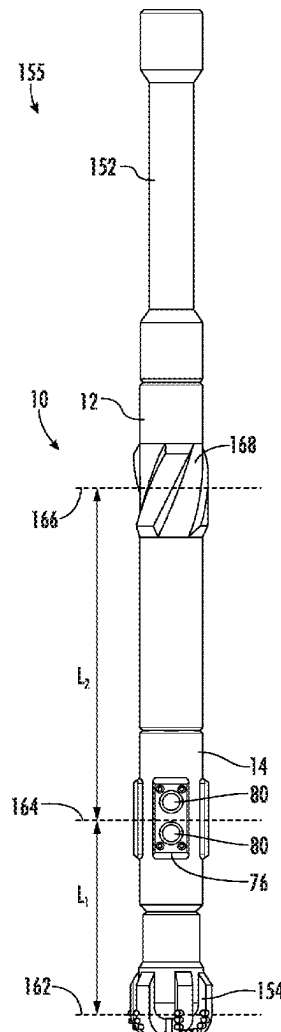


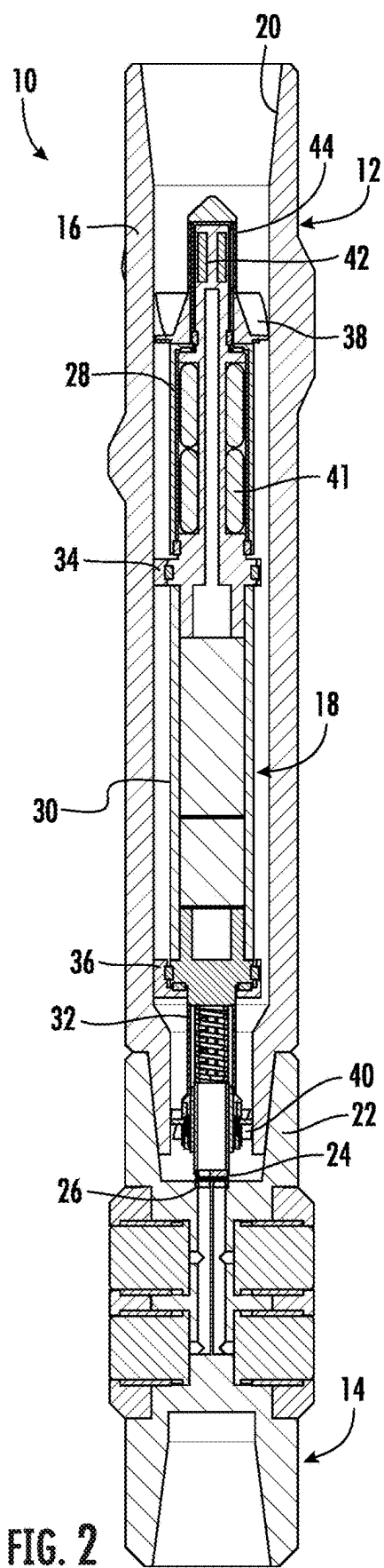


US 20250263981A1

(19) **United States**(12) **Patent Application Publication**  
**Bedouet**(10) **Pub. No.: US 2025/0263981 A1**(43) **Pub. Date: Aug. 21, 2025**(54) **SELF-CONTAINED COMPACT ROTARY  
STEERABLE SYSTEM**(52) **U.S. Cl.**CPC ..... *E21B 7/04* (2013.01); *E21B 17/1078*  
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(US)(21) Appl. No.: **19/204,058**(22) Filed: **May 9, 2025****Related U.S. Application Data**(63) Continuation of application No. 18/463,795, filed on  
Sep. 8, 2023.**Publication Classification**(51) **Int. Cl.***E21B 7/04* (2006.01)  
*E21B 17/10* (2006.01)(57) **ABSTRACT**

A self-sufficient rotary steerable system configured to provide a bottom hole assembly with a build-up rate of at least 25 degrees per 100 feet of drilling distance. The rotary steerable system has a reduced length without the removal or omission of functional components, including a power module, a control module, a communication module, a filter module, a valve module, and/or a pressure regulation module. The build-up rate is defined as a function of a length between a first contact point on a drill bit of the bottom hole assembly and a second contact point at a piston assembly of the rotary steerable system; length between the second contact point and a third contact point at a stabilizer of the rotary steerable system; the drill bit outer diameter; the piston assembly outer diameter; and the stabilizer outer diameter.





