



(43) International Publication Date
18 October 2012 (18.10.2012)

- (51) International Patent Classification:
E21B 34/08 (2006.01) *E21B 34/16* (2006.01)
E21B 34/14 (2006.01)
- (21) International Application Number:
PCT/US2011/066514
- (22) International Filing Date:
21 December 2011 (21.12.2011)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
13/085,075 12 April 2011 (12.04.2011) US
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,

[Continued on next page]

(54) Title: SAFETY VALVE WITH ELECTRICAL ACTUATOR AND TUBING PRESSURE BALANCING

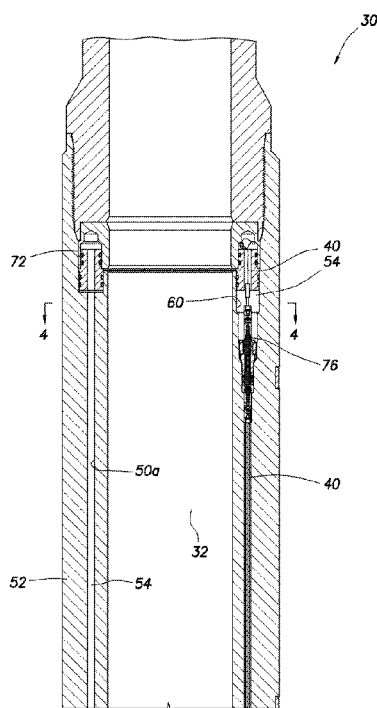


FIG. 2A

(57) Abstract: A well tool for use with a subterranean well can include a flow passage extending longitudinally through the well tool, an internal chamber containing a dielectric fluid, and a flow path which alternates direction, and which provides pressure communication between the internal chamber and the flow passage. A method of controlling operation of a well tool can include actuating an actuator positioned in an internal chamber of the well tool, a dielectric fluid being disposed in the chamber, and the chamber being pressure balanced with a flow passage extending longitudinally through the well tool, and varying the actuating, based on measurements made by at least one sensor of the well tool.



DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT,
LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE,
SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA,
GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *of inventorship (Rule 4.17(iv))*

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10 **SAFETY VALVE WITH ELECTRICAL ACTUATOR**
AND TUBING PRESSURE BALANCING

TECHNICAL FIELD

15 This disclosure relates generally to equipment utilized
and operations performed in conjunction with a subterranean
well and, in one example described below, more particularly
provides a safety valve with an electrical actuator and
tubing pressure balancing.

20

BACKGROUND

Actuators are used in various types of well tools.
Unfortunately, fluids in wells can damage or impair
operation of some well tool actuators. Therefore, it will be
25 appreciated that improvements are continually needed in the
arts of isolating well tool actuators from well fluids, and
actuating well tools.

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SUMMARY

In this disclosure, systems and methods are provided which bring improvements to the arts of isolating well tool
5 actuators from well fluids, and actuating well tools. One example is described below in which an actuator is exposed to a dielectric fluid isolated from an interior flow passage. Another example is described below in which various sensors can be used to control actuation of the well tool.

10 In one aspect, this disclosure provides to the art a well tool for use with a subterranean well. In one example, the well tool can include a flow passage extending longitudinally through the well tool, an internal chamber containing a dielectric fluid, and a flow path which
15 alternates direction. The flow path provides pressure communication between the internal chamber and the flow passage.

In another aspect, a method of controlling operation of a well tool can include actuating an actuator positioned in
20 an internal chamber of the well tool, a dielectric fluid being disposed in the chamber, and the chamber being pressure balanced with a flow passage extending longitudinally through the well tool; and varying the actuating, based on measurements made by at least one sensor
25 of the well tool.

In yet another aspect, a safety valve for use in a subterranean well is described below. In one example, the safety valve can include a flow passage extending longitudinally through the safety valve, an internal chamber
30 containing a dielectric fluid, a flow path which alternates direction, and which provides pressure communication between the internal chamber and the flow passage, an actuator

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exposed to the dielectric fluid, an operating member, and a closure member having open and closed positions, in which the closure member respectively permits and prevents flow through the flow passage. The actuator displaces the
5 operating member, which causes displacement of the closure member between its open and closed positions.

These and other features, advantages and benefits will become apparent to one of ordinary skill in the art upon careful consideration of the detailed description of
10 representative embodiments of the disclosure hereinbelow and the accompanying drawings, in which similar elements are indicated in the various figures using the same reference numbers.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

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

FIGS. 2A-D are enlarged scale representative
20 longitudinal cross-sectional views of a well tool which can embody principles of this disclosure, and which may be used in the well system and method of FIG. 1

FIGS. 3A-C are representative longitudinal cross-sectional views of the well tool.

25 FIG. 4 is a representative lateral cross-sectional view of the well tool, taken along line 4-4 of FIG. 2A.

FIG. 5 is a representative lateral cross-sectional view of the well tool, taken along line 5-5 of FIG. 3A.

30 FIG. 6 is a representative lateral cross-sectional view of the well tool, taken along line 6-6 of FIG. 3C.

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FIGS. 7A-9B are further representative cross-sectional views of the well tool.

FIG. 10 is an enlarged scale representative cross-sectional view of a floating piston assembly of the well
5 tool.

FIGS. 11A-C are representative cross-sectional views of another example of the well tool.

DETAILED DESCRIPTION

10 Representatively illustrated in FIG. 1 is a system 10 and associated method which can embody principles of this disclosure. However, the system 10 and method comprise only one example of how the principles of this disclosure can be applied in practice, and so it should be clearly understood
15 that those principles are not limited to any of the specific details of the system 10 and method described herein or depicted in the drawings.

In the FIG. 1 example, a tubular string 12 is installed in a wellbore 14 lined with casing 18 and cement 16. Well
20 fluid 20 (in this case, produced from an earth formation 22 penetrated by the wellbore 14) enters the tubular string 12 via a flow control device 24 (such as, a sliding sleeve valve, a variable choke, etc.). A packer 26 seals off an annulus 28 formed radially between the tubular string 12 and
25 the wellbore 14.

A well tool 30 selectively permits and prevents flow of the fluid 20 through a longitudinal flow passage 32 formed through the well tool and the substantial remainder of the tubular string 12. In this example, the well tool 30
30 comprises a safety valve. However, in other examples, the well tool 30 could comprise a flow control device (such as

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the flow control device 24) or another type of well tool (such as the packer 26, a chemical injection tool, a separator, etc.).

5 The well tool 30 depicted in FIG. 1 includes a closure member 34, an electronic circuit 36 and an actuator 38. The actuator 38 is used to displace the closure member 34 to and between open and closed positions in which flow of the fluid 20 is respectively permitted and prevented.

10 The closure member 34 in one example described below comprises a flapper which pivots relative to the flow passage 32 between the open and closed positions. In other examples, the closure member 34 could instead be a ball, gate, sleeve, or other type of closure member. Multiple closure members or multi-piece closure members could be
15 used, if desired.

The electronic circuit 36 in the example described below comprises a hybridized circuit, in which semiconductor dies are mounted to a circuit board with little or no packaging surrounding the dies. This significantly reduces a
20 volume requirement of the electronic circuit 36, allowing a wall thickness of the well tool 30 to be reduced. However, other types of electronic circuits may be used, if desired.

The actuator 38 in the example described below comprises an electrical actuator, such as a direct current
25 stepper motor. One advantage of such a motor is that a torque and/or force output of the motor can be conveniently regulated, and a position of an operating member displaced by the actuator 38 can be conveniently determined by monitoring a number of step pulses transmitted to the motor.
30 However, other types of electrical actuators, and other types of actuators, may be used in keeping with the scope of this disclosure.

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One or more lines 40 extend from the well tool 30 to a remote location (such as the earth's surface, a rig, a subsea location, etc.). The lines 40 can include one or more electrical conductors for conveying electrical power to the electronic circuit 36, transmitting commands, data, etc. to the well tool 30, receiving data, etc. from the well tool, etc. The lines 40 may include optical waveguides (such as optical fibers, ribbons, etc.), hydraulic conduits, and/or other types of lines, if desired.

In the example described below, the lines 40 extend internally through a conduit (for example, a conduit of the type known to those skilled in the art as a control line). The conduit protects the lines 40 during installation of the tubular string 12 in the wellbore 14, and thereafter.

However, use of the conduit is not necessary in keeping with the principles of this disclosure.

A control system 42 is located at the remote location, and is connected to the lines 40. The control system 42 may include a computing device 44 and a display 46, along with suitable memory, software, firmware, connectivity (e.g., to the Internet, to a satellite, to a telephony line, etc.), processor(s), etc., to communicate with and control operation of the well tool 30. Alternatively, the control system 42 could be as simple as a switch to either apply electrical power, or not apply electrical power, to the well tool 30.

An optional telemetry device 48 is included in the system 10 for relaying commands, data, etc. between the well tool 30 and the control system 42 at the remote location. For example, acoustic, electromagnetic, pressure pulse, a combination of short- and long-hop transmissions, or any

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other type of telemetry may be used. Wired or wireless telemetry, or a combination, may be used.

Since the fluid 20 is produced from the formation 22 through the tubular string 12, those skilled in the art
5 would refer to the tubular string as a production tubing string. The tubular string 12 could be jointed or continuous.

However, it should be understood that it is not necessary for the tubular string 12 to be a production
10 tubing string, or for the fluid 20 to be produced from the formation 22 through the tubular string. In other examples, well tools incorporating the principles of this disclosure could be used in injection operations. Well tools incorporating the principles of this disclosure are not
15 necessarily interconnected in a tubular string.

Referring additionally now to FIGS. 2A-10, a representative example of the well tool 30 is depicted in various longitudinal and lateral cross-sectional views. The well tool 30 of FIGS. 2A-10 may be used in the system 10 and
20 method of FIG. 1, or the well tool may be used in other system and methods.

In FIGS. 2A-D, a longitudinal cross-sectional view, taken along lines 2-2 of FIG. 4 is representatively illustrated. In this view, it may be seen that the well tool
25 30 includes a generally longitudinally extending flow path 50.

One section 50a of the flow path 50 is visible in FIGS. 2A-D. However, in this example, there are actually fourteen of the sections 50a-n (see FIG. 4) spaced apart
30 circumferentially in a side wall 52 of the tool 30.

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Of course, any number and/or arrangement of flow path sections may be used in other examples incorporating the principles of this disclosure. For example, the flow path sections 50a-n could be helically and/or laterally arranged.

5 In the FIGS. 2A-10 example, the sections 50a-n are arranged so that they alternate direction when viewed as a continuous flow path 50. The flow path 50 provides pressure communication between the flow passage 32 extending through the tubular string 12 and an internal generally
10 longitudinally extending chamber 62 (see FIG. 4).

The actuator 38 is positioned in the chamber 52. A dielectric fluid 54 (e.g., a silicone fluid, etc.) surrounds the actuator 38 in the chamber 62. The fluid 54 also fills a substantial majority of the flow path 50.

15 A floating piston assembly 56 (see FIGS. 9A & 10) isolates the dielectric fluid 54 from the well fluid 20, which enters the flow path 50 via an opening 58. The assembly 56 permits pressure to be balanced (e.g., at substantially equal levels) between the flow passage 32 and
20 the chamber 62 via the flow path 50, without any mixing of the fluids 20, 54.

In this manner, the chamber 62 is isolated from the well fluid 20 (which could interfere with operation of the actuator 38, electronic circuit 36, etc.), but the side wall
25 52 does not have to withstand a large pressure differential between the chamber 62 and the flow passage 32. Thus, the side wall 52 can be made thinner, due to the chamber 62 being pressure balanced with the flow passage 32.

Note that the floating piston assembly 56 is
30 reciprocally and sealingly received in a radially enlarged section 50o of the flow path 50. This allows the floating piston assembly 56 to displace more volume per unit of

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translational displacement, thereby allowing more expansion of the dielectric fluid 54 with increased temperature, and allowing for a greater range of pressure transmission (although, if the dielectric fluid 54 is substantially incompressible, very little volume change would be expected due to pressure in a typical downhole environment). A pressure relief valve or other pressure relief device 68 is provided in the floating piston assembly 56 to relieve excess pressure in the flow path 50 due, for example, to increased temperature.

The chamber 62 is one of several chambers 60, 62, 64, 66 in fluid communication with the flow path 50. The electronic circuit 36 is positioned in the chamber 66 (see FIGS. 8A & B).

A generally tubular housing 70 forms an enclosure 72 in which the electronic circuit 36 is contained, isolated from the fluid 54 in the chamber 66. The housing 70 in this example comprises a pressure bearing weldment. However, if the electronic circuit 36 can withstand the pressure in the chamber 66 (substantially the same as the pressure in the flow passage 32), then the housing 70 may not be used, or at least the housing may not have to withstand as much differential pressure.

Upper and lower manifolds 72, 74 provide fluid communication between the flow path sections 50a-o and chambers 60, 62, 64, 66. FIG. 5 depicts a lateral cross-sectional view of the upper manifold 72, and FIG. 6 depicts a lateral cross-sectional view of the lower manifold 74, taken along lines 5-5 and 6-6 of FIGS. 3A & C, respectively.

Alternating opposite ends of adjacent ones of the flow path sections 50a-o are placed in fluid communication with each other by the manifolds 72, 74. In addition, electrical

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conductors and/or optical waveguides can extend through openings in the manifolds 72, 74 (see FIG. 5).

For example, as depicted in FIG. 2A, the lines 40 can extend through the upper manifold 72 to a bulkhead connector 76 in the chamber 60. The connector 76 isolates the chamber 60 from a conduit 78 extending external to the well tool 30. The conduit 78 (and the lines 40 therein) could extend to, for example, another well tool (such as, another safety valve, the telemetry device 48, etc.), a remote location, the control system 42, etc.

In other examples, the bulkhead connector 76 may not be used, and the conduit 78 can be in fluid communication with the flow path 50 and chambers 60, 62, 64, 66. In this manner, the dielectric fluid 54 (or another fluid, such as, a chemical treatment fluid, etc.) could be injected into the flow path 50 and chambers 60, 62, 64, 66 from a remote location via the conduit 78.

For example, after installation of the well tool 30 in a well, dielectric fluid 54 could be pumped through the conduit 78 from the remote location to the flow path 50 and chambers 60, 62, 64, 66. Sufficient pressure could be applied to cause the pressure relief device 68 to open, thereby allowing the fluid to be pumped into the flow passage 32 from the flow path section 50o.

This would ensure that the flow path 50 and chambers 60, 62, 64, 66 are filled with the dielectric fluid 54. This can also allow a chemical treatment fluid (such as, a corrosion inhibitor, a precipitate reducer, etc.) to be pumped into the flow passage 32 via the conduit 78, flow path 50 and relief valve 68.

Various sensors can be included with the well tool 30. These sensors may be useful for monitoring well parameters,

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monitoring operation of the well tool, controlling the operation of the well tool, etc.

In the example of FIGS. 2A-10, a pressure and/or temperature sensor 80 is disposed in the upper manifold 72 (see FIG. 5). A position sensor 82 measures a position of an operating member 84 (see FIGS. 2B-D), which is displaced by the actuator 38 against a biasing force exerted by a biasing device 86, to thereby open or close the closure member 34.

Magnets 104 are carried on the shaft 90. A position of the magnets 104 is sensed by the position sensor 82, thereby providing a measurement of the position of the operating member 84.

