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(54) Title: HYDRAULICALLY CONTROLLED ELECTRIC INSERT SAFETY VALVE

(57) Abstract: Well systems comprising insert safety valves for use in subterranean formations are provided. An example well system comprises a mother safety valve and an insert safety valve. The mother safety valve comprises an inner diameter. The insert safety valve is disposed within the inner diameter of the mother safety valve. The insert safety valve comprises a pressure sensor on an exterior surface of the insert safety valve.

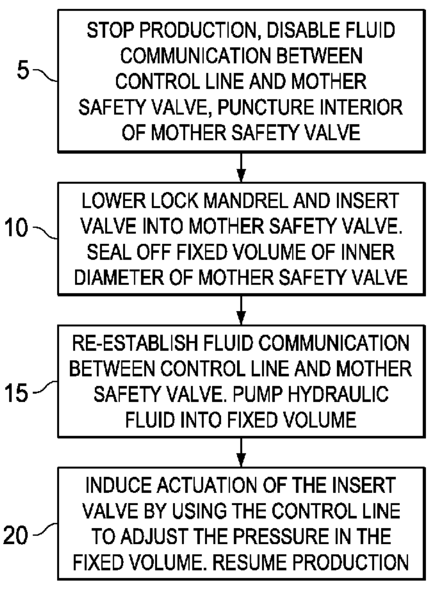

FIG. 1

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HYDRAULICALLY CONTROLLED ELECTRIC INSERT SAFETY VALVE

TECHNICAL FIELD

The present disclosure relates to downhole tools for use in a wellbore environment and more particularly to insert safety valves suitable for use at any depth, including depths of greater than 10,000 feet and with pressures exceeding 16,000 psi.

BACKGROUND

In a well completion, safety valves are installed in the upper wellbore to provide emergency closure of the production string in the event of an emergency, for example, a catastrophic failure of surface equipment. Various types of safety valves may be used. One such type of safety valve is a surface-controlled subsurface safety valve. A surface-controlled subsurface safety valve is a downhole safety valve that is operated from surface facilities through a control line strapped to the external surface of the production tubing. The control line uses hydraulic pressure to control an assembly that holds open a port that will close if the hydraulic pressure in the control line is lost.

A sub-type of surface-controlled subsurface safety valve is a deep-set surface-controlled subsurface safety valve. A deep-set surface-controlled subsurface safety valve is a downhole surface-controlled safety valve that is placed at great depths and/or pressures. Technical challenges exist with these types of safety valves. Specifically, the amount of hydraulic pressure necessary to operate the valves with the control line must be very great. Further, the amount of pressure in the control line may be so great that the pressure prevents the assembly that holds open the port from closing even if the hydraulic pressure in the control line is lost.

Two commercial types of deep-set surface-controlled subsurface safety valves exist. One type is a balanced two-line system that uses two hydraulic lines. One hydraulic line holds open the safety valve and the other balances the hydrostatic head. The second type is a gas dome charged valve, which uses the control line hydraulic pressure to hold open the safety valve and a compressed gas to balance the hydrostatic head. In either case, should the safety valve fail production must be halted so that the safety valve can be removed from the production string, and then the well must be recompleted.

Insert safety valves are valves which may be inserted into a failed safety valve. Insert safety valves are typically smaller duplicates of the failed safety valves in which they are to be inserted. Due to the complicated nature of deep-set surface-controlled subsurface safety valves, duplication of the unique features of these safety valve types on the smaller scale of the insert safety valve may not be possible. Furthermore, connection of the insert safety valve to the control line may be difficult. This may be especially true when attempting to miniaturize the balanced two-line system deep-set safety valve as the insert safety valve duplicate would also require two connections. Additionally, the insert safety valve must fall within the operating parameters, for example, the opening and closing pressures of the failed safety valve. However, the insert safety valve must possess a smaller outer diameter relative to the failed safety valve as the insert safety valve is to be inserted into the inner diameter of the failed safety valve, as such; it may be difficult to produce an insert safety valve that is able to respond to the operating parameters of the failed safety valve.

