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(54) **Title**: ACTUATION SYSTEM AND METHOD FOR A DOWNHOLE TOOL

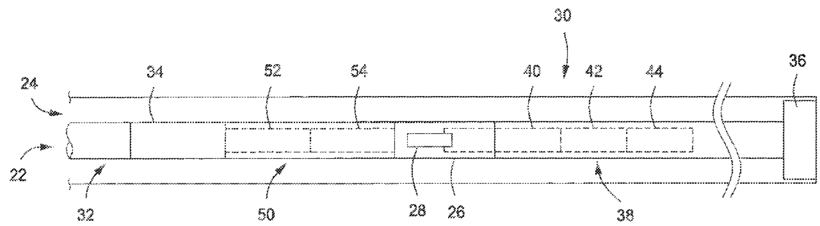

FIG. 1

(57) **Abstract**: An actuation system and method for a downhole tool. The downhole tool includes a body having an axial bore extending at least partially therethrough and a chamber disposed radially-outward from the bore. A valve is disposed within the bore and adapted to move between a first position which prevents fluid flow from the bore to the chamber through a port and a second position which permits the fluid flow from the bore to the chamber through the port. A motor, disposed within the bore, is adapted to move the valve between the first and second positions. An actuatable component of the downhole tool, e.g., a cutter block of an underreamer downhole tool, is movably coupled to the body and adapted to move from a non-actuated state to an actuated state in response to fluid flow through the port into the chamber.

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ACTUATION SYSTEM AND METHOD FOR A DOWNHOLE TOOL

BACKGROUND

[0001] Embodiments disclosed herein generally relate to downhole tools. More particularly, one or more embodiments disclosed herein relate to a system and method for the actuation of downhole tools to perform their intended operations and/or functions.

[0002] During the drilling of a wellbore, a downhole tool is oftentimes employed to perform an intended operation or function of the downhole tool, *e.g.*, an underreamer is employed to enlarge the diameter of the wellbore. Using the underreamer as an example downhole tool, the conventional underreamer has a body with an axial bore extending axially therethrough through which fluid flows. One or more cutter blocks are movably coupled to the body and adapted to transition between a retracted state and an expanded state.

[0003] The underreamer in the retracted state is run into the wellbore via a drill string. In the retracted state, the cutter blocks are folded into the body of the underreamer such that the cutter blocks are positioned radially-inward from the surrounding casing or wellbore wall. Once the underreamer reaches the desired depth in the wellbore, the underreamer is actuated into the expanded state. In the expanded state, the cutter blocks move radially-outward and into contact with the wellbore wall. The cutter blocks are then used to cut or grind the wall of the wellbore to increase the diameter thereof.

SUMMARY

[0004] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0005] A downhole tool having an actuation system is disclosed. The downhole tool includes a body having a bore axially extending at least partially therethrough and a chamber disposed radially-outward from the bore, *e.g.*, within a wall of the body. The bore is in fluid communication with the chamber through a port. A valve is disposed within the bore and adapted to move between a first position in which the valve prevents fluid flow from the bore to the chamber through the port and a second position in which the valve permits fluid to flow from the bore to the chamber through the port. A motor is disposed within the bore and adapted to move the valve between the first position and the second position. An actuatable component of the downhole tool, movably coupled to the body, is adapted to move between a non-actuated state and an actuated state in response to fluid flow into the chamber through the port. A position sensor system is disposed at least partially within the bore and is adapted to measure an axial position of the actuatable component. The position sensor system includes:

at least one magnet coupled to the actuatable component; and

a probe disposed within the bore, the probe having a plurality of boards, the probe further having plurality of magnetometers arranged in multiple arrays, with each array of the multiple arrays extending axially along, and on a different one of, the plurality of boards, each board of the plurality of boards being axially aligned and connected to each other board of the plurality of boards such that each array of the multiple arrays is circumferentially offset from each other array of the multiple arrays.Movement of the valve between the first position and the second position may include linear or rotational valve movement. In one or more embodiments disclosed herein, the downhole tool is an underreamer and the actuatable component is a cutter block which is adapted to move between a retracted state when the valve is in the first position and an expanded state when the valve is in the second position.

[0006] In another embodiment, the downhole tool includes a body having a bore axially extending at least partially therethrough and a chamber disposed radially-outward from the bore, *e.g.*, within a wall of the body. The bore is in fluid communication with the chamber through a port. A valve is disposed within the bore and adapted to move between a first position in which the valve prevents fluid flow through the port from the bore to the chamber and a second position in which the valve permits fluid flow through the port from the bore to the chamber. A motor is disposed within the bore and adapted to move the valve axially within the bore between the first position and the second position. An actuatable component of the downhole tool (such as a cutter block) is movably coupled to the body and is adapted to move between a non-actuated (or retracted) state when the valve is in the first position and an actuated (or expanded) state when the valve is in the second position. A position sensor system is disposed within the bore and is configured to measure an axial position of the actuatable component. A telemetry system, coupled to the position sensor system, is also disposed within the bore and configured to transmit a signal representative of the axial position of the actuatable component to a remote location, such as a surface location.

[0007] A method for actuating a downhole tool is also disclosed. The method includes transmitting a signal from a surface location to a downhole receiver disposed in a downhole tool. The signal controls one or more operations of a motor disposed within a bore that extends axially at least partially through a body of the downhole tool. A chamber is disposed radially-outward from the bore, *e.g.*, in a wall of the body. The motor is coupled to and moves a valve disposed within the bore between a first position and a second position. The valve prevents fluid flow through a port disposed between the bore and the chamber when the valve is in the first position and the valve permits fluid flow from the bore to the chamber through the port when the valve is in the second position. An actuatable component may be movably coupled to the body of the downhole tool and arranged and designed to move between a non-actuated state and an actuated state in response to an increase in hydraulic pressure in the chamber due to fluid flow into the chamber. The downhole tool is operated while the actuatable component thereof is actuated.

[0008] A well tool actuation system for use in a wellbore is disclosed. The well tool actuation system includes a valve disposed within an internal flow passage of a downhole tubular. The valve is arranged and designed to move between a first position sealing a port in an inner wall of the downhole tubular and a second position permitting fluid flow from the internal flow passage into the port. The valve has one or more passages therethrough to permit fluid to pass axially therethrough to a downhole drill bit regardless of the valve position. A motor is disposed within the internal flow passage of the downhole tubular to permit fluid in the internal flow passage to pass around the motor. The motor is coupled to the valve and arranged and designed to move the valve between the first position and the second position. A position sensor system is disposed at least partially within the internal flow passage and is adapted to measure an axial position of an actuatable component. The position sensor system includes:

at least one magnet coupled to the actuatable component; and

a probe disposed within the bore, the probe having a plurality of boards, the probe further having a plurality of magnetometers arranged in multiple arrays, each array of the multiple arrays extending axially along, and on a different one of, the plurality of boards, each board of the plurality of boards being directly connected to each other board of the plurality of boards such that each array of the multiple arrays is circumferentially offset from each other array of the multiple arrays. Movement of the valve between the first position and the second position may include linear or rotational valve movement.

[0009] In another embodiment, the well tool actuation system includes a valve module having a valve rotationally positioned within an internal flow passage of a downhole tubular. The valve is arranged and designed to move between a first rotational position blocking a port in an inner wall of the downhole tubular and a second rotational position permitting fluid flow into the port. The valve module and valve are also arranged and designed, *e.g.*, with passages therethrough, to permit drilling fluid to pass therethrough to a downhole drilling bit regardless of valve position. The valve is further arranged and designed to seat with a valve housing of the valve module in response to a pressure differential generated between the internal flow passage and the wellbore when drilling fluid passes through the valve module. A motor module is positioned within the internal flow passage of the downhole tubular to permit drilling fluid to pass therearound. The motor module includes a motor coupled to the valve to move the valve between the first rotational position and the second rotational position. An actuatable component, responsive to fluid flow into and through the port, is thus actuated by moving the valve from the first rotational position to the second rotational position.

[0010] A method is also disclosed. The method includes sending a command signal from an uphole location to a downhole receiver. The command signal controls the operation of a motor positioned within an internal flow passage of a downhole tubular. The motor moves a valve positioned within the downhole tubular between a first position sealing a port in an inner wall of the downhole tubular and a second position permitting fluid communication from the internal flow passage into the port. The valve is further arranged and designed to permit drilling fluid to pass therethrough to a downhole drilling bit regardless of the valve position. When the valve is in the second position, fluid communication from the internal flow passage into the port enables fluid flow into and through the port to actuate the actuatable component of the downhole tool. The method further includes measuring an axial position of the valve with a position sensor system disposed at least partially within the bore, wherein measuring the axial position of the valve includes determining a relative position of a probe including a plurality of magnetometers relative to a basket including at least one magnet, the probe further including a plurality of boards and the plurality of magnetometers being arranged in multiple arrays, each board of the plurality of boards having a different array of the multiple arrays extending axially therealong, and each board of the plurality of boards being connected to each other board of the plurality of boards such that each array of the multiple arrays is axially aligned with, and circumferentially offset from, each other of the multiple arrays

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the recited features may be understood in detail, a more particular description, briefly summarized above, may be had by reference to one or more embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings are illustrative embodiments, and are, therefore, not to be considered limiting of its scope.

[0012] Figure 1 depicts a schematic view of an illustrative downhole tool disposed within a wellbore and having an actuation system, according to one or more embodiments disclosed.

[0013] Figure 2 depicts a perspective view of an illustrative valve module, according to one or more embodiments disclosed.

[0014] Figure 3 depicts a perspective view of an illustrative motor module, according to one or more embodiments disclosed.

[0015] Figure 4 depicts a partial perspective view of the valve module and the motor module coupled by a self-aligning connector, according to one or more embodiments disclosed.

[0016] Figure 5 depicts a partial cross-sectional view of the valve module, according to one or more embodiments disclosed.

[0017] Figure 6 depicts a partial cross-sectional view of the valve module disposed in the downhole tool, according to one or more embodiments disclosed.

[0018] Figure 7 depicts a partial cross-sectional view of the valve module of Figure 6 actuated to a different operational position.

[0019] Figure 8-1 depicts a partial perspective view of a position sensing system, according to one or more embodiments disclosed.

[0020] Figure 8-2 depicts a partial perspective view of one embodiment of a sensor array portion of the position sensing system shown in Figure 8-1.

[0021] Figure 8-3 depicts a partial perspective view of the sensor array portion of the position sensing system shown in Figure 8-2, which is disposed in a drill string coupled uphole of the downhole tool, according to one or more embodiments disclosed.

[0022] Figure 9 depicts a partial cross-sectional view of the magnet basket or crown portion of the position sensing system disposed in the downhole tool, according to one or more embodiments disclosed.

[0023] Figure 10 depicts a partial perspective view of a portion of the position sensing system in the form of a diagnostic probe assembled with a positive pulse measurement-while-drilling tool, according to one or more embodiments disclosed.

[0024] Figure 11 depicts a partial cross-sectional view of the downhole tool having an illustrative actuation system but without the position sensing system, according to one or more embodiments disclosed.

[0025] Figure 12 depicts a partial cross-sectional view of the downhole tool including the valve module, according to one or more embodiments disclosed.

[0026] Figure 13 depicts a partial cross-sectional view of another portion of the downhole tool showing the valve module, according to one or more embodiments disclosed.

[0027] Figure 14 depicts a partial cross-sectional view of a drill string coupled downhole of the downhole tool and including therein an electronics section and a power source of the actuation system, according to one or more embodiments disclosed.

[0028] Figure 15 depicts a partial cross-sectional view of the downhole tool showing the valve module of Figure 13 in a first actuation position, according to one or more embodiments disclosed.

[0029] Figure 16 depicts a partial cross-sectional view of the downhole tool showing the valve module of Figure 13 in a second actuation position, according to one or more embodiments disclosed.

[0030] Figure 17 depicts a schematic view of an illustrative downhole tool disposed within the wellbore and having another actuation system, according to one or more embodiments disclosed.

[0031] Figure 18-1 depicts a partial cross-sectional view of an illustrative rotary fingered valve module disposed within the downhole tool, according to one or more embodiments disclosed.

[0032] Figure 18-2 depicts a perspective view of a fingered valve of the rotary fingered valve module of Figure 18-1, according to one or more embodiments disclosed.

[0033] Figure 19 depicts a partial cross-sectional view of the rotary fingered valve module of Figure 18-1 being coupled to a motor module by a self-aligning connector, according to one or more embodiments disclosed.

[0034] Figure 20 depicts a partial cross-sectional view of the downhole tool showing the rotary fingered valve module coupled to the motor module, according to one or more embodiments disclosed.

[0035] Figure 21 depicts a partial cross-sectional view of the downhole tool showing the rotary fingered valve module of Figure 20 in a first actuation position, according to one or more embodiments disclosed.

[0036] Figure 22 depicts a partial cross-sectional view of the downhole tool showing the rotary fingered valve module of Figure 20 in a second actuation position, according to one or more embodiments.

[0037] Figure 23 depicts a perspective view of an illustrative tapered valve component and a corresponding chamfered valve component for use with a rotary fingered valve module, according to one or more embodiments disclosed.

[0038] Figure 24 depicts a partial cross-sectional view of an illustrative rotary ported valve module that may be employed in the downhole tool, according to one or more embodiments disclosed.

[0039] Figure 25 depicts a cross-sectional view of the valve housing of the rotary ported valve module of Figure 24, according to one or more embodiments disclosed.

[0040] Figure 26 depicts a cross-sectional view of the downhole tool showing an illustrative rotary ported valve module of Figure 24 coupled to the motor module for actuating the downhole tool, according to one or more embodiments disclosed.

[0041] Figure 27 depicts a cross-sectional view of a portion of the well system of Figure 17, showing an illustrative rotary slotted valve module coupled to the motor module for actuating the downhole tool, according to one or more embodiments disclosed.

[0042] Figure 28 depicts a partial cross-sectional view of the downhole tool showing the rotary slotted valve module of Figure 27 in a first actuation position, according to one or more embodiments disclosed.

[0043] Figure 29 depicts a partial cross-sectional view of the downhole tool showing the rotary slotted valve module of Figure 27 in a second actuation position, according to one or more embodiments disclosed.

[0044] Figure 30 depicts a schematic view of an alternative valve module disposed within the downhole tool, according to one or more embodiments disclosed.

[0045] Figure 31 depicts a schematic view of another illustrative actuation system that may be disposed in a downhole tool, according to one or more embodiments disclosed.

DETAILED DESCRIPTION

[0046] In the following description, numerous details are set forth to provide an understanding of some illustrative embodiments of the present disclosure. However, it will be understood by those skilled in the art that the system and/or method may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0047] One or more embodiments of the present disclosure generally involve a system and method related to actuating a downhole tool. The downhole tools may be actuated remotely in a variety of environments, including wellbore environments. Such remote actuation, *e.g.*, between an uphole location and a downhole tool, may be conducted in any manner known to those skilled in the art and may include wired and/or wireless communication, acoustic waves, electromagnetic waves, mud pressure pulses, and/or signals transmitted via an insulated conductor. In at least one embodiment, the system and method may be used to actuate an actuatable component of the downhole tool, *e.g.*, the cutter blocks of an underreamer employed in a downhole drilling operation. System electronics and components also may be designed to provide real-time (or near real-time) confirmation of tool actuation, *e.g.*, cutter block deployment or retraction.

[0048] The actuation system may include a digital activation system combined with a real-time (or near real-time) position sensing system to both actuate and monitor actuation of the downhole tool. Signals may be sent downhole and/or uphole via a variety of telemetry techniques and systems including, for example, patterned flow systems, rotary table systems, insulated conductors, pressure pulse systems, electromagnetic systems, acoustic systems, or other suitable telemetry methods. In another embodiment, signals that are representative of position may be recorded on a downhole memory device, such as a memory chip, for later retrieval.

[0049] The actuation system, *i.e.*, the digital activation system with or without the position sensing system, may be used with a variety of downhole tools in many well related and non-well related applications. The actuation system may be installed on or coupled to a drill string, wireline, or other downhole conveyance known to those skilled in the art for actuation of a variety of well related tools, including but not limited to, underreamers and/or stabilizers. In such applications, the actuation system may be designed with modular components that may be selectively assembled in the field.

[0050] The digital (*i.e.*, actuated/de-actuated) activation system may include a valve module having a linearly movable valve assembly and/or a valve module having a rotationally movable valve assembly. The digital activation system may further include a motor module containing a motor, such as a rotary motor, and appropriate electronics. A self-aligning connector may be used to couple the valve assembly of the valve module with the motor of the motor module. The self-aligning connector may cooperate with a conversion assembly to enable conversion of rotary motion output by the motor to linear motion of the valve for actuating the downhole tool.

[0051] Figure 1 depicts a schematic view of a drill string 22 disposed in a wellbore 24, according to one or more embodiments. The drill string 22 has coupled therewith a downhole tool 26 having an actuation system 30. The downhole tool 26 may be or include an underreamer having a plurality of cutter blocks 28 movably coupled thereto which actuate between a retracted state and an expanded state. The actuation system 30 associated with downhole tool 26 of Figure 1 is provided to facilitate explanation, and it should be understood that the actuation system 30 described herein may include a variety of additional components and may be located in many types of downhole environments. The actuation system 30 may also be constructed in various configurations depending on the operational and environmental characteristics of a given application. The downhole tool 26 and a downhole tool actuation system 30 may be disposed at least partially within a bottom hole assembly 32. The bottom hole assembly 32 may include a measurement-while-drilling tool 34, such as a positive pulse measurement-while-drilling tool. The bottom hole assembly 32 via the drill string 22 is used to rotate a drill bit 36 during drilling of the wellbore 24.

[0052] The actuation system 30 includes a digital activation system 38 having a valve module 40 and a motor module 42. The motor module 42 contains a motor 82 (see Figure 3) and electronics 80 (see Figure 3) for receiving control signals and for controlling the motor 82 (see Figure 3). Power may be provided to the motor 82 via a downhole power source 44 (Figure 14), such as a battery. A turbine or positive displacement motor (neither shown) may also be coupled to the motor 82 to supply the power. The rotary motion of the motor 82 may be converted to linear/axial motion, as discussed in more detail below.

[0053] The actuation system 30 may further include a real-time (or near-real time) position sensing system 50 including a diagnostic probe section 52 and a sensor section 54 having one or more magnetic sensors. The position sensing system 50 may be coupled to or used in conjunction with the digital activation system 38 to monitor activation/actuation of the downhole tool 26, *e.g.*, by monitoring linear movement of the cutter blocks 28 (or a component coupled thereto) or one or more components of the valve module 40.

[0054] Figure 2 depicts a perspective view of an illustrative valve module 40, according to one or more embodiments. The valve module 40 includes a valve module body 56 which slidably receives the plunger or shaft 46 through an end cap 58. A landing spider 60 may be coupled to the valve module body 56 to facilitate landing and positioning of the valve module 40 within the internal flow passage or bore 106 of the downhole tubular or drill string 22 (see Figure 6), *e.g.*, centralized within the drill string 22 (or offset from the longitudinal axis of drill string 22), while allowing flow of drilling mud and/or other fluids through the drill string

22 and around/through the valve module 40 via landing spider openings 62. Centralizing the valve module 40 and the other modules of the actuation system 30 in the bore 106 of the drill string 22 allows the actuation system 30 to be used in a drill string 22 having any diameter, with the plunger head/assembly or valve 74 being sized to sealingly engage the inner diameter of the bore 106/receptacle 100 (see Figure 6). A valve assembly may be defined as the plunger or shaft 46 coupled to the plunger head/assembly or valve 74. The plunger head/assembly or valve 74 is arranged and designed with one or more axial openings 110 to permit flow of drilling mud and/or other fluids through the bore 106 (Figure 6) of the drill string 22. The valve module body 56 also encloses a conversion assembly 64 to convert rotary motion to linear motion of the plunger or shaft 46. By way of example, the conversion assembly 64 may include a threaded screw and nut coupled to the shaft 46 so as to move the shaft 46 in a linear direction upon rotation of the threaded screw within the corresponding nut. Examples of suitable conversion assemblies 64 may include lead screws, ACME screws, ball screws, and the like. However, other types of transmissions and conversion assemblies known to those skilled in the art may be used in converting rotary motion to linear motion.