Note that the position sensor 82 is not necessarily a magnetic-type position sensor. The position sensor 82 could instead be a linear variable displacement transducer, acoustic rangefinder, optical sensor, or any other type of position sensor.

A force sensor 88 (see FIG. 3A) measures a force output by the actuator 38. As mentioned above, the actuator 38 in this example comprises a stepper motor. A torque output, current draw, number of step pulses, and/or any other parameter may be measured by the sensor 88, another sensor or any combination of sensors.

The motor (via suitable gearing, clutch, brake, etc., not visible in FIGS. 3A & B) displaces a shaft 90 upward or downward (as viewed in the drawings). A sealing rod piston 92 is displaced with the shaft 90. The sealing rod piston 92 isolates the dielectric fluid 54 in the chamber 62 from the well fluid 20 in the flow passage 32.

Note that, since the chamber 62 and the flow passage 32 are at substantially the same pressure, seals 96 on the

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piston 92 do not have to seal against a large pressure differential. Nevertheless, in this example, metal-to-metal sealing surfaces 94 are provided at each end of the piston's displacement for further sealing enhancement.

5 An alternative pressure transmission device could be a bellows 98, as depicted in the example of FIGS. 11A-C. Yet another alternative could be a diaphragm or membrane. Any type of pressure transmission device which can isolate the chamber 62 from the flow passage 32, while transmitting
10 force from the actuator 38 to the operating member 84 may be used.

 The operating member 84 can be displaced to any position by the actuator 38 at any time. For example, the operating member 84 can be displaced to a position in which
15 the closure member 34 is fully closed, a position in which the closure member is fully open, a position in which an equalizing valve 100 (see FIG. 2D) is opened, etc.

 When actuating the well tool 30 from its open to its closed configuration, the actuator 38 can displace the
20 operating member 84 to its equalizing position (thereby opening the equalizing valve 100), stop at the equalizing position (e.g., using a brake of the actuator) and then continue to the open position (in which the closure member 34 is fully open). The operating member 84 can remain
25 stopped at the equalizing position until the sensor 80 indicates that pressure in the flow passage 32 above the closure member 34 has ceased increasing, until a certain time period has elapsed, until a differential pressure sensor (not shown) indicates that pressure across the
30 closure member 34 has equalized, etc.

 Measurements made by the sensor 88 can also be used to control operation of the well tool 30. For example, the

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force and/or torque output by the actuator 38 could be limited to a predetermined maximum level. In some examples, this predetermined maximum level could be changed, if desired, via the control system 42.

5 In other examples, the force and/or torque, current draw, etc., of the actuator 38 can be optimized for most efficient and/or effective operation of the well tool 30. For example, the force output by the actuator 38 could be limited when displacing the operating member 84 from the
10 closed position to the equalizing position, then increased to a greater level when the operating member begins opening the closure member 34, and then reduced after the closure member has been rotated a sufficient amount. If greater
15 of these situations (or in any other situations), an alert, alarm, etc. may be provided to an operator by the control system 42 (e.g., via the display 46).

 It may now be fully appreciated that significant improvements are provided to the arts by the principles set
20 forth in this disclosure. In an example described above, electrical connections (e.g., the bulkhead connector 76, connections at the position sensor 82, sensor 88, actuator 38, etc.), a downhole electronics housing 70 weldment, a position sensor 82 and an electrical actuator 38 are
25 installed inside of dielectric fluid 54 filled chambers 60, 62, 64, 66. All of the dielectric fluid 54 filled chambers 60, 62, 64, 66 are pressure balanced to the flow passage 32 using a flow path 50 which alternates direction multiple times.

30 The illustrated configuration contains only one electric actuator, one downhole electronics housing

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weldment, and one position sensor. However, any number of these elements may be used, as desired.

There are seven alternating dielectric fluid filled gravity assisted "U" flow path sections (fourteen total
5 sections) to separate the production fluid from the dielectric fluid, in the illustrated configuration. However, any number of flow path sections may be used, as desired.

The passageway ports that are used for the passage of the dielectric fluid balance pressure can also be used to
10 route electrical conductors or other types of lines from chamber to chamber. These ports can be sealed with static double o-ring seals (which always have substantially no differential pressure across them).

If desired, these ports could be laser welded instead
15 of being sealed with o-rings. However the pressure balance device in other examples could include a chamber where the dielectric fluid is separated from the well fluids by bellows or other types of seals.

No large magnetic coupling is used in the illustrated
20 configuration. However, a magnetic coupling could be used, in keeping with the principles of this disclosure.

Typically, the main limitation on safety valve dimensions is the wall thickness needed for the actuator. The required wall thickness can be much smaller with the
25 illustrated design, since the electric actuator can be smaller than conventional designs.

The electric actuator for the illustrated configuration does not have to be as powerful or as large as conventional electrical safety valve actuators. The actuator in the
30 illustrated configuration must only be strong enough to overcome the force of the biasing device 86 and friction.

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Since there is no differential pressure on any seals, the friction should be minimal.

A conventional rod piston 92 with leak-proof seals 96 is used in the depicted safety valve example. Note that
5 multiple rod piston seals (or even a bellows, diaphragm, etc.) could be used in place of the leak-proof seals, since there is preferably substantially no differential pressure across the seals.

Again, all of the seals in the design will preferably
10 have little to no pressure differential across them. No pressure differential should equate to very little to no leakage past the seals for long periods of time.

A hybrid electronics package design that is long with a small OD is used in the depicted safety valve example. This
15 hybrid circuit design provides a significant size reduction. Longevity at high temperatures is also increased.

In other examples, a hybrid circuit that holds high pressure and, therefore, does not need a high pressure housing may be used. This can further reduce the cost of
20 constructing the well tool.

In the depicted example, there is no welding required on any body components which experience significant tension in operation. This enhances the structural integrity of the well tool, while also reducing costs.

25 The tubing pressure balancing feature is integrated into the depicted safety valve example. This can also result in substantial cost reductions. However, in other examples, the tubing pressure balancing feature could be provided by a separate component that is connected to the dielectric fluid
30 filled chambers.

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The illustrated safety valve example also provides for addition of a downhole electronic pressure and/or temperature gauge as part of the safety valve. Such a pressure/temperature gauge can be installed into one of the pressure balancing chambers which are maintained at the pressure in the flow passage. This downhole gauge could transmit pressure and temperature information to a remote location on a same line as is used to control operation of the safety valve.

Complete system redundancy can be provided in at least three ways, due at least in part to the reduced cost of the safety valve example described above:

a. Multiple safety valves could be installed. A secondary valve could be pinned or temporarily locked in an open position. The secondary valve could be actuated (e.g., via a wireline trip) when a primary safety valve fails.

b. Multiple safety valves could be operated all the time. If any one safety valve fails, it can be locked open.

c. A safety valve could include multiple actuators, multiple control lines, and multiple sets of electronics. In the illustrated configuration, the number of alternating flow paths may be reduced, if the multiple actuators, etc. are to fit in the same size wall of the safety valve. If dielectric fluid contamination is a concern, more "U" tubes could be added, or a metal bellows pressure balancing system could be used instead, etc.

The illustrated configuration uses a currently new Honeywell changing magnetic field sensing position sensor. As a small magnet assembly carried by the shaft 90 moves, the Honeywell position sensor accurately reports the position. This solid state sensor has no moving parts inside the pressure housing and it should be much more reliable

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than a potentiometer type sensor. However, a potentiometer or other type of position sensor may be used, if desired.

There might be concerns that well fluids could eventually reach the actuation chamber if the flow path is open to the flow passage (e.g., if the floating piston assembly 56 is not used). However, the multiple alternating direction flow path sections 50a-o should be effective to prevent migration of the well fluid 20 into the chambers 60, 62, 64, 66.

10 The floating piston assembly 56 forms a physical barrier between the well fluids and the dielectric fluid, thereby preventing mixing of the fluids. The floating piston could move inward and outward with changes in pressure, but its inward movement could be limited by the compressibility of the dielectric fluid, and its outward movement could be limited by the expansiveness of the dielectric fluid.

15 A basic combination described above is a chamber filled with a dielectric fluid, with one end of a flow path connected to the chamber, and another end of the flow path in communication with the flow passage. While this integral pressure balancing feature is primarily described for an electrically actuated safety valve, it could potentially be used with other well tools, such as sliding sleeves, chemical injection valves, separators, etc.

25 The depicted electric safety valve system can include an electric actuator with downhole electronic circuitry, a downhole telemetry device (transmitter and/or receiver), and a control system at a remote location (such as, at the earth's surface, a rig, an underwater facility, etc.).

30 A position sensor can report the relative position of the operating member from the start (or the fully closed position) to the end (or the fully open position) to the

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electronic circuitry. The electronic circuitry transmits this information to the telemetry device. The telemetry device then relays the position information to the control system. In some examples, an operator at the remote location
5 can view the position of the operating member.

The control system can display when the safety valve should be fully open, for example, after a preset number of stepper motor steps have been executed. This control system computer display indication can be independent of the
10 position sensor, so that a failure of the position sensor does not affect the opening/closing functions of the safety valve.

The control system can display when the valve is in the closed position, when the control system's computer program
15 is running. The safety valve will preferably automatically close if the control system is shut down, electric power to the safety valve is lost, or a computer used to run the computer program fails.

In another example, the safety valve could go into a
20 hold state if the control system fails or is shut down, instead of the safety valve automatically closing. The reason for the failure or shutdown could be a system maintenance issue that does not require the well to be shut-in.

25 The force sensor 88 periodically reports to the control system the measured force output by the actuator. These force measurements can comprise a secondary indication of the safety valve operation, which may be used in case the position sensor 82 fails.

30 If the safety valve is a self-equalizing type (e.g., comprising the equalizing valve 100), the electronic circuitry or the control system can be preprogrammed to

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displace the operating member only to the equalizing position, and then set the brake until the operator issues a command to the control system to continue to open the safety valve to the fully open position.

5 The temperature, pressure, vibration, etc. of the electronic circuitry can be reported periodically to the control system. For example, this information can be displayed after the safety valve is closed. The temperature, pressure, vibration, etc. could also be displayed and/or
10 recorded in real time.

 The pressure and temperature in the tubular string 12 (e.g., as measured by the sensor 80) may be reported periodically to the control system 42 (e.g., the safety valve is open), or after the valve is closed, and/or in real
15 time. This can be accomplished with an integral downhole pressure/temperature gauge or other dedicated sensors.

 If the force on the actuator or the force required to open the flapper exceeds a preset limit, indicating that pressure across the flapper is not equalized, the electronic
20 circuitry can automatically command the safety valve to close (e.g., causing the actuator to reverse direction), and the force overload can be reported to the control system.

 The operator can then set this force limit to a higher level, if desired. However, the stepper motor will likely
25 dither and not open the safety valve if the maximum motor torque is reached. In this circumstance, the operator can increase the tubing pressure to equalize the pressure above the flapper to the pressure below the flapper.

 The current and voltage supplied to the clutch, brake,
30 and stepper motor are preferably reported periodically to the control system.

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The torque output of the stepper motor can be increased by decreasing a frequency of electrical step pulses transmitted to the motor. The time to open the safety valve can be optimized by increasing the frequency of the pulses
5 at the beginning of the displacement when the force output by the biasing device is lowest, and decreasing the frequency at the end of the displacement when the spring force is highest.

This functionality can be enhanced by monitoring the
10 force sensor output. If the force sensor indicates an increased force, the frequency of the step pulses can be reduced.

In order to optimize electrical power usage, the safety valve can have a demand system, whereby the power is
15 continuously monitored, and is maintained within a narrow range. The safety valve will likely have an optimum power at which it performs its function. This optimum power is sufficient to operate the valve, with a minimum amount of excess power. In this manner, smaller electrical components
20 can be used and less heat is generated in the downhole electronic circuitry, actuator, etc.

In one example, if the flow passage 32 pressure is below or above a preset limit, the valve would automatically close. A warning with a predetermined override time limit
25 could be displayed by the control system 42 before this happens, so the valve would not be closed unless circumstances warrant.

This would allow the operator to override the closure if the downhole pressure gauge failed or the pressure limits
30 are incorrect. The pressure limits could be reset at the control system 42. If the override command is not received

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during the given time period, the valve could automatically close.

The control system 42 could automatically alternate redundant clutches and/or brakes of the actuator 38.

5 Note that the electric actuator 38 and other components used in the illustrated configuration could also be used to operate a downhole choke, sliding sleeve valve, etc., instead of a subsurface safety valve. For a downhole choke, other sensors such as resistivity and a differential
10 pressure flow meter could be included in the design, so that operation of the choke could be controlled, based on the outputs of such sensors.

The electronic circuitry and/or telemetry device may be reprogrammed from the control system 42.

15 Another self-equalizing function can be included as part of the safety valve. The operating member 84 can be displaced from the closed position to a predetermined equalizing position, at which the equalizing valve 100 opens. The brake would be set, holding the operating member
20 84 in the equalizing position. The pressure gauge could be monitored, until the pressure above the closure member 34 stops increasing for a predetermined time period, then the operating member 84 would be displaced to the open position.

A well tool 30 for use with a subterranean well is
25 described above. In one example, the well tool 30 can include a flow passage 32 extending longitudinally through the well tool 30, an internal chamber 60, 62, 64, 66 containing a dielectric fluid 54, and a flow path 50 which alternates direction, and which provides pressure
30 communication between the internal chamber 60, 62, 64, 66 and the flow passage 32.

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The well tool 30 can also include a floating piston 102 in the flow path 50. The floating piston 102 may prevent the dielectric fluid 54 from flowing into the flow passage 32. The floating piston 102 can be positioned in an enlarged
5 section 50o of the flow path 50.

The well tool 30 may include an electrical actuator 38 in the dielectric fluid 54. The actuator 38 can displace a pressure transmission device (e.g., piston 92, bellows 98, etc.) which isolates the chamber 60, 62, 64, 66 from the
10 flow passage 32. The pressure transmission device may comprises a bellows 98 and/or a piston 92.

The chamber 60, 62, 64, 66 can be in fluid communication with a source of the dielectric fluid 54 via a conduit 78 extending to a remote location. A line 40 may
15 extend through the conduit 78 to an actuator 38 in the chamber 62.

The chamber 60, 62, 64, 66 can be in fluid communication with a source of chemical treatment fluid via a conduit 78 extending to a remote location. In this example
20 also, a line 40 may extend through the conduit 78 to an actuator 38 in the chamber 62.

The well tool 30 can include a pressure relief device 68. The pressure relief device 68 may permit the dielectric fluid 54 to flow into the flow passage 32 in response to
25 pressure in the chamber 60, 62, 64, 66 exceeding a predetermined pressure level.

The well tool 30 can include an actuator 38 in the dielectric fluid 54, and a force sensor 88 which senses a force applied by the actuator 38. The force applied by the
30 actuator 38 may be controlled, based on measurements made by the force sensor 88.

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The force output by the actuator 38 can vary, based on a displacement of an operating member 84 of the well tool 30 by the actuator 38. The well tool 30 can include a displacement or position sensor 82 which senses the displacement of the operating member 84.

The displacement of the operating member 84 may cause displacement of a closure member 34 which selectively permits and prevents flow through the flow passage 32. The displacement of the operating member 84 can actuate an equalizing valve 100 which equalizes pressure across the closure member 34.

The well tool 30 can include at least one of the group comprising temperature, force, pressure, position, and vibration sensors in the dielectric fluid 54. At least one of the sensors (e.g., vibration sensor 106, see FIG. 8B) and an electronic circuit 36 may be disposed in an enclosure 71 isolated from pressure in the chamber 66.

