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(54) Benævnelse: **WELL TOOLS HAVING MAGNETIC SHIELDING FOR MAGNETIC SENSOR**

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DESCRIPTION

TECHNICAL FIELD

[0001] This disclosure relates generally to equipment utilized and operations performed in conjunction with a subterranean well and, in an example described below, more particularly provides for magnetic sensing in well tools.

BACKGROUND

[0002] It can be beneficial in some circumstances to individually, or at least selectively, actuate one or more well tools in a well. However, it can be difficult to reliably transmit and receive magnetic signals in a wellbore environment.

[0003] Therefore, it will be appreciated that improvements are continually needed in the art. These improvements could be useful in, for example, controlling, communicating with, or actuating various types of well tools, etc.

[0004] US 2008/265892 A1 discloses an externally guided and directed field induction resistivity tool.

[0005] US 2013/264051 A1 discloses well tools selectively responsive to magnetic patterns.

[0006] US 4,901,069 A discloses an apparatus for electromagnetically coupling power and data signals between a first unit and a second unit and in particular between well bore apparatus and the surface.

[0007] US 5,138,263 A discloses an electromagnetic formation evaluation tool.

[0008] US 5 130 655 A discloses multiple-coil magnetic field sensor with series-connected main coils and parallel-connected feedback coils.

[0009] US 2013/314092 A1 discloses sensing the magnetic field of the earth.

SUMMARY OF THE INVENTION

[0010] In a first aspect of the present invention, there is provided a well tool according to Claim 1.

[0011] In a second aspect of the present invention, there is provided a well tool according to

Claim 6.

[0012] In a third aspect of the present invention, there is provided a well tool according to Claim 11.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

FIG. 1 is a representative partially cross-sectional view of a well system and associated method which can embody principles of this disclosure.

FIG. 2 is a representative cross-sectional view of an injection valve which may be used in the well system and method, and which can embody the principles of this disclosure.

FIGS. 3-6 are a representative cross-sectional views of another example of the injection valve, in run-in, actuated and reverse flow configurations thereof.

FIGS. 7 & 8 are representative side and plan views of a magnetic device which may be used with the injection valve.

FIG. 9 is a representative cross-sectional view of another example of the injection valve.

FIGS. 10A & B are representative cross-sectional views of successive axial sections of another example of the injection valve, in a closed configuration.

FIG. 11 is an enlarged scale representative cross-sectional view of a valve device which may be used in the injection valve.

FIG. 12 is an enlarged scale representative cross-sectional view of a magnetic sensor which may be used in the injection valve.

FIG. 13 is a representative cross-sectional view of another example of the injection valve.

FIG. 14 is an enlarged scale representative cross-sectional view of another example of the magnetic sensor in the injection valve of FIG. 13.

FIG. 15 is an enlarged scale representative cross-sectional view of an example of magnetic shielding in the injection valve of FIG. 12.

FIG. 16 is an enlarged scale representative cross-sectional view of another example of magnetic shielding in the injection valve of FIG. 12.

FIG. 17 is an enlarged scale representative cross-sectional view of yet another example of magnetic shielding in the injection valve of FIG. 12.

FIG. 18 is a representative elevational view of the magnetic shielding of FIG. 17, as viewed from position 18-18 of FIG. 17.

DETAILED DESCRIPTION

[0014] Representatively illustrated in FIG. 1 is a system 10 for use with a well, and an associated method, which can embody principles of this disclosure. In this example, a tubular string 12 is positioned in a wellbore 14, with the tubular string having multiple injection valves 16a-e and packers 18a-e interconnected therein.

[0015] The tubular string 12 may be of the type known to those skilled in the art as casing, liner, tubing, a production string, a work string, a drill string, etc. Any type of tubular string may be used and remain within the scope of this disclosure.

[0016] The packers 18a-e seal off an annulus 20 formed radially between the tubular string 12 and the wellbore 14. The packers 18a-e in this example are designed for sealing engagement with an uncased or open hole wellbore 14, but if the wellbore is cased or lined, then cased hole-type packers may be used instead. Swellable, inflatable, expandable and other types of packers may be used, as appropriate for the well conditions, or no packers may be used (for example, the tubular string 12 could be expanded into contact with the wellbore 14, the tubular string could be cemented in the wellbore, etc.).

[0017] In the FIG. 1 example, the injection valves 16a-e permit selective fluid communication between an interior of the tubular string 12 and each section of the annulus 20 isolated between two of the packers 18a-e. Each section of the annulus 20 is in fluid communication with a corresponding earth formation zone 22a-d. Of course, if packers 18a-e are not used, then the injection valves 16a-e can otherwise be placed in communication with the individual zones 22a-d, for example, with perforations, etc.

[0018] The zones 22a-d may be sections of a same formation 22, or they may be sections of different formations. Each zone 22a-d may be associated with one or more of the injection valves 16a-e.

[0019] In the FIG. 1 example, two injection valves 16b,c are associated with the section of the annulus 20 isolated between the packers 18b,c, and this section of the annulus is in communication with the associated zone 22b. It will be appreciated that any number of injection valves may be associated with a zone.

[0020] It is sometimes beneficial to initiate fractures 26 at multiple locations in a zone (for example, in tight shale formations, etc.), in which cases the multiple injection valves can provide for injecting fluid 24 at multiple fracture initiation points along the wellbore 14. In the example depicted in FIG. 1, the valve 16c has been opened, and fluid 24 is being injected into the zone 22b, thereby forming the fractures 26.

[0021] Preferably, the other valves 16a,b,d,e are closed while the fluid 24 is being flowed out of the valve 16c and into the zone 22b. This enables all of the fluid 24 flow to be directed toward forming the fractures 26, with enhanced control over the operation at that particular location.

[0022] However, in other examples, multiple valves 16a-e could be open while the fluid 24 is flowed into a zone of an earth formation 22. In the well system 10, for example, both of the valves 16b,c could be open while the fluid 24 is flowed into the zone 22b. This would enable fractures to be formed at multiple fracture initiation locations corresponding to the open valves.

[0023] It will, thus, be appreciated that it would be beneficial to be able to open different sets of one or more of the valves 16a-e at different times. For example, one set (such as valves 16b,c) could be opened at one time (such as, when it is desired to form fractures 26 into the zone 22b), and another set (such as valve 16a) could be opened at another time (such as, when it is desired to form fractures into the zone 22a).

[0024] One or more sets of the valves 16a-e could be open simultaneously. However, it is generally preferable for only one set of the valves 16a-e to be open at a time, so that the fluid 24 flow can be concentrated on a particular zone, and so flow into that zone can be individually controlled.

[0025] At this point, it should be noted that the well system 10 and method is described here and depicted in the drawings as merely one example of a wide variety of possible systems and methods which can incorporate the principles of this disclosure. Therefore, it should be understood that those principles are not limited in any manner to the details of the system 10 or associated method, or to the details of any of the components thereof (for example, the tubular string 12, the wellbore 14, the valves 16a-e, the packers 18a-e, etc.).

[0026] It is not necessary for the wellbore 14 to be vertical as depicted in FIG. 1, for the wellbore to be uncased, for there to be five each of the valves 16a-e and packers, for there to be four of the zones 22a-d, for fractures 26 to be formed in the zones, for the fluid 24 to be injected, etc. The fluid 24 could be any type of fluid which is injected into an earth formation, e.g., for stimulation, conformance, acidizing, fracturing, water-flooding, steam-flooding, treatment, gravel packing, cementing, or any other purpose. Thus, it will be appreciated that the principles of this disclosure are applicable to many different types of well systems and operations.

[0027] In other examples, the principles of this disclosure could be applied in circumstances where fluid is not only injected, but is also (or only) produced from the formation 22. In these examples, the fluid 24 could be oil, gas, water, etc., produced from the formation 22. Thus, well tools other than injection valves can benefit from the principles described herein.

[0028] Referring additionally now to FIG. 2, an enlarged scale cross-sectional view of one example of the injection valve 16 is representatively illustrated. The injection valve 16 of FIG. 2 may be used in the well system 10 and method of FIG. 1, or it may be used in other well systems and methods, while still remaining within the scope of this disclosure.

[0029] In the FIG. 2 example, the valve 16 includes openings 28 in a sidewall of a generally tubular housing 30. The openings 28 are blocked by a sleeve 32, which is retained in position by shear members 34.

[0030] In this configuration, fluid communication is prevented between the annulus 20 external to the valve 16, and an internal flow passage 36 which extends longitudinally through the valve (and which extends longitudinally through the tubular string 12 when the valve is interconnected therein). The valve 16 can be opened, however, by shearing the shear members 34 and displacing the sleeve 32 (downward as viewed in FIG. 2) to a position in which the sleeve does not block the openings 28.

[0031] To open the valve 16, a magnetic device 38 is displaced into the valve to activate an actuator 50 thereof. The magnetic device 38 is depicted in FIG. 2 as being generally cylindrical, but other shapes and types of magnetic devices (such as, balls, darts, plugs, wipers, fluids, gels, etc.) may be used in other examples. For example, a ferrofluid, magnetorheological fluid, or any other fluid having magnetic properties which can be sensed by the sensor 40, could be pumped to or past the sensor in order to transmit a magnetic signal to the actuator 50.

[0032] The magnetic device 38 may be displaced into the valve 16 by any technique. For example, the magnetic device 38 can be dropped through the tubular string 12, pumped by flowing fluid through the passage 36, self-propelled, conveyed by wireline, slickline, coiled tubing, jointed tubing, etc.

[0033] The magnetic device 38 has known magnetic properties, and/or produces a known magnetic field, or pattern or combination of magnetic fields, which is/are detected by a magnetic sensor 40 of the valve 16. The magnetic sensor 40 can be any type of sensor which is capable of detecting the presence of the magnetic field(s) produced by the magnetic device 38, and/or one or more other magnetic properties of the magnetic device.

[0034] Suitable sensors include (but are not limited to) giant magneto-resistive (GMR) sensors, Hall-effect sensors, conductive coils, a super conductive quantum interference device (SQUID), etc. Permanent magnets can be combined with the magnetic sensor 40 in order to create a magnetic field that is disturbed by the magnetic device 38. A change in the magnetic field can be detected by the sensor 40 as an indication of the presence of the magnetic device 38.

[0035] The sensor 40 is connected to electronic circuitry 42 which determines whether the sensor has detected a particular predetermined magnetic field, or pattern or combination of magnetic fields, magnetic permittivity or other magnetic properties of the magnetic device 38. For example, the electronic circuitry 42 could have the predetermined magnetic field(s), magnetic permittivity or other magnetic properties programmed into non-volatile memory for comparison to magnetic fields/properties detected by the sensor 40. The electronic circuitry 42 could be supplied with electrical power via an on-board battery, a downhole generator, or any other electrical power source.

[0036] In one example, the electronic circuitry 42 could include a capacitor, wherein an electrical resonance behavior between the capacitance of the capacitor and the magnetic sensor 40 changes, depending on whether the magnetic device 38 is present. In another example, the electronic circuitry 42 could include an adaptive magnetic field that adjusts to a baseline magnetic field of the surrounding environment (e.g., the formation 22, surrounding metallic structures, etc.). The electronic circuitry 42 could determine whether the measured magnetic fields exceed the adaptive magnetic field level.

[0037] In one example, the sensor 40 could comprise an inductive sensor which can detect the presence of a metallic device (e.g., by detecting a change in a magnetic field, etc.). The metallic device (such as a metal ball or dart, etc.) can be considered a magnetic device 38, in the sense that it conducts a magnetic field and produces changes in a magnetic field which can be detected by the sensor 40.

[0038] If the electronic circuitry 42 determines that the sensor 40 has detected the predetermined magnetic field(s) or change(s) in magnetic field(s), the electronic circuitry causes a valve device 44 to open. In this example, the valve device 44 includes a piercing member 46 which pierces a pressure barrier 48.

[0039] The piercing member 46 can be driven by any means, such as, by an electrical, hydraulic, mechanical, explosive, chemical or other type of actuator. Other types of valve devices 44 (such as those described in US patent application no. 12/688058 and in U.S. patent no. 8235103) may be used, in keeping with the scope of this disclosure.

[0040] When the valve device 44 is opened, a piston 52 on a mandrel 54 becomes unbalanced (e.g., a pressure differential is created across the piston), and the piston displaces downward as viewed in FIG. 2. This displacement of the piston 52 could, in some examples, be used to shear the shear members 34 and displace the sleeve 32 to its open position.

[0041] However, in the FIG. 2 example, the piston 52 displacement is used to activate a retractable seat 56 to a sealing position thereof. As depicted in FIG. 2, the retractable seat 56 is in the form of resilient collets 58 which are initially received in an annular recess 60 formed in the housing 30. In this position, the retractable seat 56 is retracted, and is not capable of sealingly engaging the magnetic device 38 or any other form of plug in the flow passage 36.

[0042] A time delay could be provided between the sensor 40 detecting the predetermined magnetic field or change in magnetic filed, and the piercing member 46 opening the valve device 44. Such a time delay could be programmed in the electronic circuitry 42.

[0043] When the piston 52 displaces downward, the collets 58 are deflected radially inward by an inclined face 62 of the recess 60, and the seat 56 is then in its sealing position. A plug (such as, a ball, a dart, a magnetic device 38, etc.) can sealingly engage the seat 56, and increased pressure can be applied to the passage 36 above the plug to thereby shear the shear members 34 and downwardly displace the sleeve 32 to its open position.