[0055] The valve module 40 may also include a self-aligning connector portion 66, coupled to the valve 74, designed to automatically receive a corresponding self-aligning connector portion 68 of the motor module 42 (see Figure 3), which is coupled to the motor 82. The valve connector portion 66 may include self-aligning grooves or slots 70 arranged and designed to receive and orient corresponding protrusions 72 (the “dog bone”) (Figures 3 and 4) of the motor connector portion 68. The self-aligning connector portions 66, 68 enable more efficient shipping, assembly and deployment, because tool makeup in the field is simplified, allowing for some misalignment during initial mating of the self-aligning connector portion 66 and the valve connector portion 68. In one or more embodiments, the self-aligning connector portions 66, 68 may be arranged and designed to enable downhole deployment via the drill string 22 with the self-aligning connection 84 (Figure 4) being made downhole.

[0056] Figure 3 depicts a perspective view of an illustrative motor module 42, according to one or more embodiments. The motor module 42 includes the motor 82 and an electronics section 80. The electronic section 80 is designed to include a downhole receiver or sensor to detect command signals sent downhole, *e.g.*, pressure pulse signals, vibration, drill string rpm or other telemetry methods previously disclosed, and to generate and provide control signals to the motor 82 so as to control the rotary output motion of the motor 82. In one or more embodiments, the downhole receiver or sensor may be an accelerometer. The motor 82 drives the motor connector portion 68 which, in turn, drives the valve connector portion 66. This rotary motion of the motor connector portion 68 and the valve connector portion 66 is converted to linear motion of the shaft 46 by the conversion assembly 64. The motor 82 also functions as a brake to prevent undesired back drive. The motor module 42 may include a variety of other features, such as centralizers or centralizing features 86, which may be used to help centralize the motor module 42 within a surrounding tubular or body 88 of the drill string 22 (see Figure 1). The centralizing features 86 are designed to allow fluid flow in the bore 106 of the body 88, *e.g.*, a section of the drill string 22 (Figure 1), in the annular space between the body 88 and the modules 40, 42.

[0057] Figure 4 depicts a partial perspective view of the valve module 40 and the motor module 42 joined or coupled by a self-aligning connector 84, according to one or more embodiments. The motor connector portion 68 is engaged with valve connector portion 66 to form an overall self-aligning connector 84.

[0058] Figure 5 depicts a partial cross-sectional view of the valve module 40, according to one or more embodiments. The valve connector portion 66 is coupled with a shaft or spindle 90 which is rotatably mounted within the valve module body 56 via a plurality of bearings 92. The spindle 90 includes a threaded portion 94 received in a corresponding threaded portion 96 of a nut section 98 coupled to the shaft 46. As the spindle 90 is rotated by the motor 82 (Figure 3) via the connector portion 66, the threaded portion 94 rotates with respect to the corresponding threaded portion 96 while the nut section 98 is held rotationally stationary. This causes the shaft 46 to move linearly depending on the direction of rotation of the spindle 90. The linear motion of the shaft 46 is used to drive, for example, the valve 74 to control actuation of the downhole tool 26.

[0059] Figure 6 depicts a partial cross-sectional view of the valve module 40 disposed in the downhole tool 26, and Figure 7 depicts a partial cross-sectional view of the valve module 40 of Figure 6 actuated to a different operational position. The downhole tool 26, an underreamer in this example, may include a body 88 having a bore 106 formed at least partially therethrough. The body 88 may be one component or a plurality of components coupled together. The valve module 40 may be disposed within the bore 106 of the body 88.

[0060] The valve 74 is slidably positioned within a receptacle 100 within the body 88 such that the seals 76 are in sealing engagement with the internal surface of the receptacle 100. One or more ports 102 extend through the receptacle 100 of the downhole tool 26 such that fluid communication is established between an actuation chamber 112 and the bore 106 of the downhole tool 26 through the ports 102 when the valve 74 is slidably positioned within the receptacle 100 to uncover the ports 102. The ports 102 are arranged and designed to deliver pressurized fluid to the actuation chamber 112 in the downhole tool 26. When the pressure sufficiently increases in the actuation chamber 112, the actuating member 104 (*e.g.*, a piston, such as an annular piston disposed in the chamber 112) axially moves or slides, thereby actuating the cutter blocks 28, which simultaneously move axially and radially-outward, *e.g.*, via angled channels or tracks upon which the cutter blocks are movably coupled. An illustrative underreamer that may be used with the actuation system 30 disclosed herein is shown and described in U.S. Patent No. 6,732,817, the content of which is incorporated by reference herein to the extent consistent with the present disclosure. While illustrated in Figure 6 as an underreamer, the downhole tool 26 may be or include a variety of tool types, such as valves, sliding sleeves, latches, pipe cutters, section mills, jars, fishing tools and other actuatable tools.

[0061] As shown in Figure 6, the valve 74 has been moved by the shaft 46 to a location or position within the receptacle 100 such that the seals 76 are positioned on both linear/axial sides of the ports 102 (*i.e.*, they straddle the ports 102), thus blocking flow through the ports 102. Fluid, *e.g.*, drilling mud, delivered downhole through the bore 106 of the downhole tool 26 in the direction of arrow 108 flows through axial openings 110 in the valve 74 and along the exterior of the valve module body 56 toward drill bit 36 (Figure 1). When the downhole tool 26 is to be actuated to another operational position, control signals are sent downhole to the electronics section 80 of the motor module 42, received or sensed by the downhole receiver/sensor in or proximate to the electronics section 80 and used to control the operation of the motor 82 to cause linear movement of the shaft 46. In this example, the linear movement of the shaft 46 draws the valve 74 away from the ports 102 to enable flow of pressurized fluid from the bore 106 and out through the ports 102, as illustrated in Figure 7. The fluid flows into the actuation chamber 112, as indicated by arrows 114, to cause uphole movement of an actuating member 104, which in turn moves/actuates the cutter blocks 28.

[0062] The valve module 40 and the motor module 42 of the actuation system 30 may be combined with the position sensing system 50, as disclosed herein. The position sensing system 50 may use one or more magnets to sense the position of the downhole tool 26 and/or the cutter blocks 28 and to relay that position in real-time, or near real-time, to the surface or another remote location. In another embodiment, the position sensing system 50 may determine the position of the valve module 40 and/or the cutter blocks 28 by measuring the number of revolutions of the motor 82 and/or the shaft 46.

[0063] Figure 8-1 depicts a partial perspective view of a position sensing system 50, Figure 8-2 depicts a partial perspective view of one embodiment of a sensor array portion 118 of the position sensing system 50, Figure 8-3 depicts a partial perspective view of the sensor array portion 118 within a magnet basket 122, and Figure 9 depicts a partial cross-sectional view of the magnet basket 122 of the position sensing system 50 disposed in the downhole tool, according to one or more embodiments. The position sensing system 50 may utilize a diagnostic probe section 52 (Figure 1) having a diagnostics probe 116 positioned within the body 88 of the drill string 22 via appropriate centralizing features 86. As illustrated in Figures 8-1 and 8-2, the diagnostics probe 116 may contain a sensor 118, *e.g.*, a sensor array, coupled to supporting electronics 120. The sensor array 118 may be or include a plurality of magnetometers, which are received in a corresponding crown or magnet basket 122 of a sensor section 54, illustrated in Figure 9. Relative axial movement of the magnet basket 122 with respect to the sensor array 118 is used to track the position/state of the cutter blocks 28 of the downhole tool 26. Position signals are transmitted or relayed by the electronics 120 to a surface controller to enable monitoring of the actuation of the downhole tool 26 in real-time or near real-time. Such transmission or relay of position may be conducted by the same or a different telemetry method as transmissions/relays from uphole to downhole.

[0064] By way of example and as shown in Figures 8-3 and 9, the components may be oriented so that the probe/sensor array 118 is positioned within the magnet basket 122, which contains a magnet 124 to enable monitoring of positional changes by the probe/sensor array 118. The probe/sensor array 118 is held in an interior 126 of the magnet basket 122 so as to prevent contact with the magnet basket 122. In this specific example, the sensor array 118 includes a plurality of magnetometers positioned along a desired length in a three board "star array" configuration. The three board configuration, with each board extending radially outward from a common longitudinal axis running though the probe/sensor array 118, permits the magnet 124 of the magnet basket 122 to be sensed regardless of the rotational position of the magnet basket 122. The magnet basket 122 is coupled to the mandrel 128, and both the magnet basket 122 and the mandrel 128 are adapted to move axially as the cutter blocks 28 move axially. The mandrel 128 may be coupled to a ring member 123, which is biased in one direction by a spring member 130 to facilitate return of the magnet basket 122 to a default position. Ring member 123, and thus floating mandrel 128, is moved in the opposite direction as the cutter blocks 28 are actuated and moved axially. As the actuatable component (*e.g.*, cutter blocks 28) of the downhole tool 26 is activated and/or deactivated by linear movement of the shaft 46, the actuatable component engages and pushes ring member 123 uphole against the bias of spring 130. The mandrel 128, coupled to the ring member 123, moves the magnet basket 122 and the magnet 124 with respect to the sensor array 118, *e.g.*, magnetometer array. As the position of the magnet basket 122 and the magnet 124 are indicative of the position/state of the actuatable component (*e.g.*, cutter blocks 28), the position/state of the actuatable component (*e.g.*, cutter blocks 28) may be measured, calculated, and transmitted uphole by a suitable telemetry system, *e.g.*, a positive pulse telemetry system or other disclosed telemetry system. In some applications, the positional data is transmitted to a control system, such as a computer based control system, which outputs information on the state and/or degree of tool actuation. In an alternative embodiment, the magnet basket 122 may be coupled to the valve 74 (not shown). Alternatively, the position sensing system 50 may be coupled with the actuation system 30 to monitor movement of the shaft 46 and to transmit/relay movement information to the control system.

[0065] Figure 10 depicts a partial perspective view of a portion of the position sensing system 50 in the form of a diagnostic probe 116 assembled with a positive pulse measurement-while-drilling tool, according to one or more embodiments. As illustrated in Figure 10, the diagnostics probe 116 is coupled to a pulser probe 134 of the telemetry system 132. The pulser probe 134 may be part of a positive pulse measurement-well-drilling tool and may be used to communicate signals uphole via positive pressure pulses. However, other types of telemetry systems may be used to transmit and/or receive signals, as previously disclosed. Power to the telemetry system 132 may be provided by a downhole power source 136, such as a battery probe, coupled between the pulser probe 134 and the diagnostics probe 116.

[0066] Figure 11 depicts a partial cross-sectional view of a downhole tool 26, an underreamer in this example, having an illustrative actuation system 30 without position sensing system 50, according to one or more embodiments. As best shown in Figure 12, the actuation system 30 is designed to actuate the actuatable component (*e.g.*, cutter blocks 28) of the downhole tool 26. In Figure 11, a portion of the actuation system 30 is illustrated and shows the downhole tool 26 with the cutter blocks 28 in the retracted state. The cutter blocks 28 are actuated hydraulically by actuating member 104, which is moved by pressurized drilling fluid/mud entering chamber 112 (Figure 12). The actuating flow of pressurized drilling fluid/mud into chamber 112 (Figure 12) is controlled via the valve 74 of the valve module 40 (Figure 12).

[0067] Figure 12 depicts a partial cross-sectional view of the downhole tool 26, an underreamer in this example, including the valve module 40, and Figure 13 depicts a partial cross-sectional view of another portion of the downhole tool 26 of Figure 12 showing the valve module 40, according to one or more embodiments. As disclosed above, linear movement of the valve 74 is controlled by the shaft 46 via rotation of the spindle 90 with respect to the nut assembly 98, *e.g.*, a castle nut assembly, as illustrated in Figures 12 and 13. The valve 74 is positioned to block flow through the ports 102 and, thus, to block the flow of drilling fluid/mud to the actuation chamber 112. As best illustrated in Figure 13, a motor shaft 41 may be coupled to the spindle 90 by an appropriate coupling 140 to translate the rotary output motion of the motor 82 to the spindle 90. The spindle 90 includes a lead screw portion 142, which includes the threaded portion 94 engaging the corresponding threaded portion 96 of the nut section 98. However, these components merely provide examples of mechanisms for converting the rotary output of the motor 82 to linear output of the shaft 46, and other mechanisms known to those skilled in the art may be utilized.

[0068] Figure 14 depicts a partial cross-sectional view of the drill string 22 coupled downhole of the downhole tool 26 and including therein the electronics section 80 and a power source 44 of the actuation system 30, according to one or more embodiments. The electronics section 80 and power source 44 of the actuation system 30 are disposed in the bore 106 of drill string 22 such that fluid/mud may flow in the annular space between these components and the drill string towards the drill bit (not shown). Control signals sent from the surface regarding the actuation of the downhole tool 26 are received and processed by the electronics section 80 (*e.g.*, a downhole received or sensor, such as an accelerometer or other device), as illustrated in Figure 14. The electronics section 80 and the motor 82 (coupled to the electronics section 80 as shown in Figure 12) may be energized by power downhole supplied via a power source 44. As shown, the power source 44 may include a plurality of batteries 144 positioned in a battery housing 146. By way of example, the batteries 144 may be moderate rate, downhole lithium batteries. Additionally, the battery housing 146 may be sized to allow use of various battery numbers and combinations.

[0069] The electronics section 80 may include a pressure pulse system which reads a command sequence of pressure pulses. Upon receiving the proper preprogrammed command sequence, the motor 82 (Figure 12) is powered to cause rotary motion of the motor shaft 41 (and linear motion of the shaft 46) (Figure 13) and ultimately the desired actuation of the downhole tool 26. However, various telemetry systems, as disclosed above, may be used for both controlling valve movement and for relaying signals to and/or from the position monitoring system.

[0070] Figure 15 depicts a partial cross-sectional view of a portion of the downhole tool 26 showing the valve module 40 in a first actuation position, according to one or more embodiments. Prior to actuation of the cutter blocks 28, drilling fluid/mud is pumped down through the bore 106, through the axial openings 110 in the valve 74, and along the exterior of the valve module 40 and the motor module 42 in route to the drill bit 36 (Figure 1). The design of the various modules of the actuation system 30 allows the drilling mud or other fluid to be pumped downhole during a normal drilling operation, as represented by arrows 148. However, once appropriate control signals are transmitted/relayed downhole to the electronics section 80, the motor module 42 controls the operation of the valve module 40 and the shaft 46 to translate the valve 74 in a linear direction, which in turn opens a flow path through the ports 102 (Figure 16). Prior to the motor module 42 controlling the operation of the valve module 40 to move valve 74, fluid/mud flow through the bore 106, *e.g.*, via surface pumps, is temporarily stopped to reduce any differential pressure between the bore 106 and the wellbore 24. A reduction in differential pressure reduces the force/power needed by motor 82 to move valve 74. Once the valve 74 has changed position, fluid/mud flow through the bore 106 may be resumed. The motor 82 also functions as a brake to prevent undesired back drive, *i.e.*, movement of valve 74.

[0071] Figure 16 depicts a partial cross-sectional view of the downhole tool 26 showing the valve module 40 in a second actuation position, according to one or more embodiments. The drilling fluid/mud flows outwardly through the ports 102 and into the actuation chamber 112. As the pressure in the actuation chamber 112 sufficiently builds up, the actuating member 104 moves or slides axially and thereby actuates the cutter blocks 28 into the second or expanded state. Such translation occurs as a result of differential pressure, *e.g.*, between the drilling fluid pressure in the actuation chamber 112 (via ports 102) and the wellbore pressure. As indicated by arrows 150 in Figure 16, the actuating member 104 is driven in an axial direction to force the cutter blocks 28 to simultaneously move axially and radially-outward.

[0072] The movement of the shaft 46 is designed to further move the valve 74 to expose the ports 102 which allow diverted fluid/mud flow to flow into the actuation chamber 112 and push against the actuating member 104 in the opposite direction of fluid/mud flow 148 to activate/actuate the actuatable component, *e.g.*, cutter blocks 28. When the shaft 46 is moved in reverse (*e.g.*, by signaling the motor 82 to reverse its rotation), the valve 74 translates axially to seal the bypass ports 102 so the lack of diverted mud flow (combined with spring bias via spring 130) allows the activating member 104 to be forced in the direction of the mud flow (through the bore 106) to its resting position, thus de-activating deployment of the actuatable component, *e.g.*, cutter blocks 28.

[0073] Figure 17 depicts a schematic view of an illustrative downhole tool 26 disposed within the wellbore 24 and having another actuation system 30', according to one or more embodiments. The downhole tool 26 includes a digital activation system 38'. The digital activation system 38' includes an illustrative valve module 240, which differs from the valve module 40. In various embodiments, the valve module 240 may contain a rotationally moveable valve assembly 270 or a linearly moveable valve assembly 280, as disclosed herein. The rotary output motion of the motor 82 (not shown) in the motor module 42 may either be transmitted to impart rotary motion to the rotary valve assembly 270 in the valve module 240, or the rotary output motion of the motor 82 in motor module 42 may be converted to linear/axial motion of the linear valve assembly 280 in the valve module 240.

[0074] Figure 18-1 depicts a partial cross-sectional view of an illustrative rotary fingered valve module 242 disposed within the downhole tool 26, and Figure 18-2 depicts a perspective view of a fingered valve 272 of the fingered valve module 242, according to one or more embodiments. The valve module 240 includes a rotary fingered valve module 242 having a valve housing 250 formed of an upper mandrel 252, a middle mandrel 254, and a lower mandrel 256 coupled together. The valve housing 250 receives therein a rotary valve assembly 270 including a fingered valve 272, a preload spring 274, a spring retainer 276, and a self-aligning connector portion 278. A plurality of upper surfaces 273 of the fingers 275 of fingered valve 272 engage a seating surface 253 on the middle mandrel 254 of valve housing 250. A lower surface 271 of the fingered valve 272 is acted upon by the preload spring 274. The preload spring 274 is retained by the spring retainer 276, which is coupled to an interior surface of the lower mandrel 256 of the valve housing 250.

[0075] A thrust ball bearing 279 may be provided between the preload spring 274 and the fingered valve 272, and a ring bearing 255 may be provided between the lower mandrel 256 and the fingered valve 272, to reduce rotational friction therebetween. The inner surface of lower mandrel 256 and the outer surface of the fingered valve 272 may be polished metal surfaces, and the ring bearing 255 may be formed of thermoplastic material to provide an effective low friction seal therebetween. Such a seal is well suited for a high temperature, high pressure, and abrasive downhole environment. Examples of suitable materials for the polished metal surfaces include carbide and steel. Examples of suitable materials for the ring bearing 255 include thermoplastic materials such as PEEK, Torlon and Teflon. However, other types of materials known to those skilled in the art may be used for the polished metal surfaces and for the ring bearing 255.