A method of controlling operation of a well tool 30 is also described above. In one example, the method can include actuating an actuator 38 positioned in an internal chamber 62 of the well tool 30, a dielectric fluid 54 being disposed in the chamber 62, and the chamber 62 being pressure balanced with a flow passage 32 extending longitudinally through the well tool 30; and varying the actuating, based on measurements made by at least one sensor 80, 82, 88, 106 of the well tool 30.

The actuating step can also include displacing an operating member 84. The sensor 82 may sense displacement of the operating member 84. The varying step can include changing a speed of the displacement, based on the sensed displacement of the operating member 84.

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The varying step can include changing a force and/or torque output by the actuator 38, based on the sensed displacement of the operating member 84.

5 The varying step can include varying a frequency of electrical pulses transmitted to the actuator 38.

The varying step can include closing a closure member 34, in response to the sensor 88 sensing that a force output by the actuator 38 exceeds a predetermined maximum force level.

10 The varying step can include ceasing displacement of an operating member 84, and then resuming displacement of the operating member 84. The ceasing displacement step may be performed when the actuator 38 has displaced the operating member 84 to an equalizing position, in which pressure is
15 equalized across a closure member 34. The resuming displacement step may be performed when the pressure has equalized across the closure member 34, and/or in response to a predetermined period of time elapsing from the operating member 84 being displaced to the equalizing
20 position.

The well tool 30 may comprise a safety valve. The actuator 38 may cause a closure member 34 to be alternately opened and closed to thereby respectively permit and prevent flow through the flow passage 32.

25 In particular, the above disclosure describes a safety valve 30 for use in a subterranean well. In one example, the safety valve 30 can include a flow passage 32 extending longitudinally through the safety valve 30, an internal chamber 60, 62, 64, 66 containing a dielectric fluid 54, a
30 flow path 50 which alternates direction, and which provides pressure communication between the internal chamber 60, 62, 64, 66 and the flow passage 32, an actuator 38 exposed to

- 25 -

the dielectric fluid 54, an operating member 84, and a closure member 34 having open and closed positions, in which the closure member 34 respectively permits and prevents flow through the flow passage 32. The actuator 38 can displace
5 the operating member 84, which causes displacement of the closure member 34 between its open and closed positions.

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
10 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
15 exclusive to another example's features. Instead, the scope of this disclosure encompasses any combination of any of the features.

Although each example described above includes a certain combination of features, it should be understood
20 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.

It should be understood that the various embodiments
25 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
30 of the disclosure, which is not limited to any specific details of these embodiments.

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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
5 be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

The terms "including," "includes," "comprising," "comprises," and similar terms are used in a non-limiting sense in this specification. For example, if a system,
10 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
15 limited to."

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,
20 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
25 spirit and scope of the invention being limited solely by the appended claims and their equivalents.

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WHAT IS CLAIMED IS:

1. A well tool for use with a subterranean well, the well tool comprising:

5 a flow passage extending longitudinally through the well tool;

an internal chamber containing a dielectric fluid; and

a flow path which alternates direction, and which provides pressure communication between the internal chamber
10 and the flow passage.

2. The well tool of claim 1, further comprising a floating piston in the flow path, and wherein the floating piston prevents the dielectric fluid from flowing into the
15 flow passage.

3. The well tool of claim 2, wherein the floating piston is positioned in an enlarged section of the flow path.

20

4. The well tool of claim 1, further comprising an electrical actuator in the dielectric fluid.

5. The well tool of claim 4, wherein the actuator
25 displaces a pressure transmission device which isolates the chamber from the flow passage.

6. The well tool of claim 5, wherein the pressure transmission device comprises a bellows.

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7. The well tool of claim 5, wherein the pressure transmission device comprises a piston.

5 8. The well tool of claim 1, wherein the chamber is in fluid communication with a source of the dielectric fluid via a conduit extending to a remote location, and wherein a line extends through the conduit to an actuator in the chamber.

10

9. The well tool of claim 1, wherein the chamber is in fluid communication with a source of chemical treatment fluid via a conduit extending to a remote location, and wherein a line extends through the conduit to an actuator in
15 the chamber.

10. The well tool of claim 1, further comprising a pressure relief device, and wherein the pressure relief device permits the dielectric fluid to flow into the flow
20 passage in response to pressure in the chamber exceeding a predetermined pressure level.

11. The well tool of claim 1, further comprising an actuator in the dielectric fluid, and a force sensor which
25 senses a force applied by the actuator.

12. The well tool of claim 11, wherein the force applied by the actuator is controlled, based on measurements made by the force sensor.

30

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13. The well tool of claim 1, further comprising an actuator in the dielectric fluid, and wherein a force output by the actuator varies, based on a displacement of an operating member of the well tool by the actuator.

5

14. The well tool of claim 13, further comprising a displacement sensor which senses the displacement of the operating member.

10

15. The well tool of claim 13, wherein the displacement of the operating member causes displacement of a closure member which selectively permits and prevents flow through the flow passage.

15

16. The well tool of claim 15, wherein the displacement of the operating member actuates an equalizing valve which equalizes pressure across the closure member.

20

17. The well tool of claim 1, further comprising at least one of the group comprising temperature, force, pressure, position, and vibration sensors in the dielectric fluid.

25

18. The well tool of claim 17, wherein at least one of the sensors and an electronic circuit are disposed in an enclosure isolated from pressure in the chamber.

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19. A method of controlling operation of a well tool,
the method comprising:

actuating an actuator positioned in an internal chamber
of the well tool, a dielectric fluid being disposed in the
5 chamber, and the chamber being pressure balanced with a flow
passage extending longitudinally through the well tool; and

varying the actuating, based on measurements made by at
least one sensor of the well tool.

10 20. The method of claim 19, wherein the actuating
further comprises the actuator displacing an operating
member, and wherein the sensor senses displacement of the
operating member.

15 21. The method of claim 20, wherein the varying
comprises changing a speed of the displacement, based on the
sensed displacement of the operating member.

22. The method of claim 20, wherein the varying
20 comprises changing a force output by the actuator, based on
the sensed displacement of the operating member.

23. The method of claim 20, wherein the varying
comprises changing a torque output by the actuator, based on
25 the sensed displacement of the operating member.

24. The method of claim 19, wherein the varying
comprises varying a frequency of electrical pulses
transmitted to the actuator.

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25. The method of claim 19, wherein the varying comprises closing a closure member, in response to the sensor sensing that a force output by the actuator exceeds a predetermined maximum force level.

5

26. The method of claim 19, wherein the varying comprises ceasing displacement of an operating member, and then resuming displacement of the operating member.

10

27. The method of claim 26, wherein the ceasing displacement is performed when the actuator has displaced the operating member to an equalizing position, in which pressure is equalized across a closure member.

15

28. The method of claim 27, wherein the resuming displacement is performed when the pressure has equalized across the closure member.

20

29. The method of claim 27, wherein the resuming is performed in response to a predetermined period of time elapsing from the operating member being displaced to the equalizing position.

25

30. The method of claim 19, wherein the well tool comprises a safety valve, and wherein the actuator causes a closure member to be alternately opened and closed to thereby respectively permit and prevent flow through the flow passage.

30

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31. A safety valve for use in a subterranean well, the safety valve comprising:

a flow passage extending longitudinally through the safety valve;

5 an internal chamber containing a dielectric fluid;

a flow path which alternates direction, and which provides pressure communication between the internal chamber and the flow passage;

an actuator exposed to the dielectric fluid;

10 an operating member; and

a closure member having open and closed positions, in which the closure member respectively permits and prevents flow through the flow passage,

wherein the actuator displaces the operating member,
15 which causes displacement of the closure member between its open and closed positions.

32. The safety valve of claim 31, further comprising a floating piston in the flow path, and wherein the floating
20 piston prevents the dielectric fluid from flowing into the flow passage.

33. The safety valve of claim 32, wherein the floating piston is positioned in an enlarged section of the flow
25 path.

34. The safety valve of claim 31, wherein the actuator comprises an electrical actuator.

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35. The safety valve of claim 31, wherein the actuator displaces a pressure transmission device which isolates the chamber from the flow passage.

5 36. The safety valve of claim 35, wherein the pressure transmission device comprises a bellows.

37. The safety valve of claim 35, wherein the pressure transmission device comprises a piston.

10

38. The safety valve of claim 31, wherein the chamber is in fluid communication with a source of the dielectric fluid via a conduit extending to a remote location, and wherein a line extends through the conduit to the actuator.

15

39. The safety valve of claim 31, wherein the chamber is in fluid communication with a source of chemical treatment fluid via a conduit extending to a remote location, and wherein a line extends through the conduit to
20 the actuator.

40. The safety valve of claim 31, further comprising a pressure relief device, and wherein the pressure relief device permits the dielectric fluid to flow into the flow
25 passage in response to pressure in the chamber exceeding a predetermined pressure level.

41. The safety valve of claim 31, further comprising a force sensor which senses a force applied by the actuator.

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42. The safety valve of claim 41, wherein the force applied by the actuator is controlled, based on measurements made by the force sensor.

5

43. The safety valve of claim 31, wherein a force output by the actuator varies, based on a displacement of the operating member by the actuator.

10 44. The safety valve of claim 43, further comprising a displacement sensor which senses the displacement of the operating member.

15 45. The safety valve of claim 43, wherein the displacement of the operating member actuates an equalizing valve which equalizes pressure across the closure member.

20 46. The safety valve of claim 31, further comprising at least one of the group comprising temperature, force, pressure, position, and vibration sensors in the dielectric fluid.

25 47. The safety valve of claim 47, wherein at least one of the sensors and an electronic circuit are disposed in an enclosure isolated from pressure in the chamber.

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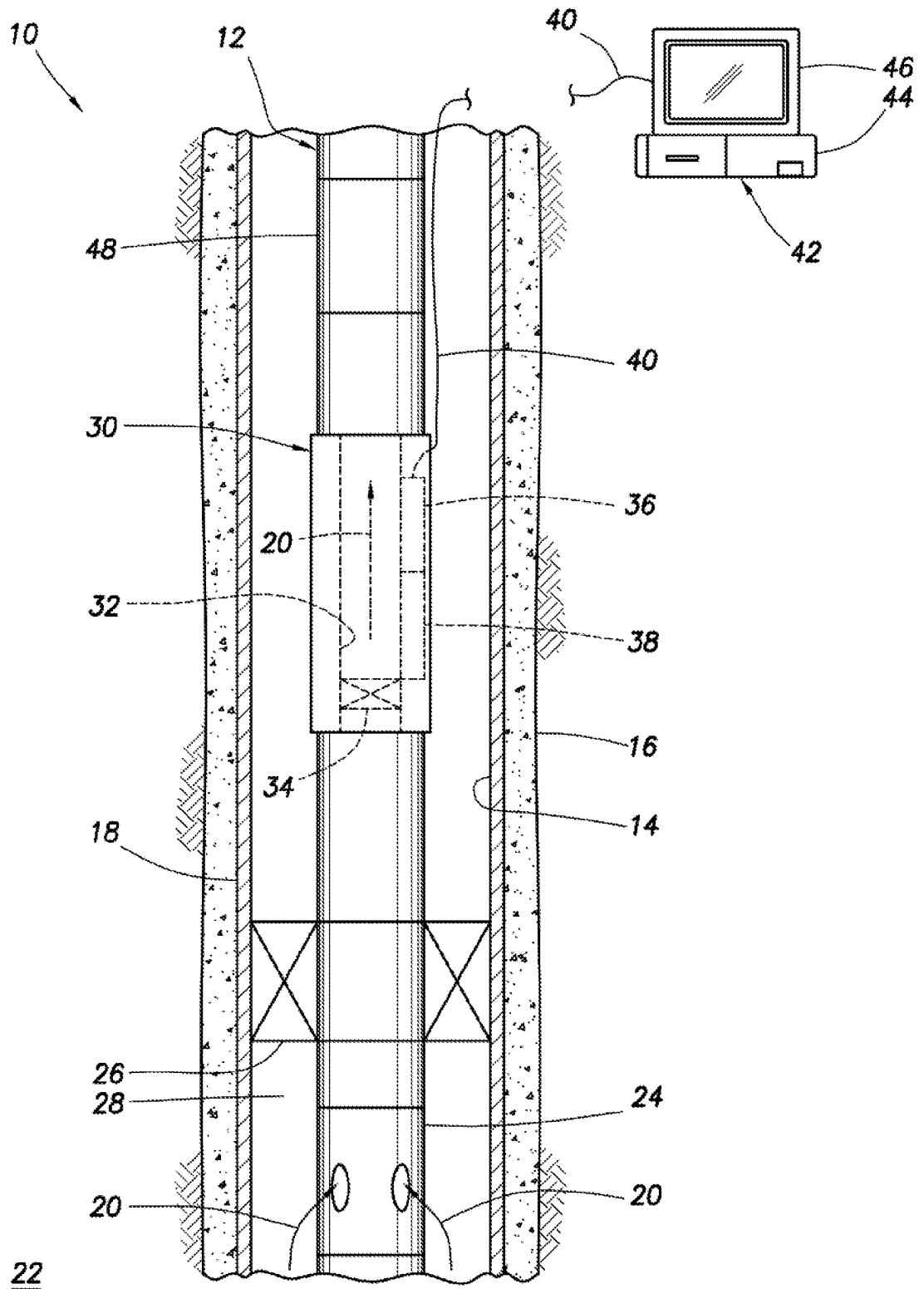
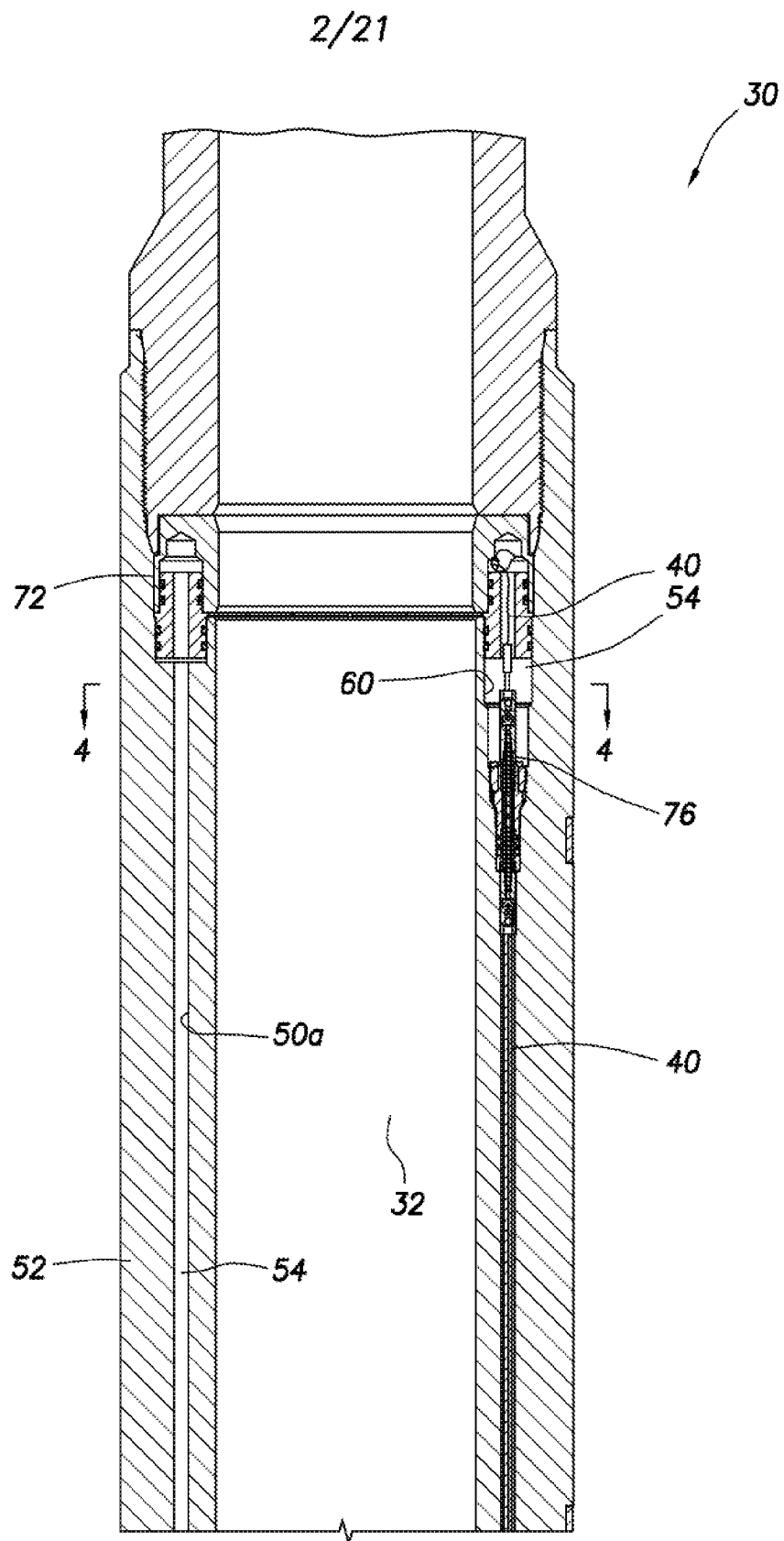