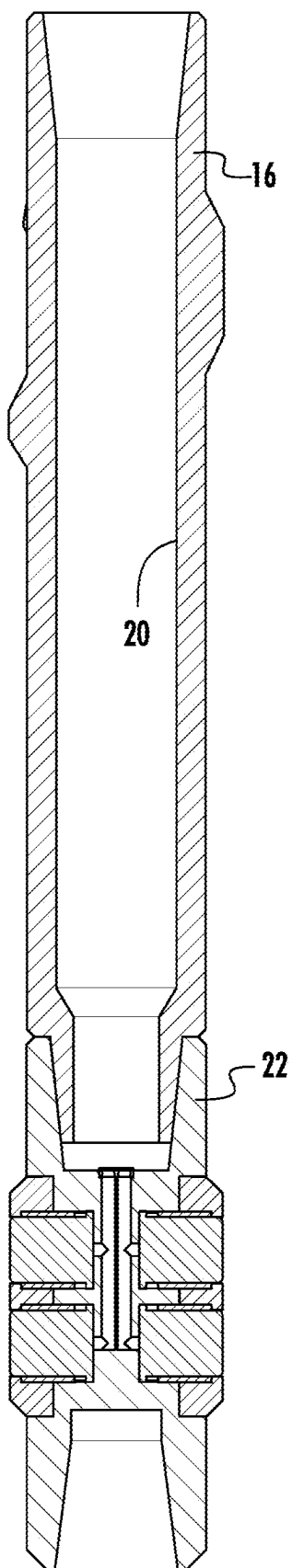


FIG. 3

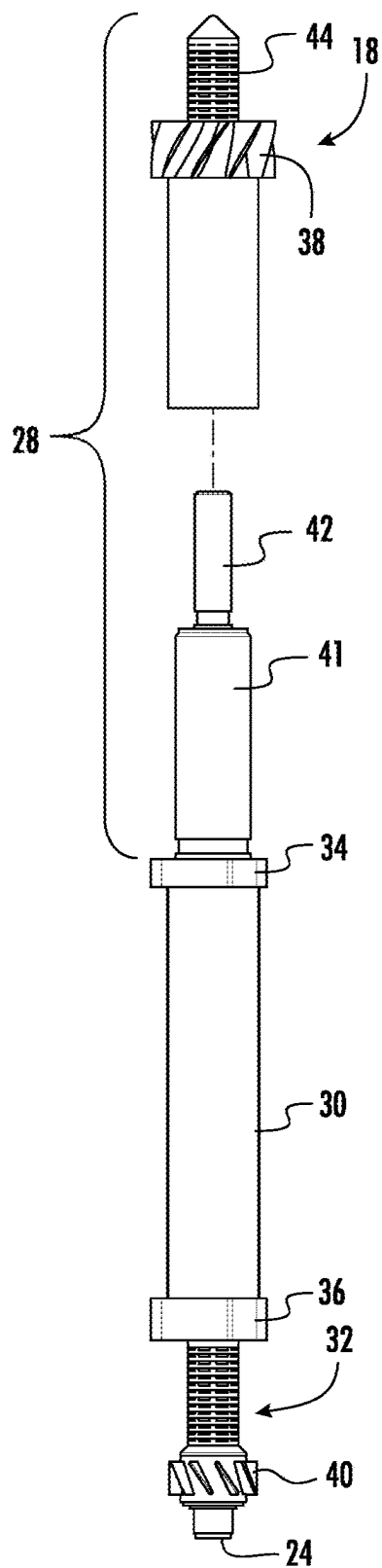


FIG. 4

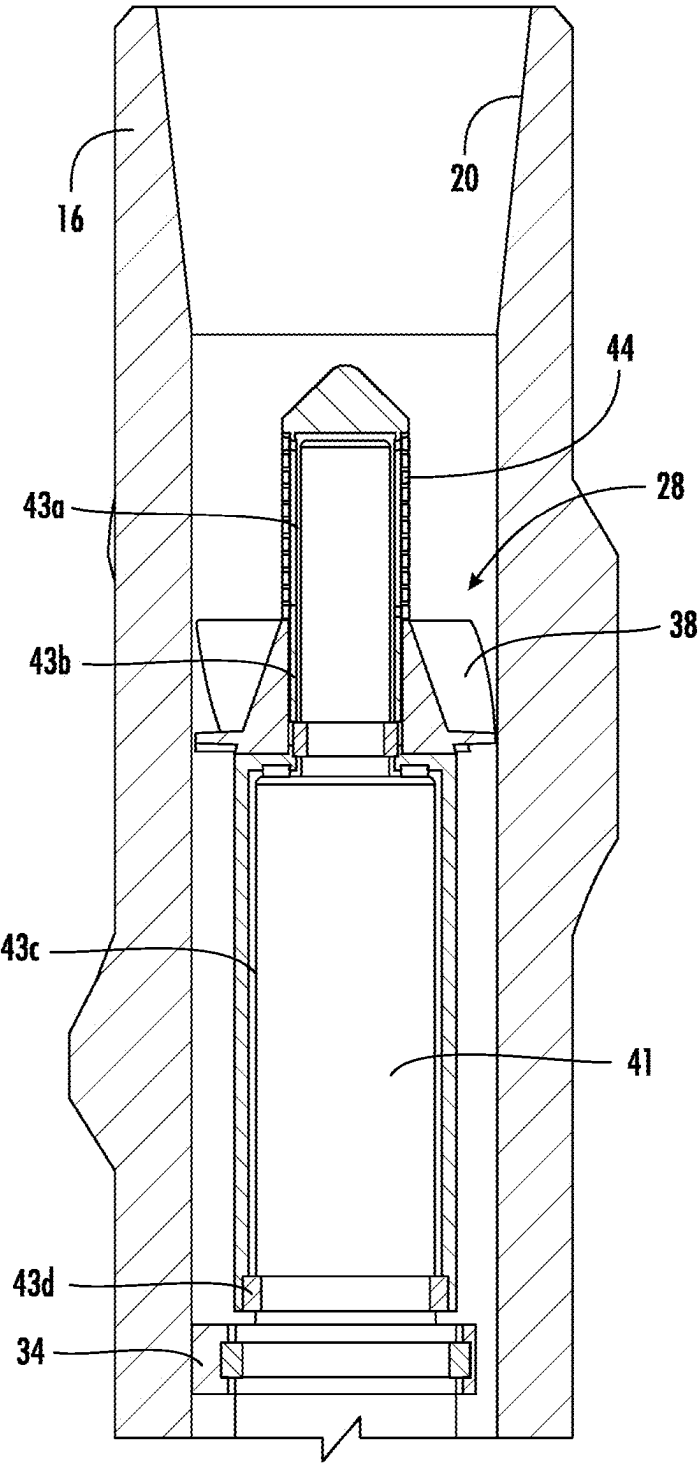


FIG. 5

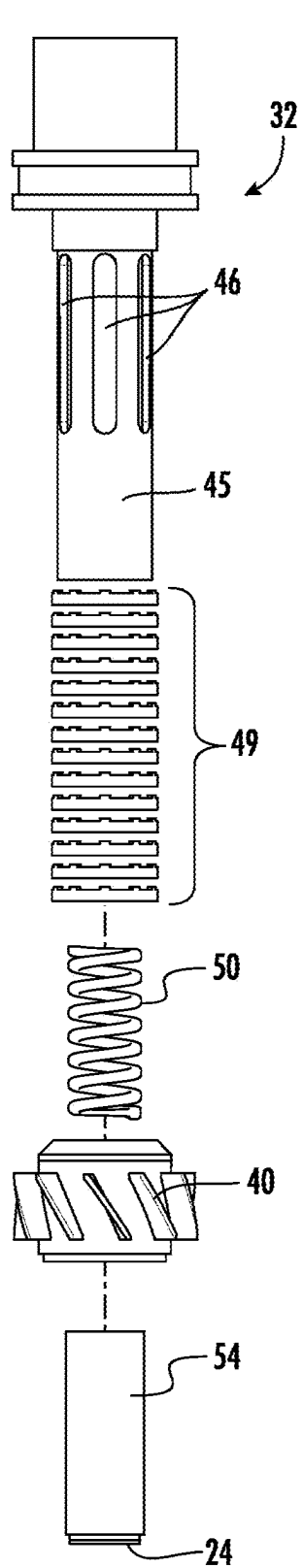


FIG. 6

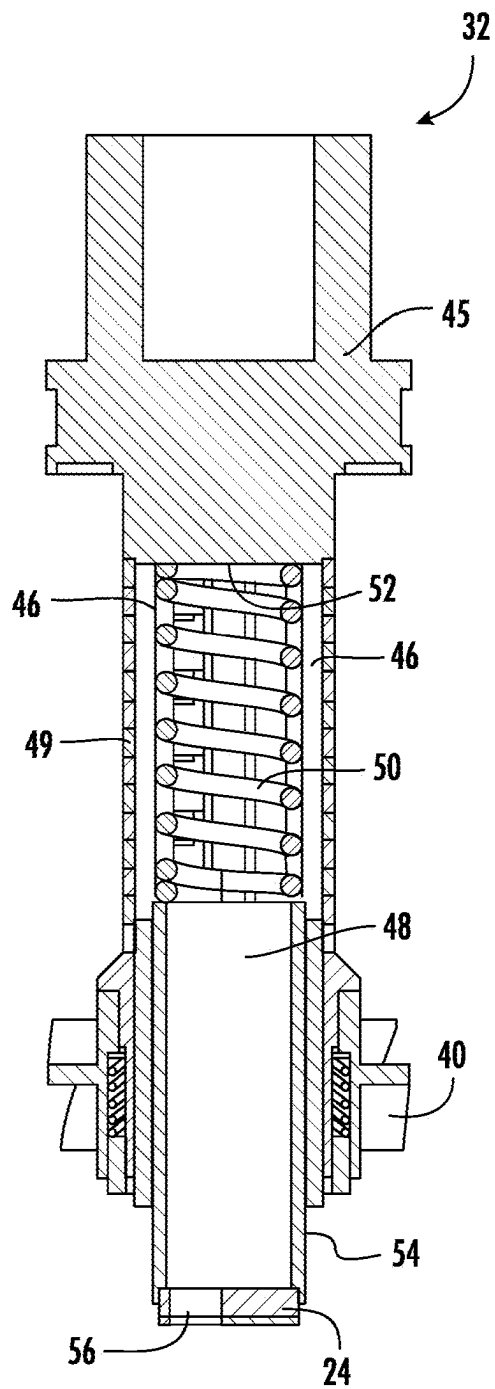


FIG. 7

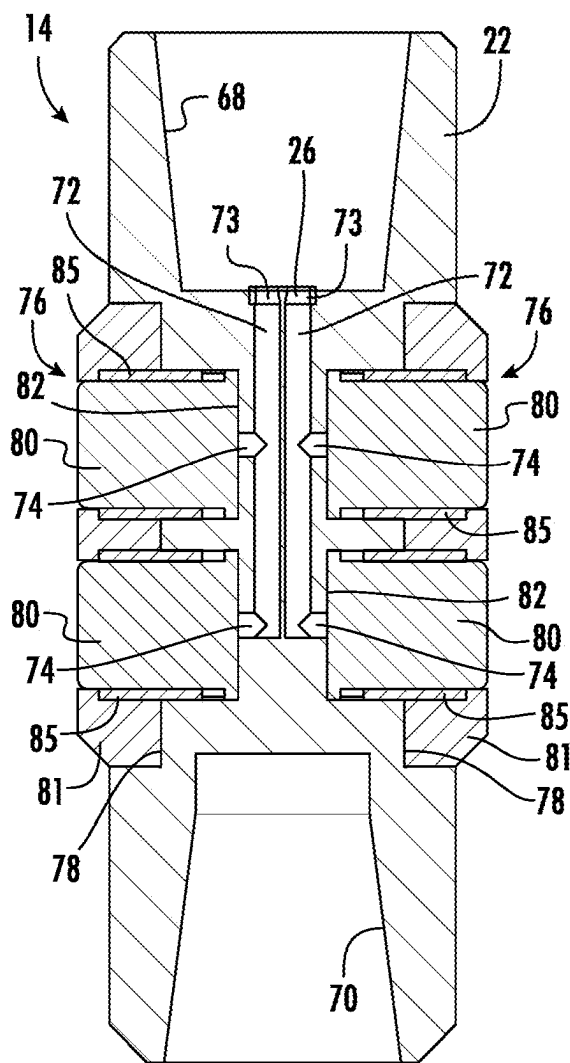


FIG. 8

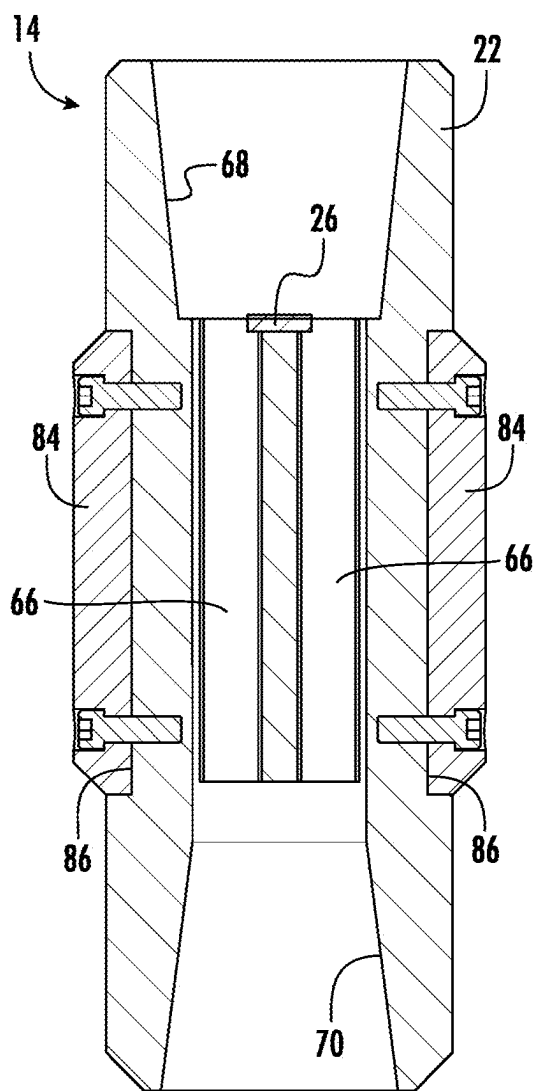
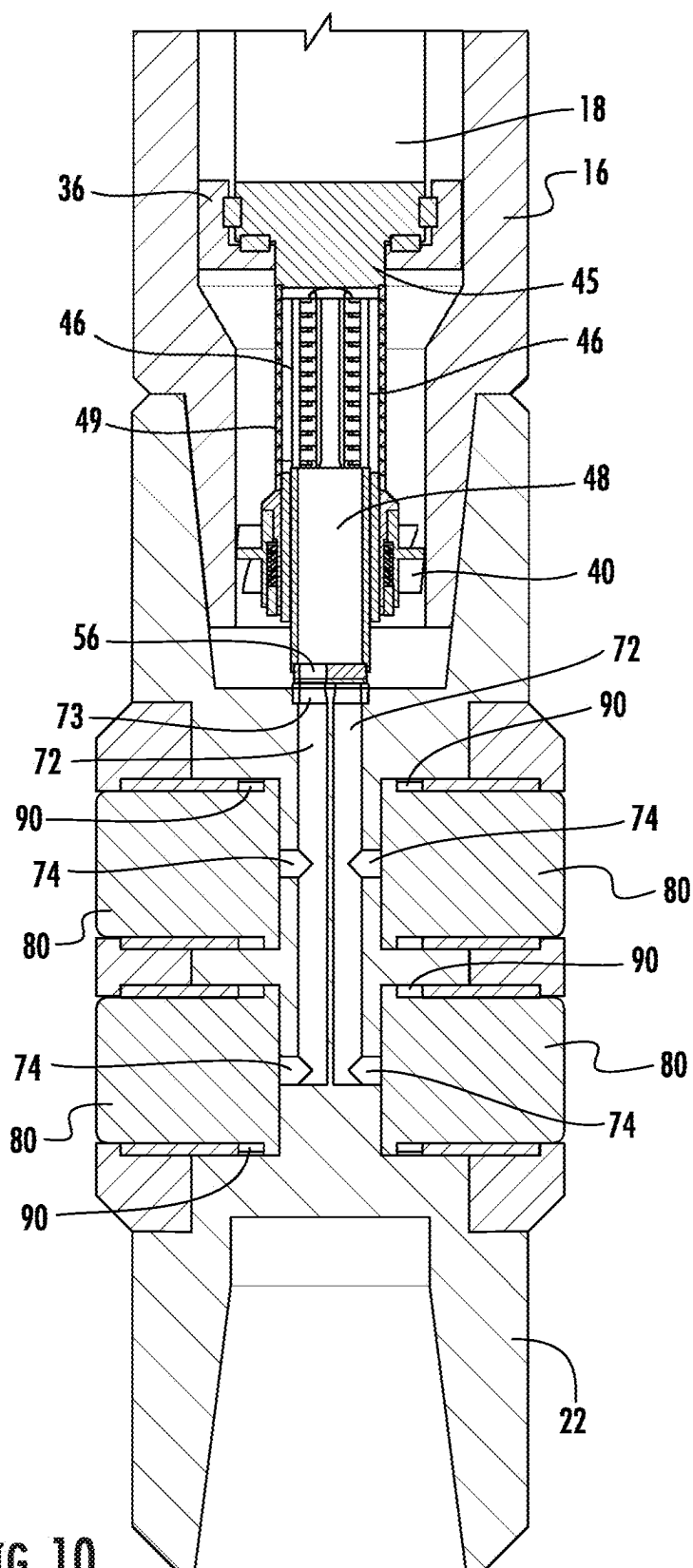