[0044] As mentioned above, the retractable seat 56 may be sealingly engaged by the magnetic device 38 which initially activates the actuator 50 (e.g., in response to the sensor 40 detecting the predetermined magnetic field(s) or change(s) in magnetic field(s) produced by the magnetic device), or the retractable seat may be sealingly engaged by another magnetic device and/or plug subsequently displaced into the valve 16.

[0045] Furthermore, the retractable seat 56 may be actuated to its sealing position in response to displacement of more than one magnetic device 38 into the valve 16. For example, the electronic circuitry 42 may not actuate the valve device 44 until a predetermined number of the magnetic devices 38 have been displaced into the valve 16, and/or until a predetermined spacing in time is detected, etc.

[0046] Referring additionally now to FIGS. 3-6, another example of the injection valve 16 is representatively illustrated. In this example, the sleeve 32 is initially in a closed position, as depicted in FIG. 3. The sleeve 32 is displaced to its open position (see FIG. 4) when a support fluid 63 is flowed from one chamber 64 to another chamber 66.

[0047] The chambers 64, 66 are initially isolated from each other by the pressure barrier 48. When the sensor 40 detects the predetermined magnetic signal(s) produced by the magnetic device(s) 38, the piercing member 46 pierces the pressure barrier 48, and the support fluid 63 flows from the chamber 64 to the chamber 66, thereby allowing a pressure differential across the sleeve 32 to displace the sleeve downward to its open position, as depicted in FIG. 4.

[0048] Fluid 24 can now be flowed outward through the openings 28 from the passage 36 to the annulus 20. Note that the retractable seat 56 is now extended inwardly to its sealing position. In this example, the retractable seat 56 is in the form of an expandable ring which is extended radially inward to its sealing position by the downward displacement of the sleeve 32.

[0049] In addition, note that the magnetic device 38 in this example comprises a ball or sphere. Preferably, one or more permanent magnets 68 or other type of magnetic field-producing components are included in the magnetic device 38.

[0050] In FIG. 5, the magnetic device 38 is retrieved from the passage 36 by reverse flow of fluid through the passage 36 (e.g., upward flow as viewed in FIG. 5). The magnetic device 38 is conveyed upwardly through the passage 36 by this reverse flow, and eventually engages in sealing contact with the seat 56, as depicted in FIG. 5.

[0051] In FIG. 6, a pressure differential across the magnetic device 38 and seat 56 causes them to be displaced upward against a downward biasing force exerted by a spring 70 on a retainer sleeve 72. When the biasing force is overcome, the magnetic device 38, seat 56 and sleeve 72 are displaced upward, thereby allowing the seat 56 to expand outward to its retracted position, and allowing the magnetic device 38 to be conveyed upward through the passage 36, e.g., for retrieval to the surface.

[0052] Note that in the FIGS. 2 & 3-6 examples, the seat 58 is initially expanded or "retracted" from its sealing position, and is later deflected inward to its sealing position. In the FIGS. 3-6 example, the seat 58 can then be again expanded (see FIG. 6) for retrieval of the magnetic device 38 (or to otherwise minimize obstruction of the passage 36).

[0053] The seat 58 in both of these examples can be considered "retractable," in that the seat can be in its inward sealing position, or in its outward non-sealing position, when desired. Thus, the seat 58 can be in its non-sealing position when initially installed, and then can be actuated to its sealing position (e.g., in response to detection of a predetermined pattern or combination of magnetic fields), without later being actuated to its sealing position again, and still be considered a "retractable" seat.

[0054] Referring additionally now to FIGS. 7 & 8, another example of the magnetic device 38 is representatively illustrated. In this example, magnets (not shown in FIGS. 7 & 8, see, e.g., permanent magnet 68 in FIG. 4) are retained in recesses 74 formed in an outer surface of a sphere 76.

[0055] The recesses 74 are arranged in a pattern which, in this case, resembles that of stitching on a baseball. In FIGS. 7 & 8, the pattern comprises spaced apart positions distributed along a continuous undulating path about the sphere 76.

[0056] However, it should be clearly understood that any pattern of magnetic field-producing components may be used in the magnetic device 38, in keeping with the scope of this disclosure. For example, the magnetic field-producing components could be arranged in lines from one side of the sphere 76 to an opposite side.

[0057] The magnets 68 are preferably arranged to provide a magnetic field a substantial distance from the device 38, and to do so no matter the orientation of the sphere 76. The pattern depicted in FIGS. 7 & 8 desirably projects the produced magnetic field(s) substantially evenly around the sphere 76.

[0058] In some examples, the pattern can desirably project the produced magnetic field(s) in at least one axis around the sphere 76. In these examples, the magnetic field(s) may not be even, but can point in different directions. Preferably, the magnetic field(s) are detectable all around the sphere 76.

[0059] The magnetic field(s) may be produced by permanent magnets, electromagnets, a combination, etc. Any type of magnetic field producing components may be used in the magnetic device 38. The magnetic field(s) produced by the magnetic device 38 may vary, for example, to transmit data, information, commands, etc., or to generate electrical power (e.g., in a coil through which the magnetic field passes).

[0060] Referring additionally now to FIG. 9, another example of the injection valve 16 is representatively illustrated. In this example, the actuator 50 includes two of the valve devices 44.

[0061] When one of the valve devices 44 opens, a sufficient amount of the support fluid 63 is drained to displace the sleeve 32 to its open position (similar to, e.g., FIG. 4), in which the fluid 24 can be flowed outward through the openings 28. When the other valve device 44 opens, more of the support fluid 63 is drained, thereby further displacing the sleeve 32 to a closed position (as depicted in FIG. 9), in which flow through the openings 28 is prevented by the sleeve.

[0062] Various different techniques may be used to control actuation of the valve devices 44. For example, one of the valve devices 44 may be opened when a first magnetic device 38 is displaced into the valve 16, and the other valve device may be opened when a second magnetic device is displaced into the valve. As another example, the second valve device 44 may be actuated in response to passage of a predetermined amount of time from a particular magnetic device 38, or a predetermined number of magnetic devices, being detected by the sensor 40.

[0063] As yet another example, the first valve device 44 may actuate when a certain number of magnetic devices 38 have been displaced into the valve 16, and the second valve device 44 may actuate when another number of magnetic devices have been displaced into the valve. In other examples, the first valve device 44 could actuate when an appropriate magnetic signal is detected by the sensor 40, and the second magnetic device could actuate when another sensor senses another condition (such as, a change in temperature, pressure, etc.). Thus, it should be understood that any technique for controlling actuation of the valve devices 44 may be used, in keeping with the scope of this disclosure.

[0064] Referring additionally now to FIGS. 10A-12, another example of the injection valve 16 is representatively illustrated. In FIGS. 10A & B, the valve 16 is depicted in a closed configuration. FIG. 11 depicts an enlarged scale view of the actuator 50. FIG. 12 depicts an enlarged scale view of the magnetic sensor 40.

[0065] In FIGS. 10A & B, it may be seen that the support fluid 63 is contained in the chamber 64, which extends as a passage to the actuator 50. In addition, the chamber 66 comprises multiple annular recesses extending about the housing 30. A sleeve 78 isolates the chamber 66 and actuator 50 from well fluid in the annulus 20.

[0066] In FIG. 11, the manner in which the pressure barrier 48 isolates the chamber 64 from the chamber 66 can be more clearly seen. When the valve device 44 is actuated, the piercing member 46 pierces the pressure barrier 48, allowing the support fluid 63 to flow from the chamber 64 to the chamber 66 in which the valve device 44 is located.

[0067] Initially, the chamber 66 is at or near atmospheric pressure, and contains air or an inert gas. Thus, the support fluid 63 can readily flow into the chamber 66, allowing the sleeve 32 to displace downwardly, due to the pressure differential across the piston 52.

[0068] In FIG. 12, the manner in which the magnetic sensor 40 is positioned for detecting magnetic fields and/or magnetic field changes in the passage 36 can be clearly seen. In this example, the magnetic sensor 40 is mounted in a plug 80 secured in the housing 30 in close proximity to the passage 36.

[0069] The magnetic sensor 40 is preferably separated from the flow passage 36 by a pressure barrier 82 having a relatively low magnetic permeability. The pressure barrier 82 may be integrally formed as part of the plug 80, or the pressure barrier could be a separate element, etc.

[0070] Suitable low magnetic permeability materials for the pressure barrier 82 can include Inconel and other high nickel and chromium content alloys, stainless steels (such as, 300 series stainless steels, duplex stainless steels, etc.). Inconel alloys have magnetic permeabilities of about 1×10^{-6}, for example. Aluminum (magnetic permeability -1.26×10^{-6}), plastics, composites (e.g., with carbon fiber, etc.) and other nonmagnetic materials may also be used.

[0071] One advantage of making the pressure barrier 82 out of a low magnetic permeability material is that the housing 30 can be made of a relatively low cost high magnetic permeability material (such as steel, having a magnetic permeability of about 9×10^{-4}, for example), but magnetic fields produced by the magnetic device 38 in the passage 36 can be detected by the magnetic sensor 40 through the pressure barrier. That is, magnetic flux can readily pass through the relatively low magnetic permeability pressure barrier 82 without being significantly distorted.

[0072] In some examples, a relatively high magnetic permeability material 84 may be provided proximate the magnetic sensor 40 and/or pressure barrier 82, in order to focus the magnetic flux on the magnetic sensor. A permanent magnet (not shown) could also be used to bias the magnetic flux, for example, so that the magnetic flux is within a linear range of detection of the magnetic sensor 40.

[0073] In some examples, the relatively high magnetic permeability material 84 surrounding the sensor 40 can block or shield the sensor from other magnetic fields, such as, due to magnetism in the earth surrounding the wellbore 14. The material 84 allows only a focused window for magnetic fields to pass through, and only from a desired direction. This has the benefit of preventing other undesired magnetic fields from contributing to the sensor 40 output.

[0074] Referring additionally now to FIGS. 13 & 14, another example of the valve 16 is representatively illustrated. In this example, the pressure barrier 82 is in the form of a sleeve received in the housing 30. The sleeve isolates the chamber 63 from fluids and pressure in the passage 36.

[0075] In this example, the magnetic sensor 40 is disposed in an opening 86 formed through the housing 30, so that the sensor is in close proximity to the passage 36, and is separated from the passage only by the relatively low magnetic permeability pressure barrier 82. The sensor 40 could, for example, be mounted directly to an external surface of the pressure barrier 82.

[0076] In FIG. 14, an enlarged scale view of the magnetic sensor 40 is depicted. In this example, the magnetic sensor 40 is mounted to a portion 42a of the electronic circuitry 42 in the opening 86. For example, one or more magnetic sensors 40 could be mounted to a small circuit board with hybrid electronics thereon.

[0077] Thus, it should be understood that the scope of this disclosure is not limited to any particular positioning or arrangement of various components in the valve 16. Indeed, the principles of this disclosure are applicable to a large variety of different configurations, and to a large variety of different types of well tools (e.g., packers, circulation valves, tester valves, perforating equipment, completion equipment, sand screens, drilling equipment, artificial lift equipment, formation stimulation equipment, formation sensors, etc.).

[0078] Although in the examples of FIGS. 2-14, the sensor 40 is depicted as being included in the valve 16, it will be appreciated that the sensor could be otherwise positioned. For example, the sensor 40 could be located in another housing interconnected in the tubular string 12 above or below one or more of the valves 16a-e in the system 10 of FIG. 1.

[0079] Multiple sensors 40 could be used, for example, to detect a pattern of magnetic field-producing components on a magnetic device 38. Multiple sensors 40 can be used to detect the magnetic field(s) in an axial, radial or circumferential direction. Detecting the magnetic field(s) in multiple directions can increase confidence that the magnetic device 38 will be detected regardless of orientation. Thus, it should be understood that the scope of this disclosure is not limited to any particular positioning or number of the sensor(s) 40.

[0080] In examples described above, the sensor 40 can detect magnetic signals which correspond to displacing one or more magnetic devices 38 in the well (e.g., through the passage 36, etc.) in certain respective patterns. The transmitting of different magnetic signals (corresponding to respective different patterns of displacing the magnetic devices 38) can be used to actuate corresponding different sets of the valves 16a-e.

[0081] Thus, displacing a pattern of magnetic devices 38 in a well can be used to transmit a corresponding magnetic signal to well tools (such as valves 16a-e, etc.), and at least one of the well tools can actuate in response to detection of the magnetic signal. The pattern may comprise a predetermined number of the magnetic devices 38, a predetermined spacing in time of the magnetic devices 38, or a predetermined spacing on time between predetermined numbers of the magnetic devices 38, etc. Any pattern may be used in keeping with the scope of this disclosure.

[0082] The magnetic device pattern can comprise a predetermined magnetic field pattern (such as, the pattern of magnetic field-producing components on the magnetic device 38 of FIGS. 7 & 8, etc.), a predetermined pattern of multiple magnetic fields (such as, a pattern produced by displacing multiple magnetic devices 38 in a certain manner through the well, or a pattern produced by displacing a magnetic device which produces a time varying magnetic field, etc.), a predetermined change in a magnetic field (such as, a change produced by displacing a metallic device past or to the sensor 40), and/or a predetermined pattern of multiple magnetic field changes (such as, a pattern produced by displacing multiple metallic devices in a certain manner past or to the sensor 40, etc.). Any manner of producing a magnetic device pattern may be used, within the scope of this disclosure.