FIG. 1



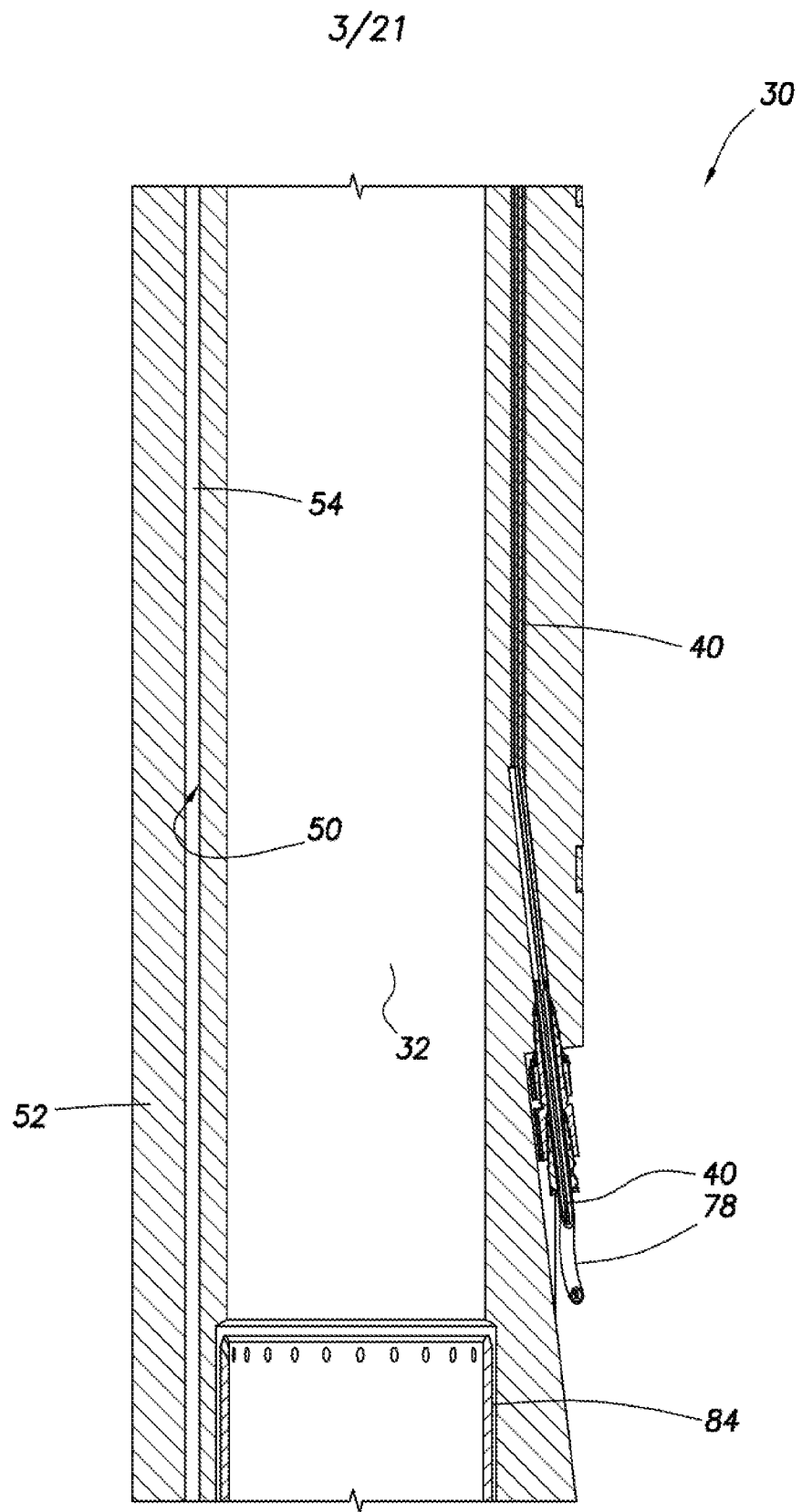


FIG. 2B

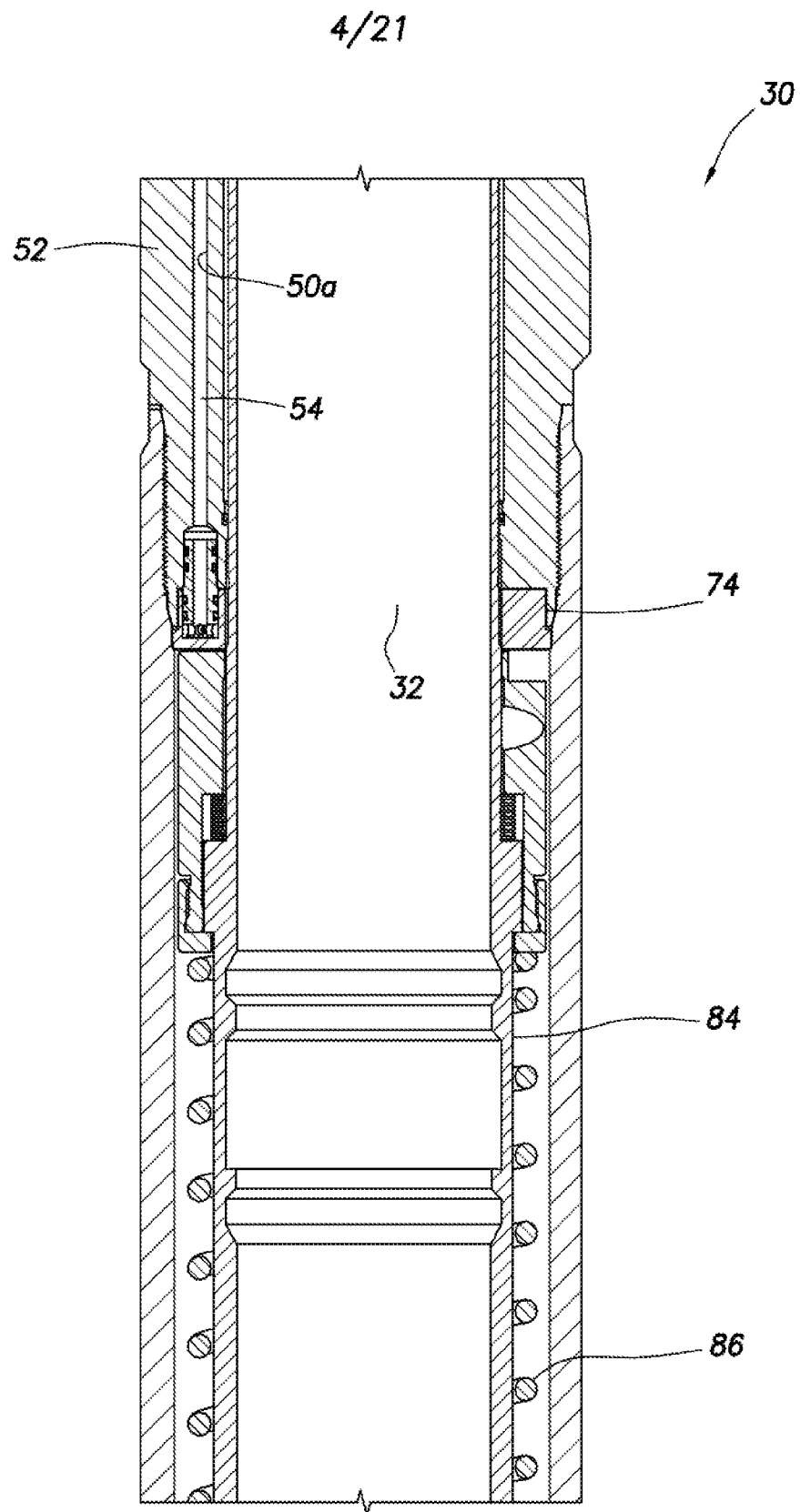


FIG. 2C

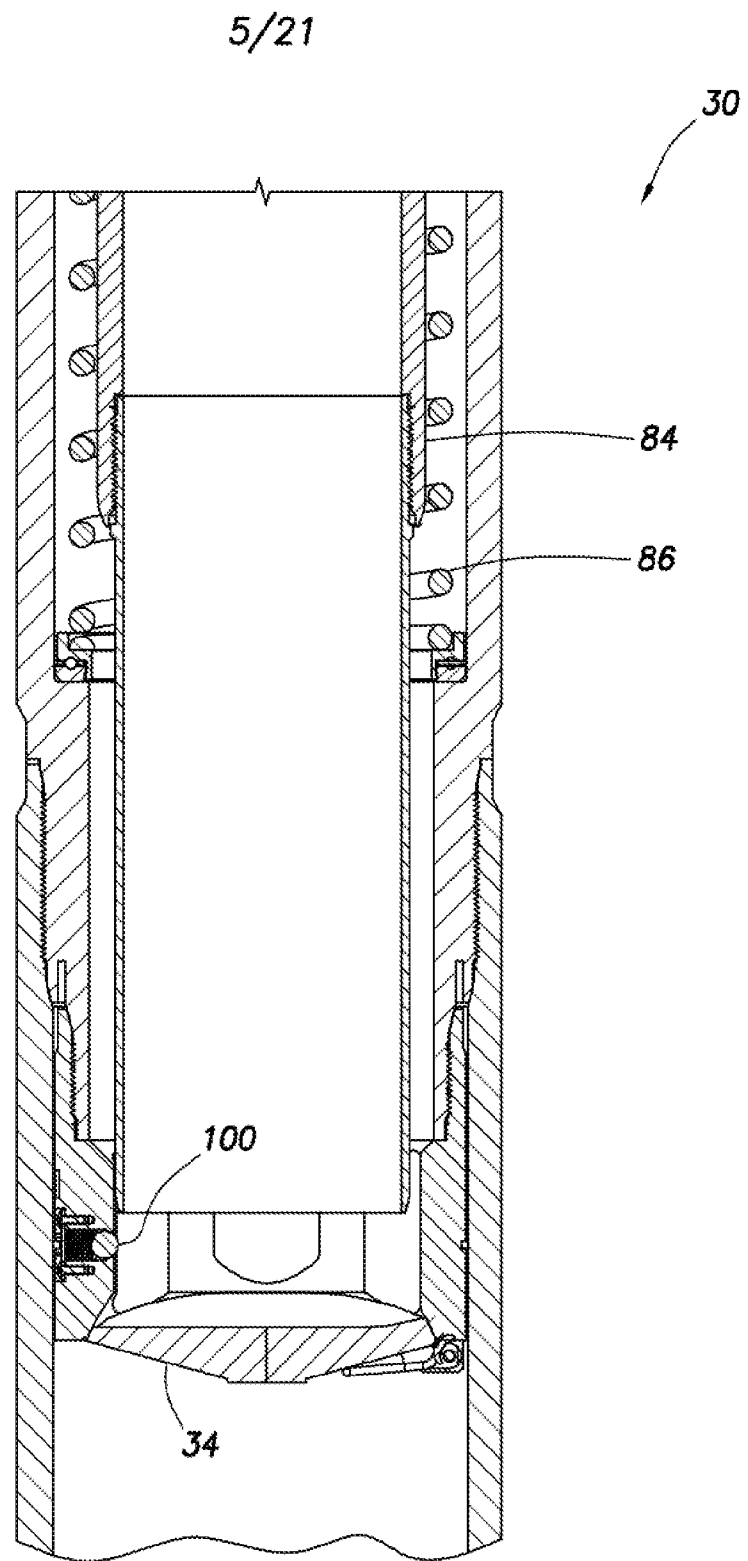


FIG.2D

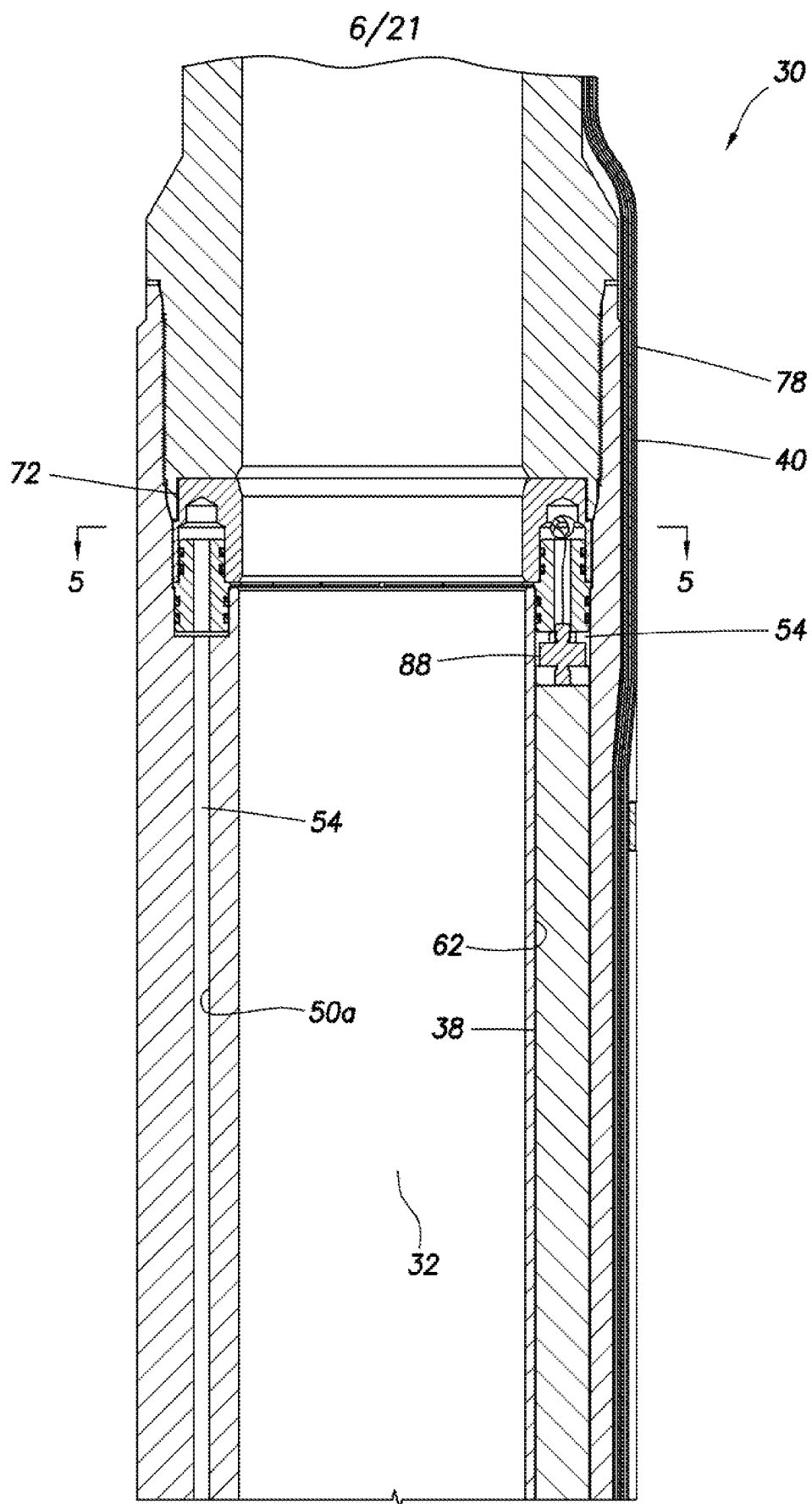


FIG.3A

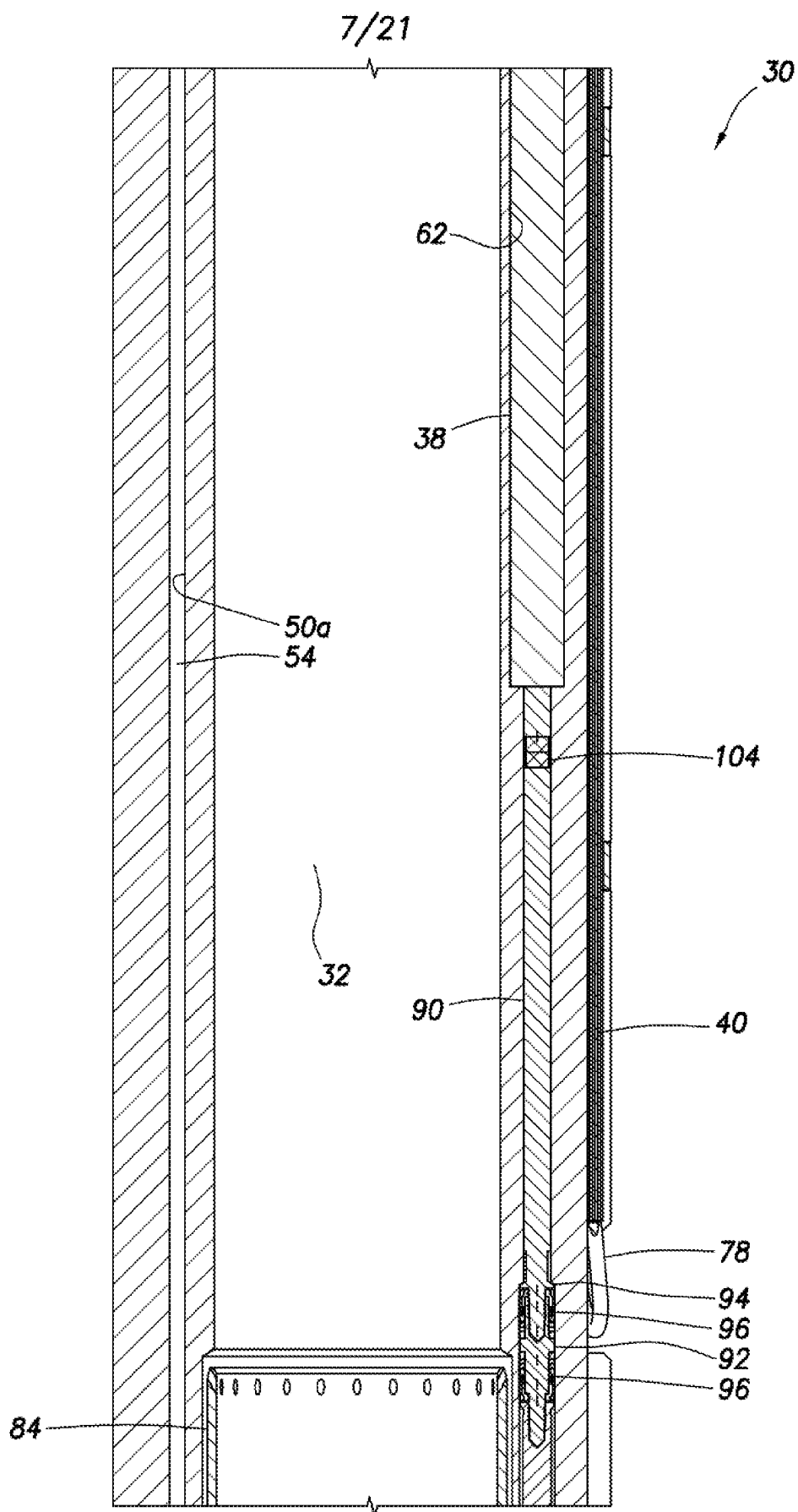