BRIEF DESCRIPTION OF THE DRAWINGS

Illustrative examples of the present disclosure are described in detail below with reference to the attached drawing figures, which are incorporated by reference herein, and wherein:

FIGURE 1 is a flow chart of a method of insertion and use of an insert safety valve;

FIGURE 2 is an elevation view of a well system;

FIGURE 3 is a cross-sectional view of a generic mother safety valve;

FIGURE 4 is a cross-sectional view of a general configuration of an insert safety valve coupled to a lock mandrel that has been inserted into a generic mother safety valve;

FIGURE 5 is cross-sectional view of a lower (bottomhole) portion of an insert safety valve in the closed position; and

FIGURE 6 is cross-sectional view of a lower (bottomhole) portion of an insert safety valve in the closed position.

The illustrated figures are only exemplary and are not intended to assert or imply any limitation with regard to the environment, architecture, design, or process in which different examples may be implemented.

DETAILED DESCRIPTION

The present disclosure relates to downhole tools for use in a wellbore environment and more particularly to insert safety valves suitable for use at any depth, including depths of greater than 10,000 feet and with pressures exceeding 16,000 psi. Strictly for purposes of clarity and ease of illustration, as used herein, “mother safety valve” refers to a safety valve in which an insert safety valve is to be inserted. The mother safety valve may be any type of safety valve, for example, a deep-set surface-controlled subsurface safety valve. As used herein, “insert safety valve” refers to a safety valve which has been inserted or is capable of insertion into a mother safety valve. As used herein, “deep-set” refers to a valve disposed in a wellbore at a depth of at least 5,000 feet below the surface of the earth or the surface of a body of water.

Disclosed examples may include a production string comprising a mother safety valve suitable to close off production fluid conduits should the need or desire arise, for example, due to catastrophic equipment failure. In the event of failure of the mother safety valve, an insert safety valve may be inserted into and locked in a desired position in the mother safety valve. Once positioned, sealing assemblies may be used to at least partially define a fixed volume between the exterior of the insert safety valve and the inner diameter of the mother safety valve. The mother safety valve may be punctured such that the hydraulic fluid from the control line may enter the fixed volume. A pressure sensor on the exterior of the insert safety valve may measure the pressure of the hydraulic fluid within the fixed volume. The pressure sensor may act as a transducer, and the generated signal may be transmitted to a processor. Based on the measured pressure, the processor may induce actuation of the insert safety valve to open or close. The insert safety valve is electrically powered, unlike the mother safety valve, and as such, does not rely on the hydraulic pressure within the control line to power its operation. Embodiments of the present disclosure and its advantages may be understood by referring to FIGURES 1 through 6, where like numbers are used to indicate like and corresponding parts.

FIGURE 1 illustrates a method for insertion and use of an insert safety valve. At step 5, production is halted in the production string. Fluid communication between the control line and the mother safety valve is halted. A downhole tool may be used to puncture a surface of the inner diameter of the mother safety valve such that hydraulic fluid from the control line which was used to power the mother safety valve may enter the inner diameter of the mother safety valve.

At step 10, an insert safety valve coupled to a lock mandrel is lowered into the desired position within the inner diameter of the mother safety valve. The lock mandrel is then locked into said desired position within the mother safety valve. Sealing assemblies, for example, packing stacks, on the exterior of the lock mandrel and the insert safety valve provide a seal between the surfaces of the inner diameter of the mother safety valve and the exterior surfaces of the lock mandrel and insert safety valve. These sealing assemblies seal off and define a fixed volume on the inner diameter of the mother safety valve. The lock mandrel is positioned and locked into place such that the fixed volume provided by the sealing assemblies is in fluid communication with the punctured surface of the mother safety valve from step 5.

At step 15, fluid communication between the control line and the mother safety valve is resumed. The hydraulic fluid flows from the control line through the mother safety valve and into the fixed volume defined between the sealing assemblies of the lock mandrel and the insert safety valve.