FIG. 9



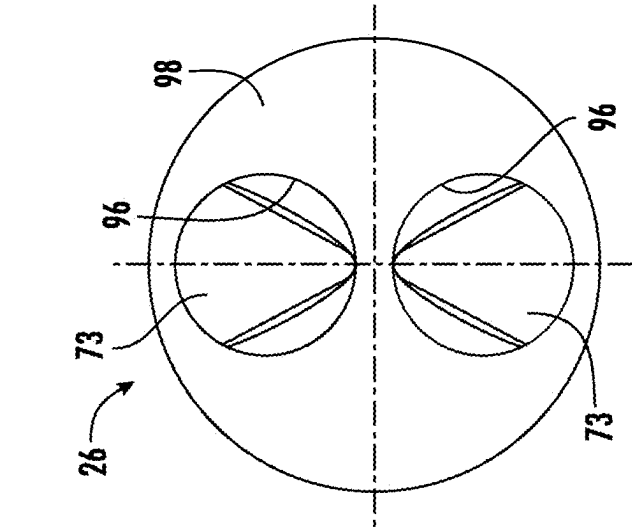


FIG. 11

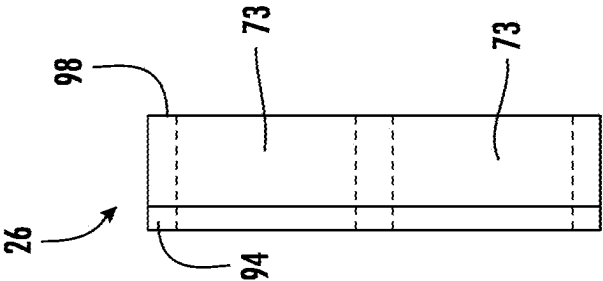


FIG. 12

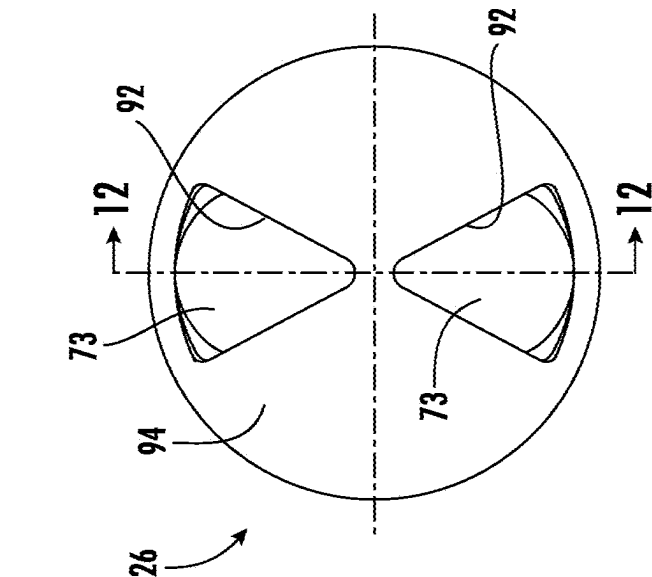


FIG. 13



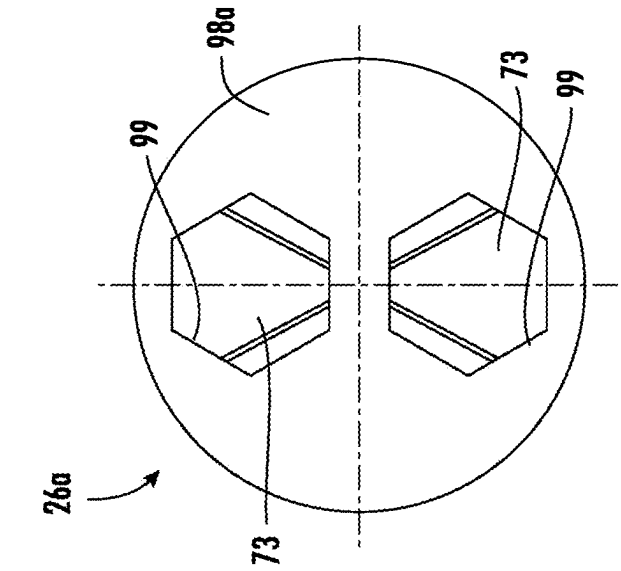


FIG. 14

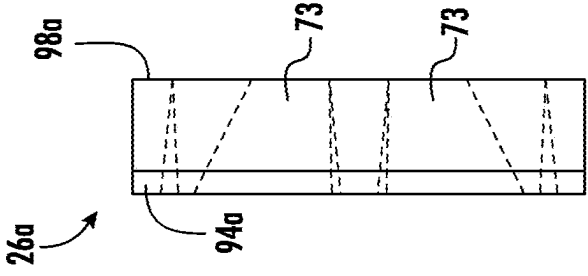


FIG. 15

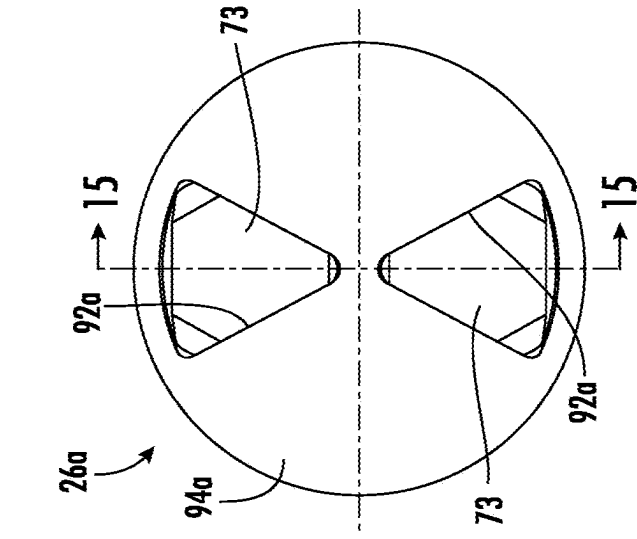


FIG. 16

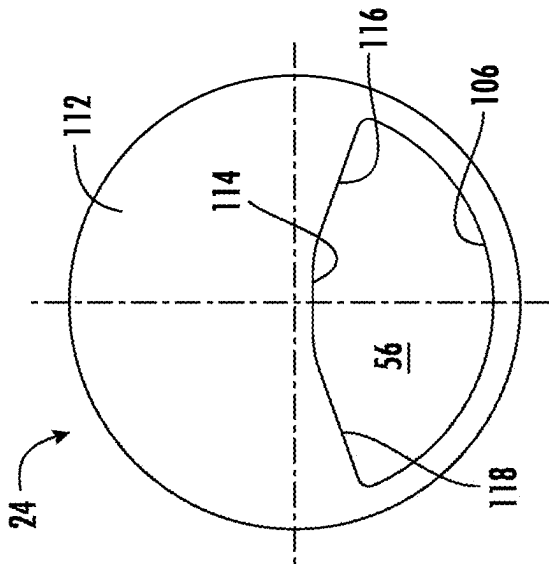


FIG. 17

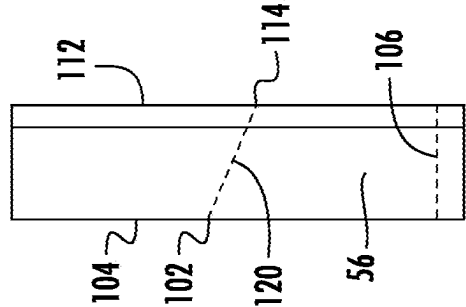


FIG. 18

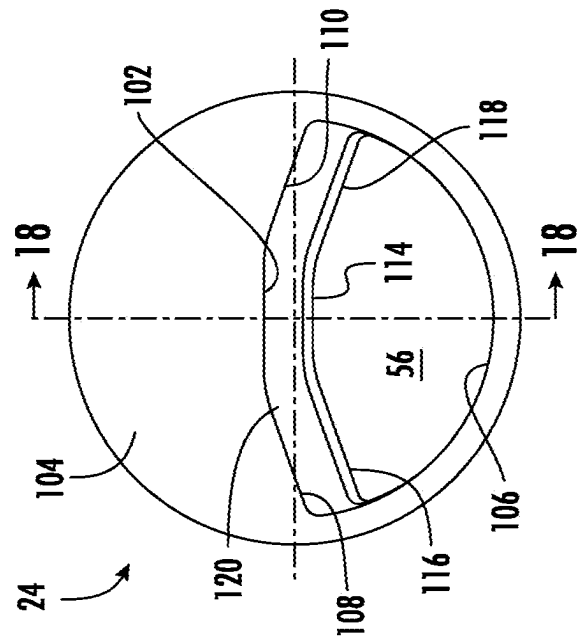


FIG. 19

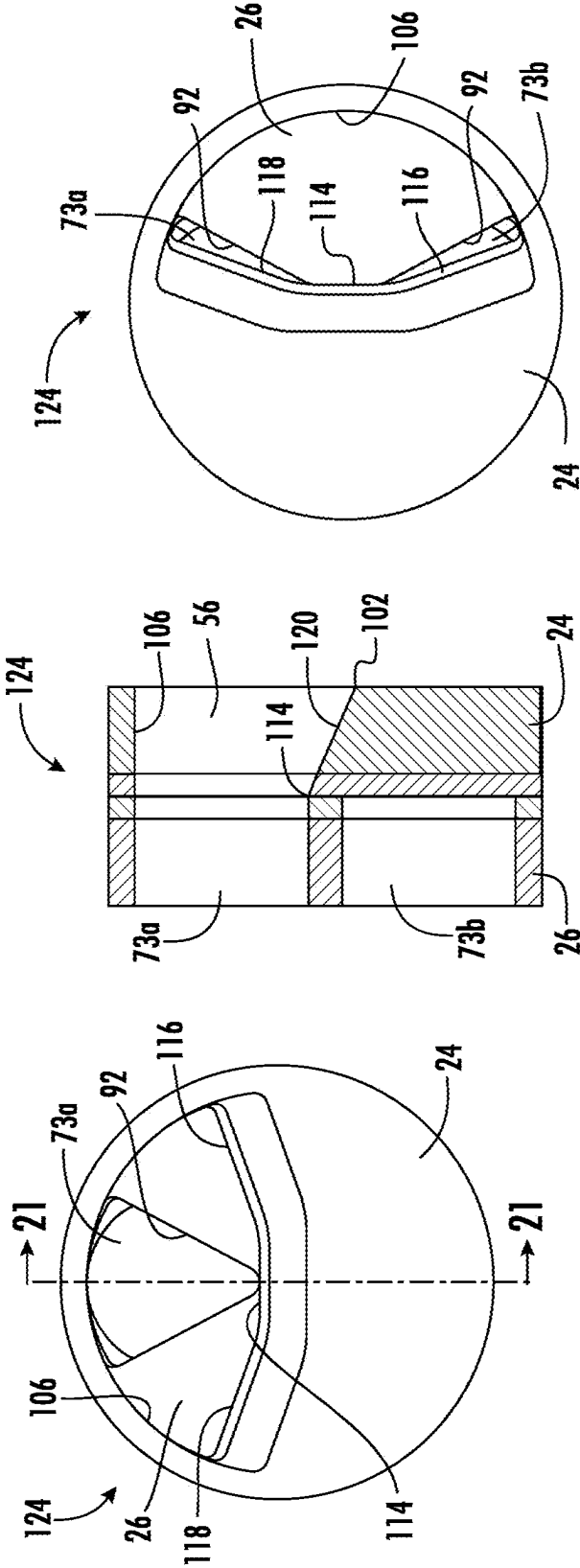


FIG. 20

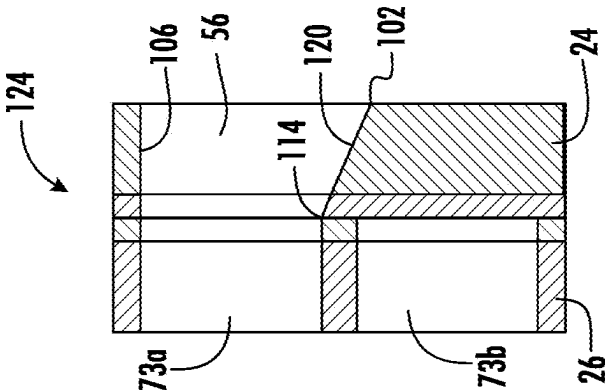


FIG. 21

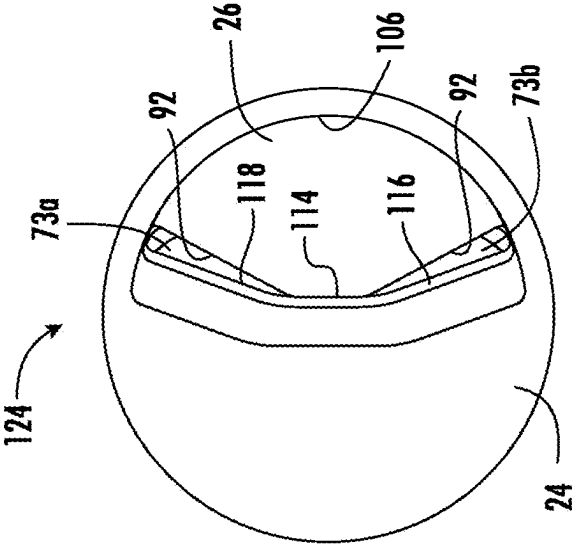


FIG. 22

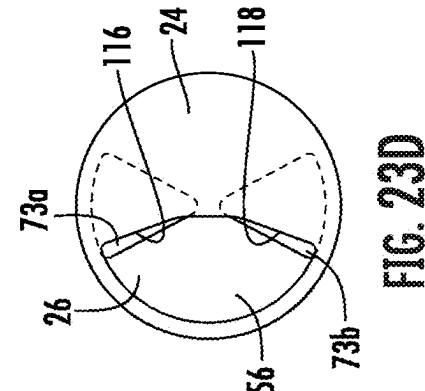


FIG. 23A

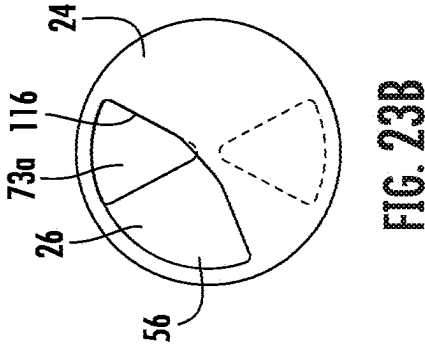


FIG. 23B

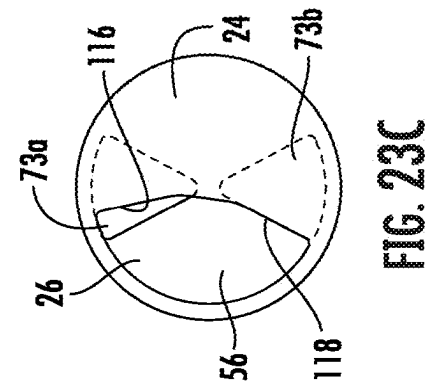


FIG. 23C

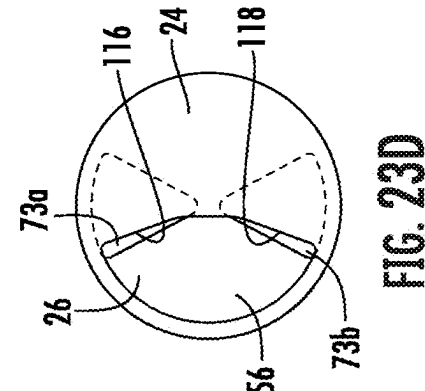


FIG. 23D

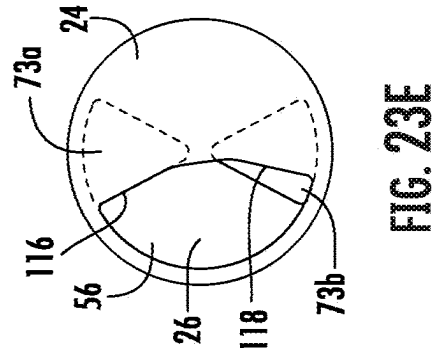


FIG. 23E

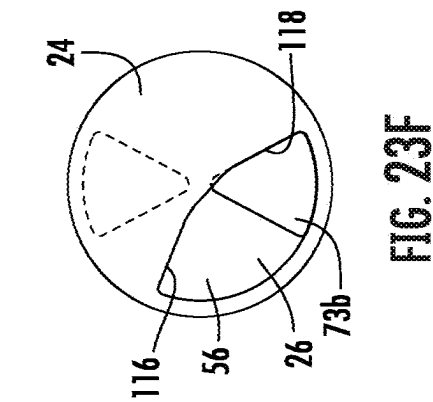


FIG. 23F

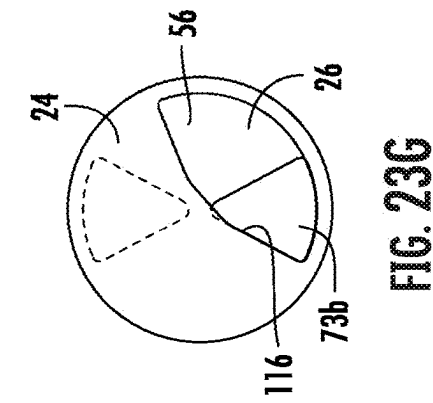


FIG. 23G

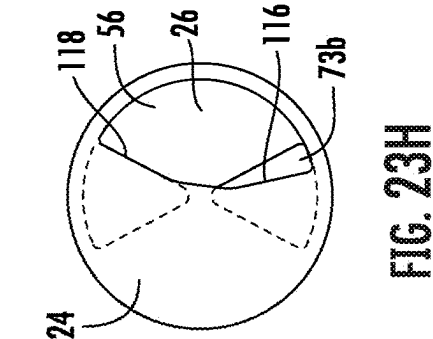


FIG. 23H

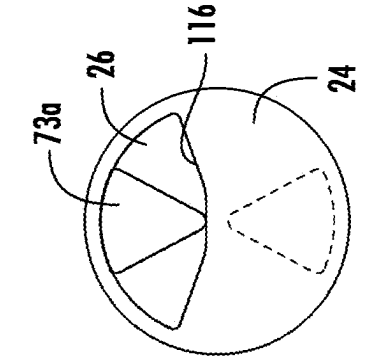


FIG. 23L

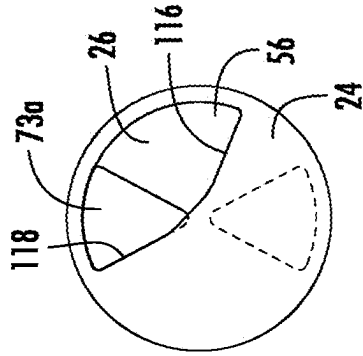


FIG. 23K

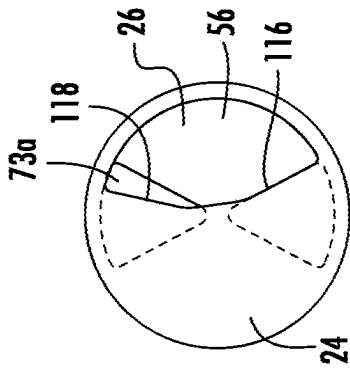


FIG. 23J

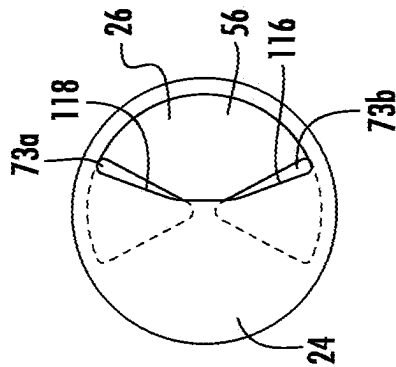


FIG. 23I

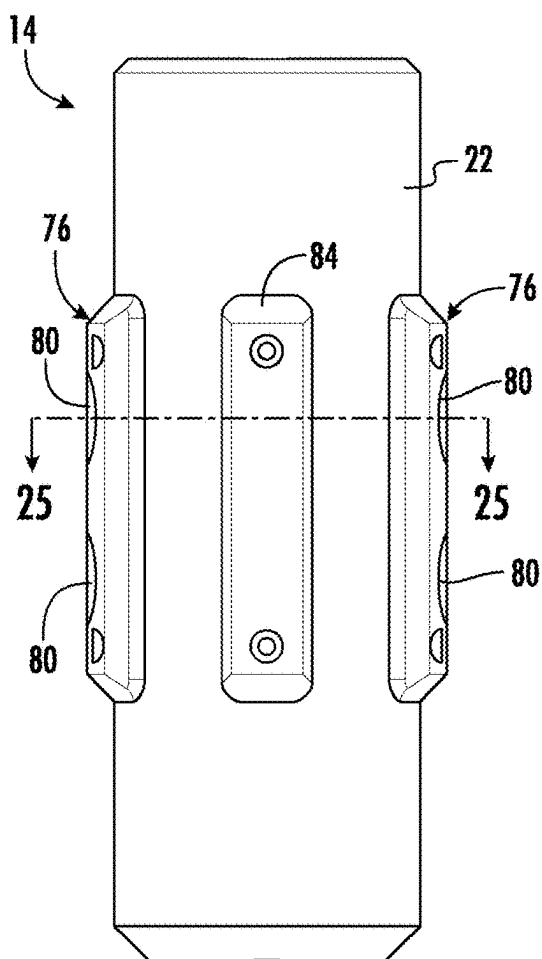


FIG. 24

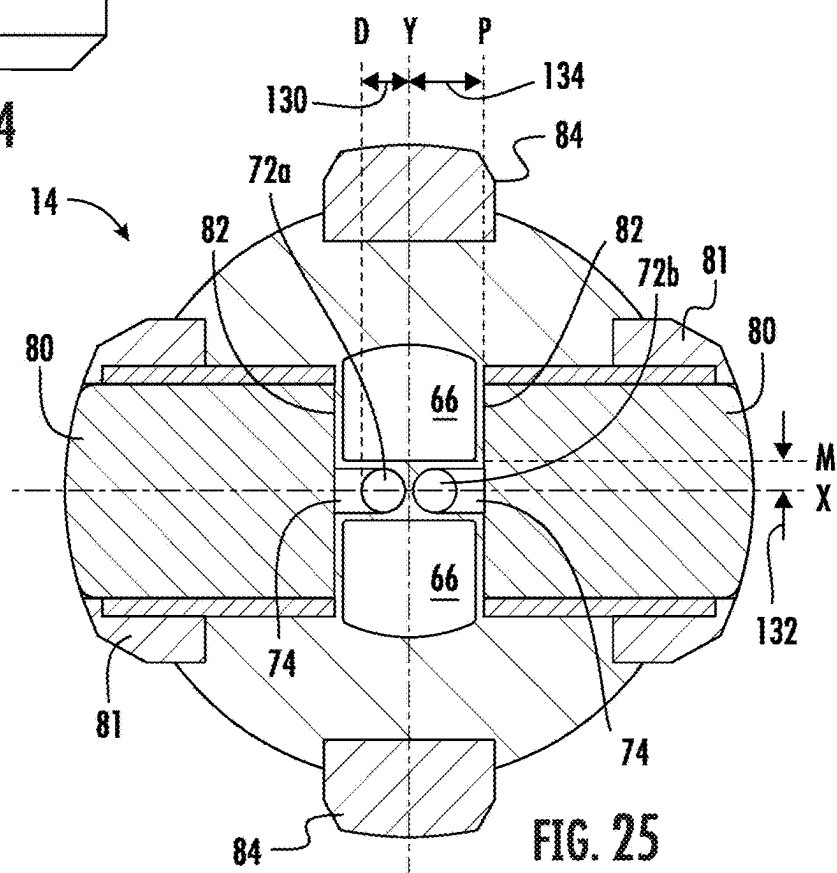


FIG. 25

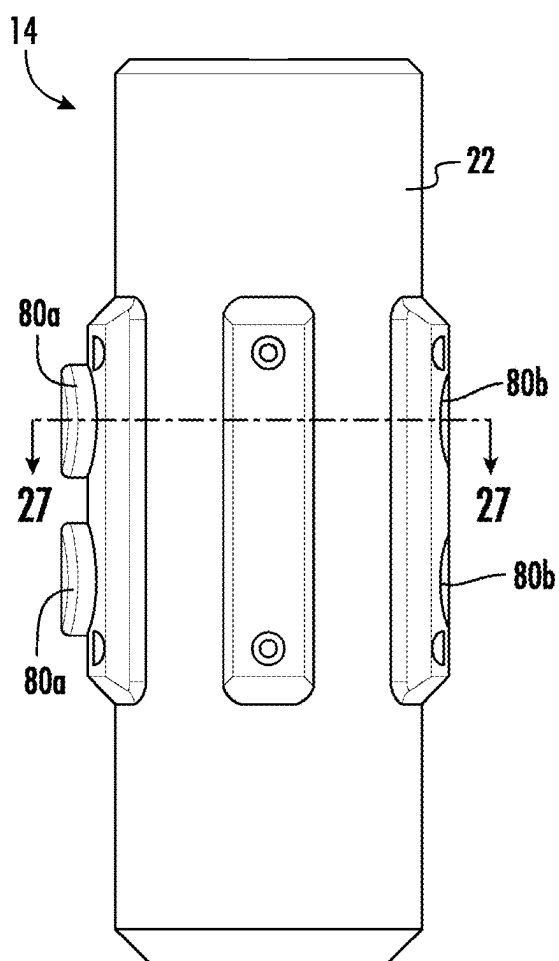


FIG. 26

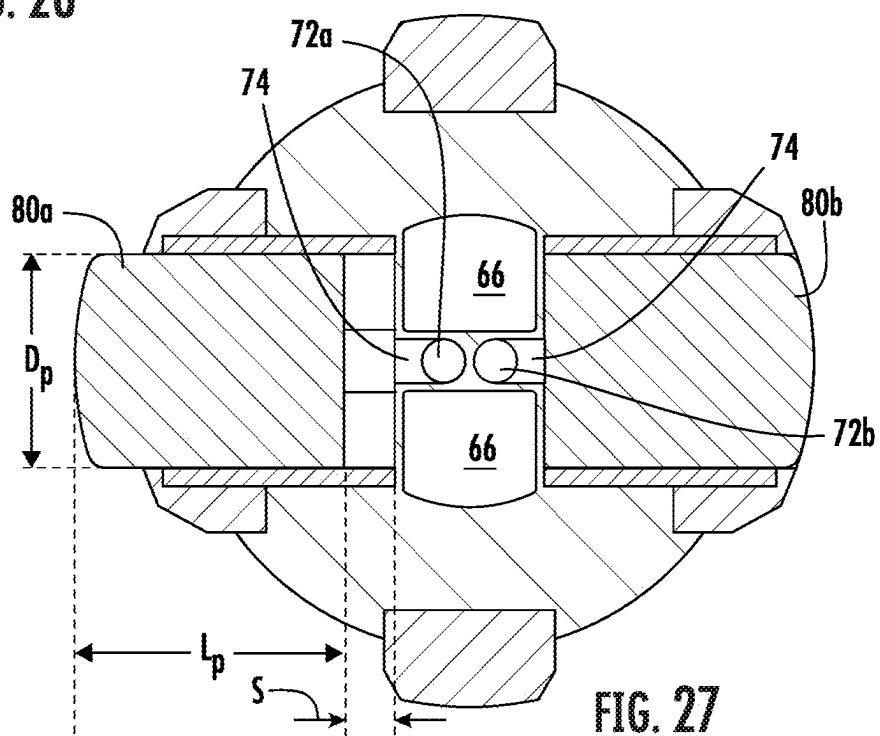


FIG. 27

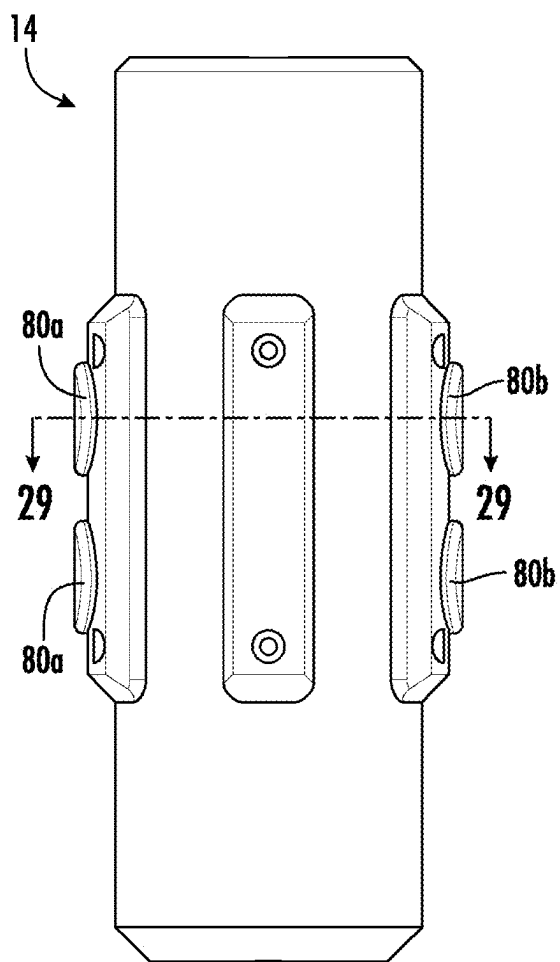


FIG. 28

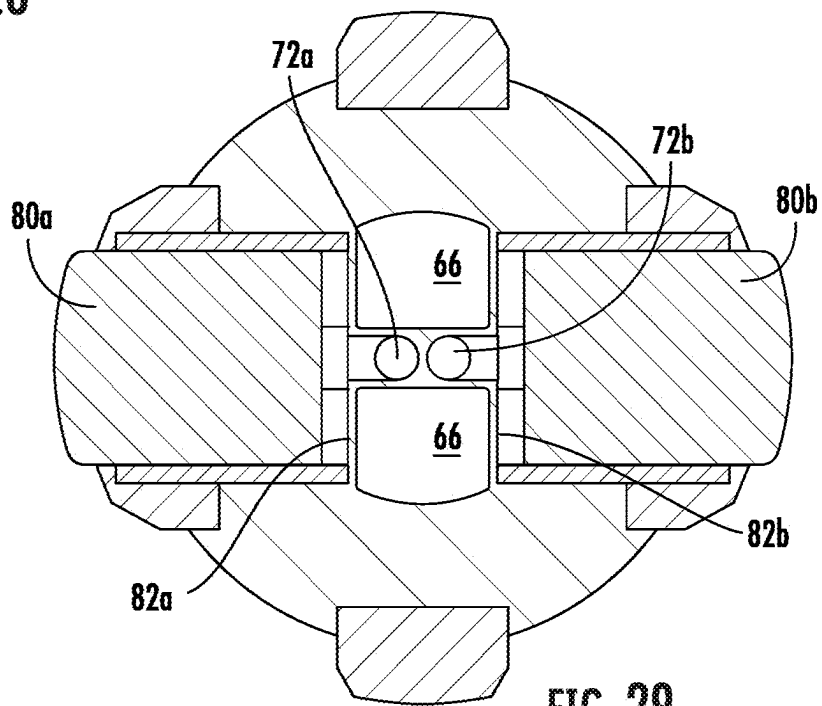


FIG. 29



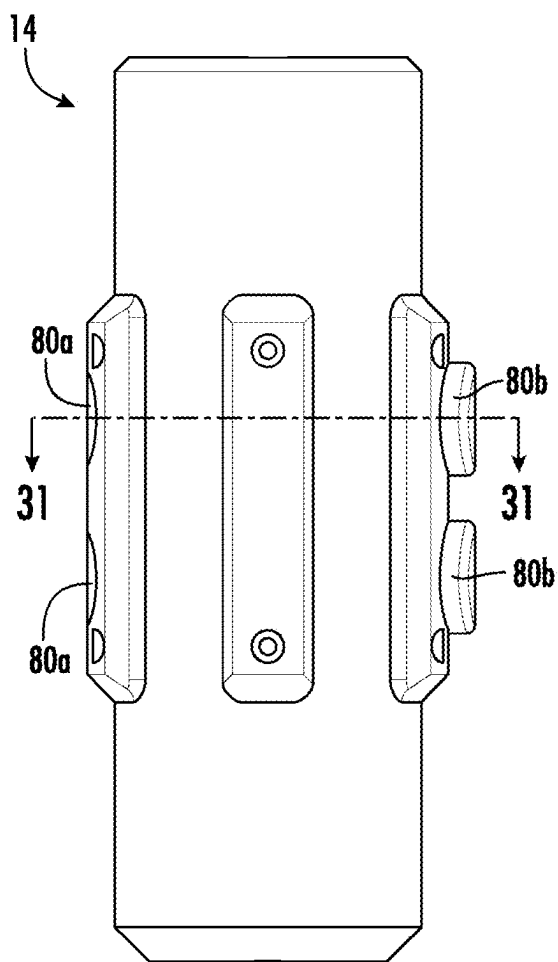


FIG. 30

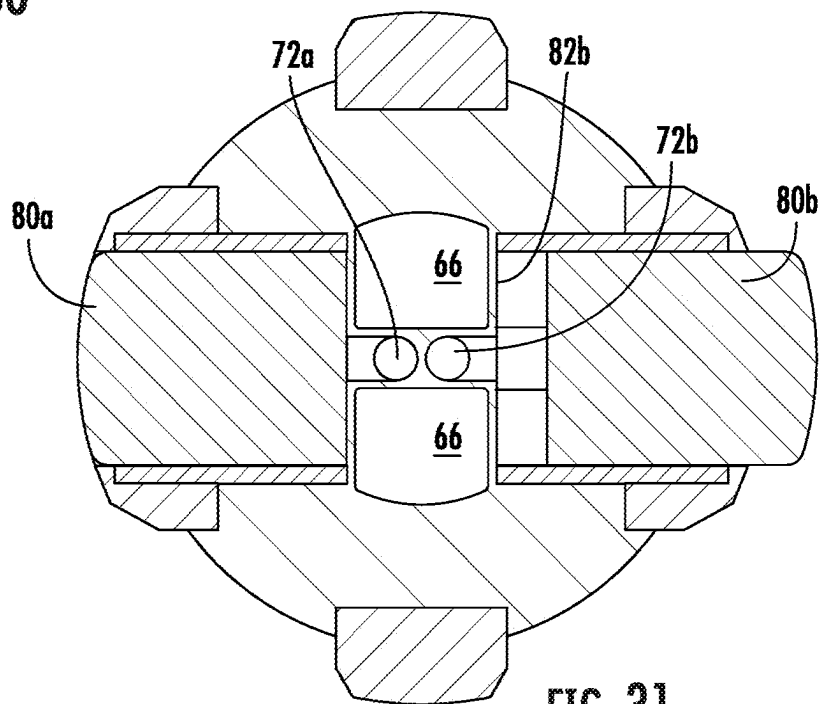


FIG. 31

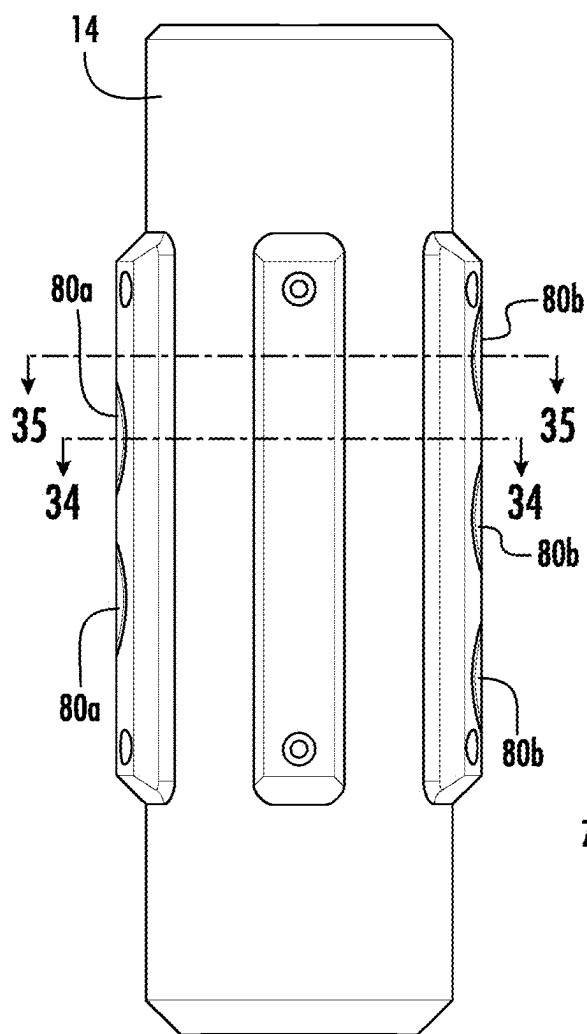


FIG. 32

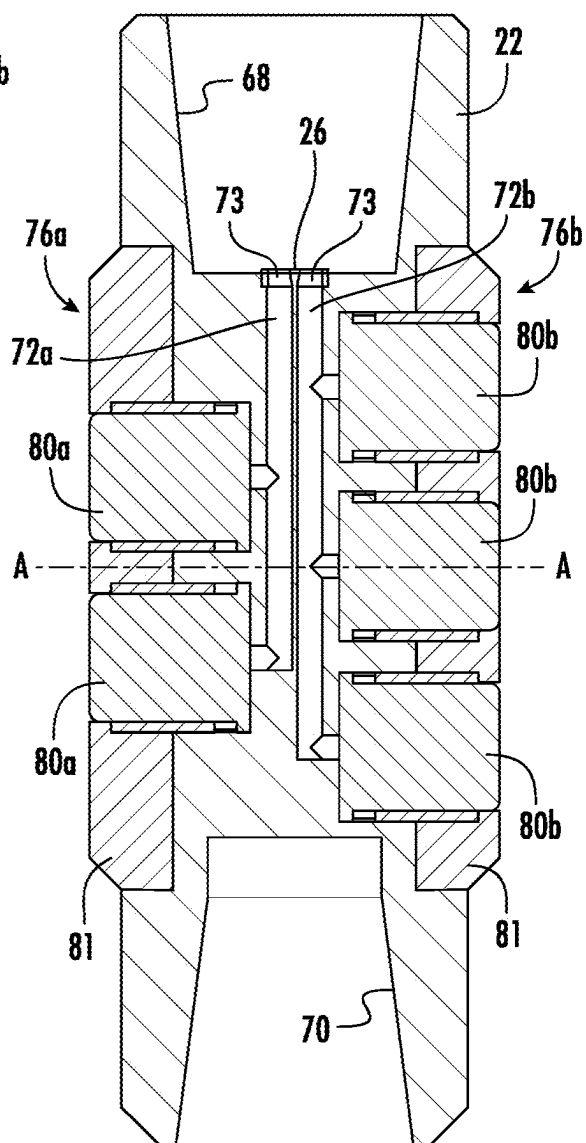


FIG. 33

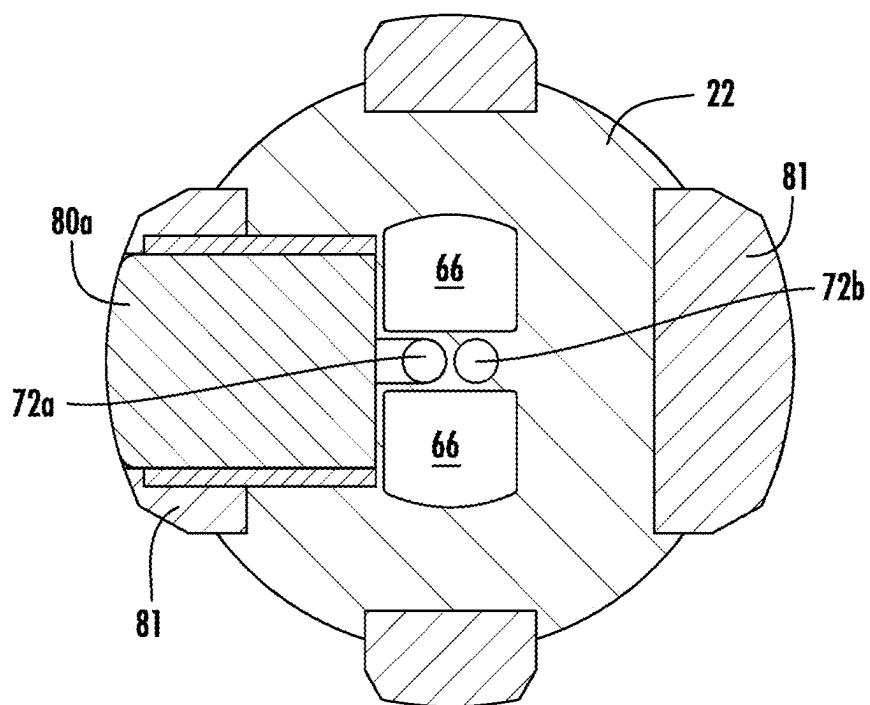


FIG. 34

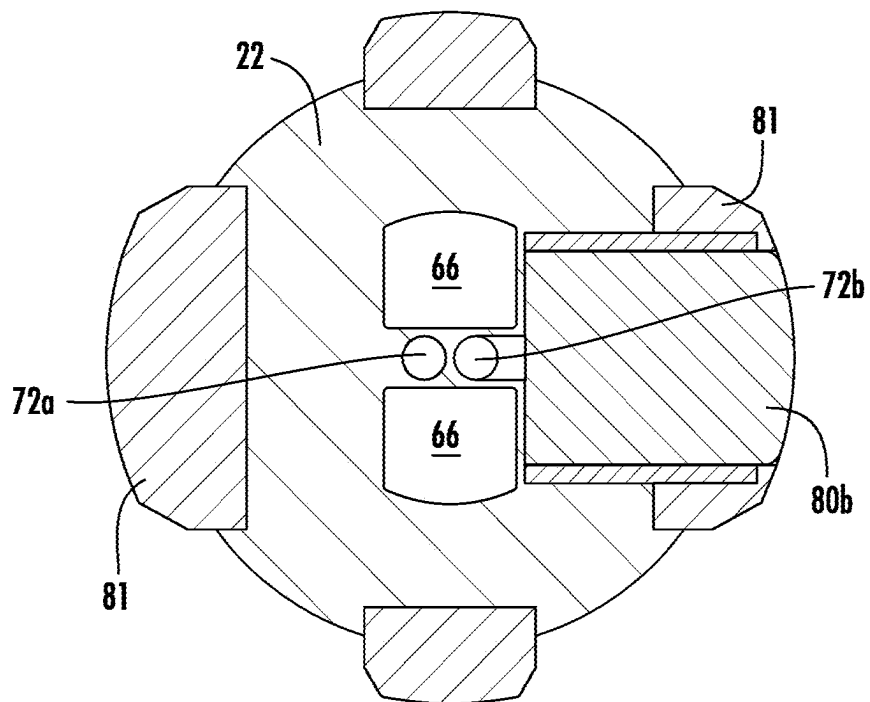
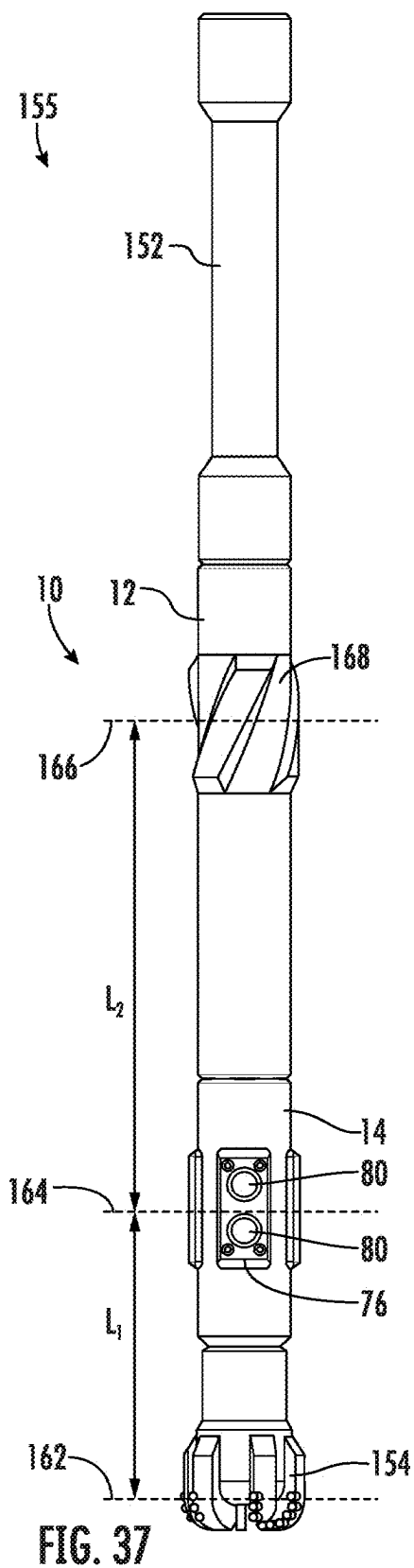
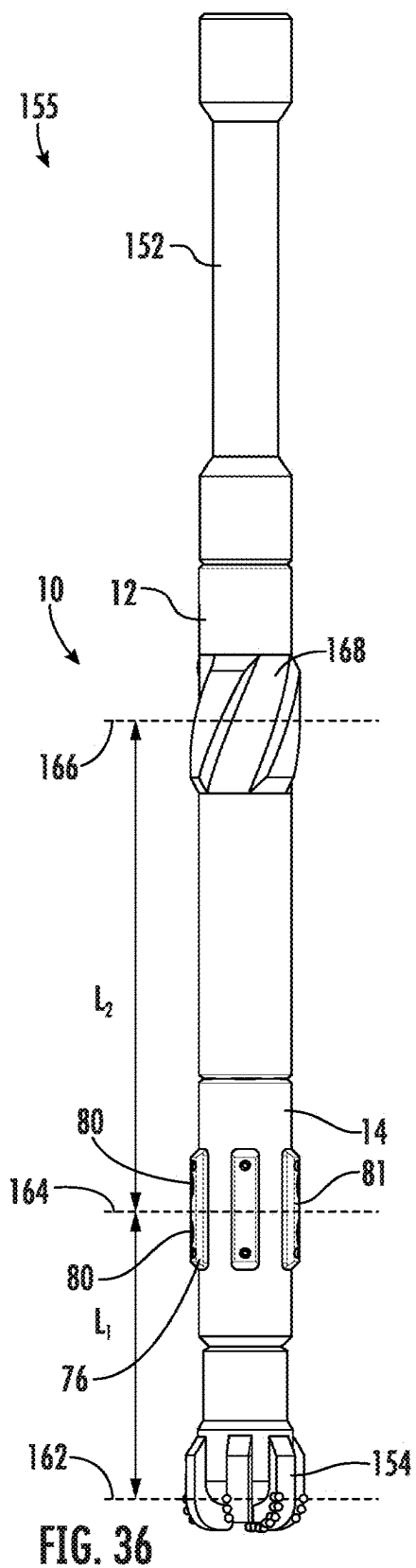


FIG. 35



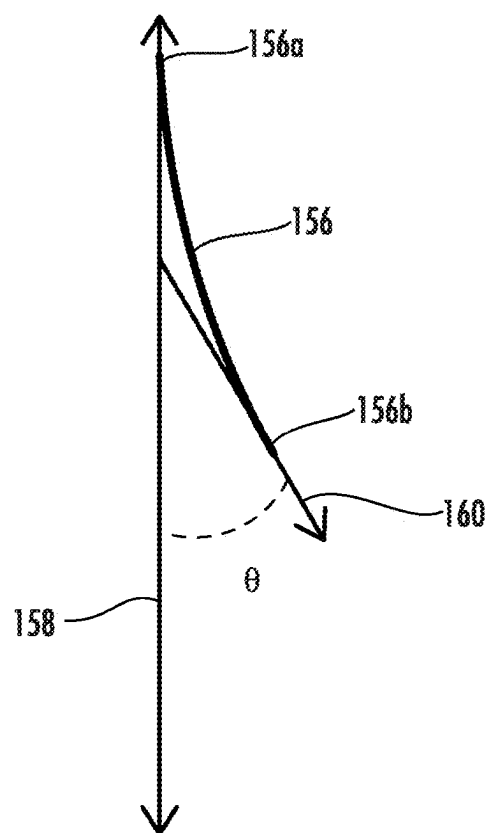


FIG. 38

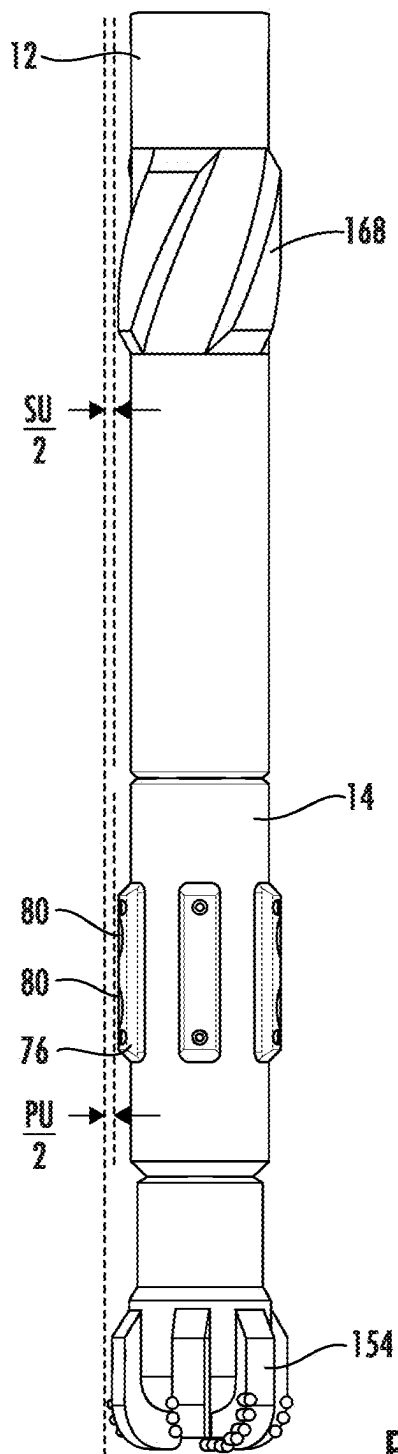


FIG. 39

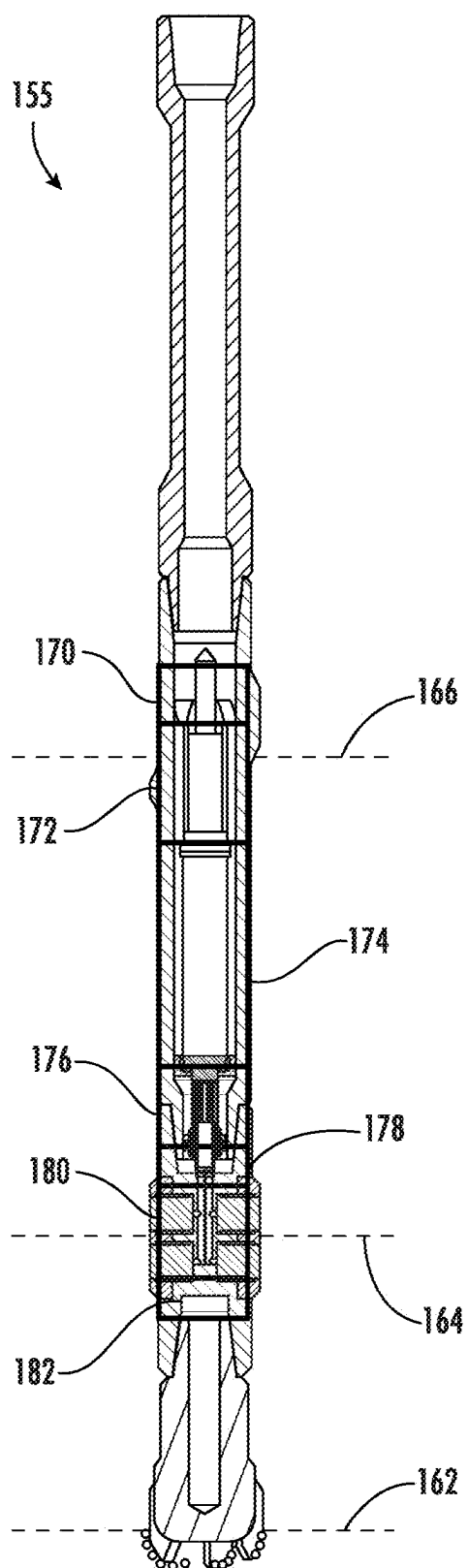


FIG. 40

## SELF-CONTAINED COMPACT ROTARY STEERABLE SYSTEM

### BACKGROUND

[0001] In the process of drilling and producing oil and gas wells, rotary steerable systems are used to control and adjust the direction in which a well is drilled. The rate at which a rotary steerable system changes the direction of a drill bit during drilling can be expressed as a build-up rate, which depends on the length of the rotary steerable system and other factors. Typical