FIG. 3B

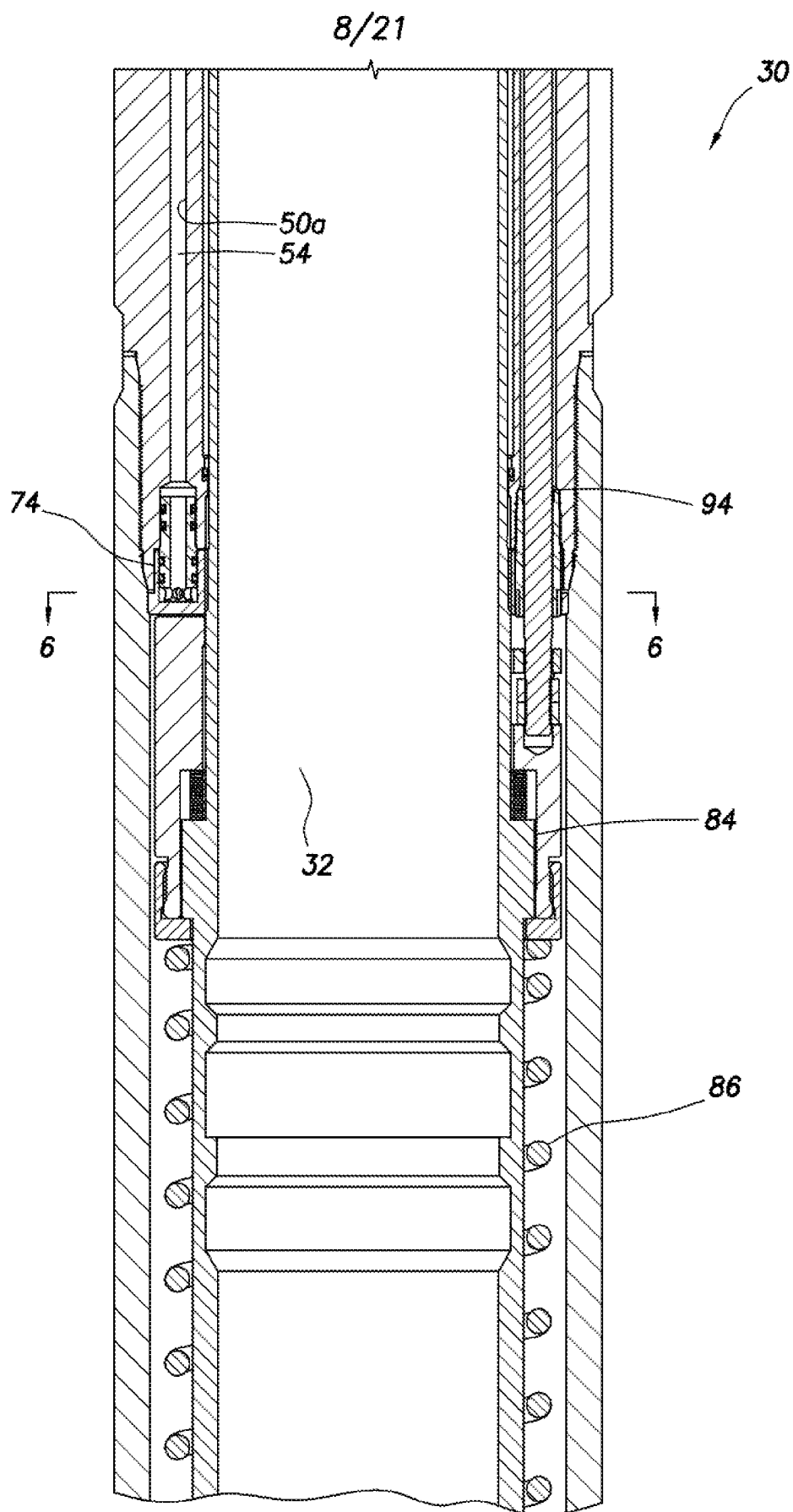


FIG.3C

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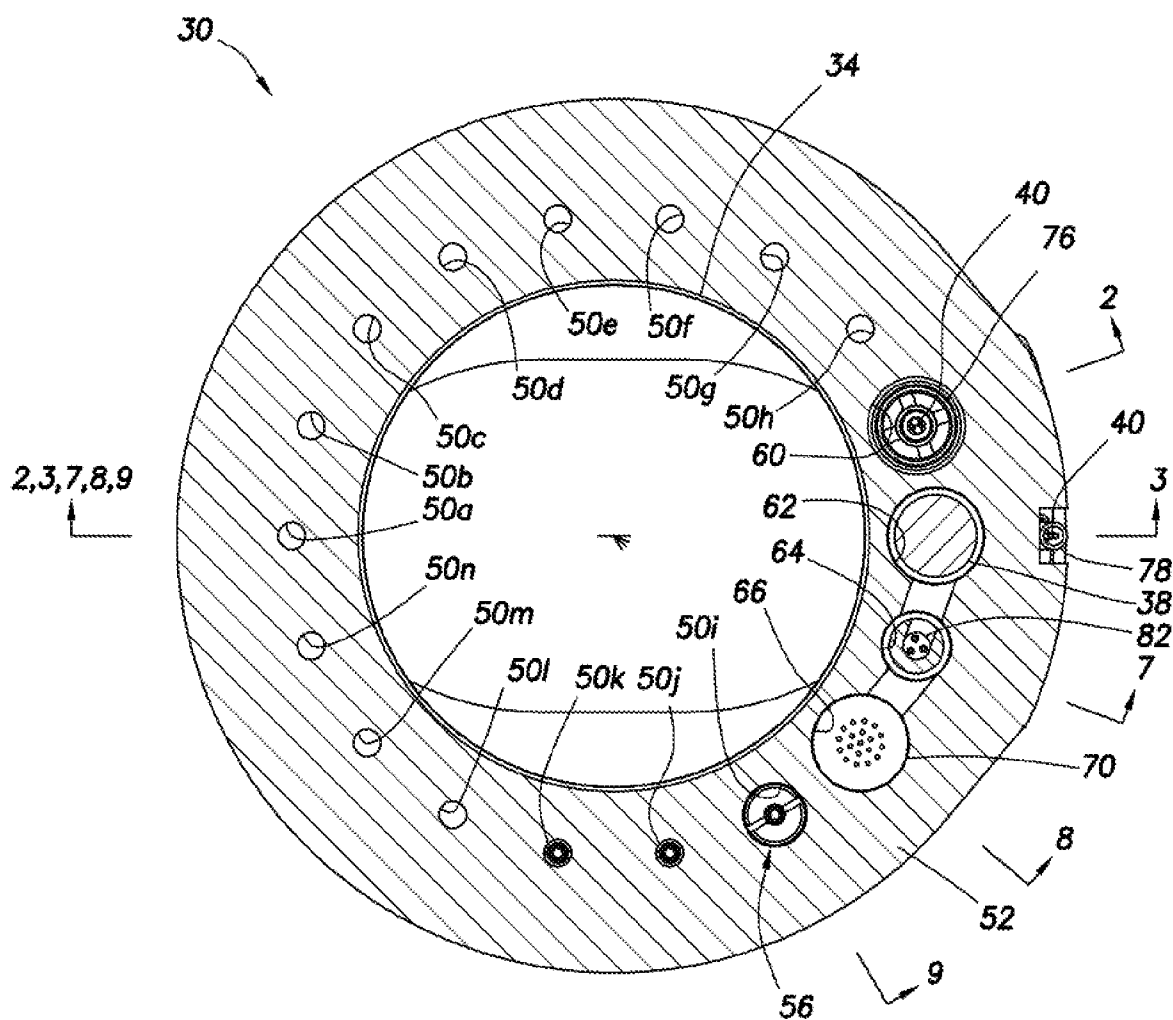


FIG. 4

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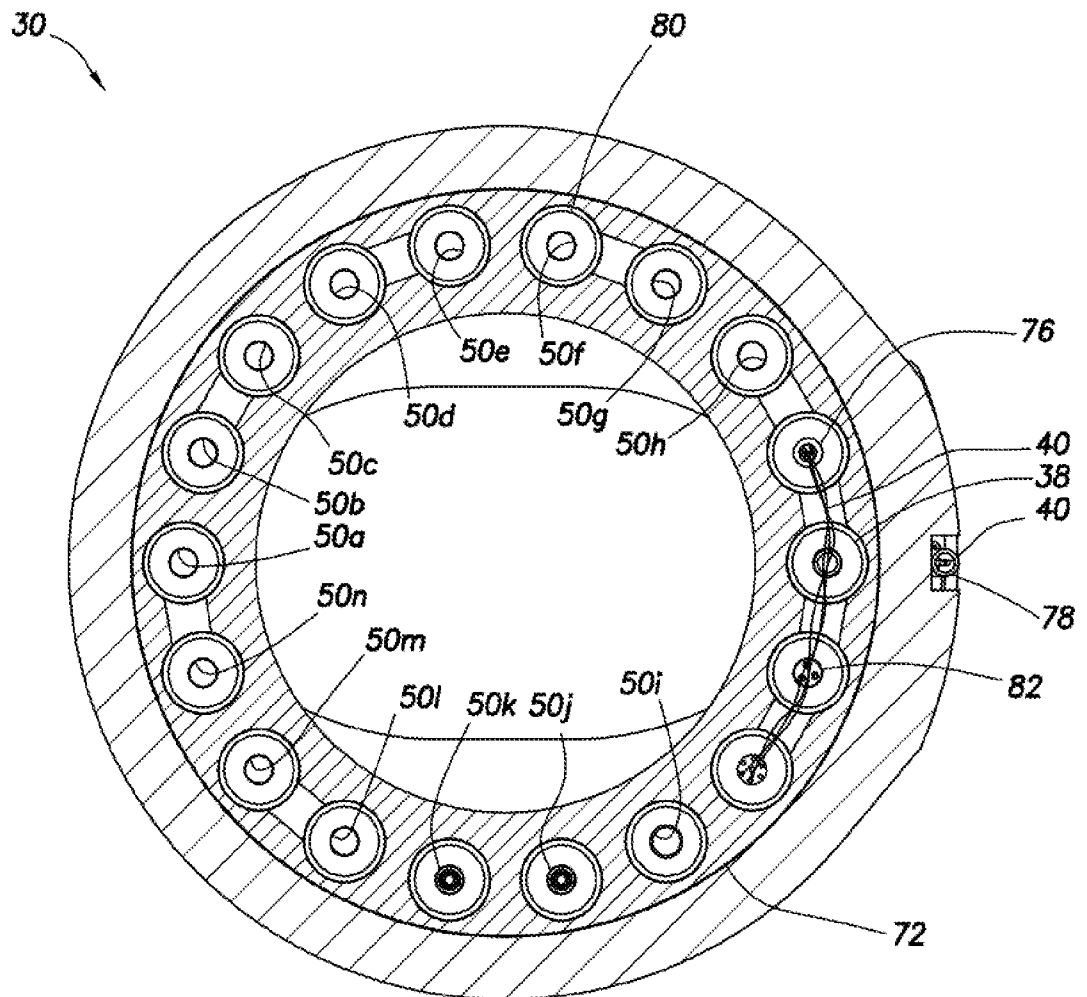