[0083] A first set of the well tools might actuate in response to detection of a first magnetic signal. A second set of the well tools might actuate in response to detection of another magnetic signal. The second magnetic signal can correspond to a second unique magnetic device pattern produced in the well.

[0084] The term "pattern" is used in this context to refer to an arrangement of magnetic field-producing components (such as permanent magnets 68, etc.) of a magnetic device 38 (as in the FIGS. 7 & 8 example), and to refer to a manner in which multiple magnetic devices can be displaced in a well. The sensor 40 can, in some examples, detect a pattern of magnetic field-producing components of a magnetic device 38. In other examples, the sensor 40 can detect a pattern of displacing multiple magnetic devices.

[0085] The magnetic pattern could be a time varying signal. The time varying signal could arise from the movement of the magnetic device 38. Alternatively, the time varying signal could arise from the magnetic device 38 producing a time varying magnetic signal. In some cases, the time varying signal could be a relatively static magnetic signal with a principal frequency less than 10 Hertz. In some cases, the time varying signal could be a quasi-static magnetic signal with a principal frequency component between 1 Hertz and 400 Hertz. In some cases, the time varying signal could be a quasi-dynamic magnetic signal with a principal frequency component between 100 Hertz and 3,000 Hertz. In other cases, the time varying signal could be a dynamic magnetic signal with a principal frequency component greater than 3,000 Hertz.

[0086] The sensor 40 may detect a pattern on a single magnetic device 38, such as the magnetic device of FIGS. 7 & 8. In another example, magnetic field-producing components could be axially spaced on a magnetic device 38, such as a dart, rod, etc. In some examples, the sensor 40 may detect a pattern of different North-South poles of the magnetic device 38. By detecting different patterns of different magnetic field-producing components, the electronic circuitry 42 can determine whether an actuator 50 of a particular well tool should actuate or not, should actuate open or closed, should actuate more open or more closed, etc.

[0087] The sensor 40 may detect patterns created by displacing multiple magnetic devices 38 in the well. For example, three magnetic devices 38 could be displaced in the valve 16 (or past or to the sensor 40) within three minutes of each other, and then no magnetic devices could be displaced for the next three minutes.

[0088] The electronic circuitry 42 can receive this pattern of indications from the sensor 40, which encodes a digital command for communicating with the well tools (e.g., "waking" the well tool actuators 50 from a low power consumption "sleep" state). Once awakened, the well tool actuators 50 can, for example, actuate in response to respective predetermined numbers, timing, and/or other patterns of magnetic devices 38 displacing in the well. This method can help prevent extraneous activities (such as, the passage of wireline tools, etc. through the valve 16) from being misidentified as an operative magnetic signal.

[0089] In one example, the valve 16 can open in response to a predetermined number of magnetic devices 38 being displaced through the valve. By setting up the valves 16a-e in the system 10 of FIG. 1 to open in response to different numbers of magnetic devices 38 being displaced through the valves, different ones of the valves can be made to open at different times.

[0090] For example, the valve 16e could open when a first magnetic device 38 is displaced through the tubular string 12. The valve 16d could then be opened when a second magnetic device 38 is displaced through the tubular string 12. The valves 16b,c could be opened when a third magnetic device 38 is displaced through the tubular string 12. The valve 16a could be opened when a fourth magnetic device 38 is displaced through the tubular string 12.

[0091] Any combination of number of magnetic device(s) 38, pattern on one or more magnetic device(s), pattern of magnetic devices, spacing in time between magnetic devices, etc., can be detected by the magnetic sensor 40 and evaluated by the electronic circuitry 42 to determine whether the valve 16 should be actuated. Any unique combination of number of magnetic device(s) 38, pattern on one or more magnetic device(s), pattern of magnetic devices, spacing in time between magnetic devices, etc., may be used to select which of multiple sets of valves 16 will be actuated.

[0092] The magnetic device 38 may be conveyed through the passage 36 by any means. For example, the magnetic device 38 could be pumped, dropped, or conveyed by wireline, slickline, coiled tubing, jointed tubing, drill pipe, casing, etc.

[0093] Although in the above examples, the magnetic device 38 is described as being displaced through the passage 36, and the magnetic sensor 40 is described as being in the valve 16 surrounding the passage, in other examples these positions could be reversed. That is, the valve 16 could include the magnetic device 38, which is used to transmit a magnetic signal to the sensor 40 in the passage 36. For example, the magnetic sensor 40 could be included in a tool (such as a logging tool, etc.) positioned in the passage 36, and the magnetic signal from the device 38 in the valve 16 could be used to indicate the tool's position, to convey data, to generate electricity in the tool, to actuate the tool, or for any other purpose.

[0094] Another use for the actuator 50 (in any of its FIGS. 2-11 configurations) could be in actuating multiple injection valves. For example, the actuator 50 could be used to actuate multiple ones of the RAPIDFRAC (TM) Sleeve marketed by Halliburton Energy Services, Inc. of Houston, Texas USA. The actuator 50 could initiate metering of a hydraulic fluid in the RAPIDFRAC (TM) Sleeves in response to a particular magnetic device 38 being displaced through them, so that all of them open after a certain period of time.

[0095] In some situations, there can be magnetic fields present in the valve 16 (or other types of well tools) not produced by the magnetic device 38. For example, in the valve 16 of FIGS. 10A-12, the housing 30 may be made of a relatively inexpensive ferromagnetic material, such as steel. After being machined, the housing 30 may be degaussed, but the degaussing may not remove all magnetism resulting from the machining. Even if the degaussing is completely effective, during transport and installation in a well the housing 30 can become magnetized.

[0096] To prevent remnant, residual or other spurious magnetic fields from interfering with detection of the magnetic device 38 by the magnetic sensor 40, the valve 16 example of FIG. 15 includes a magnetic shield 84a. The magnetic shield 84a may be made of the same relatively high magnetic permeability material 84 as described above in relation to the FIG. 12 embodiment.

[0097] Suitable relatively high magnetic permeability materials with relatively low residual magnetization (low coercivity or magnetically soft) include mu-metals, METGLAS(TM), NANOPERM(TM), electrical steel, permalloy, and other metals comprising nickel, iron and molybdenum. Other materials may be used, if desired. For example, a nano-crystalline grain structure ferromagnetic metal coating could be applied to an interior of the plug 80 (or to an enclosure of the magnetic sensor 40) surrounding the sensor to serve as the magnetic shield 84a.

[0098] In some examples, the magnetic shield 84a could have multiple layers. For example, an outer layer could have a relatively high magnetic saturation, and an inner layer could have a relatively low remnant magnetic field.

[0099] In the FIG. 15 example, the magnetic shield 84a is in an annular form surrounding the sensor 40. Since magnetization of the housing 30 would typically produce a magnetic field B generally parallel to a longitudinal axis 88 of the housing, the magnetic shield 84a can be positioned so that it is on opposite longitudinal sides (relative to the longitudinal housing axis 88) of the sensor 40.

[0100] The magnetic shield 84a is continuous from one longitudinal side 90a of the sensor 40 to the opposite longitudinal side 90b. The magnetic shield 84a is between the sensor side 90a and the housing 30, and is between the sensor side 90b and the housing. In this manner, the magnetic shield 84a can conduct the magnetic field B around the sensor 40.

[0101] Referring additionally now to FIG. 16, another example of the magnetic shield 84a is representatively illustrated. In this example, two magnetic sensors 40 are positioned in a cavity 92 formed in the magnetic shield 84a.

[0102] The cavity 92 is dome-shaped (substantially hemispherical) as depicted in FIG. 16. An exterior of the shield 84a could also be dome-shaped, if desired, but in the FIG. 16 example the exterior is cylindrical. Of course, other shapes may be used in keeping with the principles of this disclosure.

[0103] The shield 84a of FIG. 16 is positioned on opposite longitudinal sides of the sensors 40 (relative to the housing longitudinal axis 88), and so the shield can conduct a magnetic field B around the sensors. In the FIG. 16 example, the shield 84a is between the housing 30 and the opposite longitudinal sides of the sensors 40.

[0104] Referring additionally now to FIG. 17, another example of the magnetic shield 84a is representatively illustrated. In this example, the shield 84a is in the form of an arc.

[0105] The arc extends longitudinally from one side to the other of the sensors 40a,b. One end of the arc is positioned between the housing 30 and one longitudinal side of the sensors 40a,b, and an opposite end of the arc is positioned between the housing and an opposite longitudinal side of the sensors, the arc being continuous from one of its ends to the other. In this manner, the shield 84a can conduct a magnetic field B longitudinally around the sensors 40a,b.

[0106] Referring additionally now to FIG. 18, an elevational view of the magnetic sensors 40a,b and the magnetic shield 84a in the plug 80 is representatively illustrated. In this view, it can be clearly seen that the shield 84a is aligned with the longitudinal axis 88. For example, a line drawn from one end of the shield 84a to the opposite end of the shield would be parallel to the longitudinal axis 88.

[0107] The magnetic sensors 40a,b are longitudinally enclosed by the shield 84a, in that the shield is interposed between the sensors and the housing 30 on both longitudinal sides of the sensors. Although the arc shape of the shield 84a conveniently provides for the shield to extend continuously from one of its ends to the other, different shapes (such as, rectilinear) could be used. The scope of this disclosure is not limited to any particular shape of the shield 84a.

[0108] In the FIG. 18 example, the magnetic sensors 40a,b are of a type that senses a magnetic field oriented in a particular direction. Such magnetic sensors are known to those skilled in the art as one-axis or uniaxial sensors.

[0109] As depicted in FIG. 18, the sensor 40a is arranged so that it senses a magnetic field in a lateral direction 94a orthogonal to the longitudinal axis 88, and the sensor 40b is arranged so that it senses a magnetic field in a longitudinal direction 94b parallel to the longitudinal axis 88. This configuration is effective for sensing changes in magnetic field caused by presence of the magnetic device 38 in the passage 36.

[0110] However, other types, numbers and configurations of magnetic sensors can be used in keeping with the scope of this disclosure. Multiple sensors 40, and multiaxial or uniaxial sensors, may be used in any of the valve 16 examples described above (or in any other types of well tools).

[0111] In the above description of the FIGS. 15-18 examples, the magnetic shield 84a comprises a relatively high magnetic permeability and relatively low residual magnetization (low coercivity, magnetically soft) material. In this manner, the shield 84a can readily conduct all (or a substantial proportion) of an undesired magnetic field B around the sensor(s) 40, so that detection of the undesired magnetic field is mitigated and detection of magnetic field changes due to presence of the magnetic device 38 is enhanced.

[0112] In other examples, the magnetic shield 84a could comprise a diamagnetic material having a negative magnetic permeability. In this manner, the shield 84a would "repel" the undesired magnetic field B away from the sensor 40, instead of conducting the magnetic field around the sensor.

[0113] Suitable diamagnetic materials include bismuth, pyrolytic carbon and superconductors. However, other materials could be used in keeping with the scope of this disclosure. Such diamagnetic material could be used in any of the shield 84a configurations described above, or in other configurations.

[0114] The magnetic shield 84a could be used in any configurations of the valve 16 described above, or in any other types of well tools, to shield a magnetic sensor and mitigate detection of one or more magnetic fields B for which detection is not desired.

[0115] Although, in examples described above, the magnetic shield 84a is positioned between the housing 30 and opposite longitudinal sides 90a,b of the sensor(s) 40, in other examples the magnetic shield could be otherwise positioned. For example, if a magnetic field (for which detection is to be mitigated) is not oriented longitudinally, the magnetic shield 84a would not necessarily be positioned on opposite longitudinal sides of the sensor(s) 40. Instead, the magnetic shield 84a can be positioned between any opposite sides of the sensor (s) 40 oriented in a direction of the magnetic field for which detection is to be mitigated.

[0116] It may now be fully appreciated that the above disclosure provides several advancements to the art. The injection valve 16 can be conveniently and reliably opened by displacing the magnetic device 38 into the valve, or otherwise detecting a particular magnetic signal by a sensor 40 of the valve. The principles of this disclosure can be applied to a variety of well tools in which it is desired to sense changes in magnetic fields.

[0117] The above disclosure provides to the art a well tool (such as the valve 16, or packers, circulation valves, tester valves, perforating equipment, completion equipment, sand screens, etc.). In one example, the well tool can include at least one magnetic sensor 40 having first and second opposite sides 90a,b, and a magnetic shield 84a that conducts an undesired magnetic field B around, or away from, the magnetic sensor from the first opposite side 90a to the second opposite side 90b.

[0118] The magnetic shield 84a may enclose the magnetic sensor 40 on each of the first and second opposite sides 90a,b. The magnetic shield 84a can be interposed between a structure (such as the housing 30) that conducts the undesired magnetic field B and each of the first and second opposite sides 90a,b. The magnetic shield 84a may be continuous from the first opposite side 90a of the magnetic sensor 40 to the second opposite side 90b of the magnetic sensor 40.

[0119] The magnetic shield 40 can comprise a relatively high magnetic permeability material. The magnetic shield 40 can comprise a negative magnetic permeability material.

[0120] The magnetic sensor 40 may comprise first and second magnetic sensors 40a,b, the first magnetic sensor 40a sensing a magnetic field oriented in a first direction 94a, and the second magnetic sensor 40b sensing a magnetic field oriented in a second direction 94b perpendicular to the first direction 94a. The magnetic sensor 40 may be positioned in a cavity 92 in the magnetic shield 84a.