self-sufficient rotary steerable systems are over 150 inches in length and achieve build-up rates of less than 10 degrees per 100 feet of drilling. Prior art attempts at achieving higher build-up rates removed or omitted features from the rotary steerable system to reduce its length, thereby creating rotary steerable systems that are not self-sufficient. There is a need for a reduced-length, self-sufficient rotary steerable system and bottom hole assembly that achieves higher build-up rates.

### BRIEF DESCRIPTION OF THE DRAWING VIEWS

[0002] FIG. 1 is a side view of a rotary steerable system of the present invention.

[0003] FIG. 2 is a sectional view of the rotary steerable system.

[0004] FIG. 3 is a sectional view of a control sleeve and a steering section of the rotary steerable system.

[0005] FIG. 4 is a partially exploded view of a control insert configured to fit within the control sleeve.

[0006] FIG. 5 is a partial sectional view of an upper control unit of the control insert within the control sleeve.

[0007] FIG. 6 is an exploded view of a lower control unit of the control insert.

[0008] FIG. 7 is a sectional view of the lower control unit of the control insert.

[0009] FIG. 8 is a sectional view of the steering section.

[0010] FIG. 9 is a sectional view of the steering section taken along a perpendicular plane as compared to FIG. 8.

[0011] FIG. 10 is a sectional view of a lower portion of the control section and the steering section.

[0012] FIG. 11 is a top view of a valve stator of the rotary steerable system.

[0013] FIG. 12 is a sectional view of the valve stator of the rotary steerable system taken along line 12-12 in FIG. 11.

[0014] FIG. 13 is a bottom view of the valve stator of the rotary steerable system.

[0015] FIG. 14 is a top view of an alternate embodiment of the valve stator of the rotary steerable system.

[0016] FIG. 15 is a sectional view of the alternate embodiment of the valve stator of the rotary steerable system taken along line 15-15 in FIG. 14.

[0017] FIG. 16 is a bottom view of the alternate embodiment of the valve stator of the rotary steerable system.

[0018] FIG. 17 is a top view of a valve rotor of the rotary steerable system.

[0019] FIG. 18 is a sectional view of the valve rotor of the rotary steerable system taken along line 18-18 in FIG. 17.

[0020] FIG. 19 is a bottom view of the valve rotor of the rotary steerable system.

[0021] FIG. 20 is a top view of the valve assembly including the valve rotor and the valve stator, with the valve rotor in a first position.