FIG. 5

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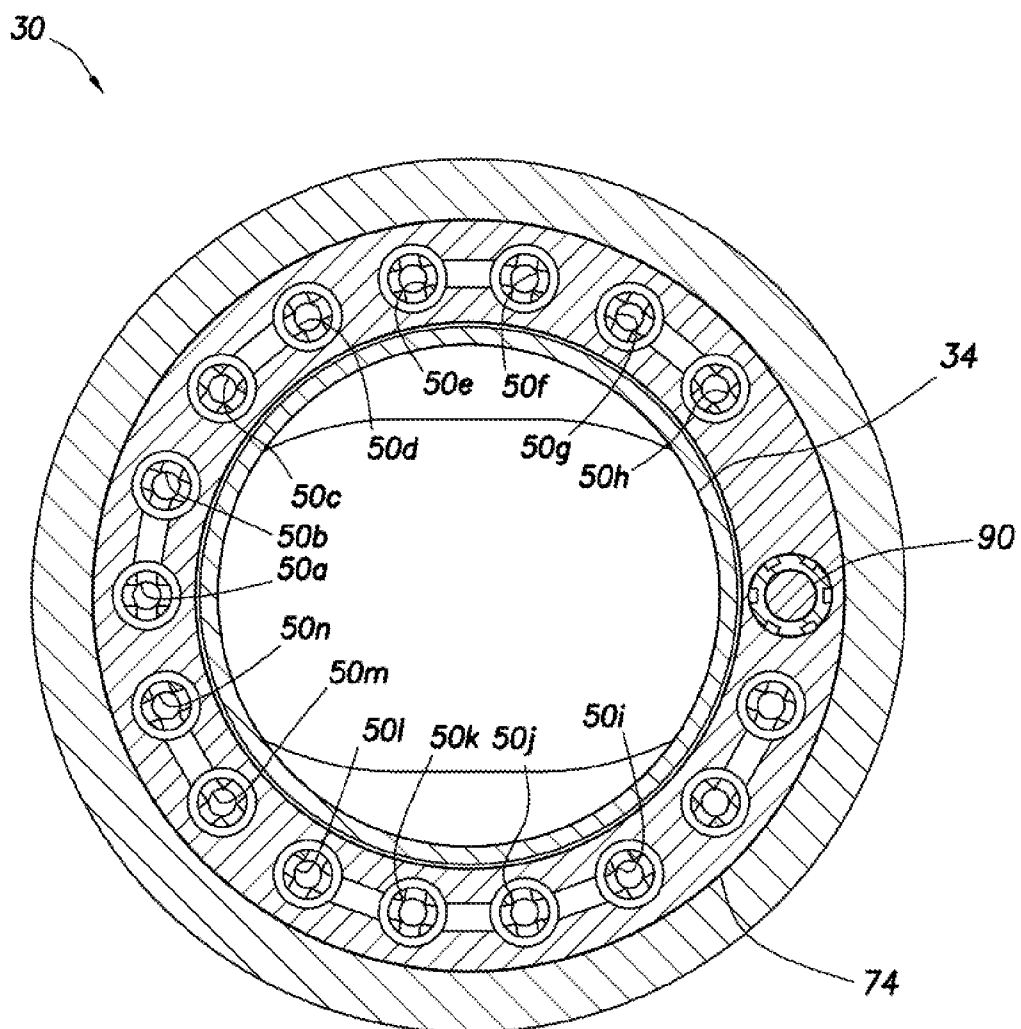
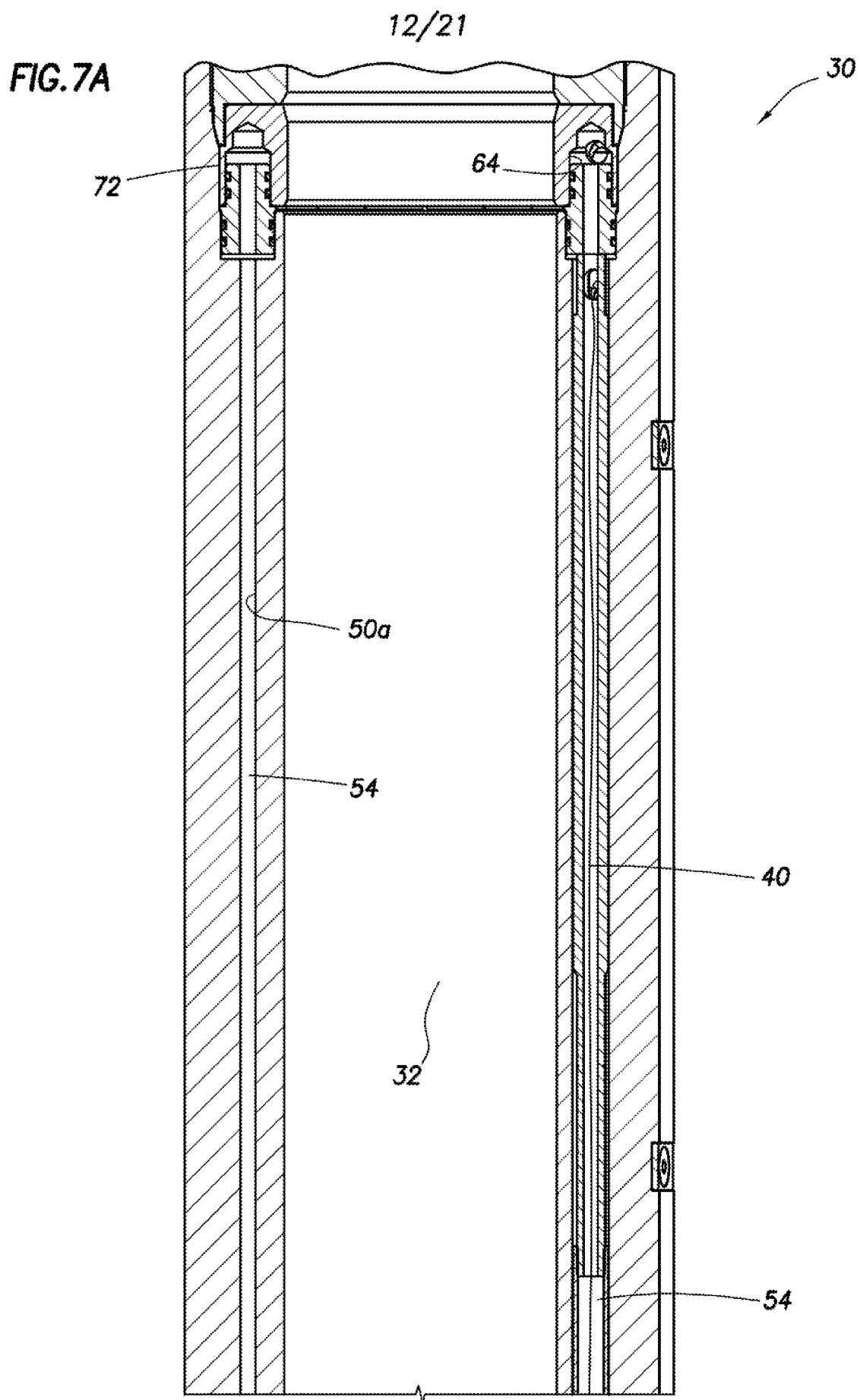