[0121] Another well tool example described above comprises a housing 30 having a longitudinal axis 88; at least one magnetic sensor 40 in the housing 30, the sensor 40 having first and second opposite longitudinal sides 90a,b relative to the housing longitudinal axis 88; and a magnetic shield 84a interposed between the housing 30 and each of the first and second opposite longitudinal sides 90a,b of the magnetic sensor 40.

[0122] The magnetic sensor 40 can comprise first and second magnetic sensors 40a,b, the first magnetic sensor 40a sensing a magnetic field oriented in a first direction 94a orthogonal to the longitudinal axis 88, and the second magnetic sensor 40b sensing a magnetic field oriented in a second direction 94b parallel to the longitudinal axis 88. The magnetic sensor 40 may be longitudinally enclosed by the shield 84a.

[0123] Also described above is a well tool example which comprises a housing 30 having a longitudinal axis 88; first and second magnetic sensors 40a,b, the first and second sensors 40a,b having first and second opposite longitudinal sides 90a,b relative to the housing longitudinal axis 88, the first magnetic sensor 40a sensing a magnetic field oriented in a first direction 94a orthogonal to the longitudinal axis 88, and the second magnetic sensor 40b sensing a magnetic field oriented in a second direction 94b parallel to the longitudinal axis 88; and a magnetic shield 84a interposed between the housing 30 and each of the first and second opposite longitudinal sides 90a,b of the first and second magnetic sensors 40a,b.

[0124] Although various examples have been described above, with each example having certain features, it should be understood that it is not necessary for a particular feature of one example to be used exclusively with that example. Instead, any of the features described above and/or depicted in the drawings can be combined with any of the examples, in addition to or in substitution for any of the other features of those examples. One example's features are not mutually exclusive to another example's features. Instead, the scope of this disclosure encompasses any combination of any of the features.

[0125] Although each example described above includes a certain combination of features, it should be understood that it is not necessary for all features of an example to be used. Instead, any of the features described above can be used, without any other particular feature or features also being used.

[0126] It should be understood that the various embodiments described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles of the disclosure, which is not limited to any specific details of these embodiments.

[0127] In the above description of the representative examples, directional terms (such as "above," "below," "upper," "lower," etc.) are used for convenience in referring to the accompanying drawings. However, it should be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

[0128] The terms "including," "includes," "comprising," "comprises," and similar terms are used in a non-limiting sense in this specification. For example, if a system, method, apparatus, device, etc., is described as "including" a certain feature or element, the system, method, apparatus, device, etc., can include that feature or element, and can also include other features or elements. Similarly, the term "comprises" is considered to mean "comprises, but is not limited to."

[0129] Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the disclosure, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to the specific embodiments, and such changes are contemplated by the principles of this disclosure. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the scope of the invention being limited solely by the appended claims.

REFERENCES CITED IN THE DESCRIPTION

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- US688058 **[0039]**
- US8235103B **[0039]**

Brøndværktøjer med magnetisk afskærmning til magnetisk sensor

Patentkrav:

1. Brøndværktøj omfattende:
mindst én magnetisk sensor (40) med første og anden modsatte sider (90a, b), hvor den første og anden modsatte side er vendt i retning mod et uønsket magnetfelt,
en magnetisk afskærmning (84a), der leder det uønskede magnetfelt omkring, eller væk fra, den magnetiske sensor fra den første modsatte side til den anden modsatte side, og
en trykbarriere (82) med en lavere magnetisk gennemtrængelighed end den magnetiske afspærring, hvor trykbarrieren er konfigureret til at tillade, af et ønsket magnetfelt påvirker den magnetiske sensor.

2. Brøndværktøj ifølge krav 1, hvor den magnetiske afspærring omslutter den magnetiske sensor på hver af den første og anden modsatte side, og/eller
hvor den magnetiske afspærring er kontinuerlig fra den første modsatte side af den magnetiske sensor til den anden modsatte side af den magnetiske sensor.

3. Brøndværktøj ifølge krav 1 eller 2, hvor den magnetiske afspærring er indsat mellem en struktur, der leder det uønskede magnetfelt, og hver af den første og anden modsatte side.

4. Brøndværktøj ifølge krav 1, 2 eller 3, hvor den magnetiske afspærring omfatter et materiale med relativt høj magnetisk gennemtrængelighed.

5. Brøndværktøj ifølge et hvilket som helst af de foregående krav, hvor den mindst ene magnetiske sensor omfatter første og anden magnetiske sensorer (40a, b), hvor den første magnetiske sensor registrerer et magnetfelt, der er vendt i en første retning (94a), og hvor den anden magnetiske sensor registrerer et magnetfelt, der er vendt i en anden retning (94b) vinkelret på den første retning, og/eller
hvor den magnetiske sensor er anbragt i et hulrum (92) i den magnetiske afskærmning.

6. Brøndværktøj omfattende:
et hus (30) med en langsgående akse (88),
mindst én magnetisk sensor (40) i huset, hvilken sensor har første og anden modsatte langsgående sider i forhold til husets langsgående akse,
en magnetisk afskærmning (84a), der er indsat mellem huset og hver af den første og anden modsatte langsgående side af den magnetiske sensor, og
en trykbarriere (82) med en lavere magnetisk gennemtrængelighed end den magnetiske afspærring, hvor trykbarrieren er konfigureret til at tillade, af et ønsket magnetfelt påvirker den magnetiske sensor.

7. Brøndværktøj ifølge krav 6, hvor den magnetiske afspærring omfatter et materiale med relativt høj magnetisk gennemtrængelighed, eller

hvor den magnetiske afspærring omfatter et materiale med negativ magnetisk gennemtrængelighed.

8. Brøndværktøj ifølge krav 6 eller 7, hvor den magnetiske afspærring er kontinuerlig fra den første modsatte side af den magnetiske sensor til den anden modsatte side af den magnetiske sensor.

9. Brøndværktøj ifølge krav 6, 7 eller 8, hvor mindst én magnetisk sensor omfatter første og anden magnetiske sensorer, hvor den første magnetiske sensor registrerer et magnetfelt, der er vendt i en første retning vinkelret på den langsgående akse, og hvor den anden magnetiske sensor registrerer et magnetfelt, der er vendt i en anden retning parallelt med den langsgående akse.

10. Brøndværktøj ifølge et hvilket som helst af kravene 6 til 9, hvor den magnetiske sensor er omsluttet af afskærmningen i langsgående retning, og/eller

hvor den magnetiske sensor er anbragt i et hulrum i den magnetiske afskærmning.

11. Brøndværktøj omfattende:

et hus (30) med en langsgående akse,

første og anden magnetiske sensorer (40a, 40b), hvilken første og anden sensor har første og anden modsatte langsgående sider i forhold til husets langsgående akse, idet den første magnetiske sensor registrerer et magnetfelt, der er vendt i en første retning vinkelret på den langsgående akse, og den anden magnetiske sensor registrerer et magnetfelt, der er vendt i en anden retning parallelt med den langsgående akse,

en magnetisk afskærmning (84a), der er indsat mellem huset og hver af den første og anden modsatte langsgående side af den første og anden magnetiske sensor, og

en trykbarriere (82) med en lavere magnetisk gennemtrængelighed end den magnetiske afspærring, hvor trykbarrieren er konfigureret til at tillade, af et ønsket magnetfelt påvirker den magnetiske sensor.

12. Brøndværktøj ifølge krav 11, hvor den magnetiske afspærring omfatter et materiale med relativt høj magnetisk gennemtrængelighed, eller

hvor den magnetiske afspærring omfatter et materiale med negativ magnetisk gennemtrængelighed.

13. Brøndværktøj ifølge krav 11 eller 12, hvor den magnetiske afspærring er kontinuerlig fra den første modsatte side af den første og anden magnetiske sensor til den anden modsatte side af den første og anden magnetiske sensor.

14. Brøndværktøj ifølge krav 11, 12 eller 13, hvor den første og anden magnetiske sensor er omsluttet af afskærmningen i langsgående retning.

15. Brøndværktøj ifølge et hvilket som helst af kravene 11 til 14, hvor den første og anden magnetiske sensor er anbragt i et hulrum i den magnetiske afskærmning.