[0076] The fingered valve 272 is arranged and designed with a plurality of spaced apart (*e.g.*, circumferentially offset) fingers 275. When the valve module 240 cooperates with the downhole tool 26 in the drill string 22 (Figure 17), rotation of the fingered valve 272 causes the fingers 275 to block or open the ports 202 (Figure 20) that deliver pressurized fluid to the actuating member 104 (Figure 20) to actuate the downhole tool 26. The fingered valve 272 further includes one or more axial openings 210 that permit flow of drilling mud and/or other fluids through the bore 106 (Figure 20) of the drill string 22 (Figure 17). The fingered valve 272 may include a bearing groove 212 along an outer surface thereof to receive the ring bearing 255, and a control groove 214 to receive a stop pin 216 extending through a wall of the lower mandrel 256 of the valve housing 250. When the fingered valve 272 is rotated, the stop pin 216 moves within the control groove 214 until the stop pin 216 reaches an end portion of the control groove 214, thereby preventing further rotation. Thus, the interaction between the stop pin 216 and the control groove 214 provides control over the angular position of the fingered valve 272 and also provides a positive stop.

[0077] Figure 19 depicts a partial cross-sectional view of the rotary fingered valve module 242 being coupled to the motor module 42 by a self-aligning valve connector portion 278, according to one or more embodiments. The self-aligning valve connector portion 278 designed to automatically receive a corresponding motor connector portion 68' of the motor module 42. The valve connector portion 278 may include a self-aligning hex-shaped receptacle 277 designed to receive and orient a corresponding hex-shaped coupling 72' of the motor connector portion 68'.

[0078] Figure 20 depicts a partial cross-sectional view of the downhole tool 26 showing the rotary fingered valve module 242 joined to the motor module 42, according to one or more embodiments. The valve module 242 is positioned within the receptacle 100 of the downhole tool 26 such that the seals 76 are in sealing engagement with the internal surface of the receptacle 100. The ports 102 (not shown) may be disposed in and extend through the receptacle 100 of the downhole tool 26. Ports 102 (not shown) will align with ports 202 within seating surface 252 of the middle mandrel 254 of valve housing 250 such that fluid communication may be established between the actuation chamber 112 and the bore 106 of the downhole tool 26 when the fingered valve 272 is rotationally positioned within the receptacle 100 to permit such fluid communication. When the ports 102, 202 deliver pressurized fluid from the bore 106 to the actuating member 104 via the actuation chamber 112, fluid under sufficient pressure acts to move the actuating member 104 and thus actuate the downhole tool 26 to another desired operational state. To rotate the fingered valve 272, the motor 82 drives the motor shaft 41 coupled to the motor connector portion 68' which, in turn, rotationally drives the valve connector portion 278 and imparts rotary motion to the fingered valve 272. The motor connector portion 68' is illustrated as received and oriented in the valve connector portion 278 to form an overall self-aligning connector 84'.

[0079] Figure 21 depicts a partial cross-sectional view of the downhole tool 26 showing the rotary fingered valve module 242 in a first actuation position, and Figure 22 depicts a partial cross-sectional view of the downhole tool 26 showing the rotary fingered valve module 242 in a second actuation position, according to one or more embodiments. In Figure 21, the valve module 242 is shown in the closed position, *i.e.*, the fingered valve 272 is positioned such that the fingers 275 block flow through the ports 202 and thus block actuating flow of drilling fluid/mud to the actuating chamber 112. Prior to actuation of the downhole tool 26, drilling fluid/mud is pumped down through the bore 106, through the axial openings 210 (Figure 18-2) in the fingered valve 272, between the self-aligning connector 84' and the spring retainer 276, and along the exterior of the motor module 42 in route to the drill bit 36 (Figure 17) as indicated by the flow arrows 220 in Figure 21. The pressure of the drilling fluid/mud in the bore 106, *e.g.*, on the interior of the drill string 22, is higher than the pressure of the drilling fluid/mud in the wellbore 24, *e.g.*, on the exterior of the drill string 22. As an example, the pressure in the bore 106 may be 800 psi to 1,000 psi higher than the pressure in the wellbore 24. Thus, there is a differential pressure across the downhole tool 26 between the bore 106 and the wellbore 24. The rotary fingered valve module 242 of Figures 18-1 makes use of this differential pressure to create an effective seal across the ports 202 when the valve module 242 is in the closed position illustrated in Figure 21.

[0080] As shown in Figure 18-2, the surface area of the lower surface 271 of the fingered valve 272 is larger than the combined surface areas of the plurality of upper surfaces 273 of the fingers 275 of the fingered valve 272. Further, in the closed position of Figure 21, the lower surface 271 of the fingered valve 272 is exposed to the higher pressure of the bore 106, whereas the upper surfaces 273 of the fingers 275 are exposed to the lower pressure of the actuation chamber 112. In this example, the actuation chamber 112 is at wellbore pressure, because the actuation chamber 112 is in fluid communication with the wellbore 24 via the nozzles 111 (Figure 20). Thus, since the surface area of lower surface 271 exposed to the higher pressure of the bore 106 is greater than the combined surface area of upper surfaces 273 exposed to the lower pressure of the wellbore 24, the net force of the differential pressure acts to push the fingered valve 272 upwardly. This upward force enables the upper surfaces 273 of the fingers 275 to remain seated against the seating surface 253 on the middle mandrel 254 of the valve housing 250, thereby enhancing the seal across the ports 202. Accordingly, the rotary fingered valve module 242 utilizes the differential pressure to enhance the seal, which inhibits leakage through the ports 202 when the valve module 242 is in the closed position, thereby preventing inadvertent actuation of the downhole tool 26.

[0081] Referring generally to Figure 22, the rotary fingered valve module 242 of Figure 18-1 is shown in the open position, *e.g.*, the fingered valve 272 is positioned such that the fingers 275 open a flow path through one or more of the ports 202 and allow the flow of drilling fluid/mud to the actuation chamber 112. When appropriate control signals are transmitted/relayed downhole to the electronic section 80 (Figure 12), the pumping of drilling fluid/mud from the surface is stopped before the motor module 42 moves the valve module 240 from the closed position illustrated in Figure 21 to the open position illustrated in Figure 22 (or *vice versa*). The pressure in the bore 106 then equalizes with the pressure in the wellbore 24 such that there is no differential pressure across the downhole tool 26. Then the motor module 42 rotates the motor shaft 41 to thereby impart rotary motion to the fingered valve 272, which in turn moves the fingers 275 out of alignment with, and opens a flow path through, one or more of the ports 202. In this manner, the motor 82 does not have to overcome the differential pressure force to rotationally move the fingered valve 272. During such rotation, the electronic section 80 (Figure 12) may monitor the current of the motor 82 as an indicator of valve module position. In particular, when the stop pin 216 engages the end portion of the control groove 214, the current of the motor 82 will spike, indicating that the valve module 242 has moved from an open position to a closed position across the ports 202 (*i.e.*, stopping flow through the ports 202 into the actuation chamber 112), or from a closed position to an open position (*i.e.*, allowing flow through the ports 202 into the actuation chamber 112). Once the valve module 242 has been moved to the open position as illustrated in Figure 22, the drilling fluid/mud is pumped down through the bore 106 and outwardly through the ports 202 against the actuating member 104, as indicated by the flow arrows 225 in Figure 22, to translate the cutter blocks 28 (Figure 17) (or other tool operation) to a desired state.

[0082] In one or more embodiments, the rotary fingered valve module 242 of Figure 18-1 is designed to maintain substantially continuous contact between the upper surfaces 273 of the fingers 275 and the seating surface 253, regardless of whether the valve module 242 is in the closed position or the open position. In the open position shown in Figure 22, the pre-load spring 274 exerts sufficient force on the fingered valve 272 to maintain such contact between the fingers 275 and the seating surface 253. The interaction between the fingers 275 and the ports 202 of the seating surface 253 are similar to the interaction between a rotor and stator to allow or prevent flow therethrough. Thus, the valve 272 with fingers 275 may be characterized as the rotor and the seating surface 253 with ports 202 may be characterized as the stator.

[0083] In the example described above, rotary movement of the fingered valve 272 is designed to expose one or more of the bypass ports 202 which allow diverted fluid/mud flow into the actuation chamber 112 to push against the actuating member 104 to activate the cutter blocks 28 (or other tool operation). Further rotation of the fingered valve 272 aligns the fingers 275 to seal the bypass ports 202 so the lack of diverted fluid flow (combined with spring bias via spring 130 of Figure 9) allows the actuating member 104 to be forced to its resting position, thus deactivating deployment of the cutter blocks 28 (or other tool operation). Thus, the actuation system 30' (Figure 17) may be activated and deactivated on demand, as disclosed above, to actuate/deactuate the downhole tool 26. Additionally, use of the self-aligning connector portions 278, 68' facilitates assembly and use of the rotary fingered valve module 242 and the motor module 42 in the field. The contained electronics 80 (Figure 12) further facilitate the use of a remote downlink to enable selective activation of the motor 82 when movement of the fingered valve 272 is desired. The position sensing system 50 may also be combined into the actuation system 30' to monitor movement of the fingered valve 272 and to transmit/relay information to, for example, a surface control system.

[0084] Figure 23 depicts a perspective view of an illustrative valve assembly 280 having a tapered first valve component 282 and a corresponding chamfered second valve component 284 for a valve module 240 that may be employed in the downhole tool 26, according to one or more embodiments. Valve assembly 280 may be employed in conjunction with the rotary fingered valve module 242 previously disclosed. As such, tapered first valve component 282 may be finger 275 and chamfered second valve component 284 may be port 202. Valve assembly 280 also employs the differential pressure across the downhole tool 26 to maintain a seal, as further disclosed below.

[0085] As shown in Figure 23, a first valve component 282 includes a conical tapered end portion 283 arranged and designed to correspond to a chamfered end portion 285 of a second valve component 284. The first valve component 282, e.g., disposed as an end portion of finger 275, is rotationally moved by operation of the motor 82 of motor module 42 (Figure 17) into and out of engagement with the second valve component 284, *e.g.*, disposed in seating surface 252 of the middle mandrel 254 of valve housing 250 . The interaction between the conical tapered end portion 283 of the first valve component 282 and the chamfered end portion 285 of the second valve component 284 creates a seating surface that provides a wedging effect to enhance sealing as compared to interactions between flat seating surfaces, *e.g.*, disclosed above with respect to the rotary fingered valve module 242. In the closed position of the valve assembly 280, the conical tapered end portion 283 of the first valve component 282 is pushed into the corresponding chamfered end portion 285 of the second valve component 284, and the differential pressure across the downhole tool 26 that occurs when drilling fluid/mud flow is pumped downhole creates a suction force on the valve components 282, 284 to maintain the seal therebetween.

[0086] To disengage the valve components 282, 284, the pumping of drilling fluid/mud flow from the surface is decreased or stopped to remove the differential pressure across the downhole tool 26 (Figure 17), and then the motor 82 of motor module 42 (Figure 17) rotates the valve assembly 280 to withdraw the first valve component 282 from the second valve component 284 in order to open a flow path through the bypass ports 102 (see, *e.g.*, Figure 22) in the receptacle 100 of the downhole tool 26. Once the valve assembly 280 has been moved to the open position, drilling fluid/mud is pumped downhole through the bore 106 and outwardly therefrom through bypass ports 102 and against actuating member 104 (see, *e.g.*, Figure 22) to translate the cutter blocks 28 (Figure 17) (or other tool operation) to a desired, actuated state.

[0087] Figure 24 depicts a partial cross-sectional view of an illustrative rotary ported valve module 244 that may be employed in the downhole tool 26, according to one or more embodiments. In this embodiment, the valve module 240 includes a rotary ported valve module 244 with a unitary valve housing 250. The valve housing 250 receives a sealing member 266 therein and a rotary valve assembly 270. The rotary valve assembly 270 includes a first valve member 264 with one or more ports 267 disposed therein. The first valve member 264 is coupled to a second valve member 262 (also part of the rotary valve assembly 270) to form a ported valve 265. The rotary valve assembly 270 further includes a preload spring 274, a spring retainer 276, and a self-aligning connector portion 278. The preload spring 274 is retained by the spring retainer 276, which is coupled to an interior surface of the valve housing 250. A thrust ball bearing 279 may be provided between the preload spring 274 and the second valve member 262, and a ring bearing 255 may be provided between the valve housing 250 and the second valve member 262 to reduce rotational friction therebetween.

[0088] The sealing member 266 and/or the first valve member 264 may be composed of, or have a surface composed of, a thermoplastic or elastomeric material, *e.g.*, PEEK, Torlon, Teflon, rubber, etc., to enhance the seal between sealing member 266 and first valve member 264. The inner surface of valve housing 250 and the outer surface of the ported valve 265 may be polished metal surfaces, and the ring bearing 255 may be formed of thermoplastic material to provide an effective low friction seal therebetween. Such a seal is well suited for a high temperature, high pressure, and abrasive downhole environment. Examples of suitable materials for the polished metal surfaces include carbide and steel. Examples of suitable materials for the ring bearing 255 include thermoplastic materials such as PEEK, Torlon and Teflon. However, other types of materials known to those skilled in the art may be used for the polished metal surfaces and for the ring bearing 255.

[0089] Figure 25 depicts a cross-sectional view the valve housing 250 of the rotary ported valve module 244 of Figure 24, according to one or more embodiments. The valve housing 250 is arranged and designed with a plurality of spaced apart openings 257 that align with the plurality of bypass ports 102 (Figure 26) when the rotary ported valve module 244 is combined with the downhole tool 26. The sealing member 266 is likewise arranged and designed with a plurality of spaced apart openings 268 that correspond to the spaced apart openings 257 in the valve housing 250 when the sealing member 266 is assembled into a recessed area 251 of the valve housing 250 (as shown in Figure 25, sealing member 266 is not disposed in recessed area 251). When the sealing member 266 is positioned within the recessed area 251, an upper surface 263 of the sealing member 266 engages a seating surface 253 on an upper end portion of the recessed area 251, and a lower surface 269 of the sealing member 266 is engaged by the first valve member 264 (Figure 24), which is, in turn, acted upon by the preload spring 274 (Figure 24) via second valve member 262 (Figure 24).

[0090] Figure 26 depicts a cross-sectional view of the downhole tool 26 showing the illustrative rotary ported valve module 244 of Figure 23 joined to the motor module 42 for actuating the downhole tool 26, according to one or more embodiments. The valve module 244 is positioned within the receptacle 100 of the downhole tool 26 such that the seals 76 are in sealing engagement with the internal surface of the receptacle 100. The ports 102 extend through the receptacle 100 of the downhole tool 26 such that fluid communication may be established between the actuation chamber 112 and the bore 106 of the downhole tool 26 when the ported valve 265 is rotationally positioned within the receptacle 100 to align the ports 267 with the openings 268, 257 in the sealing member 266 and valve housing 250, respectively. When the bypass ports 102 deliver pressurized fluid from the bore 106 to the actuating member 104 via the actuation chamber 112, fluid under sufficient pressure acts to move the actuating member 104 and thus actuate the downhole tool 26 to another desired operational state. To rotate the ported valve 265 from the closed position shown in Figure 26 to an open position, the motor 82 drives the motor shaft 41 coupled to the connector portion 68' which, in turn, rotationally drives the connector portion 278 to impart rotary motion to the ported valve 265. In Figure 26, the corresponding connector portion 68' is illustrated as received and oriented in connector portion 278 to form an overall self-aligning connector 84'.

[0091] Similar to the fingered valve 272 of Figure 18-2, the ported valve 265 of Figure 24 may include a control groove 214 (not shown) to receive a stop pin 216 (not shown) extending through a wall of the valve housing 250. When the ported valve 265 is rotated, the stop pin 216 may move within the control groove 214 until the stop pin 216 reaches an end portion of the control groove 214, thereby preventing further rotation. The interaction between the stop pin 216 and the control groove 214 thus provides control over the angular position of the ported valve 265 and also provides a positive stop.

[0092] In Figure 26, the valve module 244 is shown in the closed position, *e.g.*, ported valve 265 is positioned such that the ports 267 block flow through bypass ports 102 in the downhole tool 26 and thus block actuating flow of drilling fluid/mud to the actuating member 104. Prior to actuation of the downhole tool 26, drilling fluid/mud is pumped down through the bore 106, through the ported valve 265, around the exterior of the overall self-aligning connector 84', and along the exterior of the motor module 42 in route to the drill bit 36 (Figure 17) as indicated by the flow arrows 222 in Figure 26. Similar the rotary fingered valve module 242 of Figure 18-1, the rotary ported valve module 244 of Figure 24 makes use of the differential pressure across the downhole tool 26 between the bore 106 and the wellbore 24 such that first valve member 264 creates an effective seal across the openings 268 when the valve module 244 is in the closed position as illustrated in Figure 26.

[0093] The combined surface area of the ported valve 265 exposed to the higher pressure of the bore 106 is larger than the surface area of the first valve member 264 exposed to the lower pressure of the actuation chamber 112. The actuation chamber 112 is at the pressure of wellbore 24 since the actuation chamber 112 is in fluid communication with the wellbore 24 via the nozzles 111. Thus, since the combined surface area of the ported valve 265 exposed to the higher pressure of the bore 106 is greater than the surface area of the first valve member 264 exposed to the lower pressure of the wellbore 24, the net force of the differential pressure acts to push the ported valve 265 upwardly. This upward force enables the upper surface 263 of the sealing member 266 to remain seated against the seating surface 253 of the valve housing 250 (Figure 25), thereby enhancing the seal across the ports 102. The net force of the differential pressure also acts to push the first valve member 264 into greater sealing contact/engagement with the sealing member 266. Accordingly, the rotary ported valve module 244 utilizes the differential pressure to enhance the seal, which inhibits leakage through the ports 102 when the valve module 244 is in the closed position, thereby preventing inadvertent actuation of the downhole tool 26.

[0094] The rotary ported valve module 244 of Figure 24 is designed to maintain substantially continuous contact between the upper surfaces 263 (Figure 25) of the sealing member 266 and the valve housing 250 at the seating surface 253 (Figure 25), regardless of whether the valve module 244 is in the closed position or the open position. In the open position (not shown), the pre-load spring 274 exerts sufficient force on the ported valve 265, which thereby exerts sufficient force on the sealing member 266 via interaction between the first valve member 264 and the lower surface 269 (Figure 25) of the sealing member 266, to maintain such contact between the sealing member 266 and the seating surface 253 (Figure 25).

[0095] Rotational movement of the ported valve 265 is designed to expose the bypass ports 102 via openings 257, 267 which allow diverted mud flow to push against the actuating member 104 to actuate the cutter blocks 28 (Figure 17) (or other tool operation). Further rotation of the ported valve 265 seals the bypass ports 102 so that the lack of diverted fluid flow (combined with spring bias via spring 130 of Figure 9) permits the actuating member 104 to be forced to its resting position, thus deactivating deployment of the cutter blocks 28 (or other tool operation). Thus, the actuation system 30' may be activated and deactivated on demand, as disclosed above, to actuate/deactuate, *e.g.*, cutter blocks 28 of downhole tool 26. Additionally, use of the self-aligning connector portions 278, 68' facilitates assembly and use of the rotary ported valve module 244 and the motor module 42 in the field. As disclosed above, the electronics section 80 (Figure 12) further facilitates the use of a remote downlink to enable selective activation of the motor 82 when movement of the rotary ported valve 265 is desired. The position sensing system 50 also may be combined into the activation system 30' to monitor movement of the ported valve 265 and to transmit/relay information to, for example, a surface control system.

