embodiments, the first configuration corresponds to the first configuration **707** (shown in FIGS. **36** and **37**) of bend adjustment assembly **705** shown in FIG. **34**, the second configuration corresponds to the second configuration **709** of bend adjustment assembly **705**, and the third configuration corresponds to the third configuration **711** of bend adjustment assembly **705**.

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

What is claimed is:

1. A downhole mud motor positionable in a wellbore, comprising:

a driveshaft housing;

a driveshaft rotatably disposed in the driveshaft housing;

a bearing mandrel coupled to the driveshaft;

wherein the bend adjustment assembly includes a first configuration that provides a first deflection angle between a longitudinal axis of the driveshaft housing and a longitudinal axis of the bearing mandrel;

wherein the bend adjustment assembly includes a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from the first deflection angle, and wherein the bend adjustment assembly is configured to shift between the first configuration and the second configuration when positioned in the wellbore; and

a locking assembly comprising a locked configuration configured to lock the bend adjustment assembly into one of the first configuration and the second configuration until the downhole mud motor has at least one of reached a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth, in response to which the locking assembly is configured to actuate from the locked configuration to an unlocked configuration.

2. The downhole mud motor of claim **1**, wherein the second deflection angle is larger than the first deflection angle.

3. The downhole mud motor of claim **1**, wherein the second deflection angle is less than the first deflection angle.

4. The downhole mud motor of claim **1**, wherein the actuator assembly is configured to shift the bend adjustment assembly between the first configuration and the second configuration in response to a change in at least one of flowrate of a drilling fluid supplied to the downhole mud motor, pressure of the drilling fluid supplied to the downhole mud motor, and relative rotation between the driveshaft housing and the bearing mandrel.

5. The downhole mud motor of claim **1**, wherein the bend adjustment assembly includes a third configuration providing a third deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from at least one of the first deflection angle and the second deflection angle.

6. The downhole mud motor of claim **1**, wherein the locking assembly comprises a rupture disk configured to burst at a predefined pressure.

7. The downhole mud motor of claim **6**, wherein the locking assembly comprises a locking sleeve including a locked position and an unlocked position longitudinally spaced from the locked position, and wherein the locking sleeve is configured to shift from the locked position to the unlocked position in response to bursting of the rupture disk.

8. The downhole mud motor of claim **7**, wherein:

the bend adjustment assembly comprises an offset housing and an adjustment mandrel having a first relative angular orientation associated with the first configuration and a second relative angular orientation associated with the second configuration.

9. The downhole mud motor of claim **8**, wherein the offset housing and adjustment mandrel have a third relative angular orientation associated with a third configuration.

10. The downhole mud motor of claim **8**, wherein the locking assembly comprises a locking piston configured to lock the offset housing and the adjustment mandrel in the first relative angular orientation when in a first position.

11. The downhole mud motor of claim **10**, wherein the locking assembly comprises a first locking pin configured to lock the locking piston in the first position.

12. The downhole mud motor of claim **10**, wherein the locking assembly comprises a second locking pin configured to lock the locking piston in a second position configured to lock the offset housing and the adjustment mandrel in the second relative angular orientation.

13. The downhole mud motor of claim **8**, wherein the adjustment mandrel and offset housing comprise interlocking castellations configured to lock the offset housing and adjustment mandrel in the first relative angular orientation.

14. The downhole mud motor of claim **13**, wherein:

the adjustment mandrel has a first axial position wherein the interlocking castellations between the adjustment mandrel and offset housing are matingly engaged, and a second axial position wherein the interlocking castellations between the adjustment mandrel and offset housing are disengaged, and

the adjustment mandrel shifts from the first axial position to the second axial position in response to the locking sleeve shifting from the locked to the unlocked position.

15. The downhole mud motor of claim **14**, wherein:

the adjustment mandrel is held in the first axial position by a shear pin;

the locking assembly comprises a first locking pin configured to hold the locking piston axially separated from the adjustment mandrel when the locking sleeve is in the locked position;

the locking pin is configured to release the locking piston into contact with the adjustment mandrel when the locking sleeve is in the unlocked position; and

the locking piston is configured to apply force to the adjustment mandrel to fracture the shear pin and permit the adjustment mandrel to shift from the first axial position to the second axial position.

16. The downhole mud motor of claim **15**, wherein the bend adjustment assembly can shift between the first relative angular orientation and second relative angular orientation when the adjustment mandrel has shifted into the second axial position.

17. The downhole mud motor of claim **16**, wherein the locking assembly comprises a second locking pin configured to lock the locking piston in a second position configured to lock the offset housing and the adjustment mandrel in the second relative angular orientation.

18. The downhole mud motor of claim **16**, wherein the offset housing and the adjustment mandrel can shift between the first relative angular orientation and the second relative angular orientation up to an unlimited number of times.