DRAWINGS

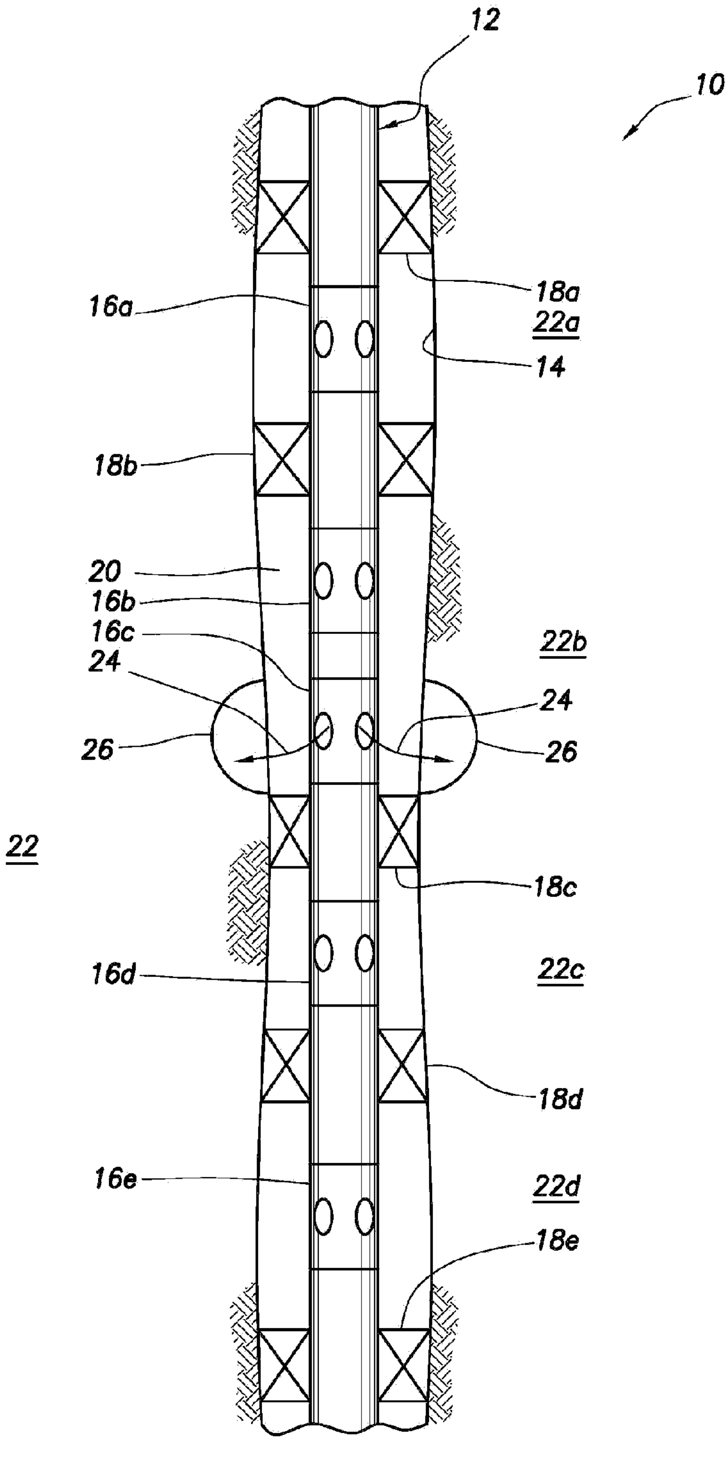


FIG. 1

FIG.2

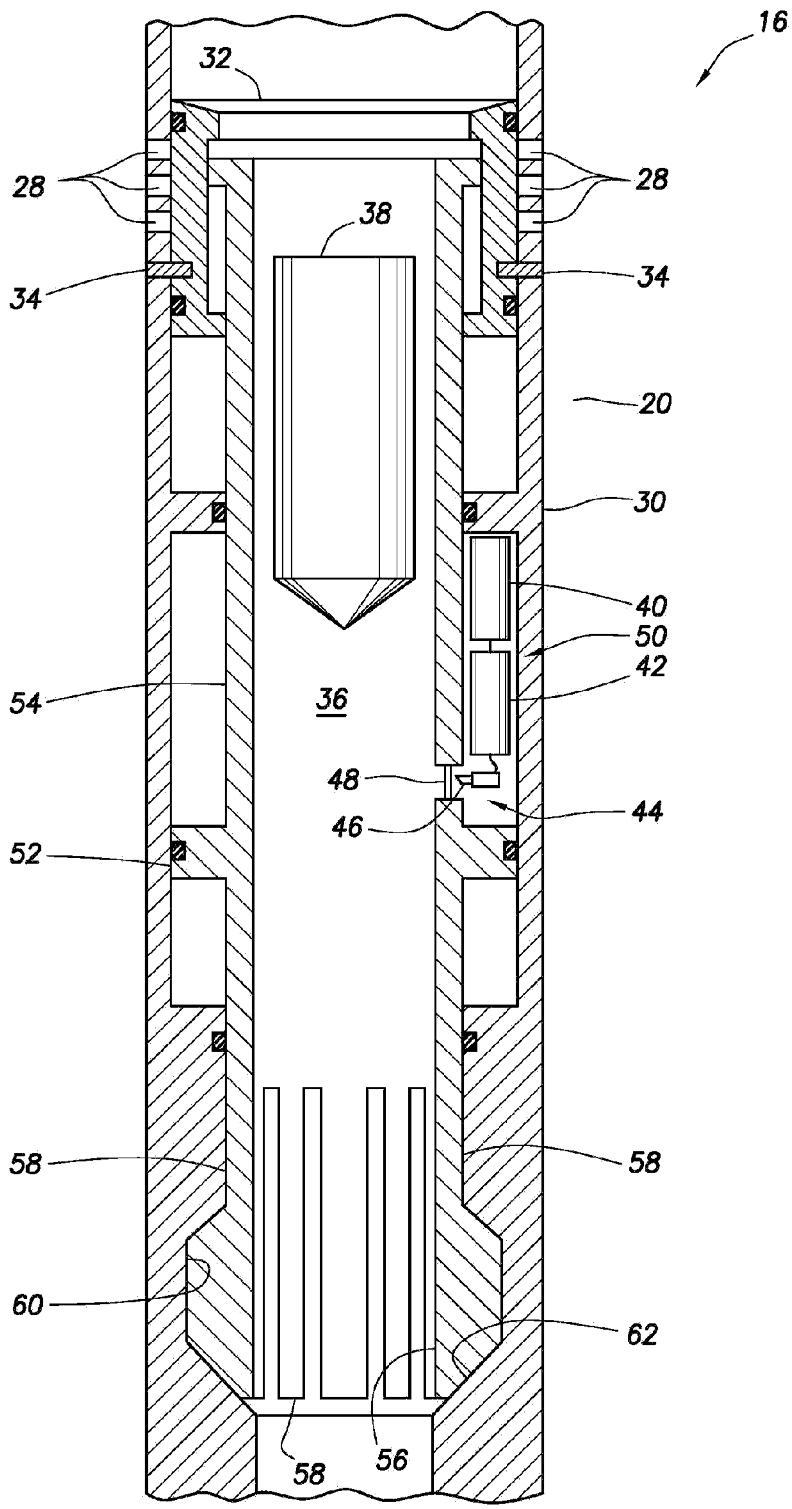


FIG.3

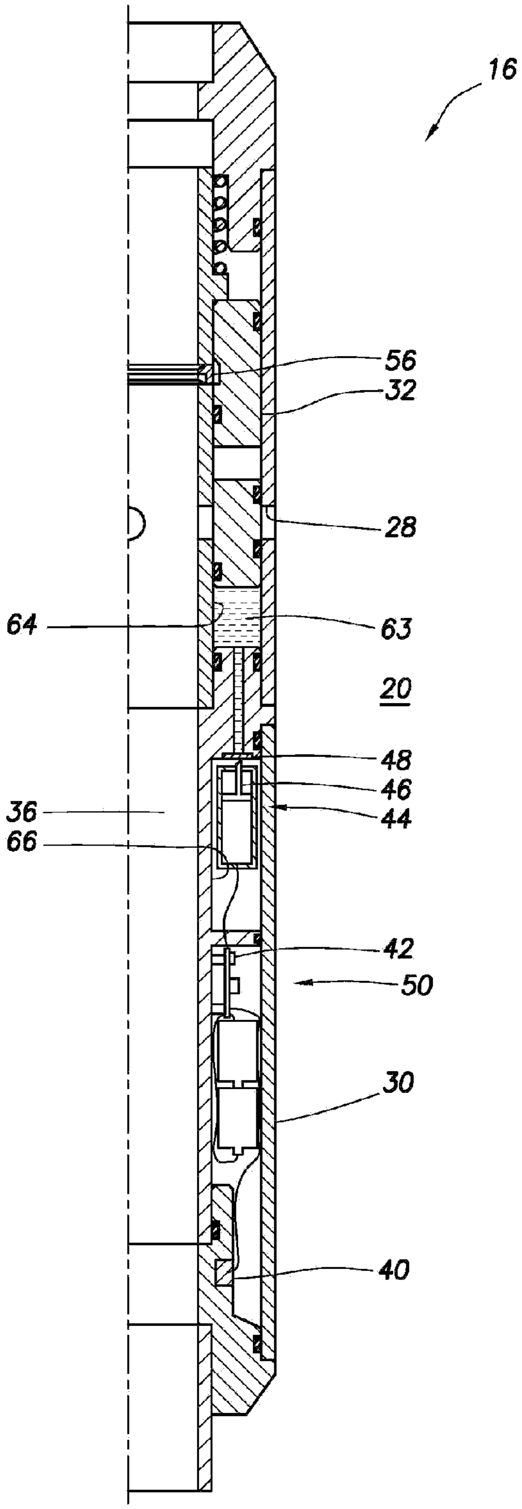


FIG.4

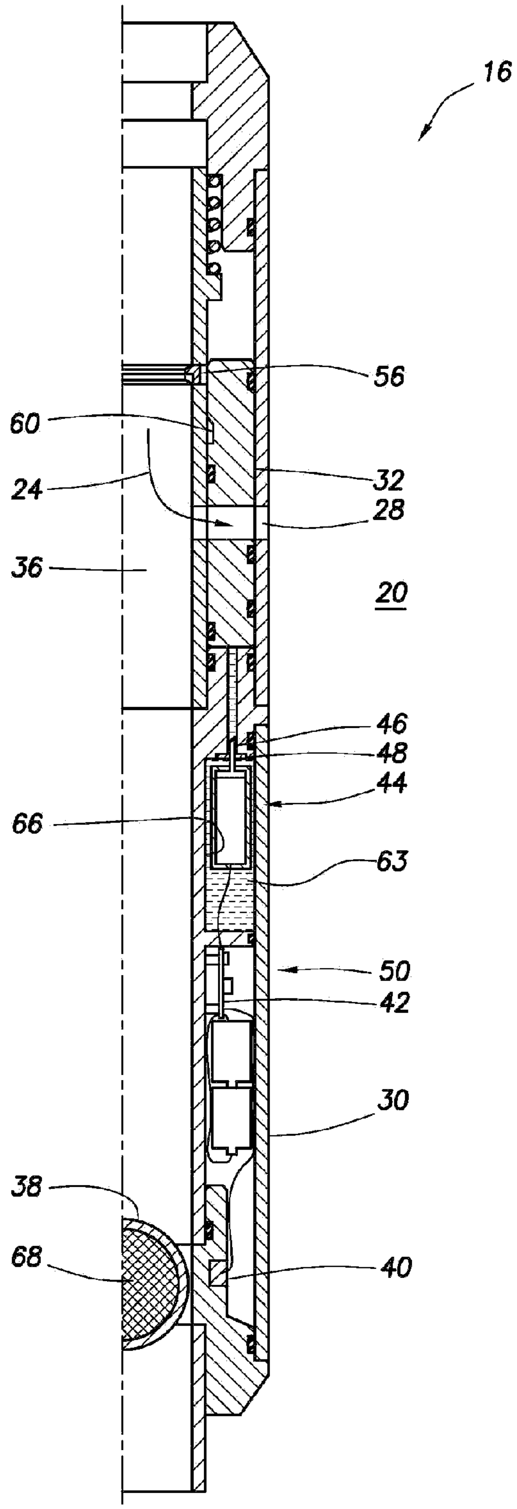


FIG.5

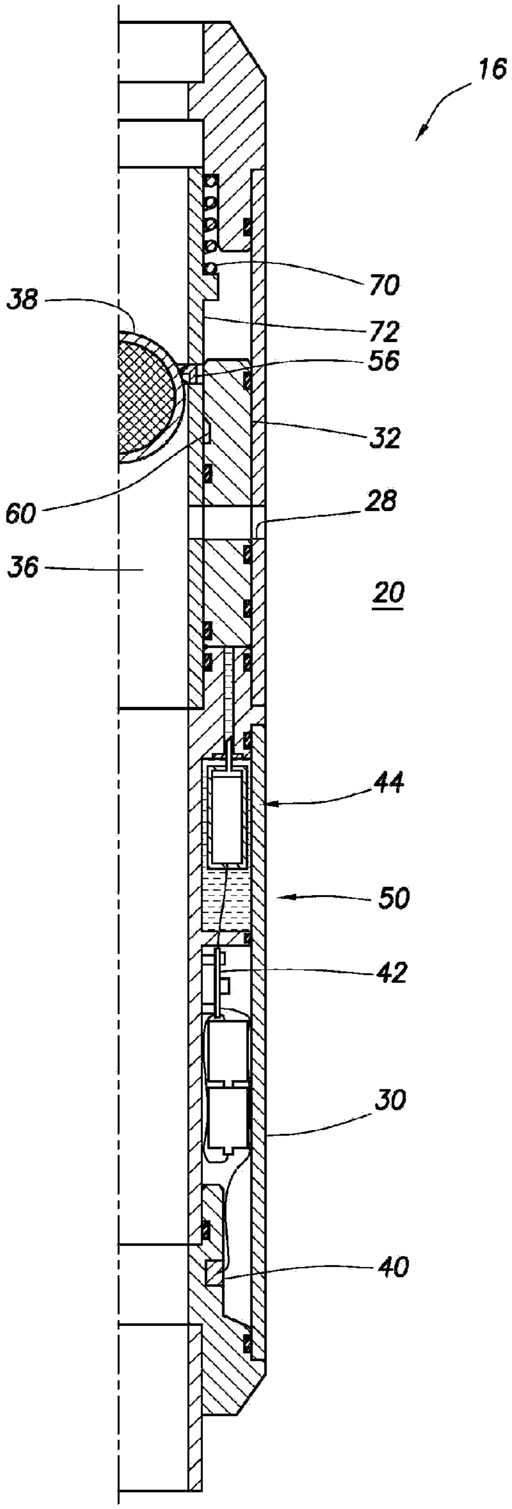
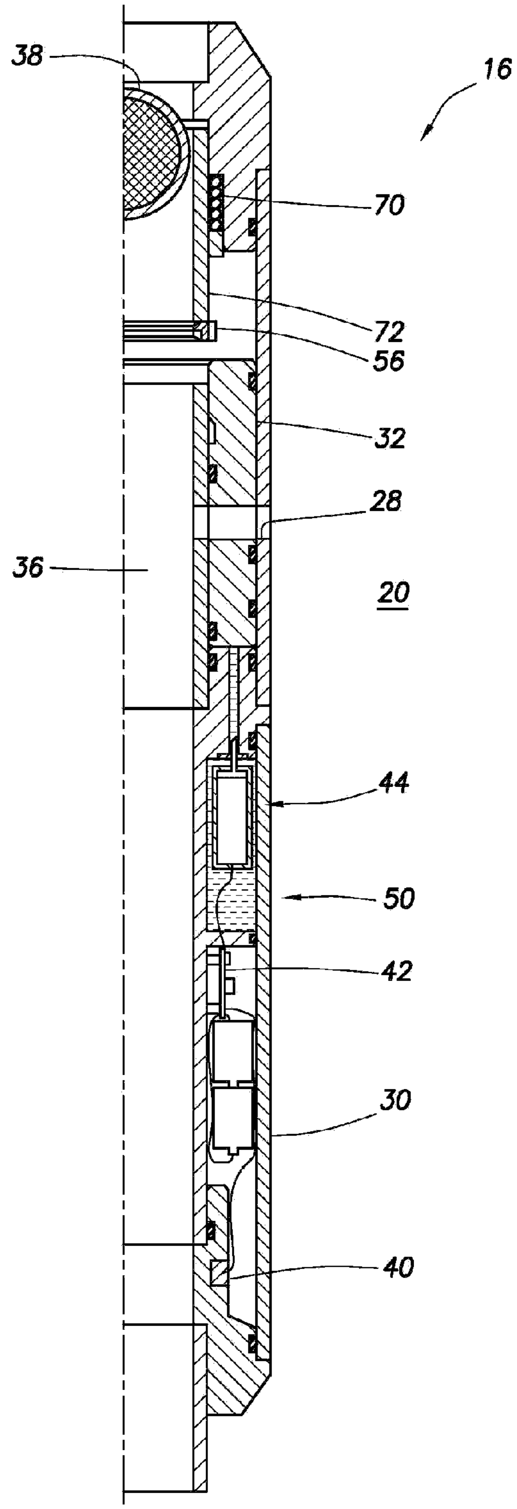