FIG. 6



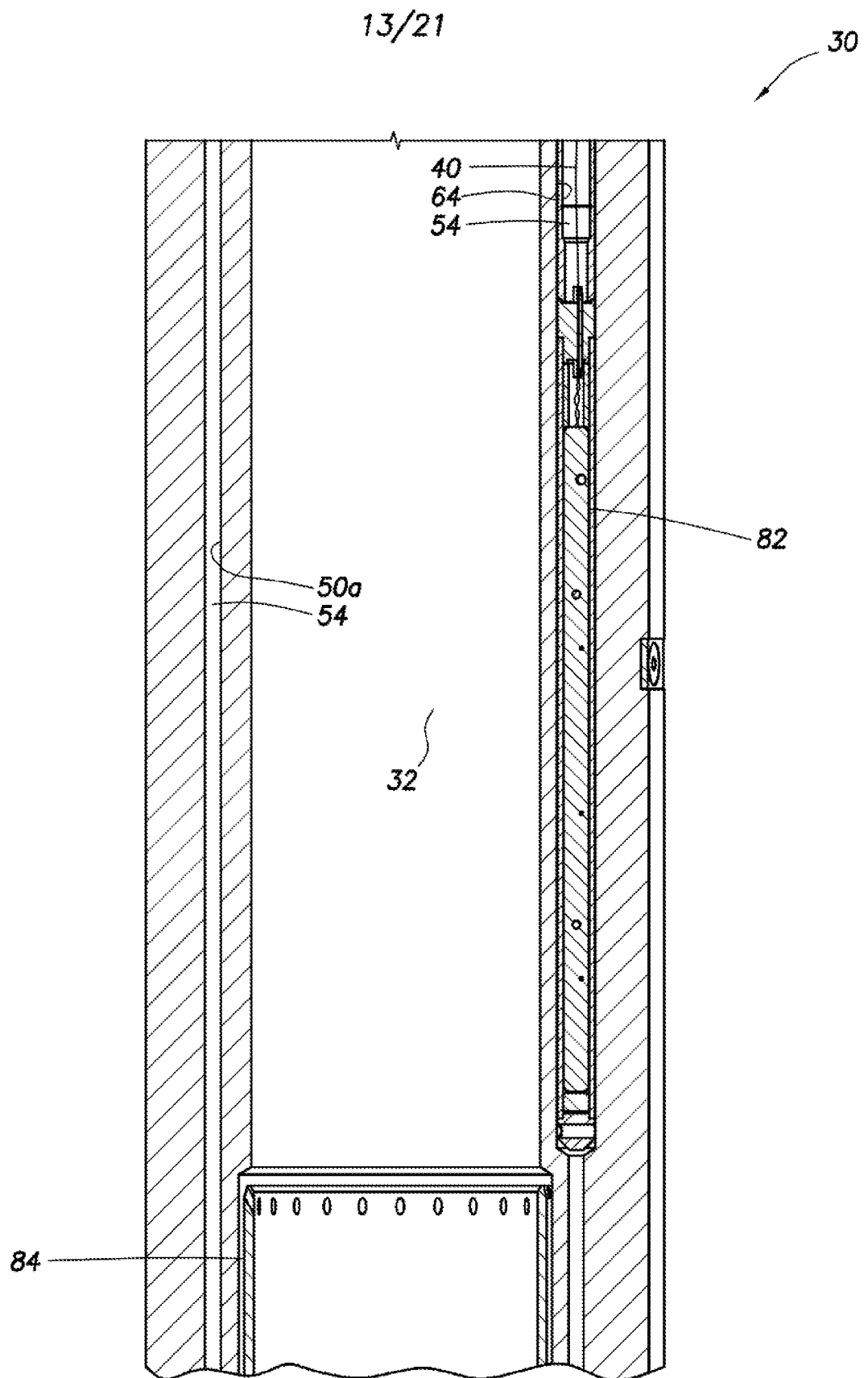


FIG. 7B

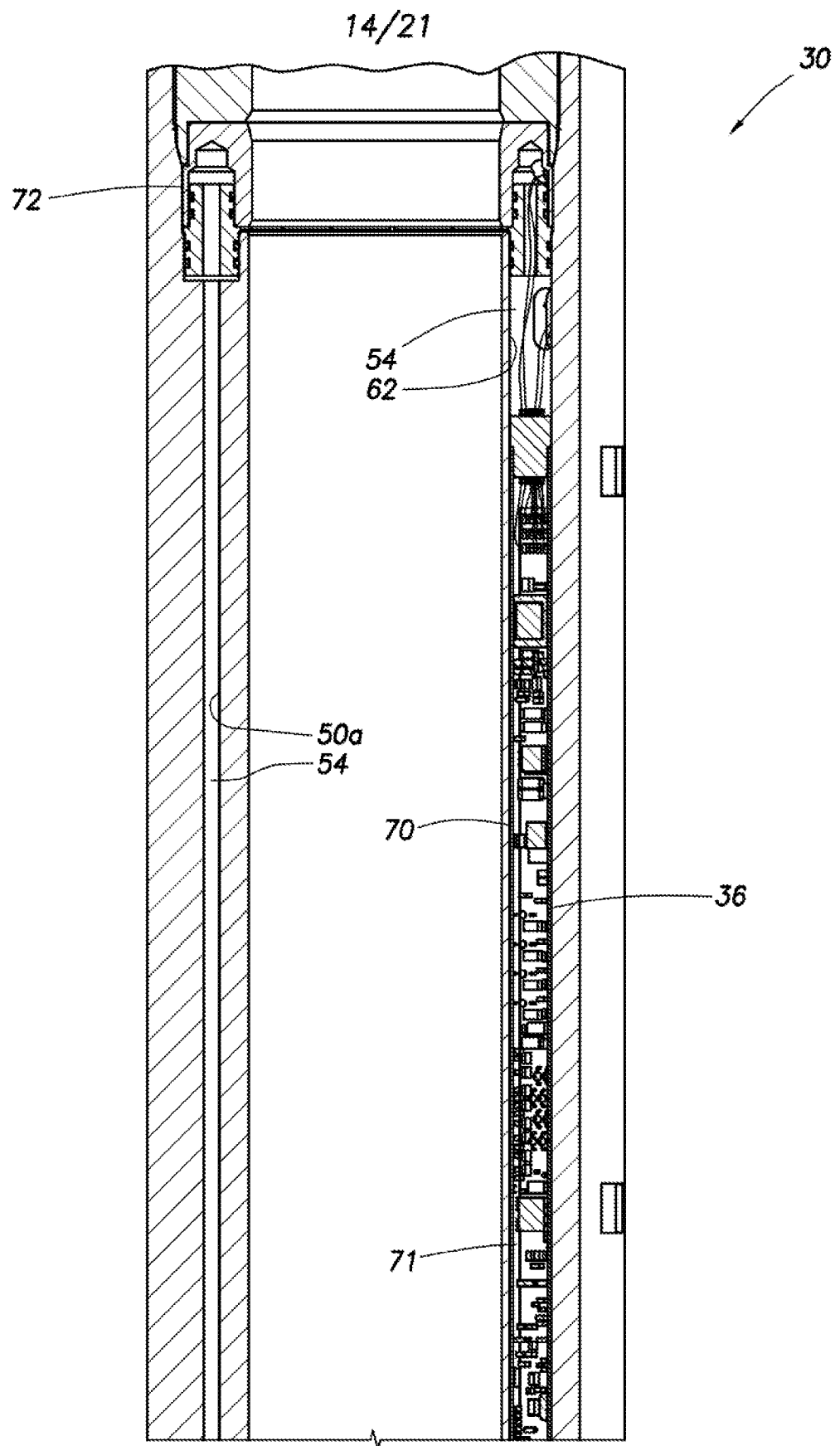


FIG.8A

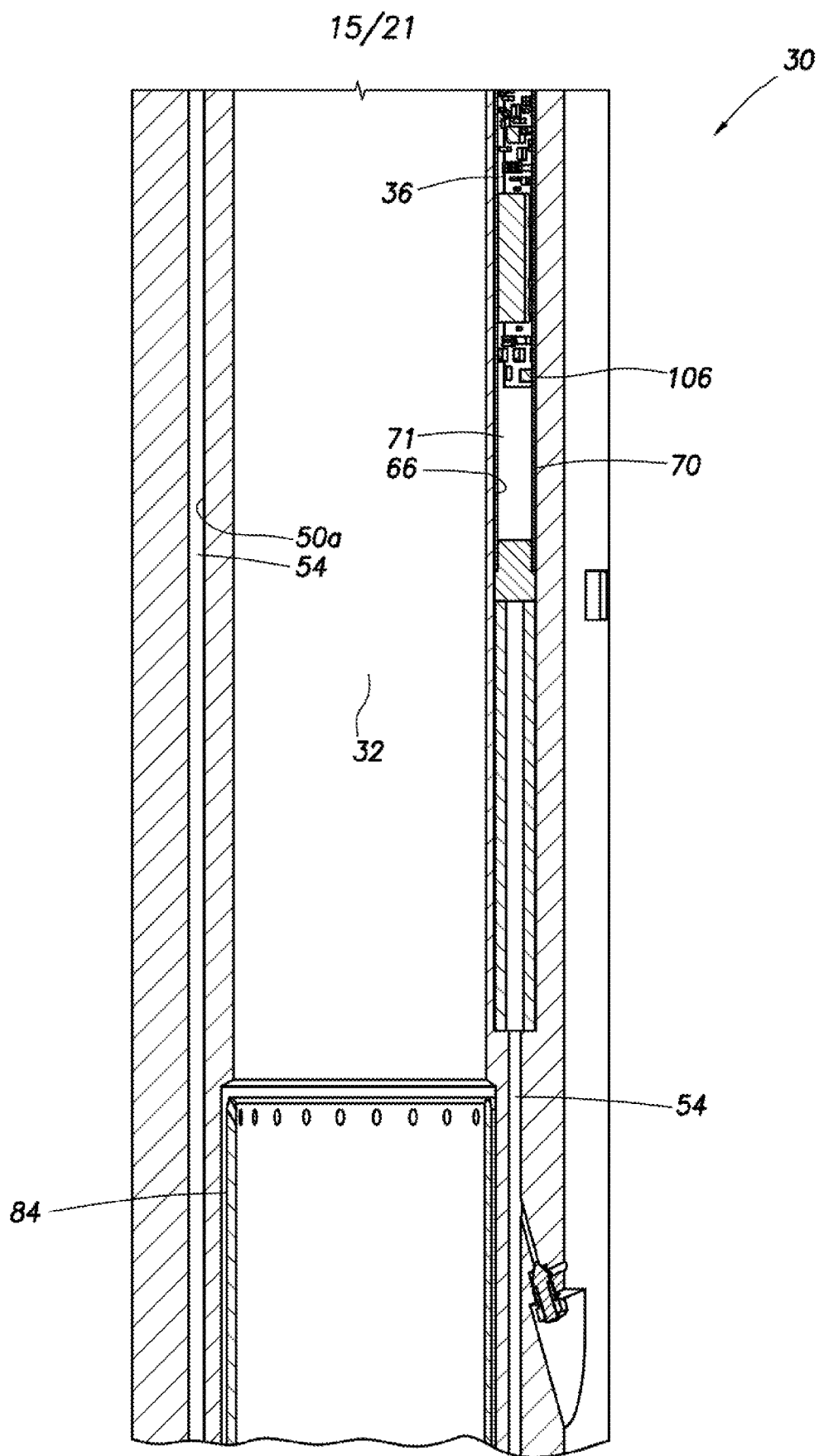


FIG. 8B

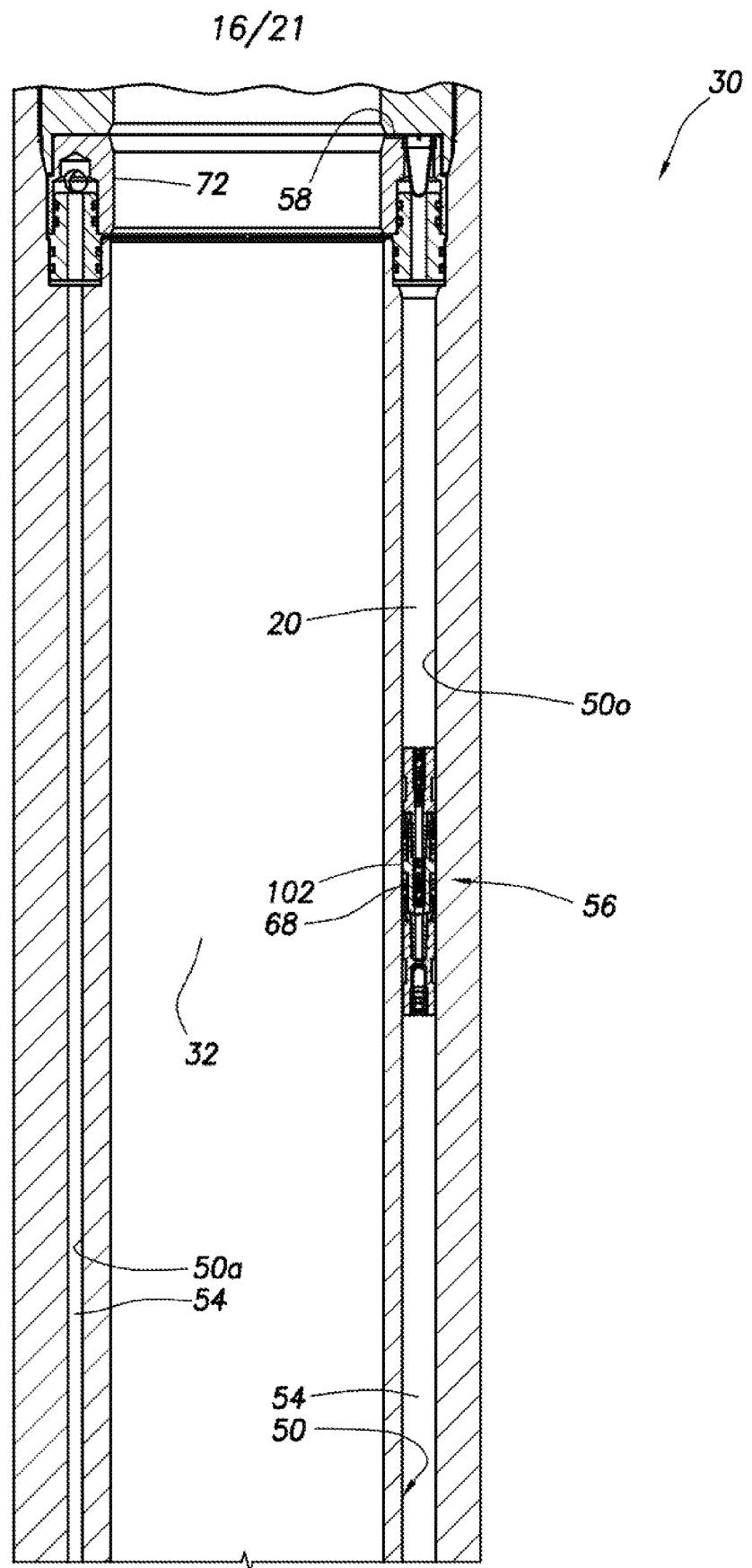


FIG.9A

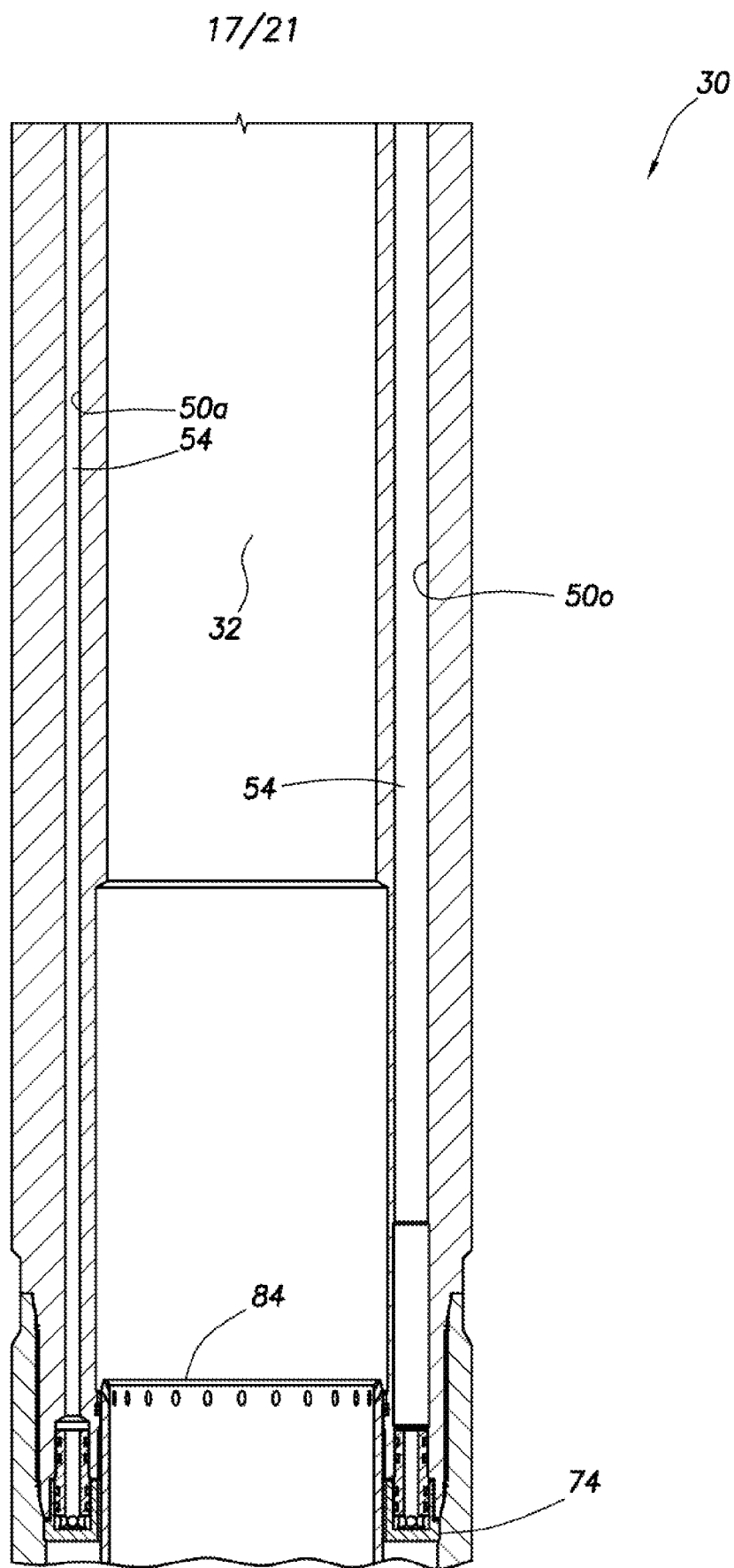


FIG. 9B

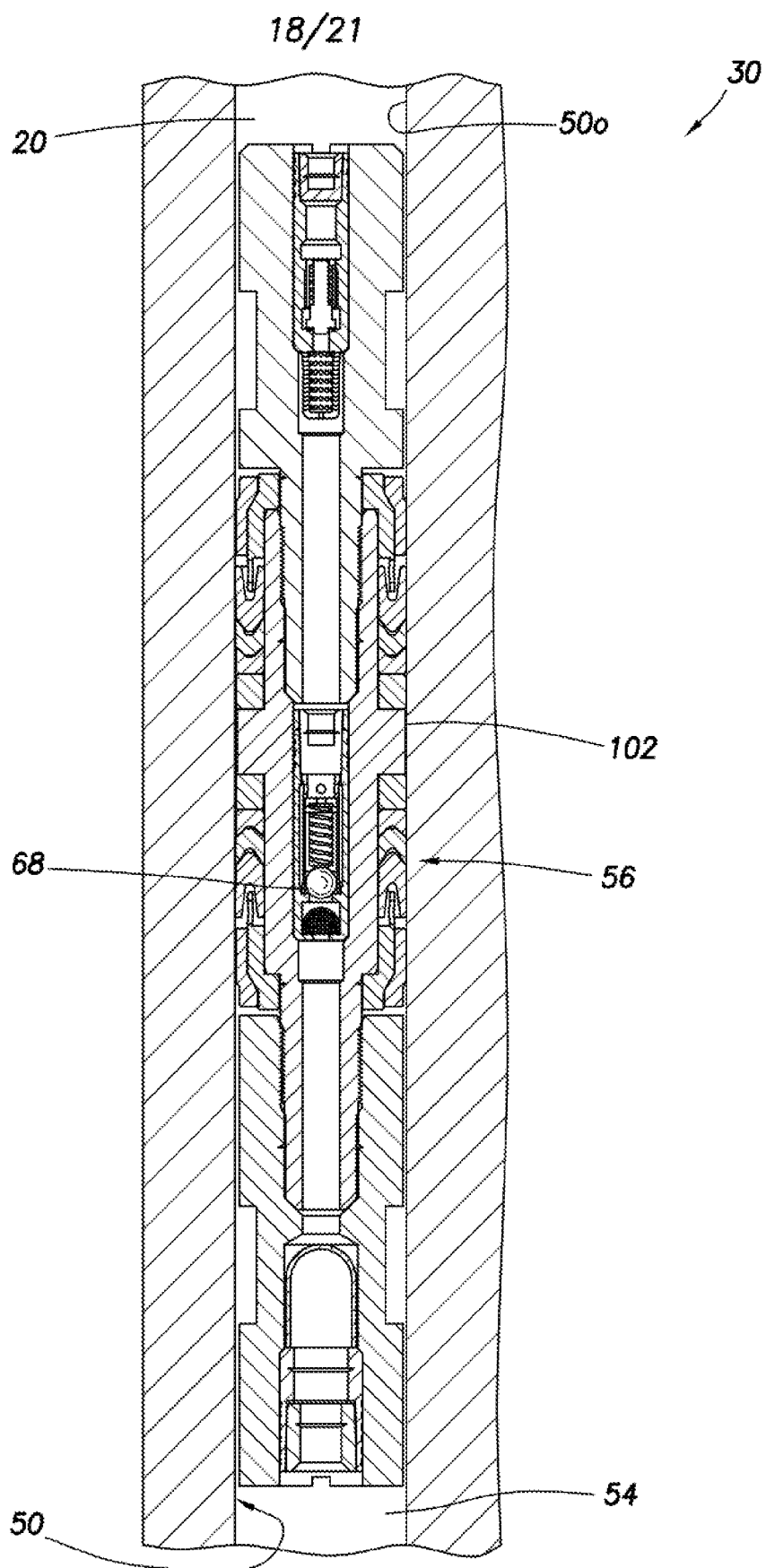


FIG.10

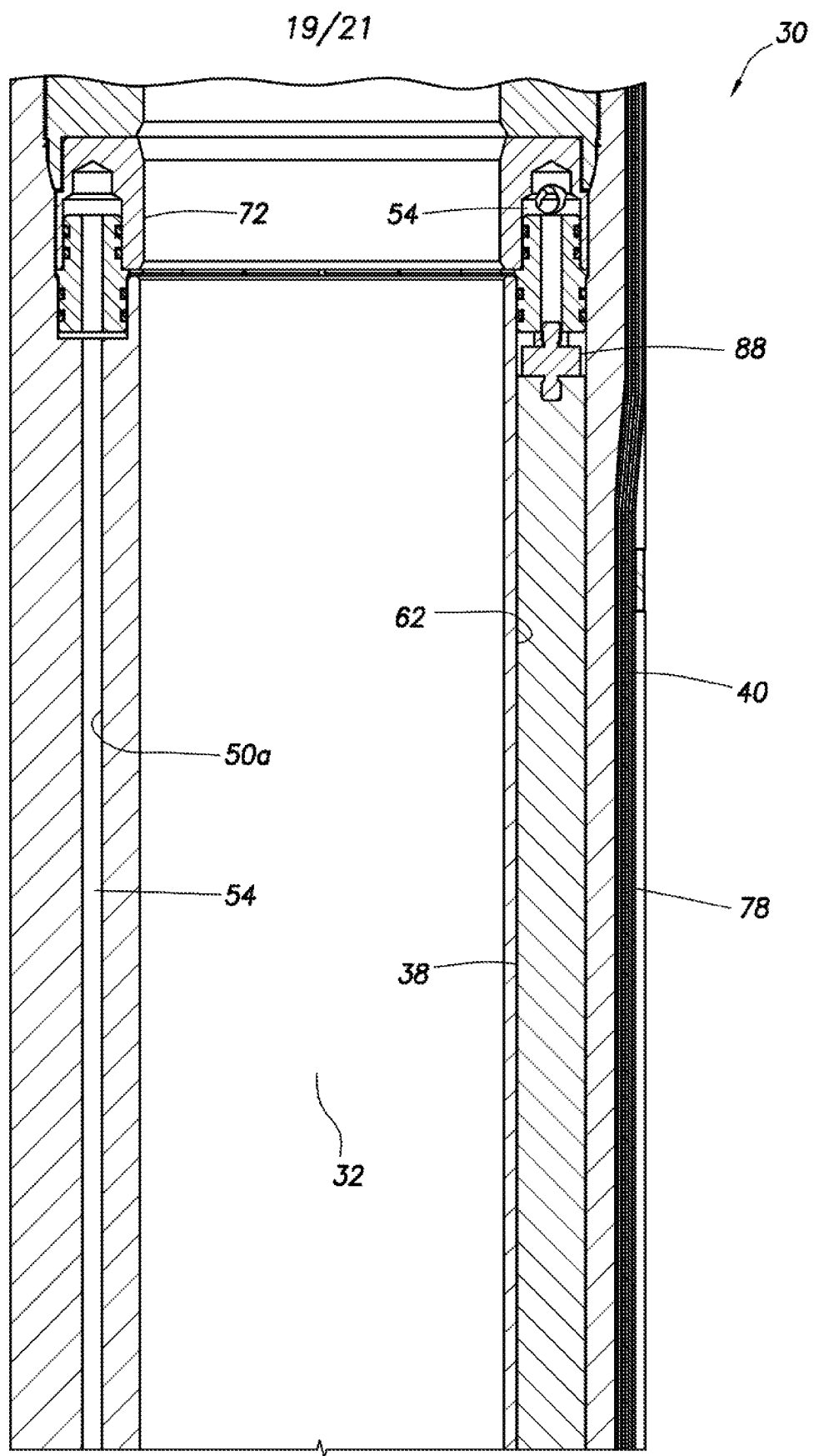


FIG. 11A

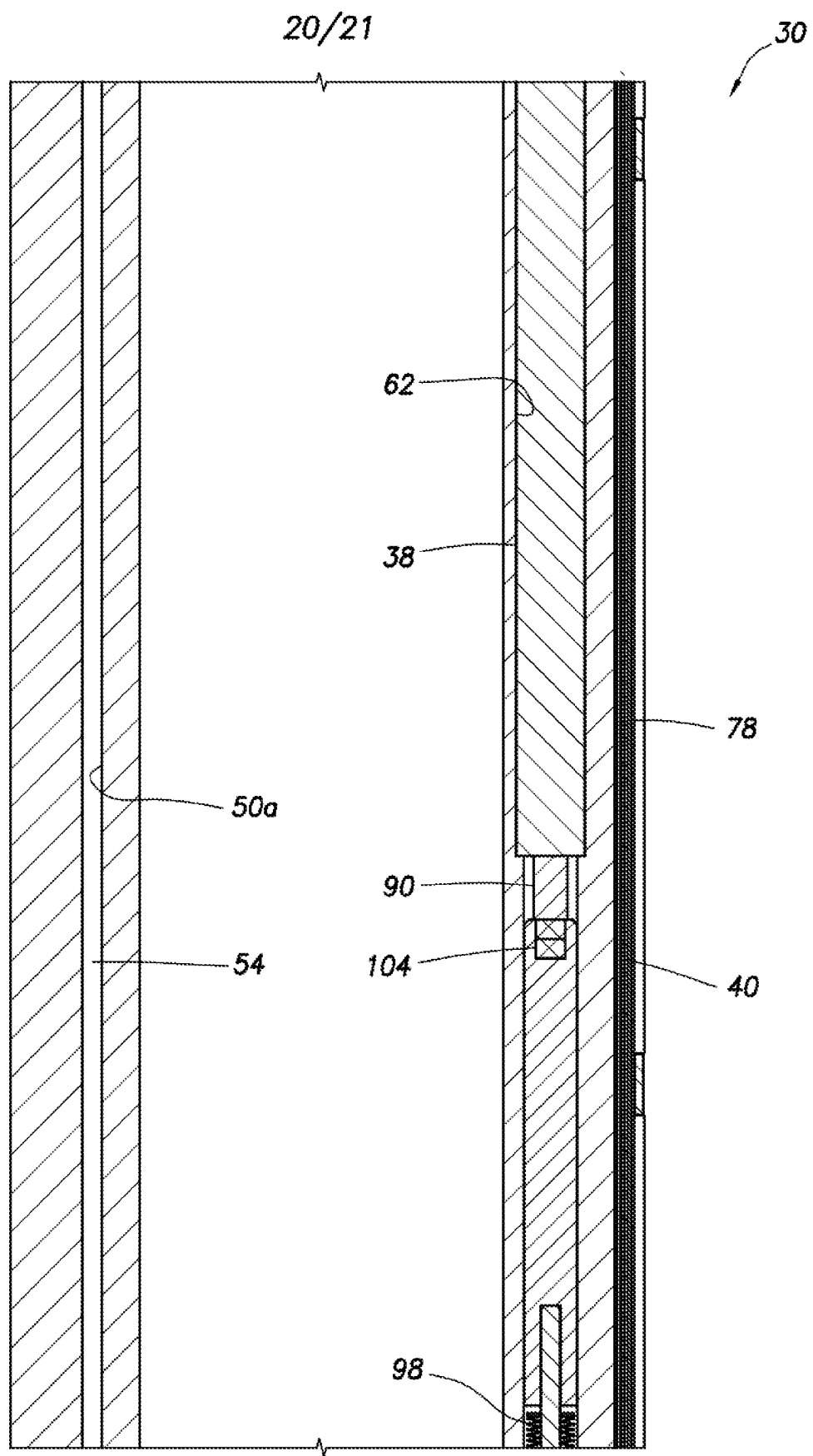


FIG. 11B

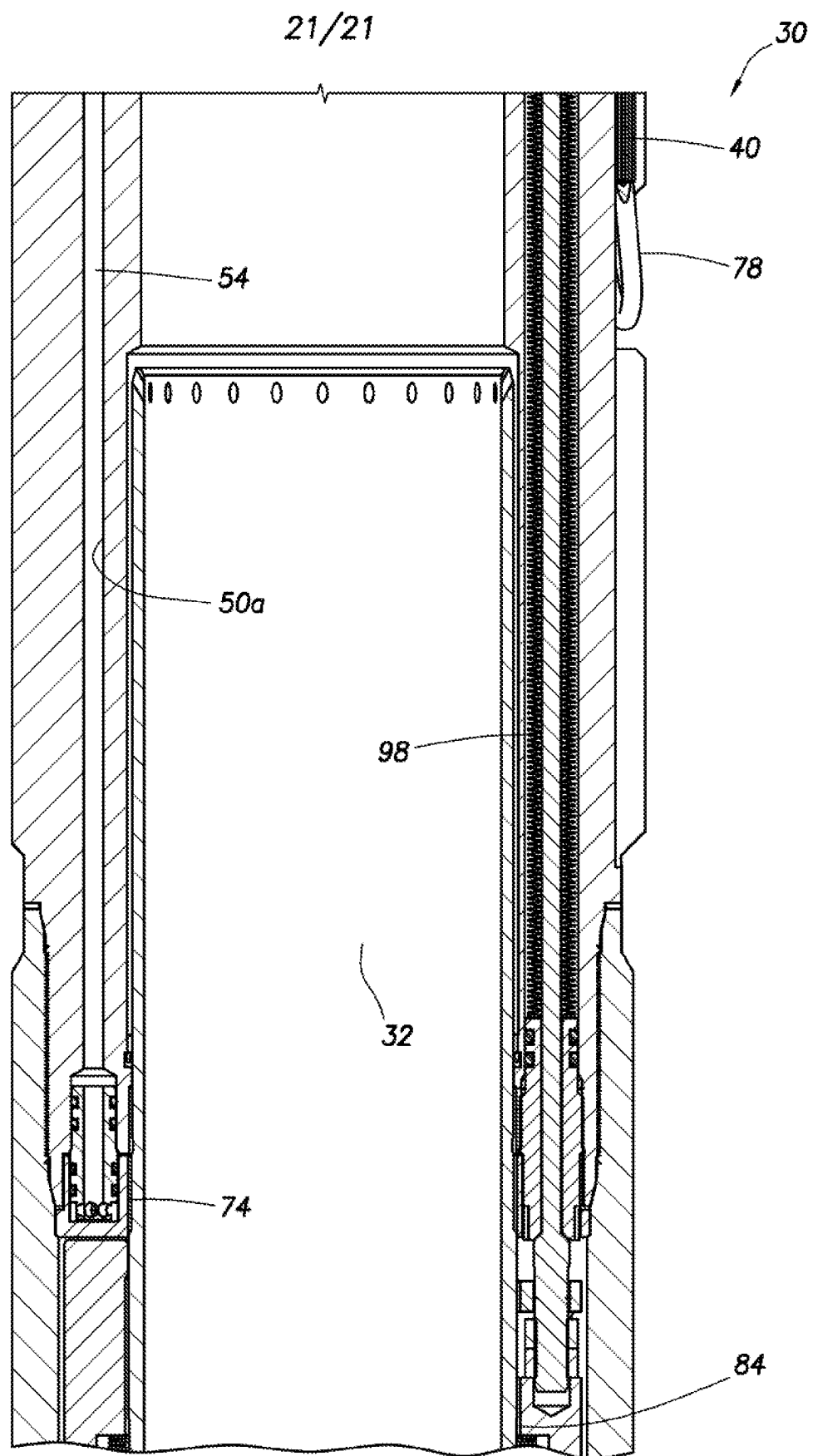


FIG. 11C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/066514**A. CLASSIFICATION OF SUBJECT MATTER*****E21B 34/08(2006.01)i, E21B 34/14(2006.01)i, E21B 34/16(2006.01)i***

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 34/08; F04B 17/00; E21B 34/00; E21B 44/00; E21B 23/00; E21B 29/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: chamber, actuator, piston, dielectric and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 97-30269 A1 (BAKER HUGHES INCORPORATED) 21 August 1997 See pages 13-20, 23 and figures 12-14, 20	1-4, 17, 18, 31-34, 46 5-16, 19-30, 35-45
A	US 2010-0051260 A1 (VICK JR., JAMES D. et al.) 04 March 2010 See paragraph 21 and figure 2	1-46
A	US 6688860 B2 (DU, MICHAEL H. et al.) 10 February 2004 See column 5, line 59 - column 6, line 65 and figure 2	1-46
A	US 7373983 B2 (MCGAVERN III, CECIL G. et al.) 20 May 2008 See column 12, line 22 - column 13, line 42 and figure 4A(2)	1-46

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

18 SEPTEMBER 2012 (18.09.2012)

Date of mailing of the international search report

25 SEPTEMBER 2012 (25.09.2012)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan
City, 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

Bonghoon Lee

Telephone No. 82-42-481-8553



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/066514

Box No. I Nucleotide and/or amino acid sequence(s) (Continuation of item 1.c of the first sheet)

1. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of :

a. a sequence listing filed or furnished

- ☐ on paper
☐ in electronic form