[0022] FIG. 21 is a sectional view of the valve assembly with the valve rotor in the first position taken along line 21-21 in FIG. 20.

[0023] FIG. 22 is a top view of the valve assembly with the valve rotor in a second position.

[0024] FIGS. 23A-23L are schematic views of the valve assembly with the valve rotor in a sequence of positions as it rotates relative to the valve stator.

[0025] FIG. 24 is a side view of the steering section in a default position.

[0026] FIG. 25 is a sectional view of the steering section in the default position, taken along line 25-25 in FIG. 24.

[0027] FIG. 26 is a side view of the steering section in a first extended position.

[0028] FIG. 27 is a sectional view of the steering section in the first extended position, taken along line 27-27 in FIG. 26.

[0029] FIG. 28 is a side view of the steering section in a neutral position.

[0030] FIG. 29 is a sectional view of the steering section in the neutral position, taken along line 29-29 in FIG. 28.

[0031] FIG. 30 is a side view of the steering section in a second extended position.

[0032] FIG. 31 is a sectional view of the steering section in the second extended position, taken along line 31-31 in FIG. 30.

[0033] FIG. 32 is a side view of an alternate embodiment of the steering section.

[0034] FIG. 33 is a sectional view of the alternate embodiment of the steering section.

[0035] FIG. 34 is a sectional view of the alternate embodiment of the steering section taken along line 34-34 in FIG. 32.

[0036] FIG. 35 is a sectional view of the alternate embodiment of the steering section taken along line 35-35 in FIG. 32.

[0037] FIG. 36 is a side view of the rotary steerable system connected between a flex shaft and a drill bit.

[0038] FIG. 37 is another side view of the rotary steerable system connected between the flex shaft and the drill bit.

[0039] FIG. 38 is a schematic representation of a build-up rate of the rotary steerable system.

[0040] FIG. 39 is another side view of the rotary steerable system connected to the drill bit.

[0041] FIG. 40 is a schematic sectional view of modules of the rotary steerable system connected between the drill bit and the flex shaft.

### DETAILED DESCRIPTION OF SELECTED EMBODIMENTS

[0042] Disclosed herein is a rotary steerable system including a steering section. The steering section includes at least one piston. In some embodiments, the steering section includes only two pistons in each transverse cross-sectional plane. A center point of a first piston is separated from a center point of a second piston by an angle greater than 120 degrees.