FIG.6



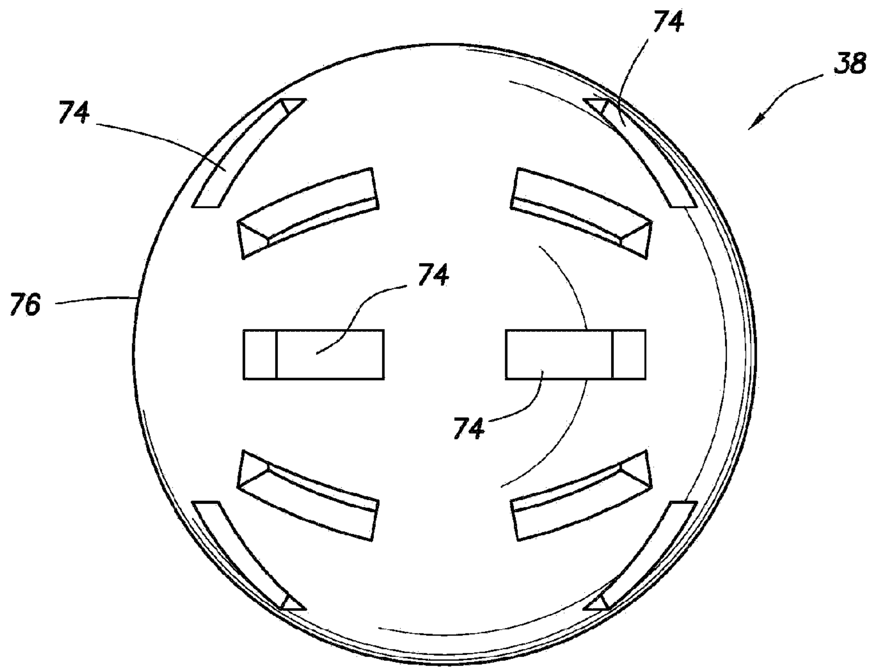


FIG.7

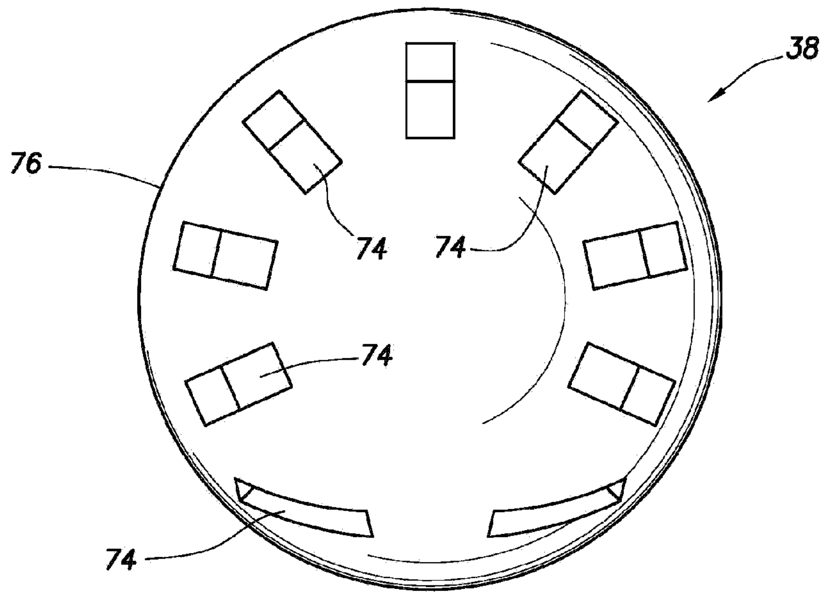


FIG.8

FIG.9

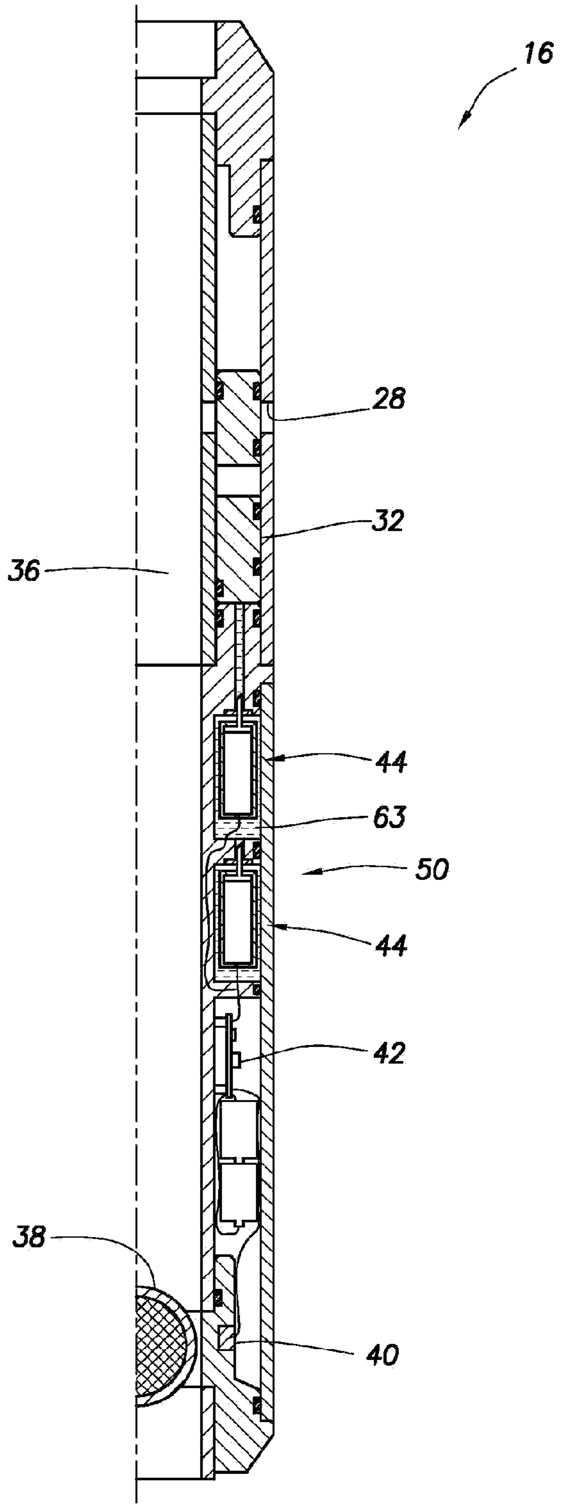


FIG. 10A

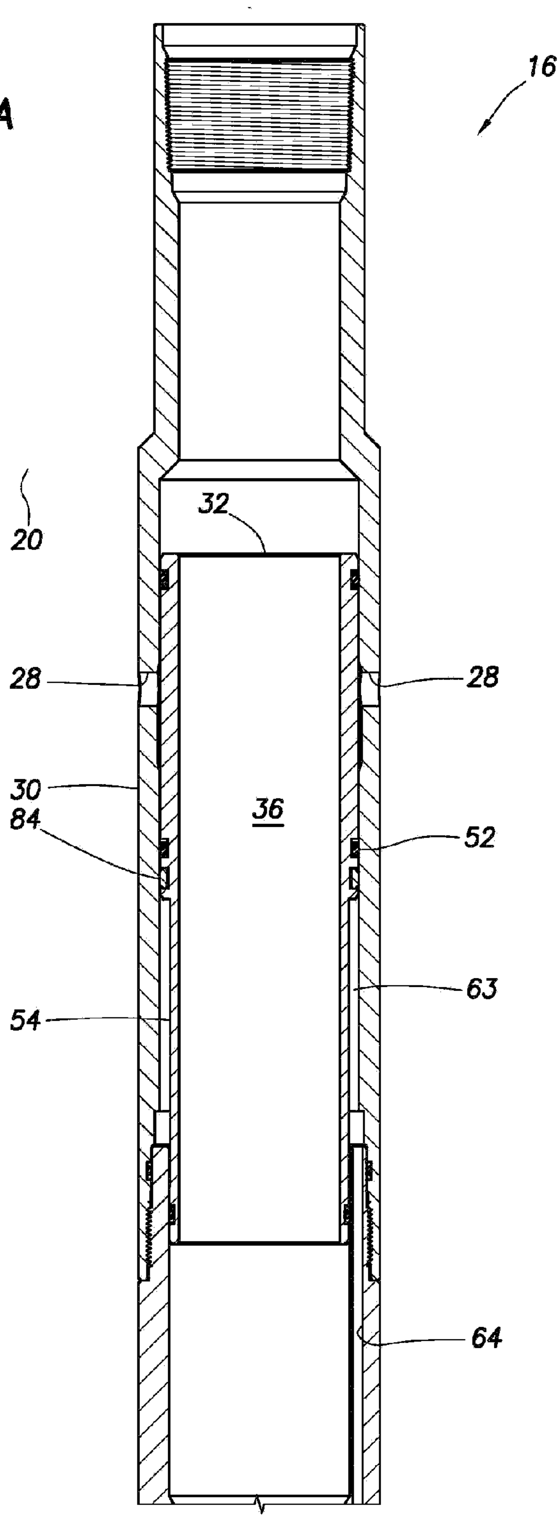
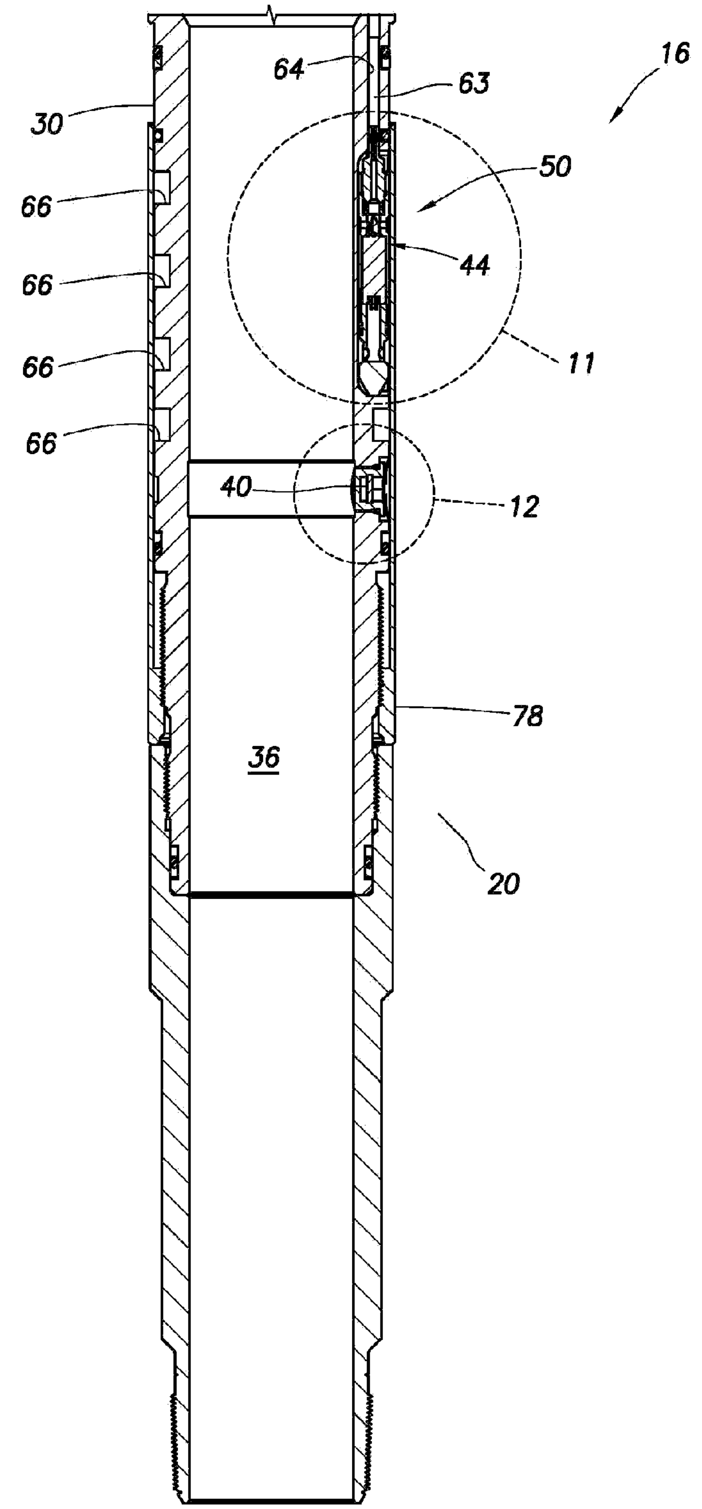