[0096] Figure 27 depicts a cross-sectional view of a portion of the well system 20' of Figure 17, showing an illustrative rotary slotted valve module 246 coupled to the motor module 42 for actuating the downhole tool 26, according to one or more embodiments. The valve housing 250 receives a rotary valve assembly 270 therein including a rotary slotted valve 292 with one or more slots 291 therein. A cowling 294 is disposed in a lower end portion of the valve 292. The rotary slotted valve 292 may be brazed to the cowling 294. The cowling 294 may include a connector portion 293 such as a threaded receptacle designed and arranged to receive a corresponding connector portion 68" such as a threaded extension, for example, on a spindle 298 coupled to the motor shaft 41. In one or more embodiments, the cowling 294 is arranged and designed to position the connector portion 292 centered or near-centered within the bore of the rotary slotted valve 292. A further coupling 296 maintains the connection between the cowling 294 and the spindle 298. The coupling 296 may include a lock nut, a helix coupling, an Oldham coupling, or any other type of suitable coupling. A plurality of ring seals 295 may be provided radially between the valve housing 250 and the rotary slotted valve 292, with at least one ring seal 295 being provided axially on either side of the slots 291. Examples of suitable materials for the ring seals 295 are PEEK, Torlon and Teflon. However, other types of materials known to those skilled in the art may be used for the ring seals 295 to provide a seal and facilitate rotation of the valve 292 within the valve housing 250. In one or more embodiments, O-ring seals 297 are provided to line the wall of each slot 291 in the slotted valve 292.

[0097] Still referring to Figure 27, the rotary slotted valve module 246 is shown combined with the downhole tool 26 and coupled to the motor module 42. In this example, the valve module 246 is positioned within the receptacle 100 of the downhole tool 26 such that the seals 76 are in sealing engagement with the internal surface of the receptacle 100. The ports 102 (Figure 28) extend through the receptacle 100 of the downhole tool 26 such that fluid communication may be established between the actuation chamber 112 and the bore 106 of the downhole tool 26 when the slotted valve 292 is rotationally positioned within the receptacle 100 to align the slots 291 with the ports 102 to permit such fluid communication. When the ports 102 deliver pressurized fluid from the bore 106 to the actuating member 104 via the actuation chamber 112, fluid under sufficient pressure acts to move the actuating member 104 and, thus, actuate the cutter blocks 28 (Figure 17) (or other tool operation) of the downhole tool 26 to a desired operational state. In this illustrated example, to rotate the rotary slotted valve 292 from a closed position to an open position, the motor 82 drives the motor shaft 41 which is coupled to the spindle 298 with connector portion 68" which, in turn, rotationally drives the cowling 294 to impart rotary motion to the slotted valve 292.

[0098] Figure 28 depicts a partial cross-sectional view of a portion of the downhole tool 26 showing the rotary slotted valve module 246 in a first actuation position, and Figure 29 depicts a partial cross-sectional view of a portion of the downhole tool 26 showing the rotary slotted valve module 246 in a second actuation position, according to one or more embodiments. In Figure 28, the valve module 246 is shown in the closed position, *e.g.*, the slotted valve 292 is positioned such that flow is blocked through the bypass ports 102 to prevent the flow of drilling fluid/mud to the actuating member 104. Prior to actuation of the downhole tool 26, the drilling fluid/mud is pumped down through the bore 106, through the openings 215 in the cowling 294, and along the exterior of the motor module 42 in route to the drill bit 36 (Figure 17) as indicated by the flow arrows 230 in Figure 28. Ring seals 295 and O-ring seals 297 (best shown in Figure 27) provide the seals to inhibit leakage through the ports 102 when the valve module 246 is in the closed position, thereby preventing inadvertent actuation of the downhole tool 26.

[0100] Referring generally to Figure 29, the rotary slotted valve module 246 of Figure 27 is shown in the open position, *e.g.*, slotted valve 292 is rotationally positioned such that slots 291 are aligned with bypass ports 102 in the downhole tool 26 to open a flow path to the actuating chamber 112 and allow actuating flow of drilling fluid/mud to the actuating member 104. When appropriate control signals are transmitted/relayed downhole to the electronic section 80 (Figure 12), the pumping of drilling fluid/mud flow from the surface is stopped before the motor module 42 moves the valve module 246 from the closed position illustrated in Figure 28 to the open position illustrated in Figure 29 (or *vice versa*). The pressure in the bore 106 then equalizes with the pressure in the wellbore 24 such that there is no differential pressure across the downhole tool 26. Then the motor module 42 rotates the motor shaft 41 and the spindle 298 to thereby impart rotary motion to the slotted valve 292, which in turn moves the slots 291 into alignment with, and opens a flow path through, the ports 102. In this manner, the motor 82 does not have to overcome the differential pressure force to rotationally move the slotted valve 292. Once the valve module 246 has been moved to the open position illustrated in Figure 29, drilling fluid/mud is pumped down through the bore 106 and outwardly through the ports 102 against the actuating member 104, as indicated by the flow arrows 235 in Figure 29, to translate the cutter blocks 28 (or other tool operation) to a desired operational state.

[0101] In the example described above, rotational movement of the slotted valve 292 is designed to expose the bypass ports 102 which allow diverted drilling fluid/mud flow to push against the actuating member 104 to activate the cutter blocks 28 (or other tool operation). Further rotation of the slotted valve 292 seals the bypass ports 102 so the lack of diverted fluid flow (combined with spring bias via spring 130 of Figure 9) allows the actuating member 104 to be forced to its resting position, thus deactivating deployment of the cutter blocks 28 (or other tool operation). Thus, the actuation system 30' may be activated and deactivated on demand, as disclosed above, to actuate/deactuate the downhole tool 26. The electronics section 80 (Figure 12) further facilitates the use of a remote downlink to enable selective activation of the motor 82 when movement of the slotted valve 292 is desired. The position sensing system 50 also may be combined into the overall system 30' to monitor movement of the slotted valve 292 and to transmit/relay information to, for example, a surface control system.

[0102] The downhole tool 26 may use a variety of components, and those components may be coupled in several configurations designed to facilitate actuation of the downhole tool 26 in many types of wells and environments. In some applications, the actuation system and method use one or more direct mechanical linkages while in other applications, as previously disclosed, the actuation system and method may be used to control fluid flow with respect to hydraulically-actuated tools. However, one or more of the actuation systems and methods disclosed herein enable their use in place of time consuming ball drop systems/methods while enabling remote control over the tool actuation. The actuation system may be used as original equipment or may be used to replace existing ball drop system to improve efficiency. Furthermore, the size and type of components as well as the configuration and arrangement of those components may vary according to the parameters of a given application and/or the characteristics of the environment in which the system and method are employed.

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[0103] Figure 30 depicts a schematic view of an illustrative valve module 40 disposed within the downhole tool 26, according to one or more embodiments, in which an actuatable component of the downhole tool 26 is actuated via a mechanical coupling between the valve module 40 and the actuatable component. The valve module 40 includes a shaft 46 coupled to a valve 74. The valve 74 may be cylindrical or any other shape to compliment the inner circumference of the body of downhole tool 26. The valve 74 may have one or more axial openings or bores 110 (see, *e.g.*, Figure 5) formed at least partially therethrough for the passage of fluid through flow passage 106. The downhole tool 26, an underreamer in this example, is actuated by linear/axial movement of the valve 74, which is moved by the shaft 46 within the bore 106. The valve 74 couples to or is adapted to couple to cutter blocks 28 via an actuating member 104. As illustrated, the actuating member 104 is coupled to the valve 74 via a direct mechanical coupling. The actuating member 104 arranged and designed to permit the cutter block 28 to move axially and radially as the actuating member 104 moves axially.

[0104] One or more seals 76, 77 are arranged and designed around the outer surface of the valve 74 to maintain fluid flow in an internal flow passage or bore 106 through the downhole tool 26 and axial openings 110 in the valve 74. During drilling of wellbore 24, fluid flows downhole through a mandrel 128, through axial openings 110 (see, *e.g.*, Figure 5) in the valve 74, and toward the drill bit 36 (not shown). Upon signaling the motor 82 to begin operation to actuate the tool, the linear/axial movement of the shaft 46 via such operation of the motor 82 causes the valve 74 to be axially moved between a first position (*i.e.*, cutter blocks 28 retracted, as shown in Figure 30) and a second position (cutter blocks 28 expanded, not shown). Operation of the motor 82 to de-actuate the downhole tool 26 causes the valve 74 to move from the second position to the first position, thereby de-actuating the cutter blocks 28 into the retracted state. During movement of the valve 74, fluid continues to flow downhole through the mandrel 128, through axial openings 110 (see, *e.g.*, Figure 5) in the valve 74, and toward the drill bit 36. When the valve 74 moves to the second position thereby actuating the cutter blocks 28 via actuating member 104, the valve 74 uncovers a nozzle 111, thereby placing the nozzle 111 in fluid communication with the fluid flowing through the bore 106. Fluid flow through the one or more nozzles 111 may assist in cleaning and/or cooling cutter blocks 28.

[0105] Figure 31 depicts a schematic view of another illustrative embodiment of the downhole tool 26 having an activation system, according to one or more embodiments. As shown, the motor 82 and conversion assembly 64 (used for linear rather than rotational valve motion) may be coupled to and positioned on an uphole side of the valve module 40. In other words, the motor 82 and the optional conversion assembly 64 may be coupled to and positioned between the valve module 40 and the surface.

[0106] As disclosed above, the electronics section 80 may include a receiver/sensor to receive a command signal from the surface to actuate the downhole tool 26. In response to the command signal, the electronics section 80 may cause the motor 82 to rotate a motor shaft 41 (not shown) coupled to the shaft 46 of a valve 74 of the valve module 40. In one embodiment, operation of motor 82 rotates motor shaft 41, thereby causing shaft 46 and valve 74 to rotate. As previously disclosed, the valve 74 may be arranged and designed to block a port 102 from the bore 106 of the downhole tool 26 in one rotational position and open the port 102 to the bore of the downhole tool 26 in another rotational position. Thus, rotation of the valve 74 to unblock the port 102 enables fluid to flow therethrough from the bore 106, *e.g.*, to actuate the downhole tool 26. In another embodiment, the conversion assembly 64 may be employed to convert the rotary movement of the motor shaft 41 to axial movement of the shaft 46 and the valve 74 of valve module 40. As previously disclosed, the valve 74 may be arranged and designed to block the port in one axial position and open the port in another axial position. Thus, axial movement of shaft 46 and valve 74 of valve module 40 to unblock port 102 enables the fluid to flow therethrough from the bore 106. The motor 82 also acts as a brake to hold the valve 74 in the actuated or de-actuated position.

[0107] The downhole tool 26 may include a vibration sensor 310, such as an accelerometer. The vibration sensor 310 may be disposed within the bore 106 of, or coupled to, the downhole tool 26 or to the actuation system. The vibration sensor 310 may be adapted to measure vibration of the downhole tool 26, for example, when the downhole tool 26 is in operation, *e.g.*, increasing the diameter of the wellbore 24, milling a window through casing, etc. In one or more embodiments, the axial position of the valve 74 of valve module 40 and/or the cutter blocks 28 (see Figure 11), if downhole tool 26 is an underreamer, may be determined by measuring the number of revolutions of the motor 82 and/or the shaft 46. These vibration and position measurements may be transmitted to the surface via a telemetry system, *e.g.*, by one or more mud pulses, as disclosed herein. For example, in the embodiment illustrated in Figure 31, the electronics section 80 may cause a second motor 302 to shaft 304 to rotate a rotor 308 with respect to a stator 306. The movement of the rotor 308 with respect to the stator 306 may cause mud pulses that transmit the vibration and/or the position measurements to the surface. In at least one embodiment, the rotor 308 and the stator 306 may have axial openings formed therethrough, and the pressure pulse is formed with the openings in the rotor 308 become aligned with the openings in the stator 306. A power source 44, such as one or more batteries, may be used to power the electronics section 80, the vibration sensor and/or motors 82, 302.

[0108] As used herein, the terms "inner" and "outer;" "up" and "down;" "upper" and "lower;" "upward" and "downward;" "above" and "below;" "inward" and "outward" and other like terms as used herein refer to relative positions to one another and are not intended to denote a particular direction or spatial orientation. The terms "couple," "coupled," "connect," "connection," "connected," "in connection with," and "connecting" refer to "in direct connection with" or "in connection with via another element or member." The terms "hot" and "cold" refer to relative temperatures to one another.

[0109] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from "Actuation System and Method for a Downhole Tool." Accordingly, all such modifications are intended to be included within the scope of this disclosure. In the claims, means-plus-function clauses (*i.e.*, the claim expressly uses the words 'means for' together with an associated function) are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures.

[0110] Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, *e.g.*, the combination of any lower value with any upper value, the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated. Certain lower limits, upper limits and ranges appear in one or more claims below. All numerical values are "about" or "approximately" the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0111] Various terms have been defined above. To the extent a term used in a claim is not defined above, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Furthermore, all patents, test procedures, and other documents cited in this application are fully incorporated by reference to the extent such disclosure is not inconsistent with this application and for all jurisdictions in which such incorporation is permitted.

[0112] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof.

[0113] It is to be understood that, if any prior art is referred to herein, such reference does not constitute an admission that such prior art forms a part of the common general knowledge in the art, in Australia or any other country.

[0114] In the claims that follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

CLAIMS

What is claimed is:

1. A downhole tool having an actuation system, comprising:

a body having a bore axially extending at least partially therethrough,

a chamber disposed radially-outward from the bore and being in fluid communication with the bore through a port;

a valve disposed within the bore and adapted to move between a first position in which the valve prevents fluid flow from the bore to the chamber through the port and a second position in which the valve permits the fluid to flow from the bore to the chamber through the port;

a motor disposed within the bore and adapted to move the valve between the first position and the second position;

an actuatable component movably coupled to the body, the actuatable component adapted to move from a non-actuated state to an actuated state in response to fluid flow into the chamber through the port; and

a position sensor system disposed at least partially within the bore and adapted to measure an axial position of the actuatable component, wherein the position sensor system includes:

at least one magnet coupled to the actuatable component; and

a probe disposed within the bore, the probe having a plurality of boards, the probe further having plurality of magnetometers arranged in multiple arrays, with each array of the multiple arrays extending axially along, and on a different one of, the plurality of boards, each board of the plurality of boards being axially aligned and connected to each other board of the plurality of boards such that each array of the multiple arrays is circumferentially offset from each other array of the multiple arrays.

2. The downhole tool of claim 1, wherein the valve is arranged and designed to move axially within the bore between the first position and the second position.

3. The downhole tool of claim 1 or claim 2, further comprising a conversion assembly coupled between the motor and the valve that converts rotary motion of the motor into axial motion of the valve.

4. The downhole tool of any one of claims 1 to 3, further comprising an actuating member responsive to hydraulic pressure of fluid flow into the chamber, the actuating member arranged and designed to move the actuatable component from the non-actuated state to the actuated state in response to increased hydraulic pressure due to fluid flow into the chamber.

5. The downhole tool of any one of claims 1 to 4, wherein each array of the plurality of arrays includes a plurality of magnetometers arranged along an axial length of a respective board disposed within the probe.

6. The downhole tool of any one of claims 1 to 5, further comprising a telemetry system disposed within the bore, the telemetry system arranged and designed to transmit a signal representative of the axial position of the actuatable component to a remote location.

7. The downhole tool of claim 1, wherein the actuatable component engages and moves a mandrel, the axial position of the mandrel representative of the state of the actuatable component.

8. The downhole tool of claim 1, wherein the downhole tool is an underreamer.

9. A well tool actuation system for use in a wellbore, comprising:

a valve disposed within an internal flow passage of a downhole tubular and arranged and designed to move between a first position sealing a port in an inner wall of the downhole tubular and a second position permitting fluid flow from the internal flow passage into the port, the valve having one or more passages therethrough to permit fluid to pass axially therethrough to a downhole drill bit regardless of the valve position;

a motor disposed within the internal flow passage of the downhole tubular to permit fluid in the internal flow passage to pass around the motor, the motor coupled to the valve and arranged and designed to move the valve between the first position and the second position; and

a position sensor system disposed at least partially within the internal flow passage and adapted to measure an axial position of an actuatable component, the position sensor system including:

at least one magnet coupled to the actuatable component; and

a probe disposed within the bore, the probe having a plurality of boards, the probe further having a plurality of magnetometers arranged in multiple arrays, each array of the multiple arrays extending axially along, and on a different one of, the plurality of boards, each board of the plurality of boards being directly connected to each other board of the plurality of boards such that each array of the multiple arrays is circumferentially offset from each other array of the multiple arrays.

10. The well tool actuation system of claim 9, further comprising a downhole receiver coupled to the motor and adapted to receive a signal from a remote location, the signal controlling one or more operations of the motor to move the valve between the first position and the second position.

11. The well actuation system of claim 9, wherein the valve is arranged and designed to move axially within the internal flow passage between the first position and the second position.

12. The well actuation system of claim 11, further comprising a conversion assembly coupled between the motor and the valve that converts rotary movement of a shaft of the motor into axial movement of the valve.

13. The well actuation system of claim 9, further comprising a telemetry system disposed within the internal flow passage, the telemetry system arranged and designed to transmit a real time signal representative of the axial position of the actuatable component to a remote location.

14. The well actuation system of claim 9, wherein the valve and motor are modular and may be individually deployed and retrieved from surface to a downhole location of the wellbore.

15. The well actuation system of claim 9, wherein the motor is coupled to the valve through a self-aligning coupling.

16. The well actuation system of claim 15, wherein the self-aligning coupling includes a valve connector portion that slideably engages a motor connector portion of the self-aligning coupling.

17. A method, comprising:

transmitting a signal from a surface location to a downhole receiver disposed in a downhole tool, the signal controlling one or more operations of a motor disposed within a bore that extends axially at least partially through a body of the downhole tool, the motor coupled to and moving a valve disposed within the bore between a first position and a second position, the valve preventing fluid flow through a port disposed between the bore and a chamber disposed radially-outward from the bore when the valve is in the first position and the valve permitting fluid flow from the bore into the chamber through the port when the valve is in the second position, the fluid flow into the chamber causing hydraulic pressure to increase within the chamber thereby actuating an actuatable component of the downhole tool;

operating the downhole tool while the actuatable component of the downhole tool is actuated; and

measuring an axial position of the valve with a position sensor system disposed at least partially within the bore, wherein measuring the axial position of the valve includes determining a relative position of a probe including a plurality of magnetometers relative to a basket including at least one magnet, the probe further including a plurality of boards and the plurality of magnetometers being arranged in multiple arrays, each board of the plurality of boards having a different array of the multiple arrays extending axially therealong, and each board of the plurality of boards being connected to each other board of the plurality of boards such that each array of the multiple arrays is axially aligned with, and circumferentially offset from, each other of the multiple arrays.

18. The method of claim 17, wherein a conversion assembly coupled between the motor and the valve converts rotary movement of a shaft of the motor to axial movement of the valve.

19. The method of claim 17, further comprising determining an axial position of the actuatable component based on the axial position of the valve.

20. The method of claim 17, further comprising transmitting the axial position of the actuatable component to the surface location via a telemetry system disposed within the bore.

21. The method of claim 20, wherein the transmitting is conducted via a telemetry method selected from the group consisting of pressure pulse, acoustic waves, electromagnetic waves and insulated conductor.