[0043] The rotary steerable system also includes a valve assembly configured to direct a portion of a drilling fluid flowing through the rotary steerable system into a distribution flow passage, thereby activating one of the pistons and causing the piston to extend in a radially outward direction. A ratio of the diameter of each distribution flow passage to the steering section diameter is at least 0.07. The distribution



flow passages are contained within a central area of the steering section. A ratio of the diameter of the central area to the steering section diameter is 0.5 or less. An activation duration of each set of pistons is about 180 degrees of rotation of a valve rotor. A ratio of the stroke length of each piston to the diameter of the steering section is greater than 0.06. As used herein, “diameter of the steering section” and “steering section diameter” both mean the minimum outer diameter of any portion of the assembled steering section (i.e., the outer diameter of the smallest portion of the assembled steering section). For example, in some embodiments, the steering section diameter may be the outer diameter of steering housing 22.

[0044] In some embodiments, the rotary steerable system also includes a control section. A combined length of the control section and the steering section is below 150 inches, preferably below 80 inches.

[0045] FIGS. 1-37 illustrate embodiments of the rotary steerable system disclosed herein, with many other embodiments within the scope of the claims being readily apparent to skilled artisans after reviewing this disclosure.

[0046] With reference to FIGS. 1-3, rotary steerable system 10 includes control section 12 and steering section 14, each having a generally cylindrical shape. Control section 12 includes electronic components, sensors, and actuators for determining a drilling direction or tool face required and for orienting the steering section.

[0047] Control section 12 includes control sleeve 16 and control insert 18 disposed within inner bore 20 of control sleeve 16. Control insert 18 is configured for rotation relative to control sleeve 16. In one embodiment, control insert 18 is configured to remain stationary with respect to a surrounding subterranean formation, such that control sleeve 16 rotates around control insert 18. In other words, control insert 18 may be configured to remain geo-stationary. A lower end of control sleeve 16 is secured to an upper end of steering housing 22 of steering section 14. In this way, control sleeve 16 is rotationally secured to steering housing 22. As used herein, “rotationally secured” means secured together such that two components rotate together (i.e., there is no relative rotation between two components under normal operating conditions).

[0048] A lower end of control insert 18 includes a valve rotor 24, which cooperates with valve stator 26 secured to steering housing 22. Valve rotor 24 rotates relative to valve stator 26 as control insert 18 rotates relative to control sleeve 16 and steering housing 22.

[0049] Referring now to FIGS. 2 and 4-6, control insert 18 may include upper control unit 28, electronics unit 30, and lower control unit 32. Control insert 18 may also include guide 34 secured to upper control unit 28 and guide 36 secured to lower control unit 32. Guide 34 and 36 may be rotationally secured to control sleeve 16, while upper and lower control units 28 and 32 rotate within guides 34 and 36, respectively. Control insert 18 may further include upper impeller 38 rotationally secured to upper control unit 28 and lower impeller 40 rotationally secured to lower control unit 32. Upper and lower impellers 38 and 40 may be sized and configured such that the outer ends of impellers 38 and 40 are in close proximity a surface of inner bore 20 of control sleeve 16. Guides 34 and 36 and impellers 38 and 40 may stabilize a position of control insert 18 within inner bore 20 of control sleeve 16 while control insert 18 therein.

[0050] Referring again to FIG. 2, upper control unit 28 may include a magnetic brake 41 which functions as an actuator to apply rotational torque in a direction that is opposite to a rotational direction of control sleeve 16 and steering housing 22. In this way, the magnetic brake assembly adjusts the rotation rate of control insert 18 relative to control sleeve 16. As a drilling fluid flows through inner bore 20 of control sleeve 16, the drilling fluid flows through spaces in impeller 38, thereby applying a rotational force on impeller 38 and upper control unit 28. In one embodiment, upper control unit 28 also includes a power generation mechanism. The magnetic brake assembly may be the only actuator in rotary steerable system 10.

[0051] With reference to FIGS. 4 and 5, upper control unit 28 may also include upper filter 44. In one embodiment, upper filter 44 may be formed of rings with shoulders such that the stacking of the rings creates small interstices that function to filter. As drilling fluid flow through inner bore 20 of control sleeve 16, a small amount of drilling fluid may flow through upper filter 44 and through intermediate spaces 43a, 43b, 43c, and 43d surrounding antenna 42 and magnetic brake 41. Upper filter 44 removes larger particles from the drilling fluid to allow a small amount of clean fluid to flow in the intermediate spaces 43a-43d. Allowing only clean fluid to flow in intermediate spaces 43a-43d prevents the two parts of upper control unit 28 from seizing up and/or from creating additional drag between the two parts of upper control unit 28. The majority of the drilling fluid flows around the exterior surface of filter 44 and through the spaces in impeller 38.

[0052] Electronics unit 30 may include sensors. For example, electronics unit 30 may include a magnetometer for sensing a north-south direction, an accelerometer for sensing inclination, and a gyrometer for sensing rotation of the control unit relative to a surrounding subterranean formation. Control insert 18 may be configured to adjust the magnetic brake assembly in the upper control unit 28 based on measurements taken by the sensors in electronics unit 30. In some embodiments, the rotary steerable system 10 includes no batteries and only a small amount of memory (e.g., flash memory only). In these embodiments, the electronics unit 30 may include antenna 42 for transmitting measurement data and other data to a measurement-while-drilling (“MWD”) unit secured above the rotary steerable system 10, and the MWD unit may store the received data in a memory. Antenna 42 of the electronics unit 30 may be formed of an electromagnetic antenna.

[0053] With reference to FIGS. 6 and 7, lower control unit 32 may include housing 45 with flow passages 46. Flow passages 46 are configured to allow a drilling fluid in an annular space between control sleeve 16 and housing 45 to flow into inner space 48 within housing 45. Lower control unit 32 may also include lower filter 49 configured to surround and cover flow passages 46 in order to filter drilling fluid as it flows through flow passages 46 and enters inner space 48. In one embodiment, lower filter 49 may be formed of rings with shoulders such that the stacking of the rings creates small interstices that function to filter. Lower control unit 32 may further include spring 50 disposed within inner space 48 and configured to bias valve rotor 24 in a direction toward the valve stator 26 and steering section 14. For example, an upper end of spring 50 may engage transverse surface 52 of housing 45, while lower end of spring 50 engages an upper end of spacer 54 to apply a downward

force on the valve rotor 24, which is secured to a lower end of spacer 54. As a drilling fluid flows through the annular space between control sleeve 16 and housing 45, a portion of the drilling fluid may flow through flow passages 46, into inner space 48, and through a rotor port 56 of valve rotor 24. The remainder of the drilling fluid flowing through the annular space may flow through spaces in impeller 40 outside of housing 45.

[0054] With reference now to FIGS. 8 and 9, steering section 14 includes parallel main flow passages and distribution flow passages. Steering housing 22 includes two main flow passages 66 extending from upper inner bore 68 to lower inner bore 70. Steering housing 22 also includes two distribution flow passages 72 each extending from a stator port 73 of valve stator 26 to one or more feed channels 74. Steering section 14 also includes two piston assemblies 76, each at least partially secured within a receptacle 78 in an outer surface of steering housing 22. Each piston assembly 76 includes one or more pistons 80 each disposed within a piston sleeve 85, all disposed within piston clamp 81, which is configured to be secured within piston receptacle 82 in steering housing 22. Pistons 80 are configured to slide in a radial direction within piston receptacles 82. Each feed channel 74 extends from a distribution flow passage 72 to a piston receptacle 82. Steering section 14 of rotary steerable system 10 may include not more than two pistons in each transverse cross-sectional plane, with the center points of the pistons separated by an angle greater than 120 degrees. Steering section 14 may include not more than two sets of pistons.

[0055] Steering section 14 may further include spacers 84, each at least partially disposed within spacer receptacles 86 in an outer surface of steering housing 22. In one embodiment, spacers 84 are secured to steering housing 22 using bolts or screws. As used herein, “piston” means any structure configured to extend, when activated, in a radial direction from a tool to which it is secured or in which it is incorporated. For example, “piston” includes a pad, a wedge arrangement, and a cam arrangement.

[0056] Referring to FIG. 10, as a drilling fluid flows through the annular space between control sleeve 16 and control insert 18, a portion of the drilling fluid may flow through flow passages 46 and into inner space 48 of housing 45. The drilling fluid within inner space 48 may flow through rotor port 56 of valve rotor 24 and through a stator port 73 of valve stator 26 that is aligned with rotor port 56. As valve rotor 24 rotates relative to valve stator 26, rotor port 56 aligns with each of the stator ports 73 in sequence over time. Accordingly, the drilling fluid flowing through rotor port 56 will flow through each of the stator ports 73 in sequence over time. Drilling fluid that flows through one of the stator ports 73 flows through the connecting distribution flow passage 72, through each of the connected feed channels 74, and into connected piston receptacles 82 in order to apply a force and displace piston 80 in a radial outward direction. In some embodiments, and in order to provide an exhaust path for when the piston retracts from an open position, the drilling fluid can flow through leak channels 90 between pistons 80 and piston receptacles 82, or in another embodiment, it may leak between the piston and the guide sleeve, through diametral space between the two or through a channel formed in the sleeve or in the piston that connect piston receptacles 82 to the wellbore. In another embodiment, the leak channels may be located through the piston body to

connect piston receptacles 82 to the wellbore. In another embodiment, the leak channel may be located between the guide sleeve and the steering body.

[0057] FIGS. 11-13 illustrate one embodiment of valve stator 26, which includes two stator ports 73 positioned on opposite sides of valve stator 26. In other words, the central point of the outer boundary of one stator port 73 is 180 degrees from the central point of the outer boundary of the second stator port 73. In this embodiment, the shape of each stator port 73 varies across the thickness of valve stator 26. For example, each stator port 73 may be defined by a wedge-shaped opening 92 on first side 94 of valve stator 26 and defined by a circular opening 96 on second side 98 of valve stator 26. First side 94 is configured to engage valve rotor 24, and second side 98 is configured to engage distribution flow passages 72. The sides of the wedge-shaped opening 92 may be formed of straight lines, which align with side boundaries of rotor port 56 to provide sharper actuations of pistons. While the circular openings 96 are configured to align with the distribution flow passages 72. The transition of the shape of stator ports 73 across the thickness of valve stator 26 reduces the length of transition flow lines needed between the valve assembly and the pistons 80. In other embodiments, each stator port 73 may be defined by wedge-shaped opening 92 on first side 94 of valve stator 26 and defined by a polygon-shaped opening on second side 98 of valve stator 26. In still other embodiments, stator ports 73 may have the same shape across the thickness of valve stator 26.

[0058] FIGS. 14-16 illustrate an alternate embodiment of valve stator 26a. In this embodiment, each stator port 73 is defined by a wedge-shaped opening 92a on first side 94a of valve stator 26a. Each stator port 73 is defined by a polygon-shaped opening 99 on second side 98a of valve stator 26a.

[0059] FIGS. 17-19 illustrate one embodiment of valve rotor 24, which includes only one rotor port 56. In this embodiment, the shape of rotor port 56 varies across the thickness of valve rotor 24. For example, rotor port 56 may be defined by inner boundary 102 outer boundary 106, and side boundaries 108 and 110 on first side 104 of valve rotor 24. Side boundaries 108 and 110 interconnect inner and outer boundaries 102 and 106 on first side 104. A center point of first side 104 is positioned between inner boundary 102 and outer boundary 106. In other words, rotor port 56 includes the center point of first side 104. Inner boundary 102 of rotor port 56 remains constant throughout the thickness of valve rotor 24. On second side 112 of valve rotor 24, rotor port 56 may be defined by outer boundary 106, inner boundary 114, and side boundaries 116 and 118. Side boundaries 116 and 118 interconnect inner and outer boundaries 102 and 106 on second side 112. Inner boundary 114 is positioned between outer boundary 106 and a center point of second side 112. In other words, the center point of second side 112 is not included within rotor port 56. Valve rotor 24 may include sloped surface 120 in the transitions between inner boundaries 102 and 114, side boundaries 108 and 116, and side boundaries 110 and 118, respectively.

[0060] Side boundaries 116 and 118 of first side 104 of rotor port 56 may have the same shape as the side boundaries of wedge-shaped openings 92 of stator ports 73. For example, each of the side boundaries 116 and 118 and each of the side boundaries of wedge-shaped openings 92 may be formed of a straight line extending in a radial direction.

[0061] Referring now to FIGS. 20-22, valve assembly 124 may include valve rotor 24 and valve stator 26, with valve rotor 24 rotating relative to valve stator 26. In this embodiment, outer boundary 106 of rotor port 56 aligns with the outer boundary of wedge-shaped openings 92 of stator ports 73, and inner boundary 114 of rotor port 56 aligns with the inner boundary of wedge-shaped openings 92 of stator ports 73. In a first position shown in FIGS. 20 and 21, rotor port 56 is aligned with all of the wedge-shaped opening 92 of a single stator port 73. In this first position, a first stator port 73a is “open” and a second stator port 73b (not shown in this view) is “closed.” As valve rotor 24 rotates, the side boundaries 116 and 118 of rotor port 56 cross over the side boundaries of wedge-shaped openings 92 of stator ports 73, thereby alternately opening and closing stator ports 73a and 73b. The angular separation of side boundary 116 from side boundary 118 and the angular separation of the two side boundaries of each wedge-shaped opening 92 together define the duration for which each stator port 73 is open (i.e., activation duration of each stator port 73). These angular separations also define whether both stator ports 73 are partially open at a single point in time, and if so, the duration for which both stator ports 73 are simultaneously partially open. In certain embodiments, the opening angle of the rotor port 56 (i.e., the angular distance between side boundaries 116 and 118 within rotor port 56) is at least 110 degrees. As used herein, “opening angle” is the rotational distance between two radial boundaries within an opening. In some embodiments, the side boundaries of the two wedge-shaped openings 92 are separated by at least 110 degrees or between 110 degrees and 170 degrees, or any subrange therein. In certain embodiments, the side boundaries of the two wedge-shaped openings 92 are separated by at least 125 degrees. In further embodiments, the side boundaries of the two wedge-shaped openings 92 are separated by an angle between 140 degrees and 170 degrees. In a second position shown in FIG. 22, rotor port 56 is aligned with a portion of stator port 73a and a portion of stator port 73b.

[0062] FIGS. 23A-23L illustrate valve assembly 124 with valve rotor 24 in various sequential positions relative to valve stator 26 over time. In this embodiment, valve rotor 24 rotates in a counter-clockwise direction. In other embodiments, valve rotor 24 rotates in a clockwise direction. In still other embodiments, valve rotor 24 is maintained in a geo-stationary position while valve stator 26 rotates with steering section 14 and control sleeve 16 in a clockwise direction. FIG. 23A illustrates the first position shown in FIGS. 20 and 21, in which rotor port 56 is aligned with first stator port 73a such that first stator port 73a is fully open and second stator port 73b is closed. First stator port 73a remains fully open through the time when side boundary 116 of rotor port 56 aligns with a side boundary of the wedge-shaped opening of first stator port 73a, as shown in FIG. 23B.

[0063] As shown in FIG. 23C, further rotation of valve rotor 24 causes side boundary 116 of rotor port 56 to move across first stator port 73a thereby reducing the open cross-sectional area of first stator port 73a and reducing the fluid flow rate through first stator port 73a. The first stator port 73a is partially open and the second stator port 73b is closed through the time when side boundary 118 of rotor port 56 aligns with a first side boundary of the wedge-shaped opening of second stator port 73b, as shown in FIG. 23C. Further rotation of valve rotor 24 causes side boundary 118 of rotor port 56 to move past the first side boundary of

second stator port 73b, thereby placing both first and second stator ports 73a and 73b in partially open positions, as shown in FIG. 23D. In this embodiment, the valve assembly is configured to have first and second stator ports 73a and 73b partially open simultaneously as shown in FIG. 23D. The valve assembly remains in this simultaneous partially open position until side boundary 116 aligns with a second side boundary of first stator port 73a to place first stator port 73a in the closed position, as shown in FIG. 23E. As valve rotor 24 rotates further and side boundary 118 of rotor port 56 moves across the second stator port 73b, second stator port 73b is further opened and the fluid flow rate through the second stator port 73b increases. During this time, first stator port 73a is closed and second stator port 73b is partially open.