19. The downhole mud motor of claim **16**, wherein the offset housing and the adjustment mandrel can shift between the second relative angular orientation and a third relative angular orientation up to an unlimited number of times.

20. A downhole mud motor positionable in a wellbore, comprising:

a driveshaft housing;

a driveshaft rotatably disposed in the driveshaft housing;

a bearing mandrel coupled to the driveshaft;

wherein the bend adjustment assembly includes a first configuration that provides a first deflection angle between a longitudinal axis of the driveshaft housing and a longitudinal axis of the bearing mandrel;

wherein the bend adjustment assembly includes a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from the first deflection angle;

an actuator assembly configured to shift the bend adjustment assembly between the first configuration and the second configuration when the mud motor is disposed in the wellbore; and

a locking assembly configured to prevent the actuator assembly from shifting the bend adjustment assembly between the first configuration and the second configuration until the mud motor has at least one of reached a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth.

21. The downhole mud motor of claim **20**, wherein the locking assembly comprises a rupture disk configured to burst at a predefined pressure.

22. The downhole mud motor of claim **21**, wherein the locking assembly comprises a locking sleeve including a locked position and an unlocked position longitudinally spaced from the locked position, and wherein the locking sleeve is configured to shift from the locked position to the unlocked position in response to bursting of the rupture disk.

23. The downhole mud motor of claim **22**, wherein:

the bend adjustment assembly comprises an offset housing and an adjustment mandrel having a first relative angular orientation associated with the first configuration and a second relative angular orientation associated with the second configuration; and

the locking assembly comprises a locking piston configured to lock the offset housing and the adjustment mandrel in the first relative angular orientation when in a first position.

24. The downhole mud motor of claim **23**, wherein the locking assembly comprises a first locking pin configured to lock the locking piston in the first position.

25. The downhole mud motor of claim **23**, wherein the locking assembly comprises a second locking pin configured to lock the locking piston in a second position configured to lock the offset housing and the adjustment mandrel in the second relative angular orientation.

26. The downhole mud motor of claim **20**, wherein the actuator assembly is configured to shift the bend adjustment assembly between the first configuration and the second configuration in response to a change in at least one of flowrate of a drilling fluid supplied to the downhole mud motor, pressure of the drilling fluid supplied to the downhole mud motor, and relative rotation between the driveshaft housing and the bearing mandrel.

27. The downhole mud motor of claim **20**, wherein the bend adjustment assembly includes a third configuration providing a third deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel that is different from at least one of the first deflection angle and the second deflection angle.

28. A method for forming a deviated wellbore using a downhole mud motor, comprising:

(a) positioning a bend adjustment assembly of the downhole mud motor in the wellbore in a first configuration that provides a first deflection angle between a longitudinal axis of a driveshaft housing of the downhole mud motor and a longitudinal axis of a bearing mandrel of the downhole mud motor;

(b) locking the bend adjustment assembly into the first configuration with a locking assembly of the bend adjustment assembly that is disposed in a locked configuration;

(c) automatically shifting the locking assembly from the locked configuration to an unlocked configuration upon at least one of the mud motor reaching a predefined depth in the wellbore, and a mud weight has reached a predefined mud weight threshold at a given depth; and

(d) with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, shifting the bend adjustment assembly from the first configuration to a second configuration that provides a second deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel, the second deflection angle being different from the first deflection angle.

29. The method of claim **28**, wherein (c) comprises:

(c1) bursting a rupture disk of the locking assembly; and

(c2) longitudinally shifting a locking sleeve of the locking assembly from a locked position to an unlocked position.

30. The method of claim **29**, wherein (c) comprises:

(c3) laterally shifting a locking pin from a first lateral position to a second lateral position in response to longitudinally shifting the locking sleeve to the unlocked position.

31. The method of claim **29**, wherein (c) comprises:

(c4) shifting a locking piston of the locking assembly from a locked position to an unlocked position in response to laterally shifting the locking pin to the unlocked position.

32. The method of claim **28**, wherein (d) comprises:

(d1) pumping drilling fluid into the wellbore from the surface pump at a reduced flowrate that is less than the drilling flowrate for a first time period; and

(d2) following the first time period, pumping drilling fluid in the wellbore from the surface pump at an increased flowrate that is different than the reduced flowrate for a second time period.

33. The method of claim **28**, further comprising:

(e) with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, shifting the bend adjustment assembly from the second configuration to the first configuration.

34. The method of claim **28**, further comprising:

(e) with the downhole mud motor positioned in the wellbore and the locking assembly in the unlocked configuration, shifting the bend adjustment assembly from the second configuration to a third configuration that provides a third deflection angle between the longitudinal axis of the driveshaft housing and the longitudinal axis of the bearing mandrel, the third deflection angle being different from at least one of the first deflection angle and the second deflection angle.

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