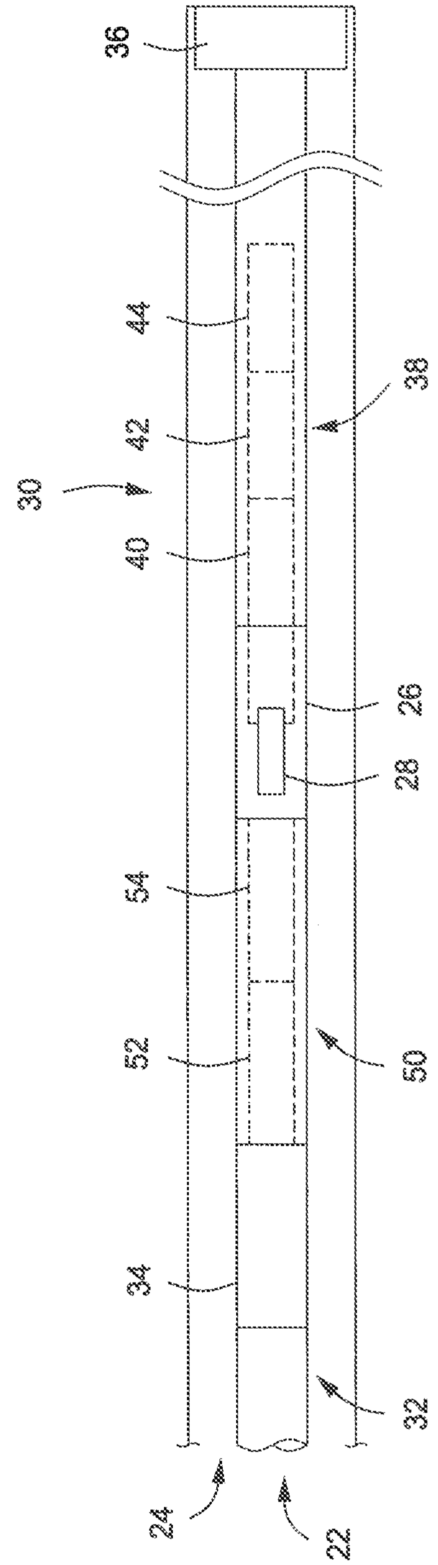

FIG. 1

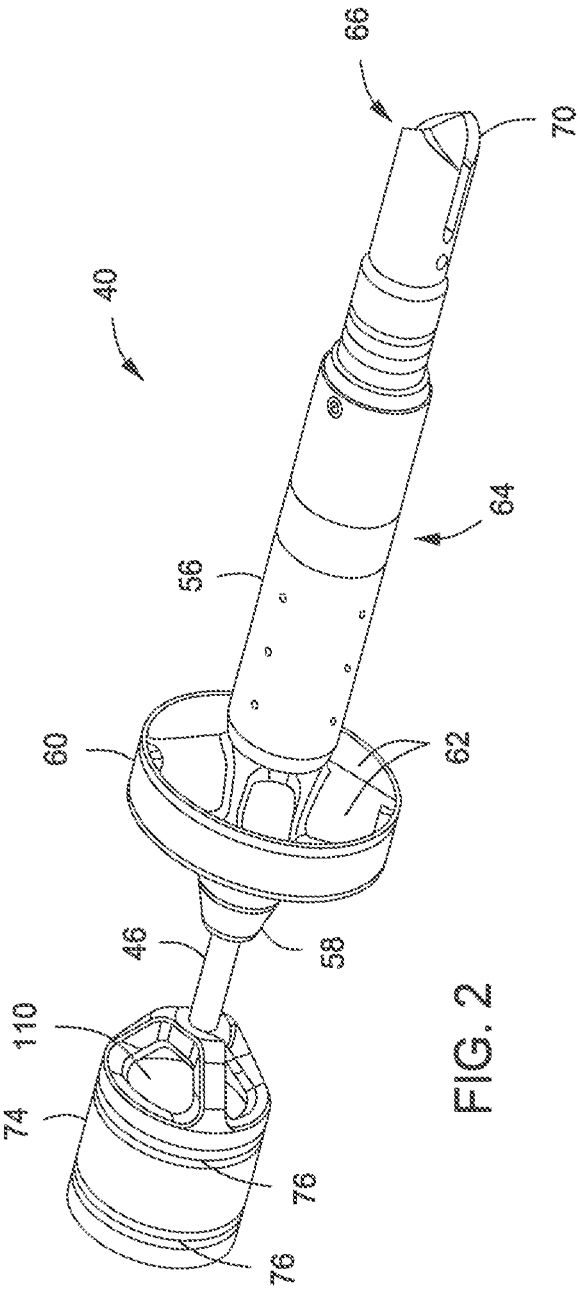

FIG. 2

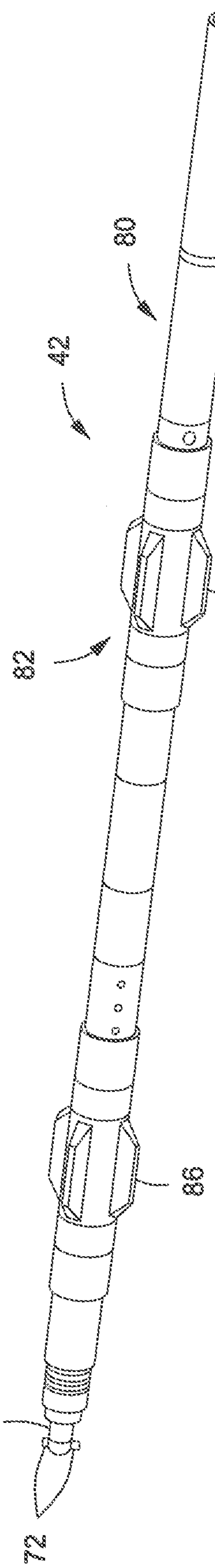

FIG. 3

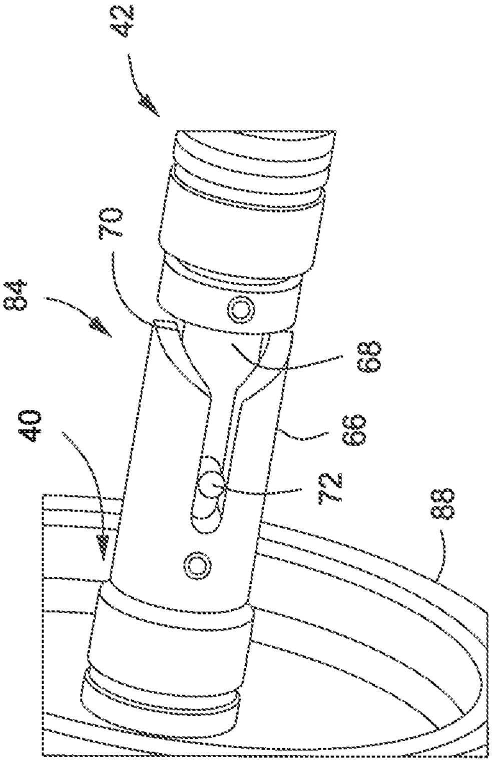
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FIG. 4

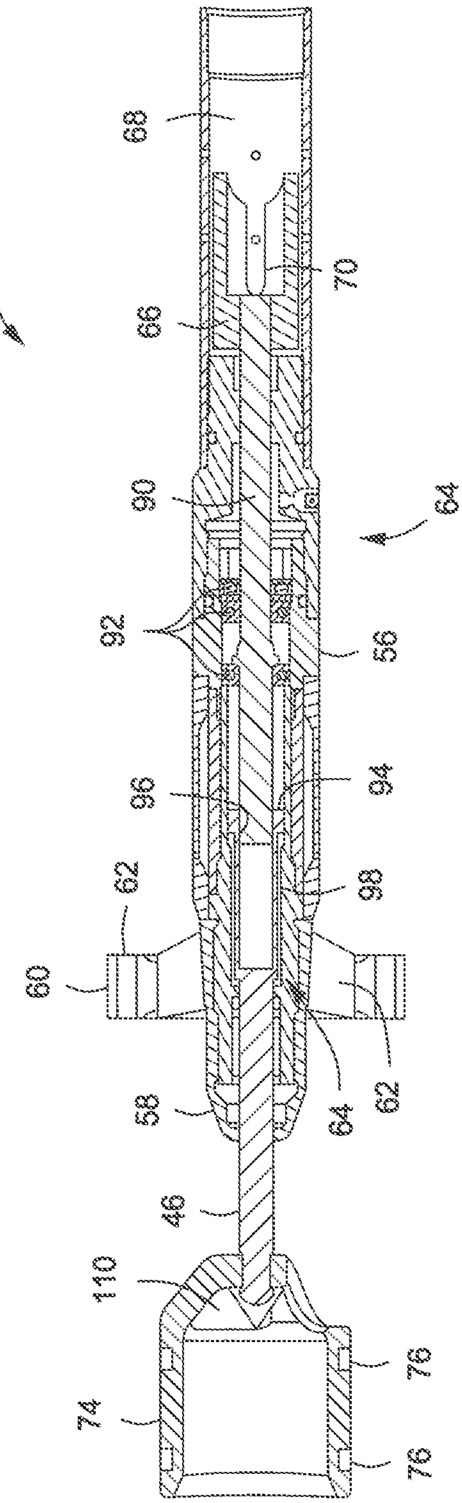
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FIG. 5

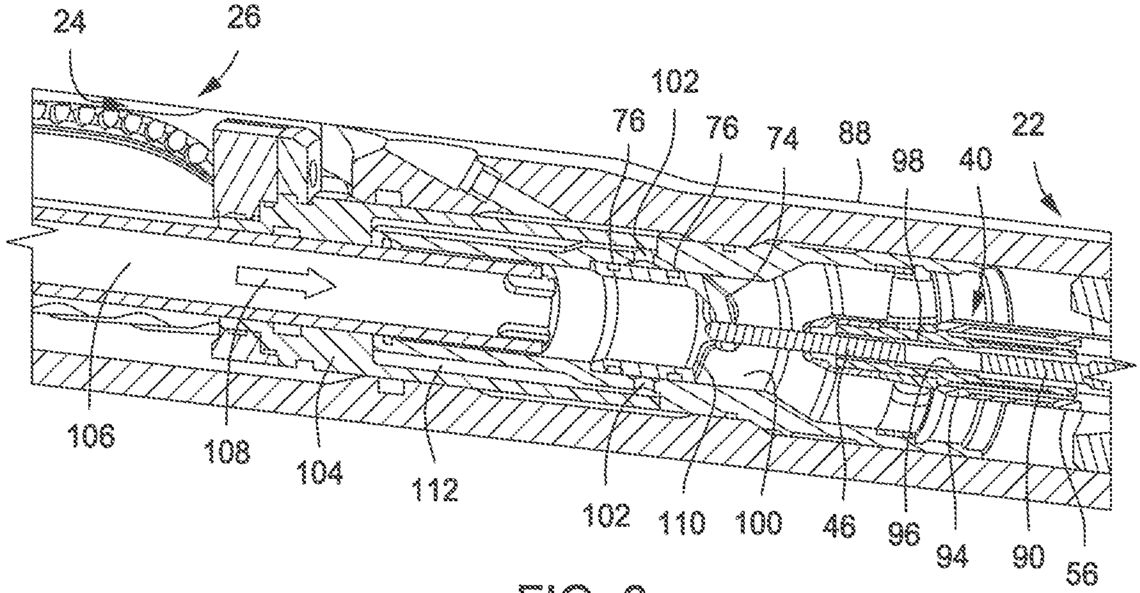
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FIG. 6

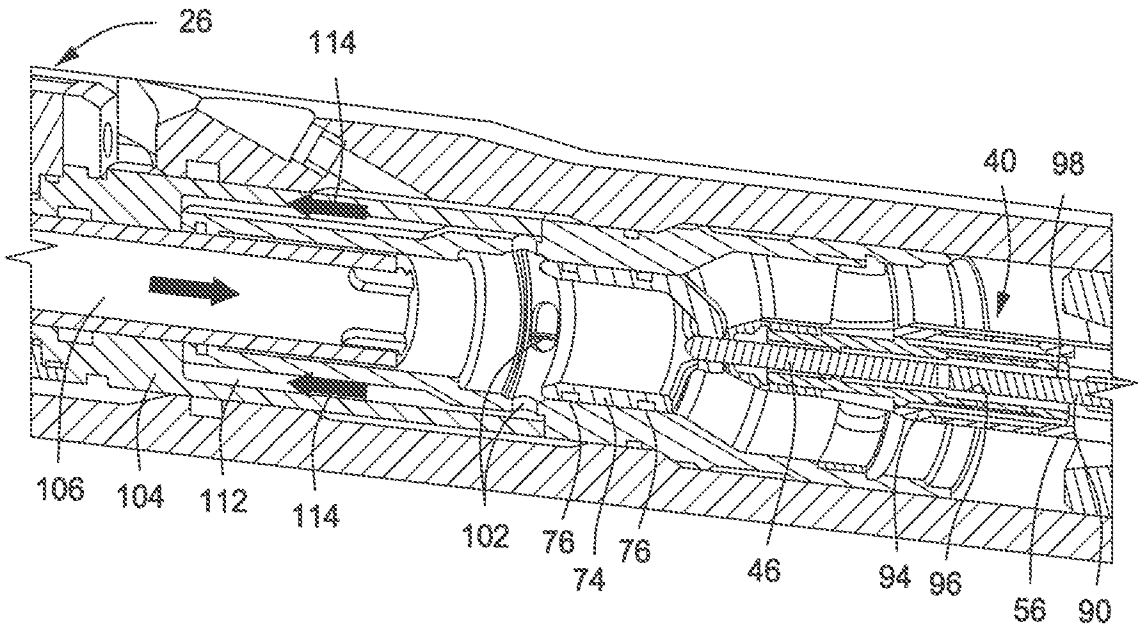
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FIG. 7