FIG. 10B



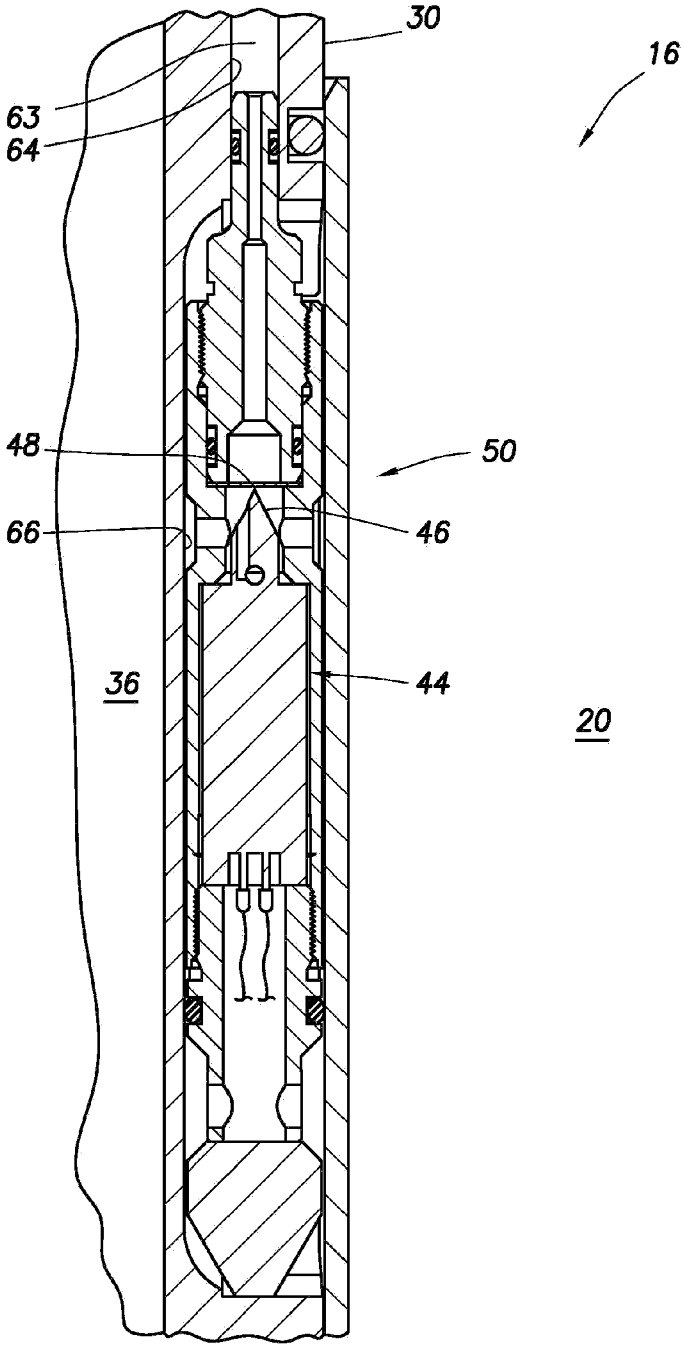


FIG.11

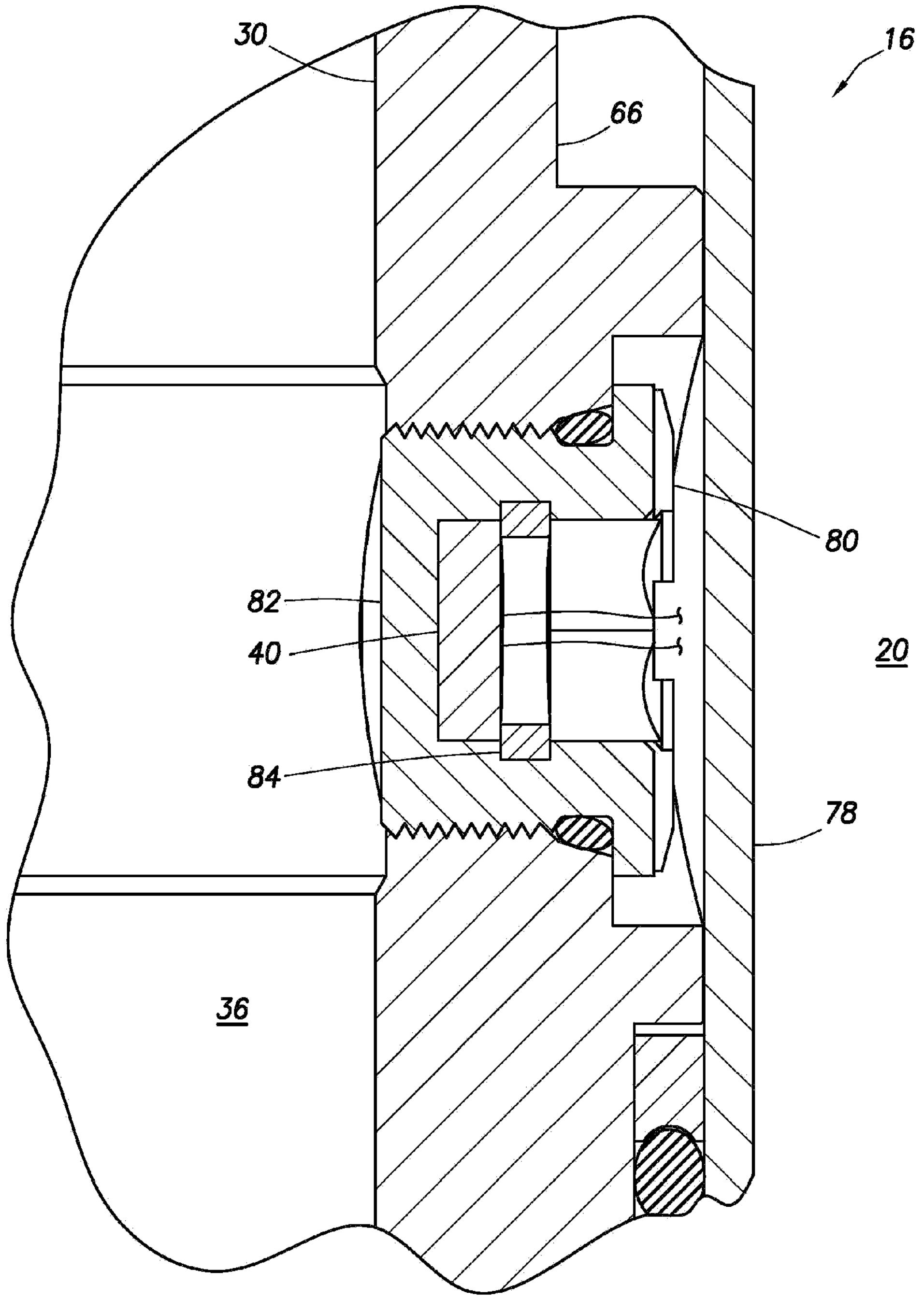
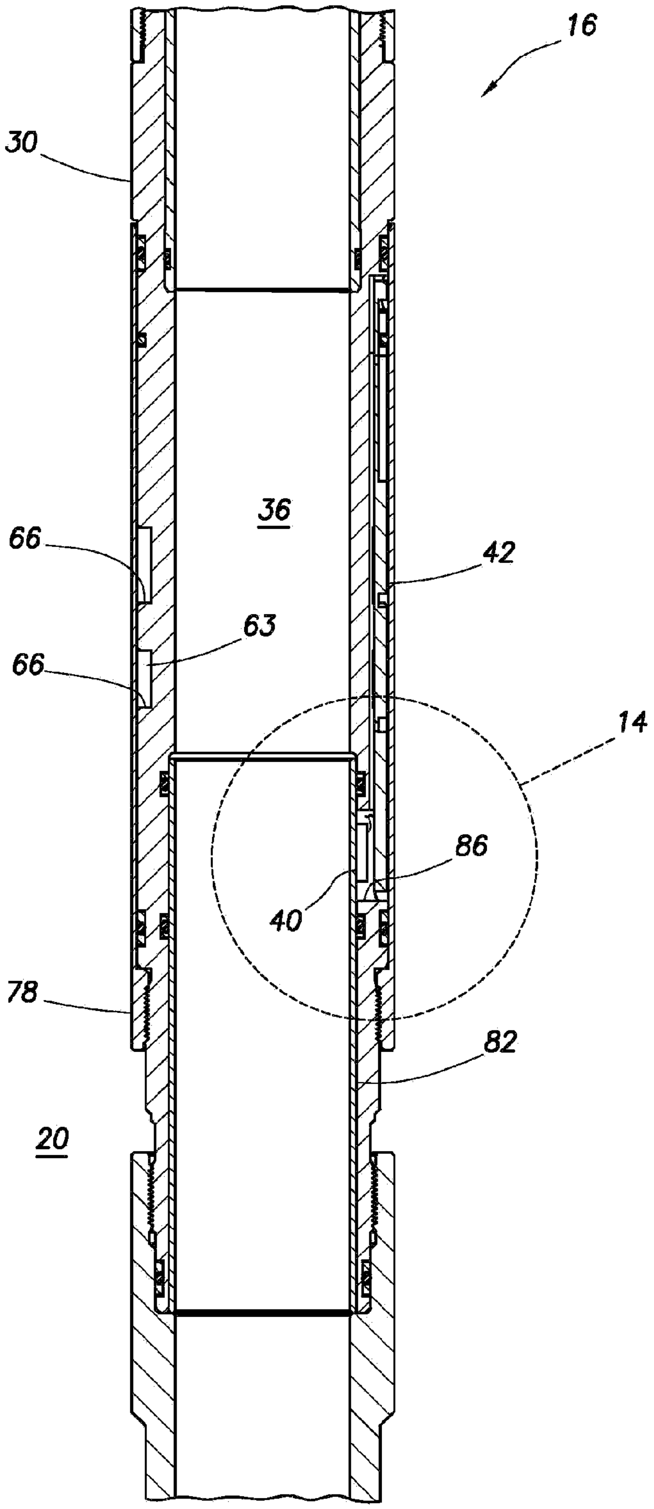