b. time of filing or furnishing

- ☐ contained in the international application as filed
☐ filed together with the international application in electronic form
☐ furnished subsequently to this Authority for the purposes of search

2. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

3. Additional comments:

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/066514**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 47
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claim 47 is referring itself and the scope of claim 47 is not clearly defined.
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

The independent claims 1, 19, 31 share at least one of "flow passage in the well tool", "internal chamber", "dielectric fluid in the chamber", "flow path in pressure communication between the chamber and the passage", "actuator in the chamber" with each other as common technical features.

However, these technical features lacks novelty/inventive step in that WO 97/30269 A1 discloses "production tube", "motor housing filled with dielectric fluid", "compensation cylinders", "drive unit".

Thus there is no technical relationship left over the prior art among the inventions described in said independent claims. Accordingly, said independent claims do not share a single general inventive concept. Hence, there is lack of unity a posteriori (PCT Rule 13.1 and 13.2).

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2011/066514

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 97-30269 A1	21.08.1997	AU 1997-21259 B2 AU 2125997 A AU 729246 B2 CA 2218259 A1 CA 2218259 C GB 2316113 A GB 2316113 B GB 9721870 D0 NO 325021 B1 NO 974752 A NO 974752 D0 US 06041857 A WO 97-30269 A1	25.01.2001 02.09.1997 25.01.2001 21.08.1997 11.01.2005 18.02.1998 16.08.2000 17.12.1997 14.01.2008 12.12.1997 14.10.1997 28.03.2000 21.08.1997
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US 7373983 B2	20.05.2008	US 2004-0045714 A1 US 2007-0181305 A1 US 7188674 B2	11.03.2004 09.08.2007 13.03.2007