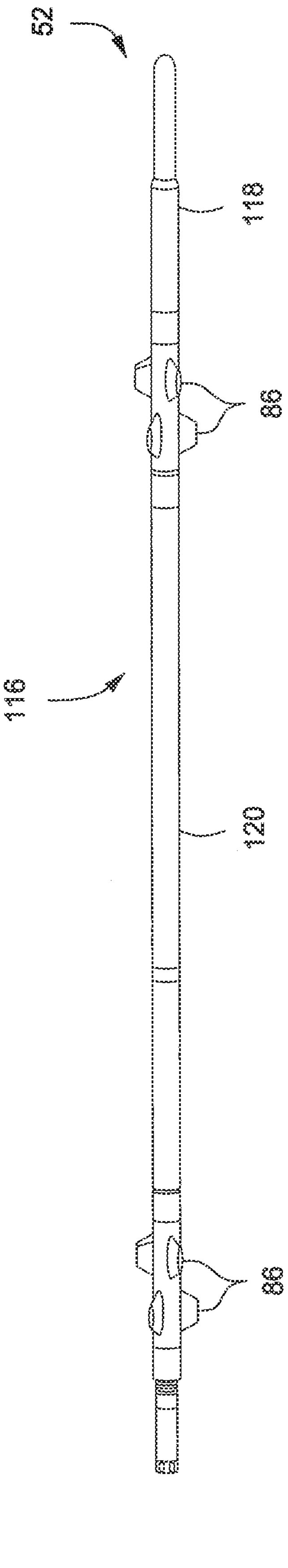

FIG. 8-1

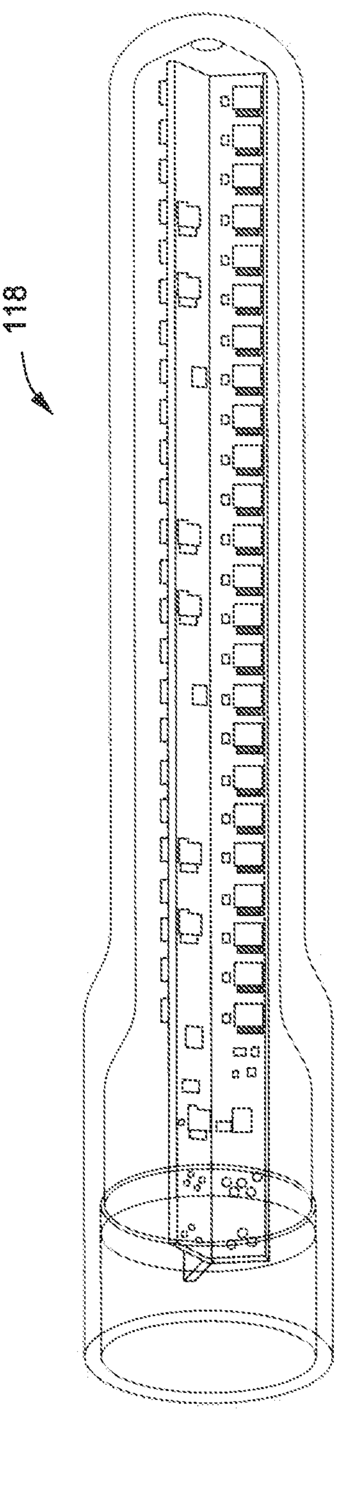

FIG. 8-2

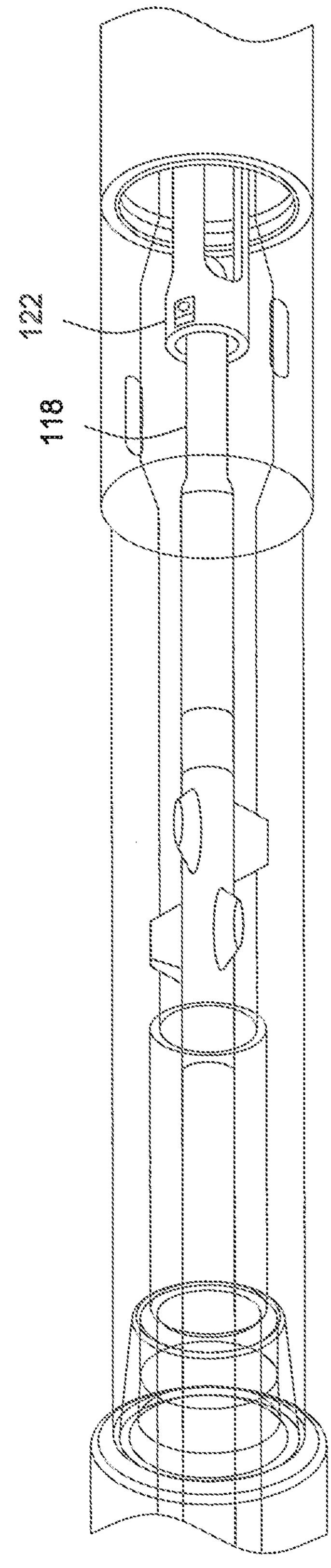

FIG. 8-3

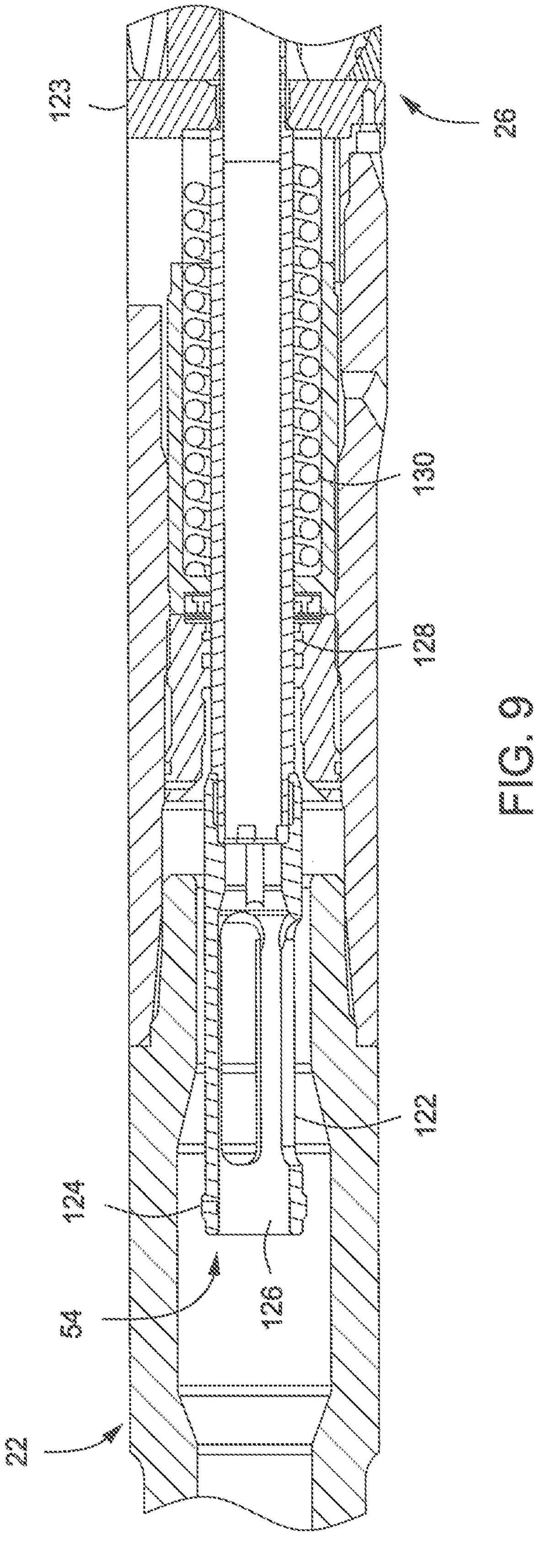

FIG. 9

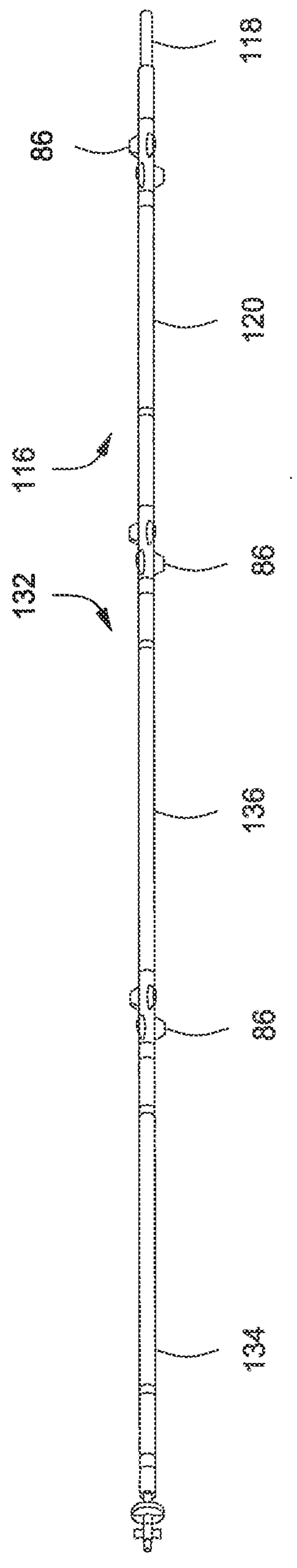
118
86
120
116
86
132
136
86
134

FIG. 10

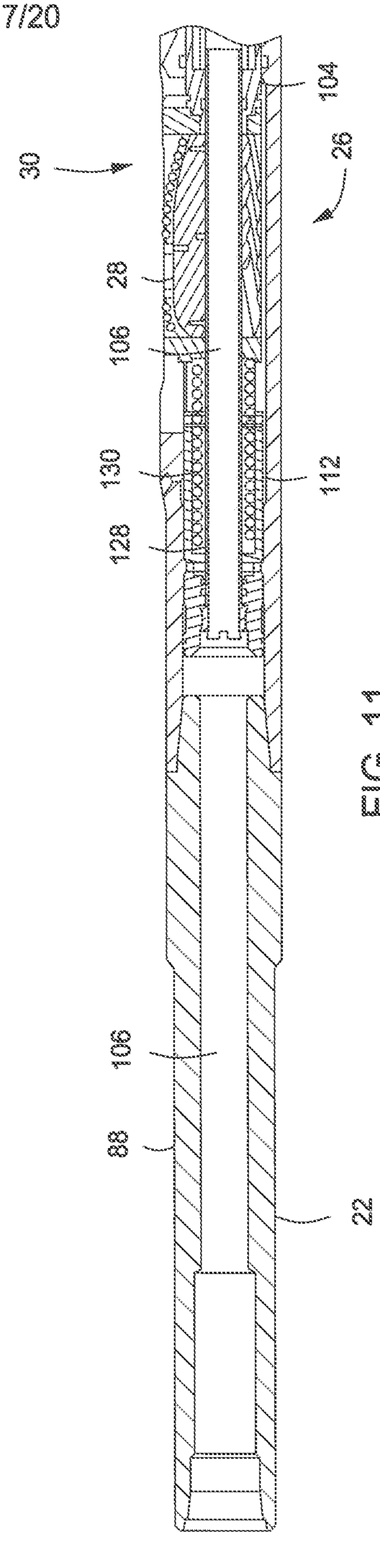
104
30
26
28
106
130
112
128
106
88
22

FIG. 11

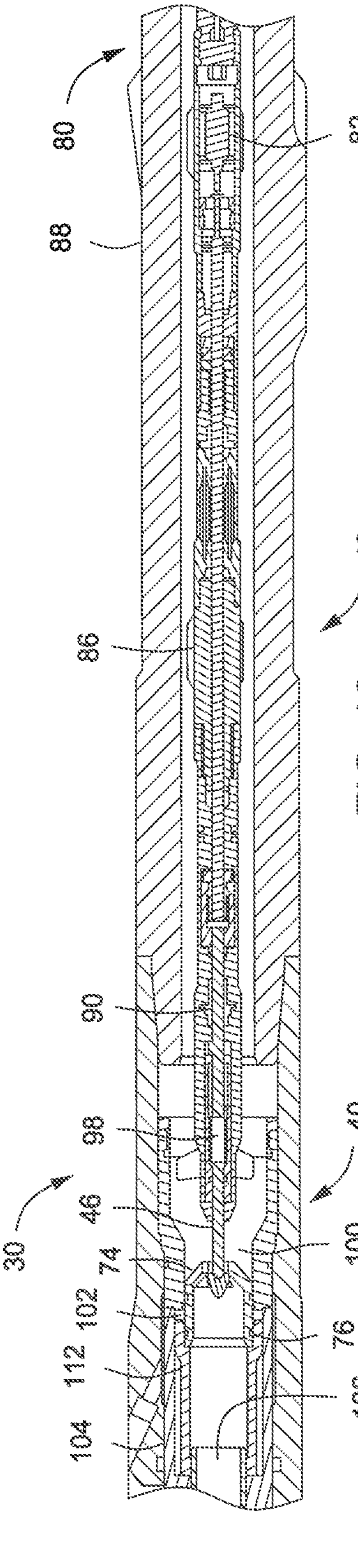
80
82
88
86
42
90
98
40
30
46
100
74
102
76
112
106
104

FIG. 12

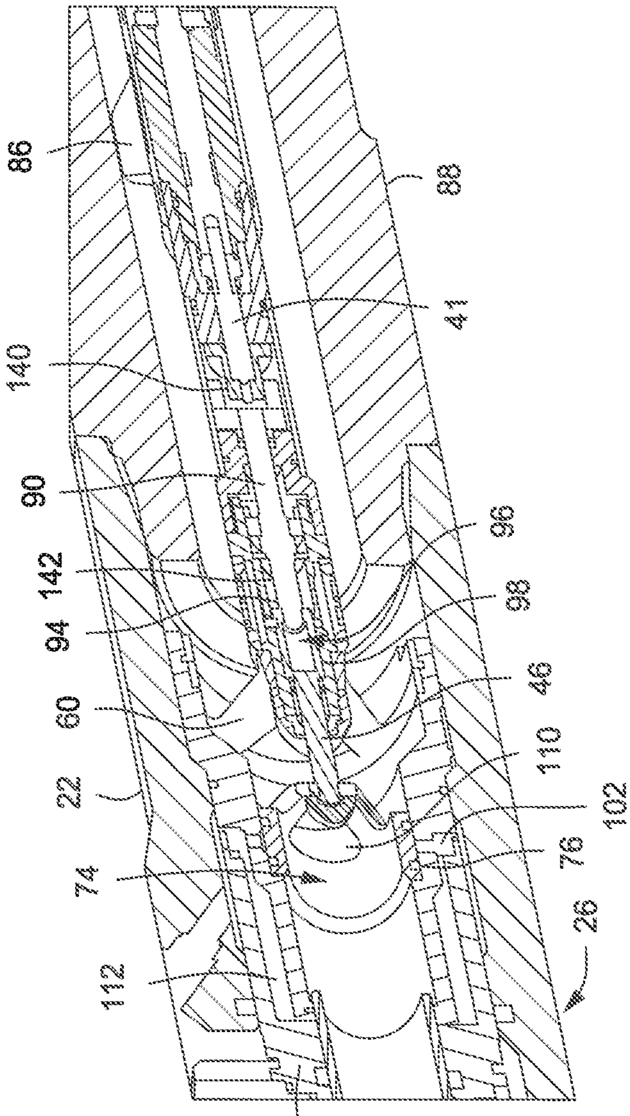
86
88
41
140
90
96
142
98
94
46
60
110
22
102
74
76
112
26
104

FIG. 13

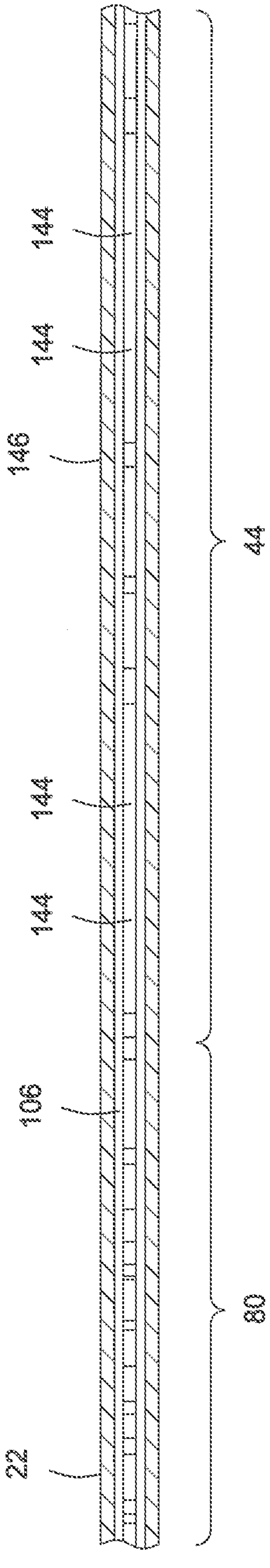
144
144
146
144
144
106
22
44
80

FIG. 14

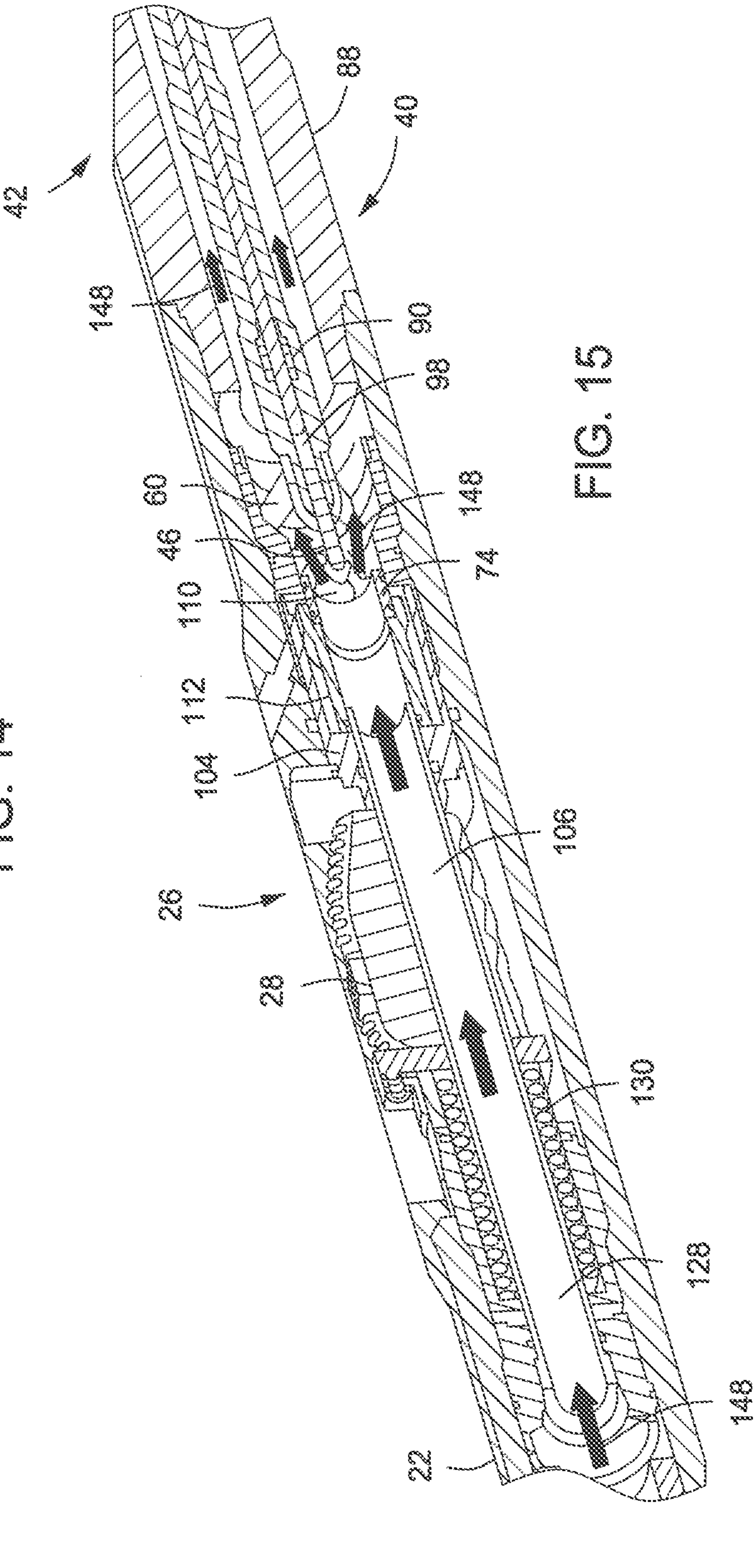
88
40
42
148
90
98
60
148
46
74
110
112
104
106
26
28
130
128
148
22

FIG. 15

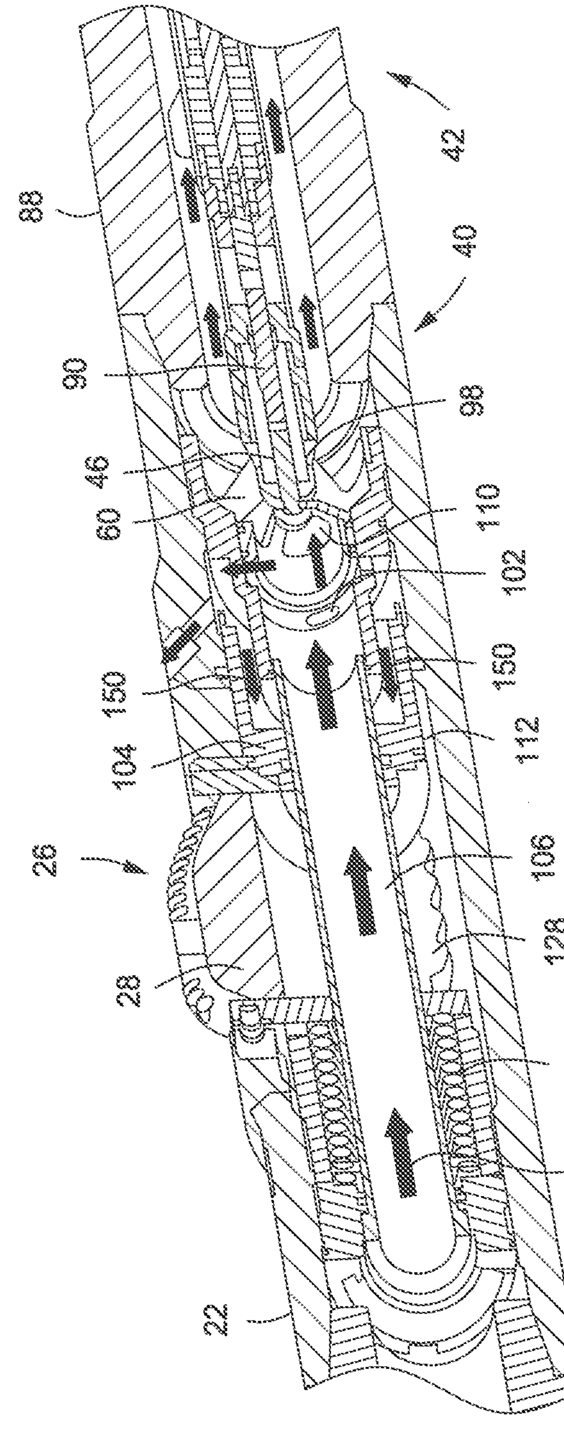
88
42
40
90
98
46
60
110
102
150
150
104
112
26
106
28
128
130
148
22

FIG. 16

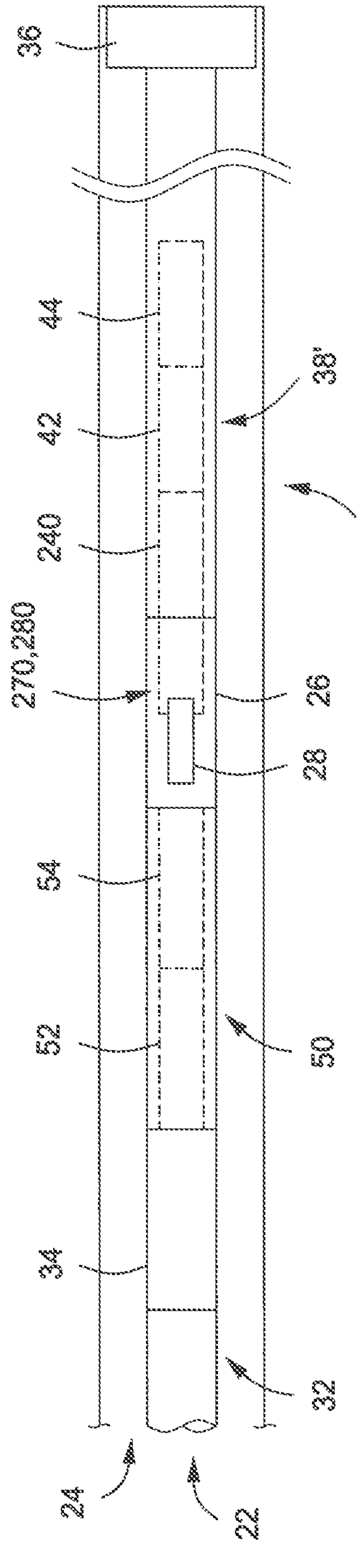
36
20'
44
38'
42
240
30'
270,280
26
28
54
52
50
34
32
24
22