[0064] As shown in FIG. 23F, second stator port 73b is placed in a fully open position when side boundary 118 of rotor port 56 aligns with a second side boundary of second stator port 73b. Second stator port 73b remains in the fully open position through the time when side boundary 116 of rotor port 56 aligns with the first side boundary of second stator port 73b as shown in FIG. 23G.

[0065] As shown in FIG. 23H, further rotation of valve rotor 24 causes side boundary 116 of rotor port 56 to move across second stator port 73b, thereby reducing the open cross-sectional area of second stator port 73b and reducing the fluid flow rate therethrough. The first stator port 73a is closed and the second stator port 73b is partially open through the time when side boundary 118 of rotor port 56 aligns with the first side boundary of first stator port 73a, as shown in FIG. 23H. Further rotation of valve rotor 24 causes side boundary 118 of rotor port 56 to move past the first side boundary of first stator port 73a to place both stator ports 73a and 73b in partially open positions, as shown in FIG. 23I. The valve assembly remains in this simultaneous partially open position until side boundary 116 of rotor port 56 aligns with the second side boundary of second stator port 73b to place second stator port 73b in the closed position, as shown in FIG. 23J. As valve rotor 24 continues to rotate and side boundary 118 of rotor port 56 moves across the first stator port 73a, first stator port 73a is further opened and the fluid flow rate through the first stator port 73a increases. During this time, first stator port 73a is partially open and second stator port 73b is closed. As shown in FIG. 23K, first stator port 73a is placed in the fully open position when side boundary 118 of rotor port 56 aligns with the second side boundary of first stator port 73a. FIG. 23L again illustrates the valve assembly in the first position, in which first stator port 73a is fully open and second stator port 73b is closed. Table 1 lists the positions of the stator ports in each view of FIG. 23.

TABLE 1

Figure	Position of First stator port 73a	Position of Second stator port 73b
FIG. 23A	Fully open	Closed
FIG. 23B	Fully open	Closed
FIG. 23C	Partially open	Closed
FIG. 23D	Partially open	Partially open
FIG. 23E	Closed	Partially open
FIG. 23F	Closed	Fully open
FIG. 23G	Closed	Fully open
FIG. 23H	Closed	Partially open

TABLE 1-continued

Figure	Position of First stator port 73a	Position of Second stator port 73b
FIG. 23I	Partially open	Partially open
FIG. 23J	Partially open	Closed
FIG. 23K	Fully open	Closed
FIG. 23L	Fully open	Closed

[0066] The theoretical activation duration of each stator port **73a**, **73b** (i.e., the rotation of valve rotor **24** for which such stator port **73a** or **73b** is fully or partially open) may be greater than 120 degrees, preferably greater than 150 degrees, and most preferably about 180 degrees. The embodiment illustrated in FIG. **23** provides a theoretical activation duration of about 180 degrees. Second stator port **73b** is partially or fully open from the time that side boundary **118** of rotor port **56** crosses the first side boundary of second stator port **73b** (immediately after the position illustrated in FIG. **23C**) until the time that side boundary **116** crosses the second side boundary of second stator port **73b** (immediately before FIG. **23J**).

[0067] FIGS. **24** and **25** illustrate steering section **14** in a default position in which pistons **80** are in retracted positions. This embodiment of rotary steerable system **10** includes two pistons **80**, with the center points of the two pistons **80** separated by about 180 degrees. Because steering section **14** includes only two pistons **80** in each transverse cross-sectional plane, distribution flow passages **72a** and **72b** may be positioned within a central area of steering housing **22**. In some embodiments, main flow passages **66** may extend from the central area outward radially. Distribution flow passages **72a**, **72b** and main flow passages **66** may be positioned between piston receptacles **82**. Optionally, main flow passages **66** may also extend beyond the space between piston receptacles **82**. The position of the distribution flow passages **72a**, **72b** in the central area within the same transverse cross-sectional plane as pistons **80** eliminates the need for a spider to rearrange flow lines through a length of the steering unit (i.e., distribution flow passages remain in the central area from the valve assembly **124** to the feed channels **74** and pistons **80**).

[0068] In certain embodiments, the central area may be defined by a circular path that includes the center of the inner boundary of each piston receptacle **82** and is centered on the center of the steering section **14**. In other embodiments, the central area may be defined by a central diameter surrounding the center of the steering section **14**. The central diameter may be in the range of 1.5 inches to 3.0 inches, preferably about 1.75 inches to about 2.5 inches, or any subrange therein. In certain embodiments, the central diameter may be about 1.75 inches in a steering unit having a diameter less than or equal to 5.25 inches, about 2 inches in a steering unit having a diameter less than or equal to 6.75 inches, and about 2.5 inches in a steering unit having a diameter less than or equal to 9 inches. A ratio of the central diameter to the steering section diameter may be 0.5 or less, 0.4 or less, preferably 0.33 or less, more preferably 0.3 or less.

[0069] In the embodiment illustrated in FIG. **25**, steering section **14** includes axis **x** and axis **y** intersecting at the central point of steering section **14** as shown. The central area in which distribution flow passages **72** are positioned is defined by distribution distance **130** between the central

point and a line **D** extending from an outer most point on one of the distribution flow passages **72**. Line **M** is defined by the inner boundary of one of the main flow passages **66**. Line **M** is spaced apart from the central point by main distance **132**. Line **P** is defined by the inner boundary of one of the piston receptacles **82**. Line **P** is spaced apart from the central point by piston distance **134**. In this embodiment, distribution distance **130** is greater than main distance **132**, and piston distance **134** is greater than distribution distance **130**. In other words, at least a portion of each main flow passage **66** is closer to the central point of the steering section than the outer boundary of the distribution flow passages **72**. Additionally, at least a portion of each main flow passage **66** is closer to the central point of the steering section than the inner boundary of the piston receptacle **82** and the position of the piston in its retracted position.

[0070] The rotary steerable system disclosed herein includes distribution flow passages **72a**, **72b** having larger diameters and main flow passages **66** having larger diameters than in conventional rotary steerable systems. The larger diameters of these flow lines reduce the fluid flow speed, prevent a water hammer effect, reduce erosion, and reduce pressure drop in order to preserve energy. A ratio of a diameter of each distribution flow passage **72a**, **72b** to a diameter of steering section **14** may be at least 0.07. In certain embodiments, a diameter of each distribution flow passage **72a**, **72b** is about 0.35 inches in a steering section **14** having a diameter of at least 5.25 inches, about 0.5 inches in a steering section **14** having a diameter of at least 6.75 inches, and about 0.67 inches in a steering section **14** having a diameter of at least 9 inches.

[0071] With reference to FIGS. **10**, **13**, and **20-23**, valve assembly **124** (shown in FIGS. **20-23**) may be positioned at the upper end of the distribution flow passages (shown in FIGS. **10**) such that circular openings **96** on the second side **98** of stator ports **73** (shown in FIG. **13**) align with distribution flow passages **72**. Specifically, circular opening **96** of stator port **73a** aligns with distribution flow passage **72a**, and circular opening **96** of stator port **73b** aligns with distribution flow passage **72b**. As valve rotor **24** rotates relative to valve stator **26** (as shown in FIG. **23**), stator ports **73a** and **73b** circulate through fully open, partially open, and closed positions, thereby directing fluid flowing through inner space **48** within housing **45** of lower control unit **32** into first distribution flow passage **72a**, second distribution flow passage **72b**, or a combination thereof.

[0072] FIGS. **26** and **27** illustrate steering section **14** in a first extended position when first stator port **73a** is fully open (as shown in FIGS. **23A** and **23B**). In this position, valve assembly **124** directs the fluid within inner space **48** of lower control unit **32** into first distribution flow passage **72a**. Specifically, the drilling fluid that has entered inner space **48** of lower control unit **32** flows through rotor port **56** of valve rotor **24**, through first stator port **73a**, through first distribution flow passage **72a**, through feed channels **74**, and into first piston receptacles **82a**. The fluid flowing into first piston receptacles **82a** applies a radial outward force on first pistons **80a**, thereby causing first pistons **80a** to move in a radially outward direction. In this first extended position, first pistons **80a** may engage a wall of a wellbore being drilled through a subterranean formation in order to adjust the direction in which the wellbore is drilled further. The

drilling fluid that flows through the spaces in impeller **40** flows through main flow passages **66**, thereby bypassing the piston assemblies **76**.

[0073] Referring again to FIG. **27**, each piston **80a** and **80b** may have a length of  $L_p$  and a diameter of  $D_p$ . In some embodiments a ratio of each piston's length to the piston's width is between 1 and 1.4, preferably between 1.1 and 1.3, or any subrange therein. For example, each of the pistons may have a length of 2.09 inches and a diameter of 1.73 inches, resulting in a ratio of about 1.2. In another example, the pistons may have a length of 2.88 inches and a diameter of 2.43 inches, resulting in a ratio of about 1.2. In yet another example, the pistons may have a length of 3.78 inches and a diameter of 3.12 inches, resulting in a ratio of about 1.2.

[0074] Additionally, each piston **80a** and **80b** extends a stroke length  $S$  from its default position when activated. The pistons may have a ratio of stroke length to piston diameter that is greater than 0.06, preferably greater than 0.7, or about 0.08. For example, the stroke length of the piston may be between 0.3 inches and 0.5 inches in an embodiment having a steering section diameter of at least 5.25 inches. In another example, the stroke length of the piston may be between 0.4 inches and 0.6 inches in an embodiment having a steering section diameter of at least 6.75 inches. In yet another example, the stroke length of the piston may be between 0.6 inches and 0.8 inches in an embodiment having a steering section diameter of at least 9 inches.

[0075] FIGS. **28** and **29** illustrate steering section **14** in a neutral position when first and second stator ports **73a**, **73b** are both partially open (as shown in FIGS. **23D** and **23I**). In this position, valve assembly **124** directs the fluid within inner space **48** of lower control unit **32** into both first and second distribution flow passages **72a**, **72b**. As the fluid flow through first stator ports **73a** and ultimately into piston receptacles **82a** decreases, a force exerted by a wall of a wellbore on pistons **80a** may overcome the outward force of the fluid flow into piston receptacles **82a**, which may force pistons **80a** to retract in a radially inward direction into piston receptacles **82a**. The excess fluid in receptacle **82a** is expelled through the exhaust port. Simultaneously, the drilling fluid flowing through second stator port **73b** flows through second distribution flow passage **72b**, through feed channels **74**, and into piston receptacles **82b**. The fluid flowing into piston receptacles **82b** begins to apply a radial outward force on second pistons **80b**, thereby causing second pistons **80b** to begin moving in a radially outward direction.

[0076] FIGS. **30** and **31** illustrate steering section **14** in a second extended position when second stator port **73b** is fully open (as shown in FIGS. **23F** and **23G**). In this position, valve assembly **124** directs all fluid within inner space **48** of lower control unit **32** into second distribution flow passage **72b**. As the fluid flow through second stator ports **73b** and ultimately into piston receptacles **82b** increases, the fluid flow applies a greater radial outward force on second pistons **80b**, thereby causing second pistons **80b** to fully extend in the radially outward direction. In this second extended position, second pistons **80b** may engage the wall of the wellbore in order to adjust the drilling in an opposite direction. In all positions of the steering section **14**, the drilling fluid that flows through the spaces in impeller **40** flows through main flow passages **66**, thereby bypassing the piston assemblies **76**.

[0077] The theoretical activation duration of each piston **80a**, **80b** (i.e., the rotation of valve rotor **24** for which each piston **80a**, **80b** is fully or partially extended) is equivalent to the theoretical activation duration of each stator port **73a**, **73b**, which is discussed above. Rotary steerable system **10** may be configured to provide a theoretical activation duration of each piston **80a**, **80b** that is greater than 120 degrees, preferably greater than 150 degrees, and most preferably about 180 degrees. The actual observed activation duration of each piston **80a**, **80b** may be less than the theoretical activation duration because of actuation timing delays. As used herein, "activation duration" means the angle of rotation of valve rotor **24** during which a specified component is activated by or receives by fluid flow. The two-piston configuration of the rotary steerable system disclosed herein may provide a greater activation duration of each piston as compared to conventional rotary steerable systems including three-piston configurations due to fewer transitions in each rotation of the valve and due to larger angular separation of the side boundaries of each stator port.

[0078] Steering section **14** may include any number of pistons within the piston assemblies. In this embodiment illustrated in FIGS. **32-35**, steering section **14** includes a first piston assembly **76a** including two pistons **80a** and a second piston assembly **76b** including three pistons **80b**. In the illustrated embodiment pistons **80a** may be staggered along the axial length of steering housing **22** relative to pistons **80b**, as shown in FIG. **33**. In other words, the steering section **14** includes only one piston in a transverse cross-sectional plane, such as plane A-A. In other embodiments, the offset pistons are separated by a length that is equal to the steering section diameter. Alternatively, the steering section **14** may include only a one piston.

[0079] Referring now to FIGS. **36** and **37**, rotary steerable system **10** may be secured downstream of flex shaft **152** and upstream of drill bit **154** in a bottom hole assembly **155**.

[0080] The rotary steerable system of the present invention, which includes a steering section and a control section, is significantly shorter than conventional rotary steerable systems. The combined length of the steering section and the control section is less than 150 inches, less than 125 inches, less than 100 inches, less than 80 inches, less than 75 inches, less than 70 inches, less than 65 inches, or any subrange therein. In one embodiment, the rotary steerable system has a minimum diameter of about 5.25 inches, and a combined length of about 63 inches. In another embodiment, the rotary steerable system has a minimum diameter of about 6.75 inches, and a combined length of about 67 inches. In still another embodiment, the rotary steerable system has a minimum diameter of about 9 inches, and a combined length of about 74 inches.

[0081] Alternatively, the rotary steerable system has a length to steering section diameter ratio of less than 16, less than 14, less than 11, less than 10, less than 9, or any subrange therein. As used herein, "length to steering section diameter ratio" means a ratio of the combined length of the steering section and control section to the minimum outer diameter of the steering section or the control section (in inches). For example, but not by way of limitation, the rotary steerable system may have a diameter less than or equal to 5.25 inches, and a length to steering section diameter ratio of less than 13, less than 12, or any subrange therein. Alternatively, the rotary steerable system may have a diameter less than or equal to 6.75 inches, and a length to steering

section diameter ratio of less than 11, less than 10, or any subrange therein. In other embodiments, the rotary steerable system may have a diameter less than or equal to 9 inches, and a length to steering section diameter ratio of less than 9.

[0082] With reference again to FIGS. 36 and 37, flex shaft 152 may be secured above rotary steerable system 10, and drill bit 154 may be secured below rotary steerable system 10. The reduced length of the rotary steerable system 10 positions flex shaft 152 closer to drill bit 154 than in conventional rotary steerable systems, thereby enabling the rotary steerable system to turn the drill bit path by a smaller radius. For example, the rotary steerable system disclosed herein may enable a maximum turn rate of 14 degrees per 100 feet. In another embodiment, the rotary steerable system disclosed herein may enable a maximum turn rate of 18 degrees per 100 feet. In yet another embodiment, the rotary steerable system disclosed herein may enable a maximum turn rate of 24 degrees per 100 feet. In effect, the reduced length rotary steerable system 10 behaves as a hybrid push-the-bit/point-the-bit system as control section 12 and steering section 14 are deflected (i.e., pushed) as one and become pointed in the desired direction. The maximum turn rate values may be affected by environmental conditions, including conditions within a wellbore or conditions of a subterranean formation.