FIG.12

FIG.13



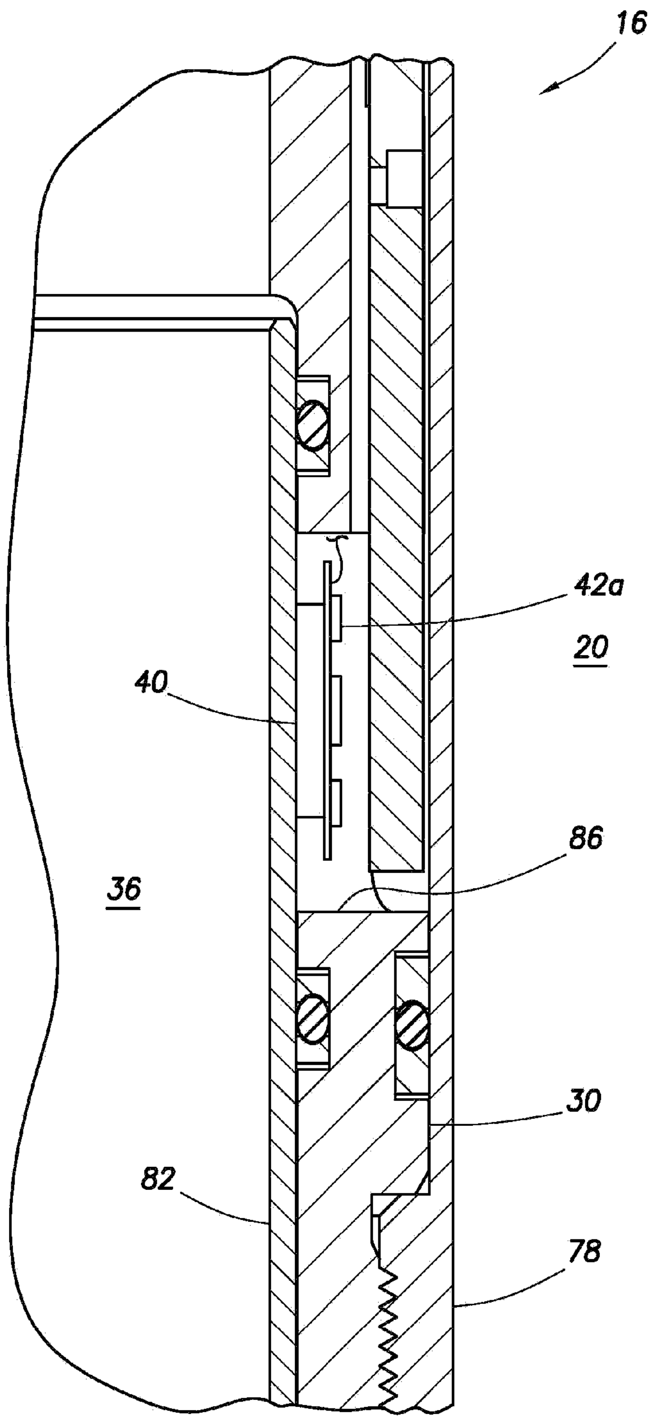


FIG.14

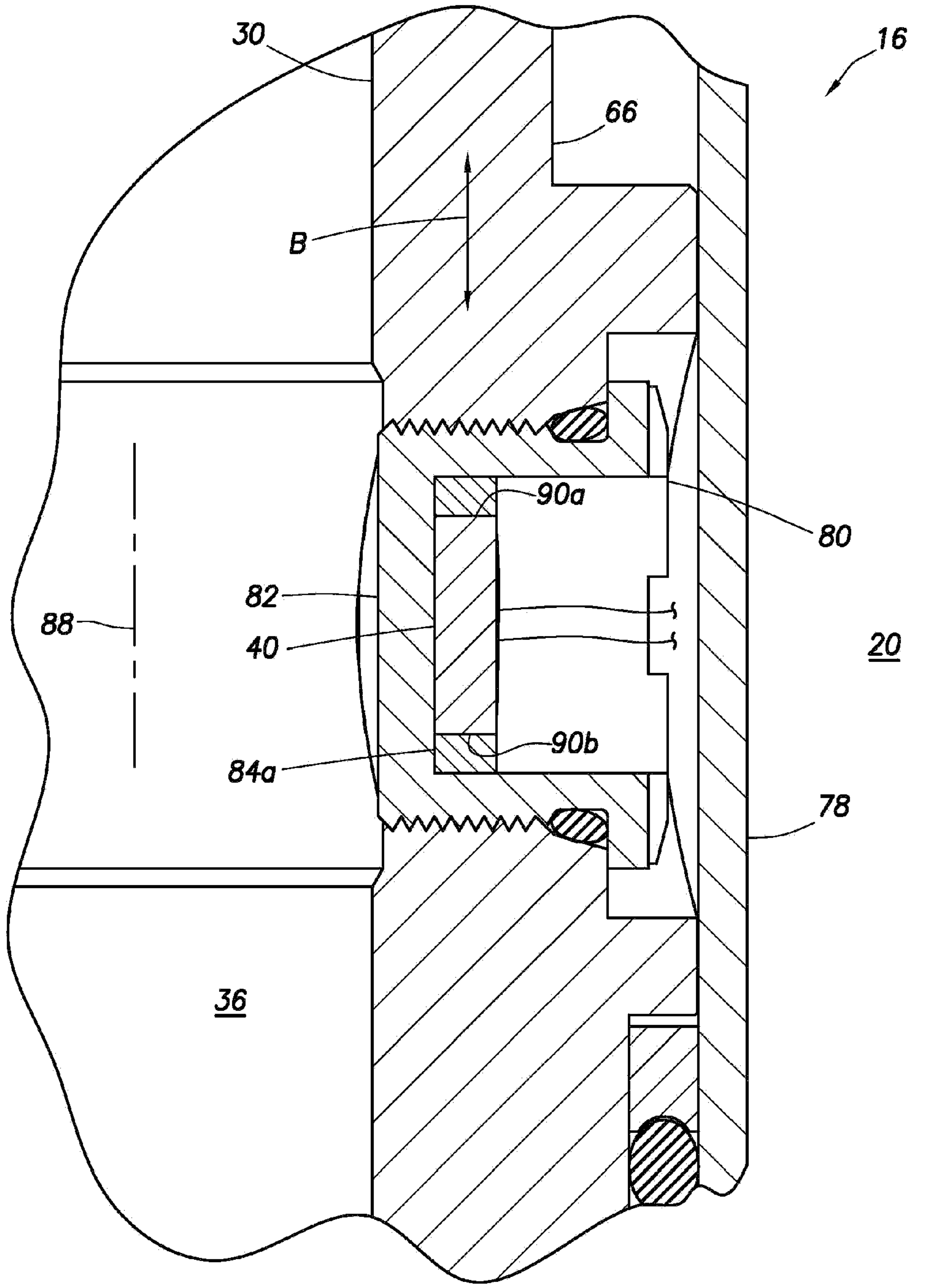


FIG.15

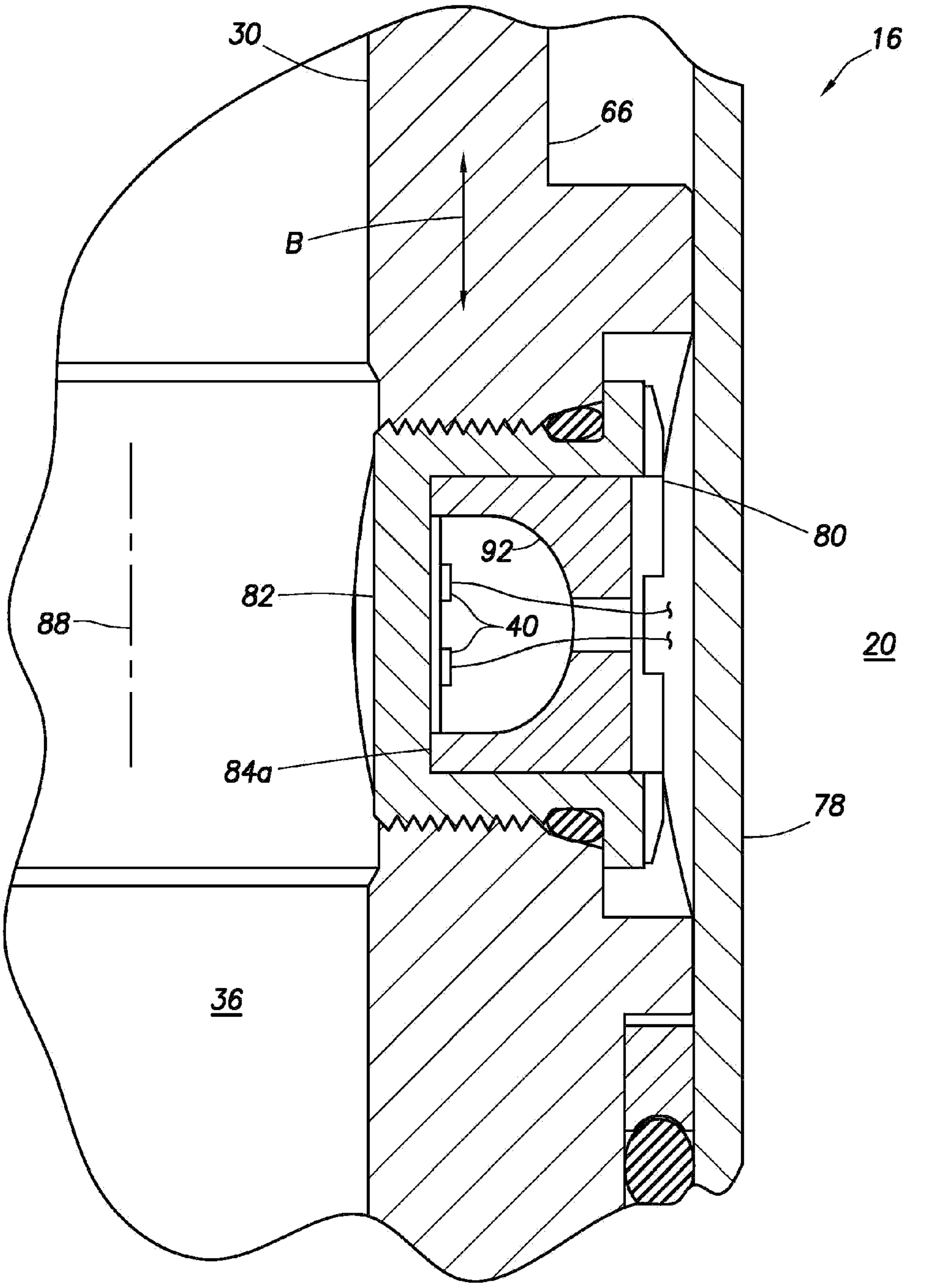


FIG.16

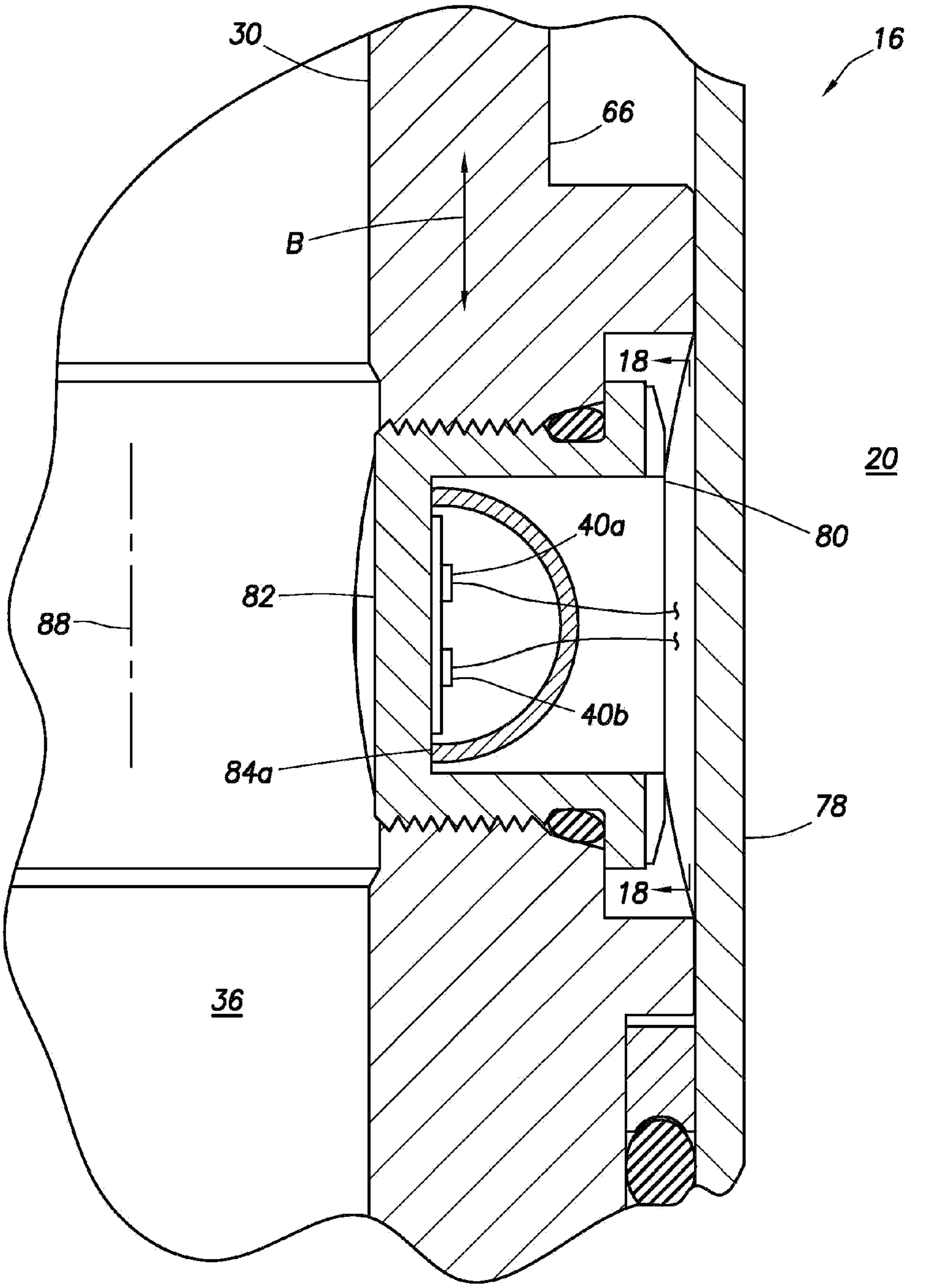


FIG.17

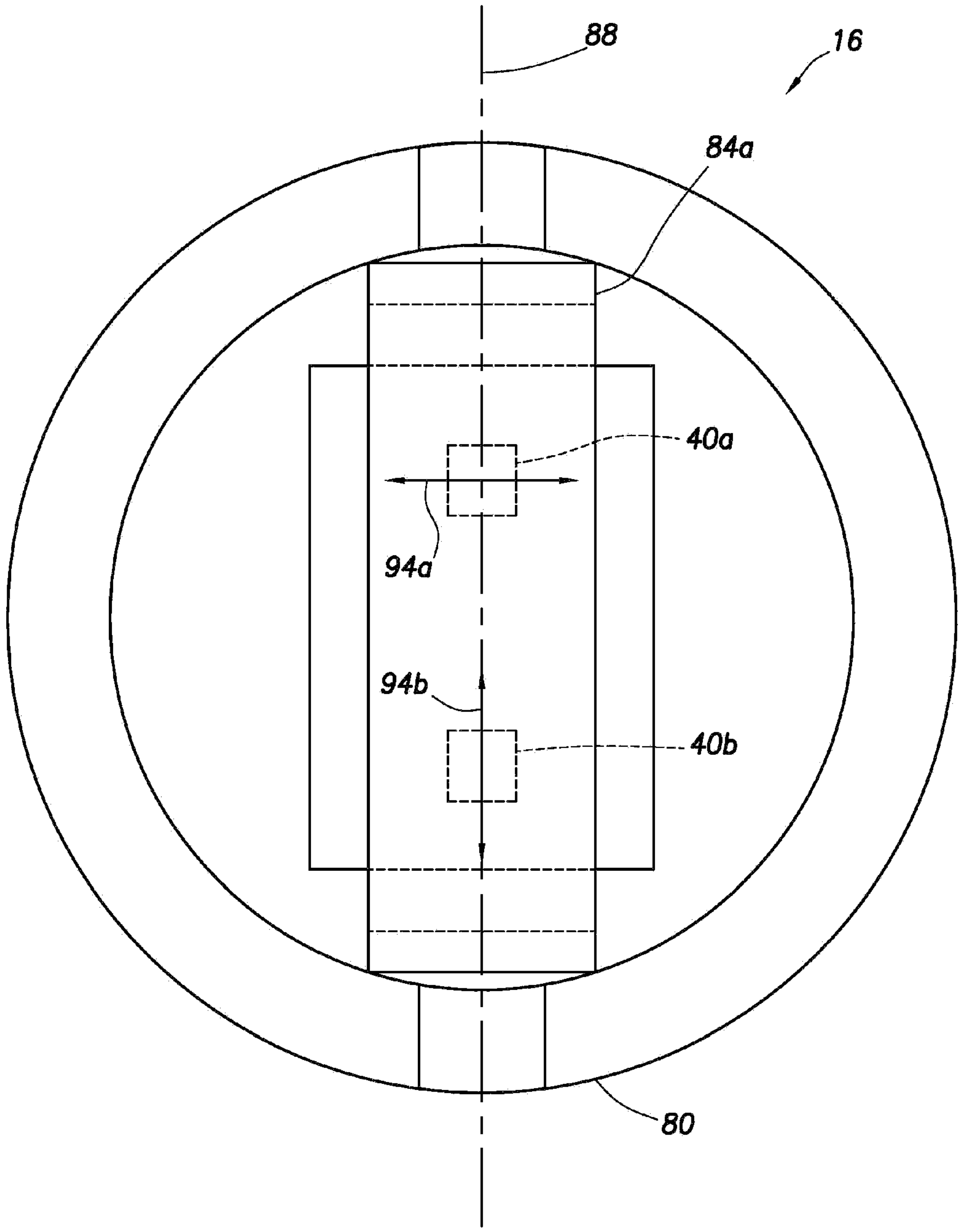


FIG.18