FIG. 17

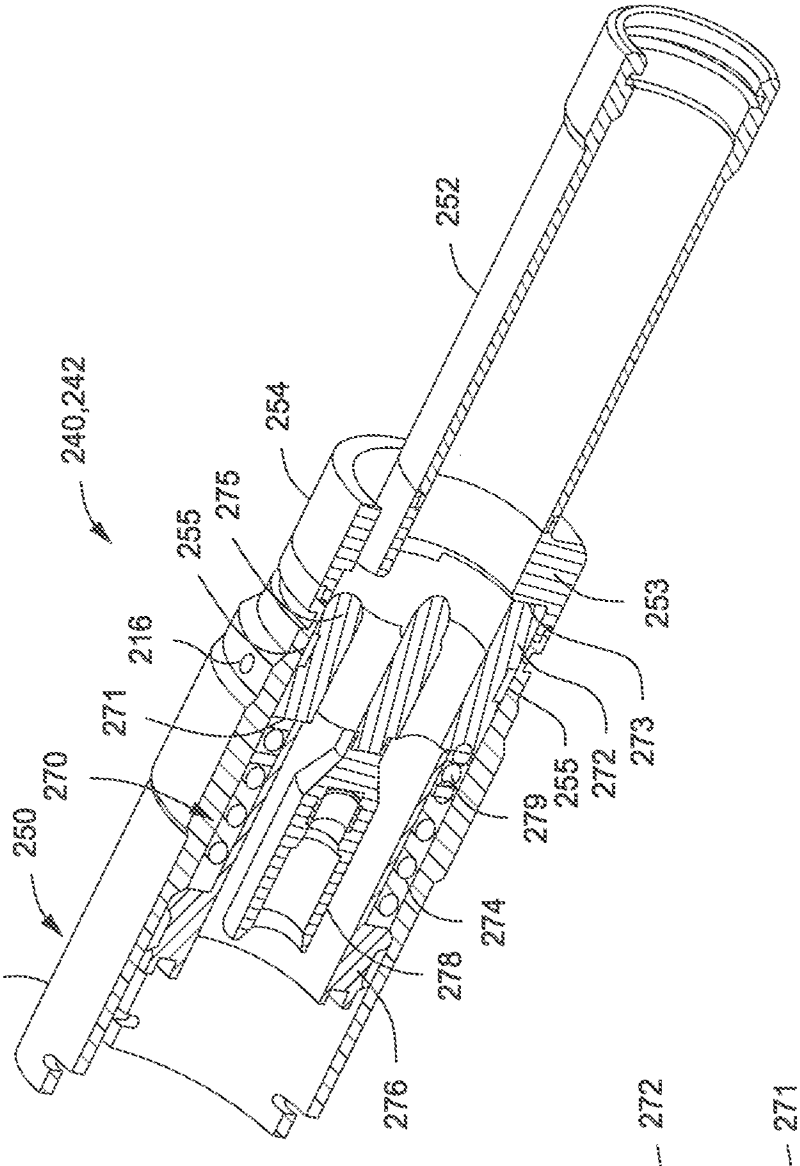

FIG. 18-1

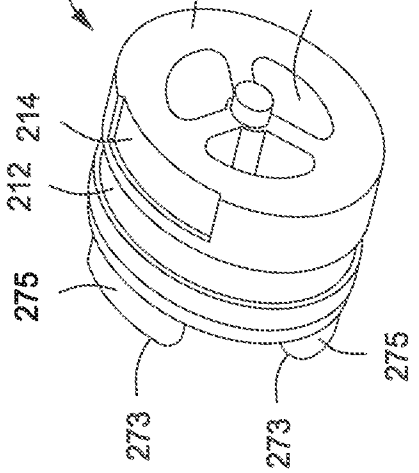

FIG. 18-2

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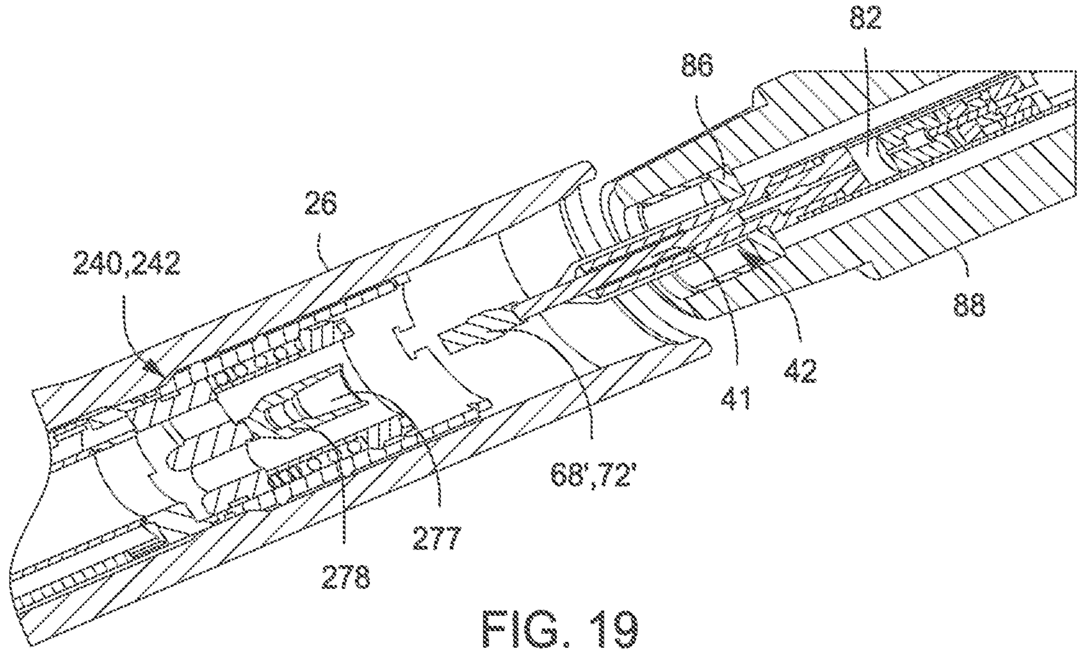


FIG. 19

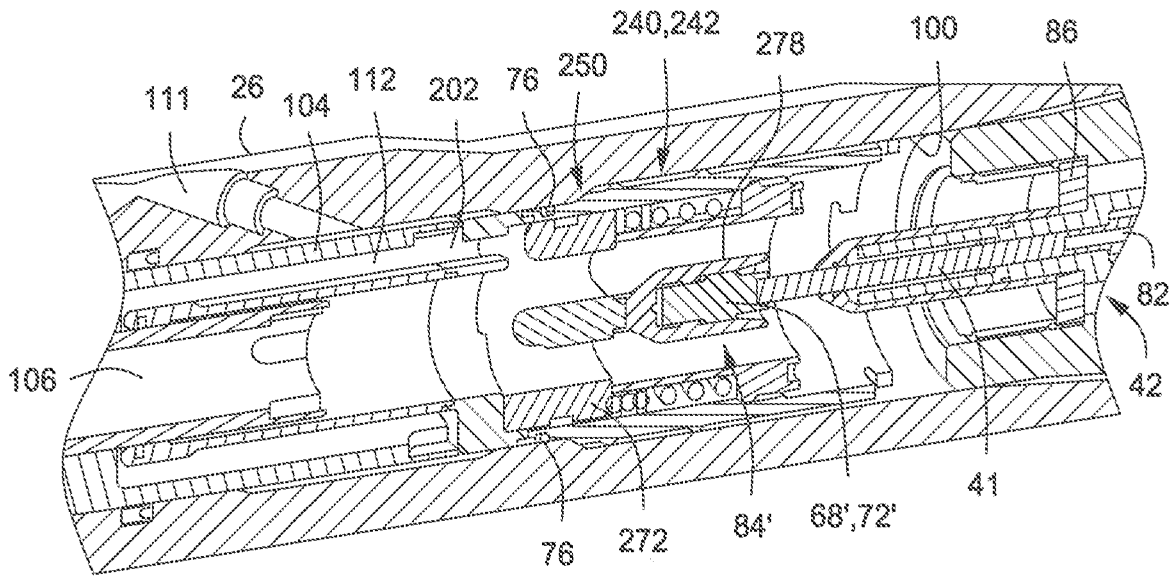
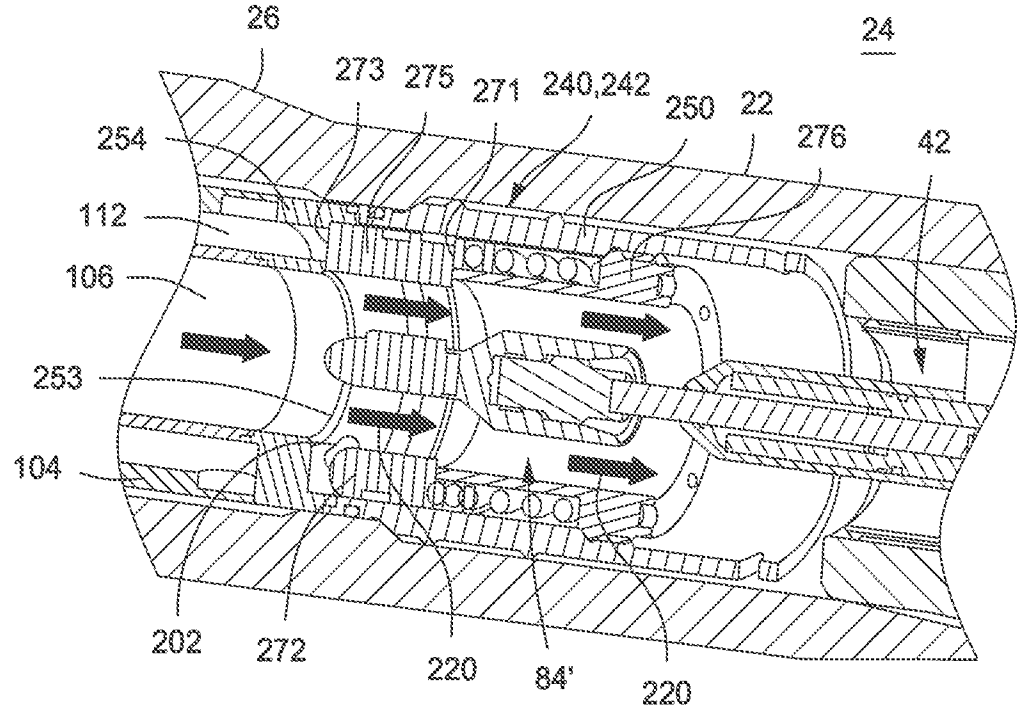
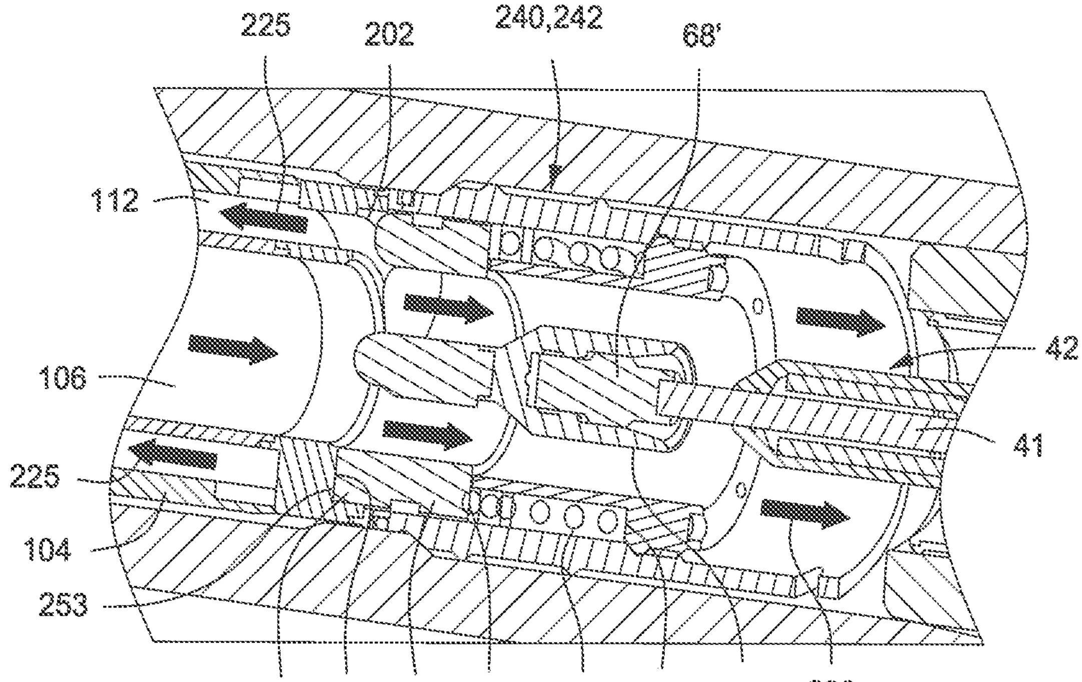