[0083] The reduced length of the rotary steerable system of the present invention is achieved due to several features. For example, lower filter 49 and valve assembly including valve rotor 24 and valve stator 26 are incorporated into a single module, as shown in FIG. 10. In contrast, conventional rotary steerable systems include separate modules for filters and valves. Additionally, the absence of a battery reduces the length of control section 12. Another example is the use of smaller memory components, such as micro-electromechanical systems (“MEMS”), in the control section 12. Conventional rotary steerable systems teach away from smaller memory components in favor of larger memory components capable of storing data required for well surveys. Further, the rotary steerable system disclosed herein includes only three sensors in control section 12, thereby reducing the length of the control section 12. Conventional rotary steerable systems include a greater number of sensors, which require a greater length of the control section. Another example is the transition of the shape of stator ports 73 across the thickness of valve stator 26, which reduces the length of transition flow lines needed in steering housing 22 between the valve assembly and the pistons 80. Furthermore, the central position of distribution flow passages 72 within steering section 14 eliminates the requirement for a spider, which transposes the main flow and distribution flow lines between the valve and pistons in conventional rotary steerable systems.

[0084] The reduced length of the rotary steerable system disclosed herein provides the commercial advantage of requiring less material for construction, thereby reducing costs of manufacturing and maintenance. In some embodiments, the components of the rotary steerable system disclosed herein are more accessible from outside of the rotary steerable system, which enables users to perform certain additional maintenance tasks in any location without the need for transporting the rotary steerable system to a shop.

[0085] In other embodiments, the rotary steerable system of the present invention includes only a steering section without a control section. In this embodiment, the elements

of the control section may be incorporated into the steering section, positioned in adjacent devices in the drill string, eliminated, or any combination thereof.

[0086] As illustrated in FIGS. 2-9, the rotary steerable system disclosed herein, such as rotary steerable system 10, includes nine modules, with each module comprising a unit that may be maintained, assembled, disassembled, or exchanged independently of the other modules. The modules of the rotary steerable system disclosed herein are listed in Table 2 below.

TABLE 2

Modules of steering section 14	Steering housing 22 Pistons 80 Piston clamps 81 Spacers 84 Screw sets for spacers 84
Modules of control section 12	Control sleeve 16 Guides 34, 36 with bolts Electronics 30, lower control unit 32, and inner portions of upper control unit 28 Housing of upper control unit 28

[0087] The rotary steerable system of the present invention is configured to provide a bottom hole assembly (BHA) that achieves higher build-up rates (BUR) than BHAs including conventional rotary steerable systems. The high BUR of the BHA disclosed herein is achievable largely due to the short distance between certain contact points at which the BHA may contact the wellbore during drilling operations, as well as other factors such as drill bit diameter, piston pads under-gauge, and stabilizer under-gauge. The different factors contributing to the high BUR of the present invention are discussed in detail below.

[0088] BUR is a measure of the rate at which a rotary steerable system causes a BHA to turn, often expressed in degrees per 100 feet of drilling. FIG. 38 is a schematic representation of the BUR of a BHA traveling along path 156. The BHA may include a rotary steerable system connected between a flex shaft and a drill bit. The BHA may begin at first point 156a with a direction of travel generally along first axis 158. During travel along path 156, the BHA may turn at a particular rate, thereby changing the direction of travel. The BHA's direction of travel when it reaches second point 156b may be along second axis 160. The overall change in direction of travel from first axis 158 to second axis 160 during travel is represented in FIG. 38 as angle  $\theta$ . BUR may thus be expressed as the angle  $\theta$  in degrees between first axis 158 and second axis 160 per 100 feet of travel along path 156. By way of example only, a BHA or a rotary steerable system with a BUR of 10 degrees per 100 feet may travel a distance of 300 feet at an angle  $\theta$  of 30 degrees. In some embodiments, the BUR of a BHA or a rotary steerable system varies over a distance and a local BUR may be measured over a shorter distance.

[0089] Referring back to FIGS. 36-37, BHA 155 may include first contact point 162, second contact point 164, and third contact point 166. In one embodiment, first contact point 162 may be on drill bit 154, while second and third contact points 164 and 166 are on rotary steerable system 10. First contact point 162 may be defined by the location of the first set of upstream cutters of drill bit 154. At this first contact point 162, the first upstream cutters of drill bit 152 may contact the wellbore. Second contact point 164 may be

defined by the center point of piston assembly **76**. In some embodiments, second contact point **164** is a center point between the two pistons **80**. At this second contact point **164**, the two pistons **80** may contact the wellbore when in an actuated configuration and piston clamp **81** may contact the wellbore when the pistons **80** are in a retracted configuration. Third contact point **166** may be defined as the center point of stabilizer **168** of control section **12**. At this third contact point **166**, stabilizer **168** may contact the wellbore. Third contact point **166** may be disposed proximate to flex shaft **152**. The proximity of third contact point **166** and flex shaft **152** enhances the BUR achieved by BHA **155**.

**[0090]** A first distance  $L_1$  from first contact point **162** to second contact point **164** represents the length of the BHA between the first upstream cutters of drill bit **154** and the center point between the two pistons **80** of piston assembly **76**. A second distance  $L_2$  from second contact point **164** to third contact point **166** represents the length of the rotary steerable system from the center point between the two pistons **80** of piston assembly **76** to the center point of stabilizer **168**. Together, first distance  $L_1$  and second distance  $L_2$  are the overall distance from first contact point **162** to third contact point **166**, representing the length of the BHA between the first upstream cutters of drill bit **154** to the center point of stabilizer **168**.

**[0091]** The first distance  $L_1$  and second distance  $L_2$  may alternatively be expressed as ratios of length to drill bit diameter  $D_0$ . The drill bit diameter  $D_0$  is the diameter of drill bit **154** at the first cutter, i.e., at first contact point **162**. The drill bit diameter  $D_0$ , which may be equivalent to a nominal hole diameter, may typically be 6 inches, 8.5 inches, or 12.25 inches. As one skilled in the art will understand, the drill bit diameter  $D_0$  may be any diameter sufficient for drilling a wellbore. Thus, first ratio  $R_1$  may be the ratio of distance  $L_1$  to drill bit diameter  $D_0$ , while second ratio  $R_2$  may be the ratio of distance  $L_2$  to drill bit diameter  $D_0$ .

**[0092]** FIG. **39** illustrates additional details of the present invention. Pads under-gauge (PU) may be defined as the difference between drill bit diameter  $D_0$  and the outer diameter of the rotary steerable system at piston assembly **76** with pistons **80** in the retracted position. In this way, PU is the difference between drill bit diameter  $D_0$  and the outer diameter of the rotary steerable system at second contact point **164**. By way of example only, PU may be 0.25 inches to 0.5 inches or any subrange therein, preferably, 0.35 inches to 0.4 inches or any subrange therein, and more preferably, 0.375 inches. As one skilled in the art will recognize, half of PU, i.e.,  $PU/2$ , is illustrated on one side of rotary steerable system **10** in FIG. **39**, with the other half extending on the opposite side of the rotary steerable system **10**. Stabilizer under-gauge (SU) may be defined as the difference between drill bit diameter  $D_0$  and the outer diameter of stabilizer **168**. In this way, SU is the difference between drill bit diameter  $D_0$  and the outer diameter of the rotary steerable system **10** at third contact point **166**. By way of example only, SU may be 0 inches to 0.25 inches or any subrange therein, preferably, 0.12 inches to 0.15 inches or any subrange therein, and more preferably, 0.125 inches. As one skilled in the art will recognize, half of SU, i.e.,  $SU/2$ , is illustrated on one side of rotary steerable system **10** in FIG. **39**, with the other half extending on the opposite side of rotary steerable system **10**.

**[0093]** The BHA's BUR may be calculated according to the following formula using the above parameters:

$$BUR = \frac{216,000}{\pi D_0^2 (R_1 + R_2)} \left[ \frac{PU}{R_1} + \frac{PU}{R_2} - \frac{SU}{R_2} \right]$$

TABLE 3

Variable	Definition
$R_1$	Ratio = $\frac{L_1}{D_0}$
$R_2$	Ratio = $\frac{L_2}{D_0}$
$L_1$	Length from first contact point to second contact point (inches)
$L_2$	Length from second contact point to third contact point (inches)
$D_0$	Outer diameter of drill bit (inches)
PU	Pads under-gauge (inches) = $D_0 - D_p$
SU	Stabilizer under-gauge (inches) = $D_0 - D_s$
$D_p$	Outer diameter of rotary steerable system at piston assembly (inches)
$D_s$	Outer diameter at rotary steerable system at stabilizer (inches)

**[0094]** By way of example only, the rotary steerable system may have a pads under-gauge PU of 0.375 inches and a stabilizer under-gauge SU of 0.125 inches. Such a rotary steerable system may have a drill bit diameter  $D_0$  of 6 inches, 8.5 inches, or 12.25 inches. Such a rotary steerable system may have a first distance  $L_1$  of 23 inches or less, 21 inches or less, 19 inches or less, 17 inches or less, 15 inches or less, 13 inches or less, or any subrange therein. Such a rotary steerable system may have a second distance  $L_2$  of 39 inches or less, 43 inches or less, 49 inches or less, 55 inches or less, 76 inches or less, 75 inches or less, or any subrange therein. The overall length of the rotary steerable system may thus be 88 inches or less, 79 inches or less, 72 inches or less, 68 inches or less, 64 inches or less, 62 inches or less, or any subrange therein. Such a rotary steerable system may have a BUR of at least 25 degrees per 100 feet of drilling distance.

**[0095]** The above formula calculates a maximum theoretical BUR of a particular BHA. The actual BUR achieved by a BHA may also depend on other factors, such as the amount of force exerted by the pistons **80** when in the actuated configuration, the distance of the piston extension, the inclination of the wellbore, the amount of axial load on the BHA, and many others.

**[0096]** The BHA disclosed herein is autonomous and self-sufficient. It does not require any external function from another system or tool. Even though the high BUR is achieved largely by the BHA's shorter overall length, the BHA remains a self-sufficient tool. In other words, the reduced length of the rotary steerable system and BHA is not achieved by removing or omitting certain functional components from the tool. As illustrated in FIG. **40**, the BHA **155** may include certain functional components or modules, including communication module **170**, power module **172**, control module **174**, filter module **176**, valve module **178**, steering module **180**, and pressure regulation module **182**. One embodiment of each of these modules is illustrated in FIGS. **1-35** and described above.

[0097] Communication module 170 may include an antenna for transmitting measurement data and other data to an MWD unit secured above the rotary steerable system. Communication module 170 may be positioned between first contact point 162 and third contact point 166. In alternate embodiments, communication module 170 may be positioned between second contact point 164 and third contact point 166. In other embodiments, such as the embodiment illustrated in FIG. 40, communication module 170 may be positioned at least partially downstream of an upstream end of stabilizer 168. In other words, at least a portion of communication module 170 is disposed between an upstream end of stabilizer 168 and first contact point 162.

[0098] Power module 172 is configured to generate power for the rotary steerable system. Accordingly, the presence of power module 172 eliminates the need to use batteries for powering the rotary steerable system. Power module 172 may be positioned between first contact point 162 and third contact point 166. In some embodiments, such as the embodiment depicted in FIG. 40, power module 172 may be positioned between second contact point 164 and third contact point 166.

[0099] Control module 174 may be configured to determine the position of the rotary steerable system during drilling and may include, for example, an electronics unit having sensors such as a magnetometer for sensing a north-south direction, an accelerometer for sensing inclination, and a gyrometer for sensing rotation of the control unit relative to a surrounding subterranean formation. Control module 174 may be positioned between first contact point 162 and third contact point 166. In some embodiments, such as the embodiment depicted in FIG. 40, control module 174 may be positioned between second contact point 164 and third contact point 166.

[0100] Filter module 176 may be configured to filter diverted drilling fluid that will be used to actuate the pistons of the rotary steerable system. Filter module 176 may include any combination of components configured to filter solid particles from drilling fluid or other fluid. In certain embodiments, filter module 176 may include a filter formed of rings with shoulders such that the stacking of the rings creates small interstices that function to filter. In other embodiments, filter module 176 may include a cylinder including slots, such as a one-piece cylinder including axially arranged slots. Filter module 176 may be positioned between first contact point 162 and third contact point 166. In some embodiments, such as the embodiment depicted in FIG. 40, filter module 176 may be positioned between second contact point 164 and third contact point 166.

[0101] Valve module 178 may be configured to divert drilling fluid to actuate the pistons of the rotary steerable system and may include, for example, a valve rotor and valve stator, the position of which determine which pistons are actuated. Valve module 178 may be positioned between first contact point 162 and third contact point 166. In some embodiments, such as the embodiment depicted in FIG. 40, valve module 178 may be positioned between second contact point 164 and third contact point 166.

[0102] Steering unit module 180 may be configured to turn the rotary steerable system during drilling. In certain embodiments, steering unit module 180 may include pistons that may be actuated by valve module 178. In other embodiments, steering unit module 180 may include pads that may be actuated by valve module 178. In still other embodi-

ments, steering unit module 180 may include pads actuated by pistons, which are in turn actuated by valve module 178. In one such embodiment, hinged pads may cover pistons and the pistons may push the pads open by rotating the hinged pads around a hinge axis. Steering unit module 180 may be positioned between first contact point 162 and third contact point 166. In some embodiments, steering unit module 180 may form the second contact point 164 as illustrated in FIG. 40.

[0103] Pressure regulation module 182 may be configured to add some pressure drop to the system if necessary. Pressure regulation module 182 may include, for example, a flow restrictor. Pressure regulation module 182 may be positioned between first contact point 162 and third contact point 166. In some embodiments, such as the embodiment illustrated in FIG. 40, pressure regulation module 182 may be positioned between first contact point 162 and second contact point 164. In other embodiments, pressure regulation module 182 may be positioned between second contact point 164 and third contact point 166.

[0104] As used herein, “upper” and “lower” are to be interpreted broadly to include “proximal” and “distal” such that the structures may not be positioned in a vertical arrangement. Additionally, the elements described as “upper” and “lower” may be reversed such that the structures may be configured in the opposite vertical arrangement.

[0105] Except as otherwise described or illustrated, each of the components in this device has a generally cylindrical shape and may be formed of steel, another metal, or any other durable material. Portions of the rotary steerable system may be formed of a wear resistant material, such as tungsten carbide or ceramic coated steel.

[0106] Each device described in this disclosure may include any combination of the described components, features, and/or functions of each of the individual device embodiments. Each method described in this disclosure may include any combination of the described steps in any order, including the absence of certain described steps and combinations of steps used in separate embodiments. Any range of numeric values disclosed herein includes any subrange therein. “Plurality” means two or more. “Above” and “below” shall each be construed to mean upstream and downstream, such that the directional orientation of the device is not limited to a vertical arrangement.

[0107] While preferred embodiments have been described, it is to be understood that the embodiments are illustrative only and that the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalents, many variations and modifications naturally occurring to those skilled in the art from a review hereof.

1. A bottom hole assembly, comprising:

a drill bit having a first contact point;

a rotary steerable system including a steering section, a power module, and a stabilizer; wherein the steering section has a second contact point and the stabilizer has a third contact point; wherein the power module is configured to generate power for the rotary steerable system, wherein the power module is disposed between the first contact point and the third contact point;

wherein the bottom hole assembly is configured to achieve a build-up-rate (BUR) of at least 25 degrees per 100 feet of drilling.



2. The bottom hole assembly of claim 1, wherein the power module is disposed between the second contact point and the third contact point.

3. The bottom hole assembly of claim 1, further comprising a control module disposed between the first contact point and the third contact point.

4. The bottom hole assembly of claim 3, wherein the control module is disposed between the second contact point and the third contact point.

5. The bottom hole assembly of claim 3, further comprising a communication module disposed between the first contact point and an upstream end of the stabilizer.

6. The bottom hole assembly of claim 5, wherein the communication module is disposed between the first contact point and the third contact point.

7. The bottom hole assembly of claim 5, further comprising a filter module disposed between the first contact point and the third contact point.

8. The bottom hole assembly of claim 7, wherein the filter module is disposed between the second contact point and the third contact point.

9. The bottom hole assembly of claim 7, further comprising a valve module disposed between the first contact point and the third contact point.

10. The bottom hole assembly of claim 9, wherein the valve module is disposed between the second contact point and the third contact point.

11. The bottom hole assembly of claim 9, further comprising a pressure regulation module disposed between the first contact point and the third contact point.

12. (canceled)

13. (canceled)

14. (canceled)

15. (canceled)

16. (canceled)

17. (canceled)

18. (canceled)

19. (canceled)

20. (canceled)

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