FIG. 20



26
24
273
275
271
240,242
250
22
276
42
254
112
106
253
104
202
272
220
84'
220

FIG. 21



225
202
240,242
68'
112
42
106
41
225
104
253
275
273
272
271
274
276
278
220

FIG. 22

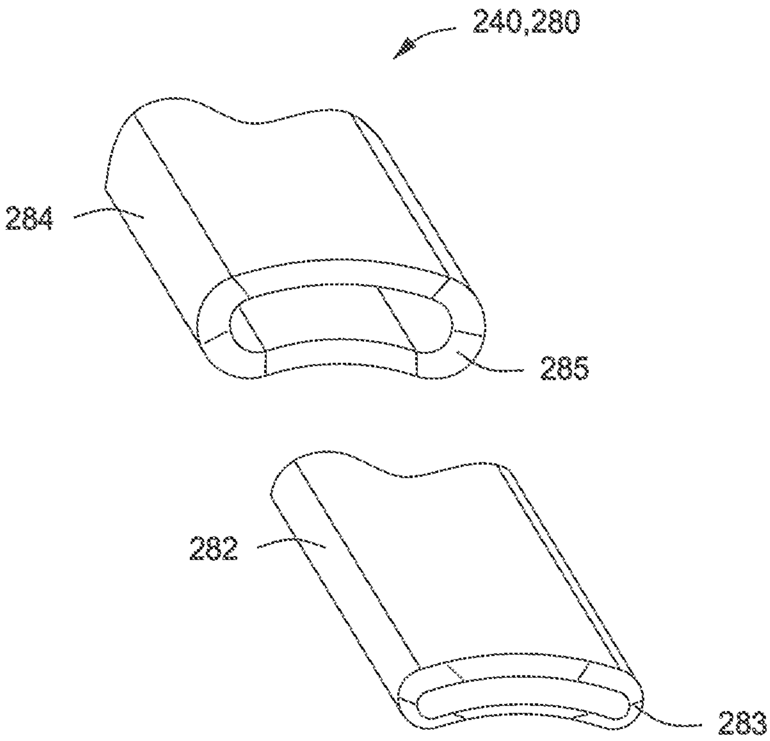


FIG. 23

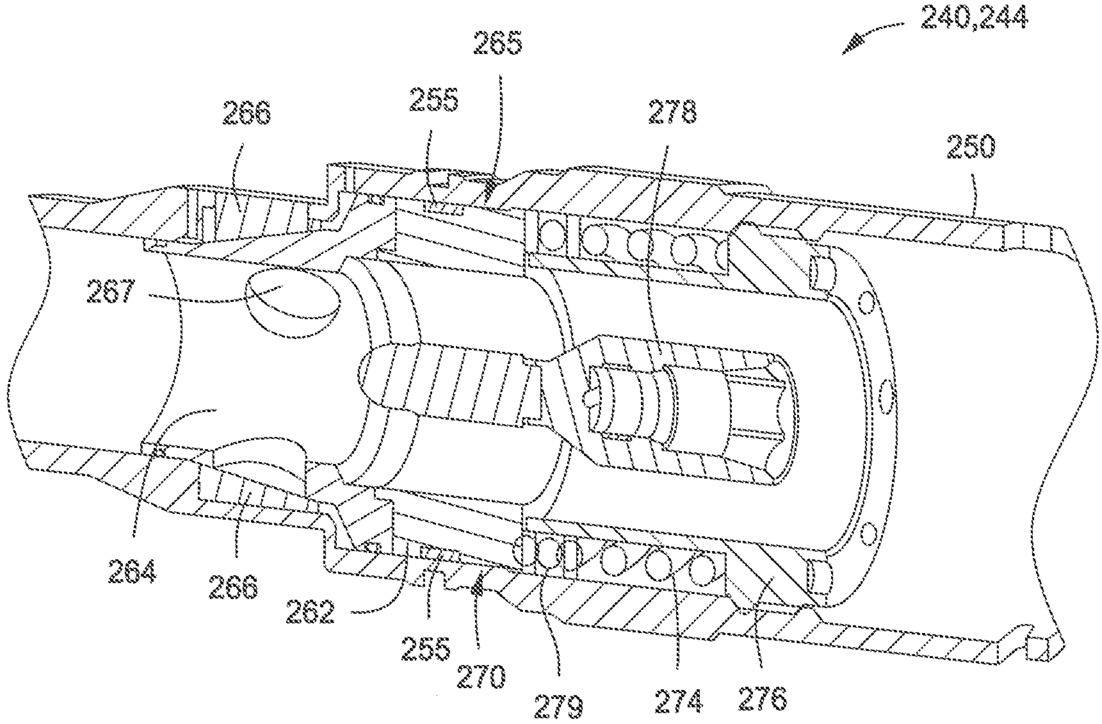

240,244
265
255
278
266
250
267
264
266
262
255
270
279
274
276

FIG. 24

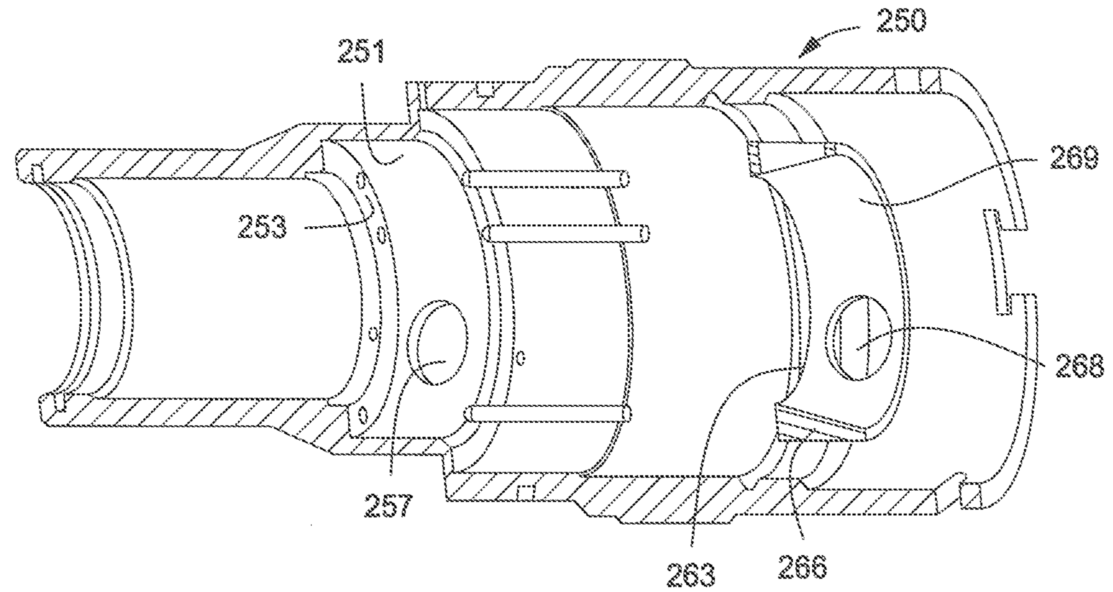

250
251
269
253
268
257
263
266

FIG. 25

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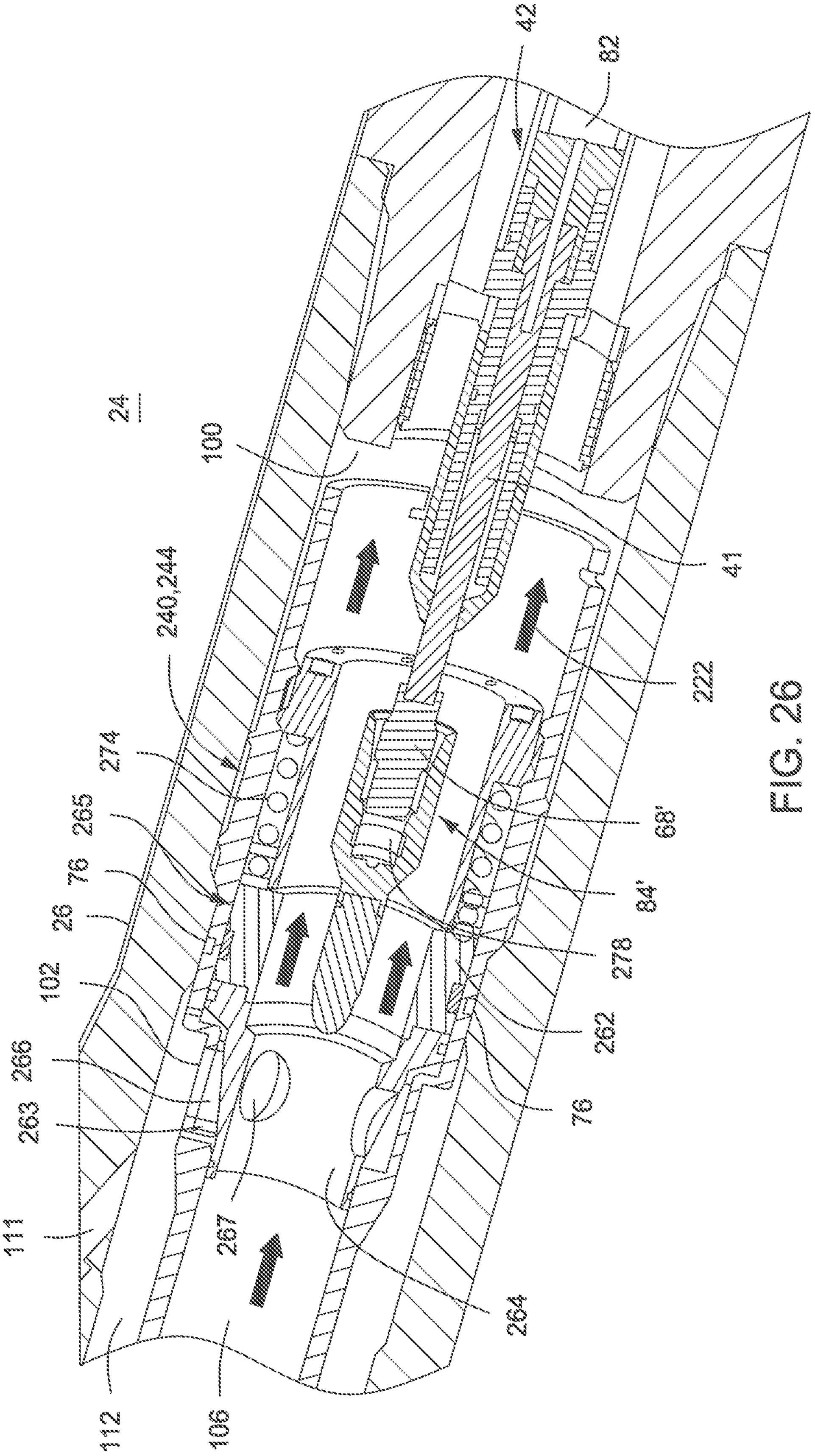
42
82
24
100
41
240,244
222
274
68'
265
84'
76
26
278
102
262
266
263
76
111
267
264
112
106

FIG. 26

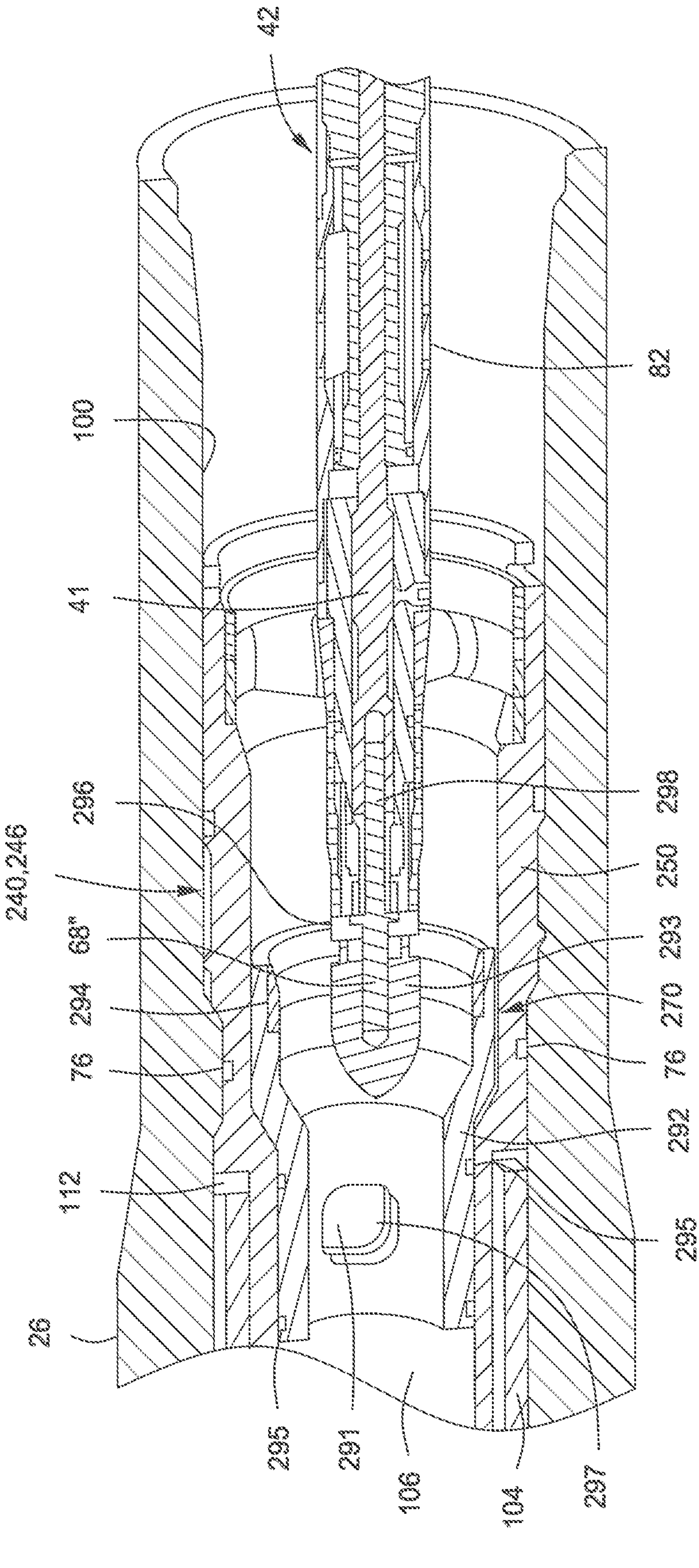
42
82
100
41
296
298
240,246
250
68"
293
294
270
76
76
292
112
295
26
295
291
106
104
297

FIG. 27

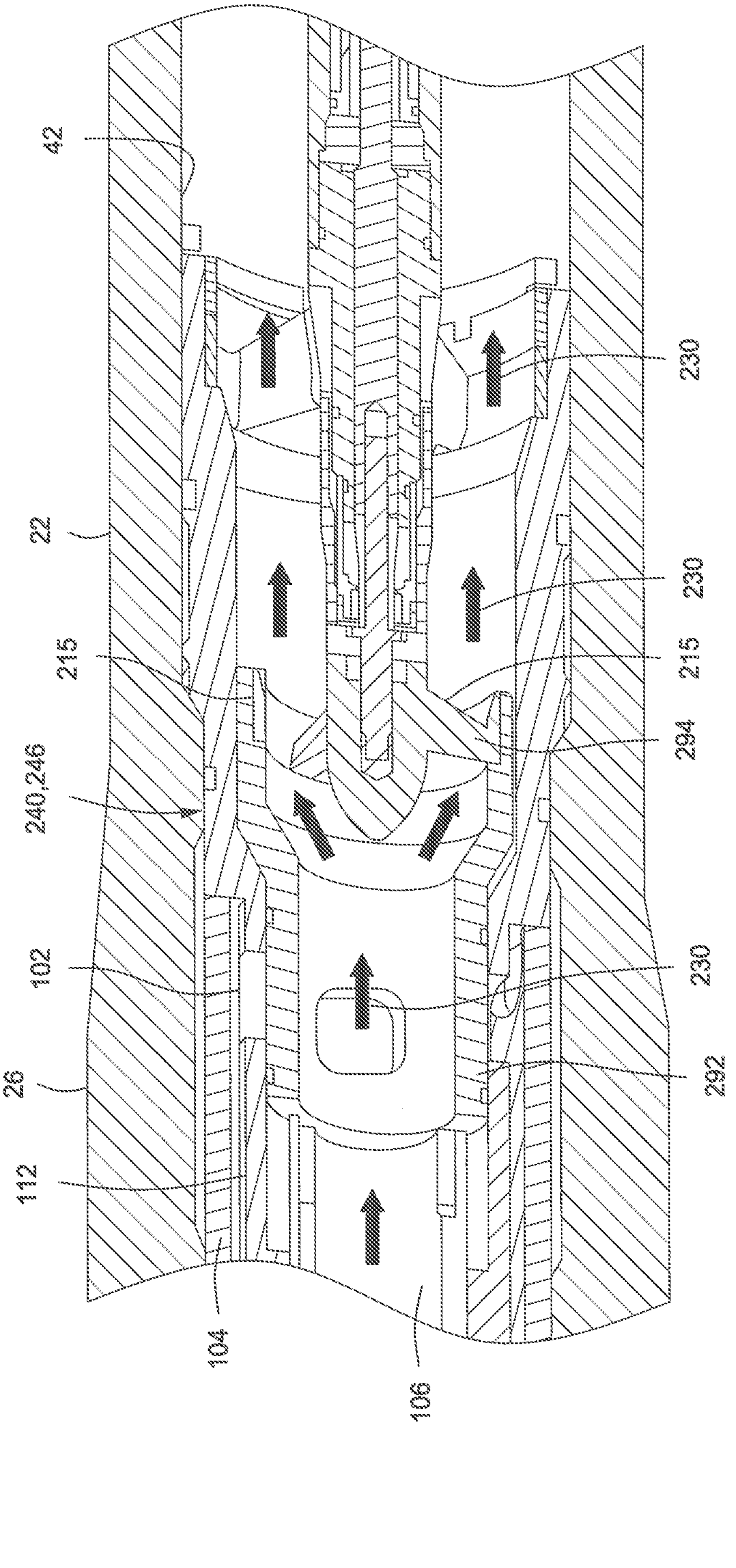

FIG. 28

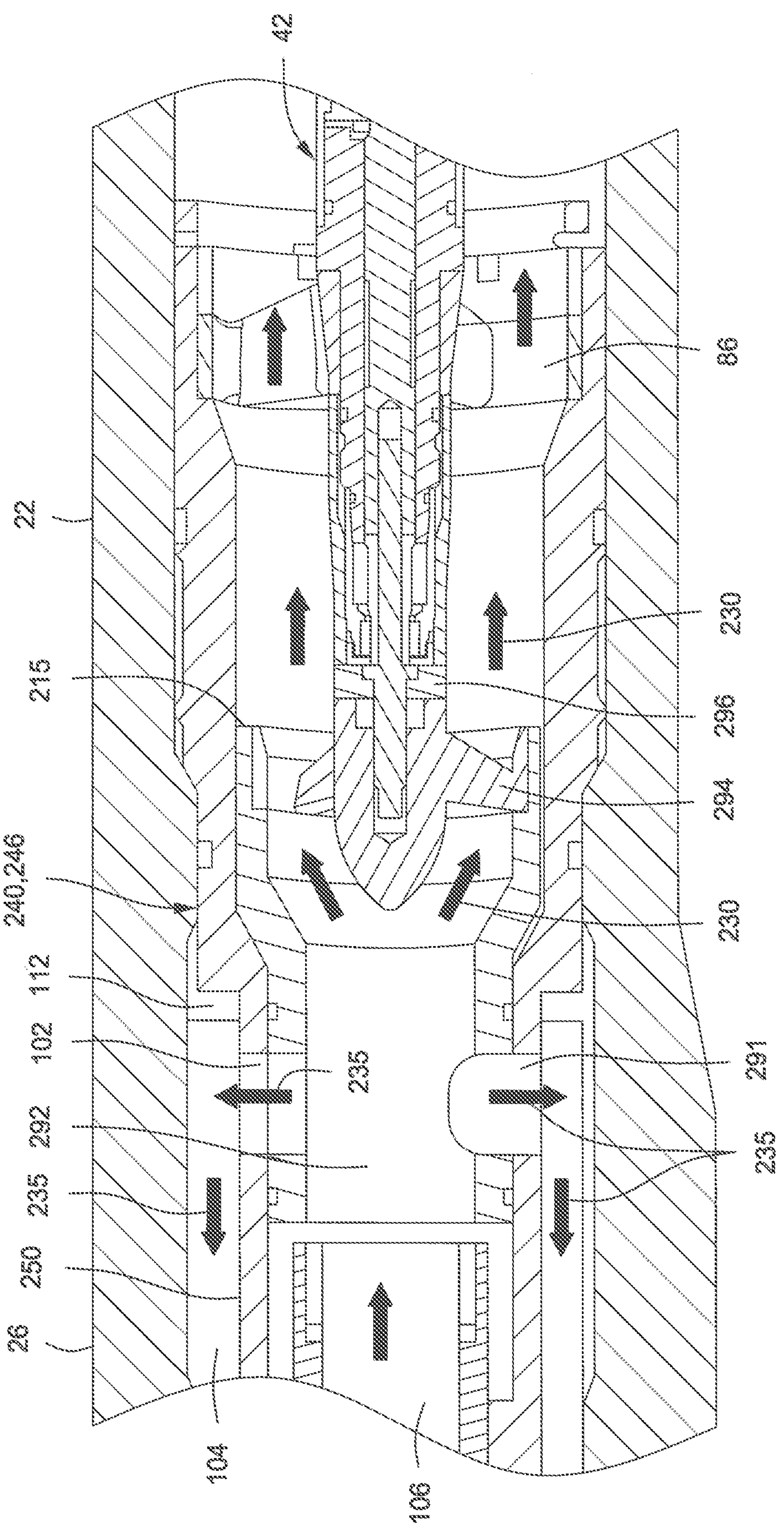
42
86
22
230
215
296
294
240,246
230
112
102
235
291
292
235
235
250
26
104
106

FIG. 29

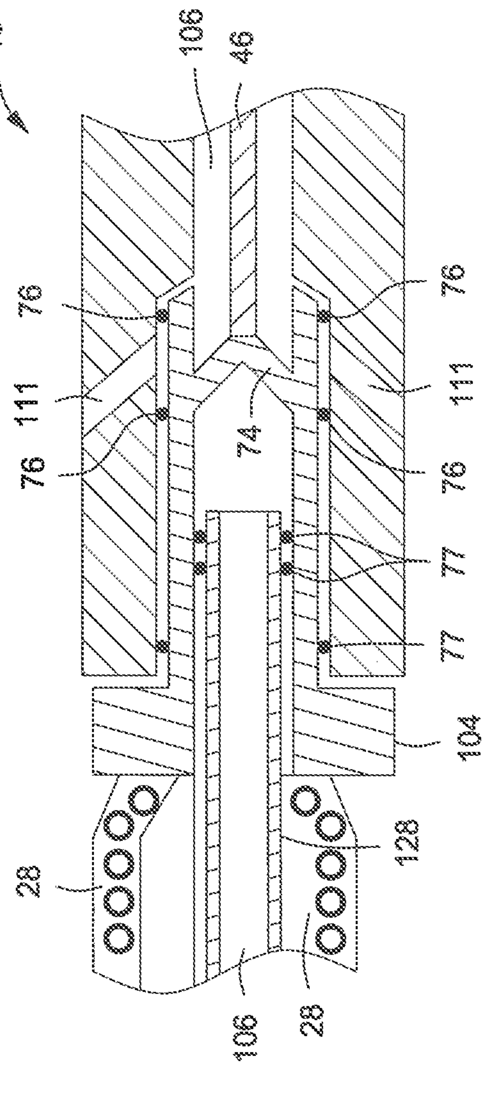
40
106
46
76
111
76
74
77
104
28
128
106
28

FIG. 30

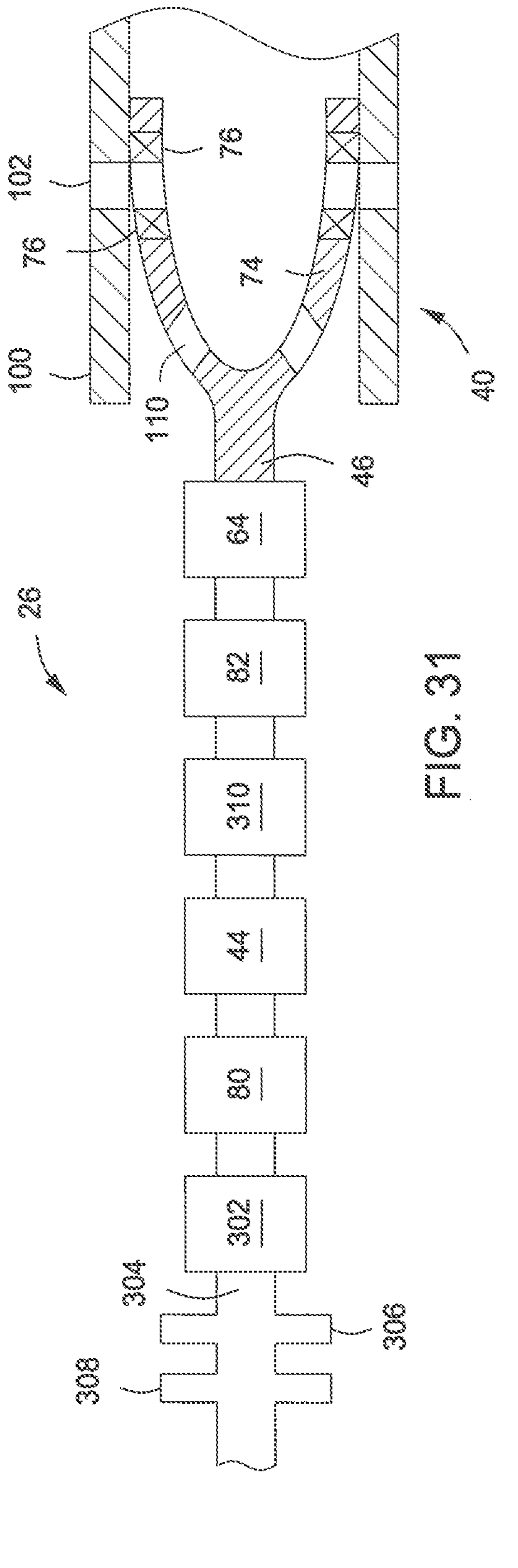
102
76
76
74
100
110
40
46
64
26
82
310
44
80
302
304
306
308

FIG. 31