At step 20, a pressure sensor measures the pressure of the hydraulic fluid in the fixed volume. This measurement is conveyed to a processor which induces electrical actuation of the insert safety valve in response to the measurement. The processor is preprogrammed to open the insert safety valve at a desired pressure and to close the insert safety valve at a desired pressure. As such, the control line may be used to control the operation of the insert safety valve yet is not used to power the operation of the insert safety valve. Because the control line is not used to hydraulically power the operation of the insert safety valve, the insert safety valve may be used at any depth, including depths greater than 10,000 feet and depths with pressures greater than 16,000 psi. When the insert safety valve has been successfully installed, production may be resumed.

In examples, the insert safety valve may be inserted into a mother safety valve at any depth and pressure. For example, the insert safety valve may be inserted into a mother safety valve disposed in a wellbore at a depth of 1,000 feet, 2,000 feet, 3,000 feet, 4,000 feet, 5,000 feet, 6,000 feet, 7,000 feet, 8,000 feet, 9,000 feet, 10,000 feet, or at a depth of greater than 10,000 feet.

Modifications, additions, or omissions may be made to the method without departing from the scope of the present disclosure. For example, the order of the steps may be performed in a different manner than that described, and some steps may be performed at the same time. Additionally, each individual step may include additional steps without departing from the scope of the present disclosure.

FIGURE 2 is an elevation view of a well system 100. Well system 100 may include floating production system 102 located on the surface of a body of water 104. Well system 100 may also include production string 106 coupled to subsea tree 108 which is positioned at the wellhead of well 110. Production string 106 may be used to produce hydrocarbons such as oil and gas from subterranean formation 112 via well 110. As shown in FIGURE 2, well 110 is substantially vertical (e.g., substantially perpendicular to the surface). Although not illustrated in FIGURE 2, portions of well 110 may be substantially horizontal (e.g., substantially parallel to the surface), or at an angle between vertical and horizontal. Production string 106 may comprise a safety valve 114 at any point of production string 106 as desired. For example, the safety valve 114 may be uphole or downhole of the subsea tree 108. In the example of FIGURE 2, the safety valve 114 is a subsurface safety valve and is disposed within the well 110 downhole of the subsea tree 108.

The terms uphole and downhole may be used to refer to the location of various components relative to the bottom or end of well 110. For example, a first component described as uphole from a second component may be further away from the end of well 110 than the second component. Similarly, a first component described as being downhole from a second component may be located closer to the end of well 110 than the second component.

FIGURE 3 is a cross-sectional view of a generic mother safety valve 200. It is to be understood that the illustrated mother safety valve 200 is described only for the purposes of illustration and is not intended to represent any specific type of safety valve. Control line 202 is coupled to the mother safety valve 200 at port 204. Control line 202 may be used to transport hydraulic fluid pumped into control line 202 via a hydraulic pump (not shown). Control line 202 may be any type of conduit necessary to transport hydraulic fluid and should also be sufficient for operations at the desired pressure and depth and compatible with use for the desired safety valve. In the illustrated mother safety valve 200, the hydraulic pressure from control line 202 induces piston assembly 206 to move sheath 208 into such a position to push flapper assembly 210 against the surface of the inner diameter 212 of mother safety valve 200. The flapper assembly 210 remains in the open position allowing fluid communication through the mother safety valve 200 so long as the hydraulic pressure in control line 202 is maintained. Should the hydraulic pressure in control line 202 be reduced, compressed spring 214 may return sheath 208 to its uphole position. Flapper assembly 210 may then close, and fluid communication through mother safety valve 200 is disabled. In examples, mother safety valve 200 may be any type of surface-controlled subsurface safety valve. For example, mother safety valve 200 may be a deep-set surface-controlled subsurface safety valve. Alternatively, mother safety valve 200 may be a surface-controlled subsurface safety valve that is not deep-set. Although mother safety valve 200 is illustrated in FIGURE 3 as using a piston assembly 206 and compressed spring 214 to actuate the opening of the mother safety valve 200, the mother safety valve 200 may utilize any assembly for operation that utilizes hydraulic pressure via a control line 202, or other such conduit, to power the operation of mother safety valve 200. For example, the mother safety valve 200 may utilize a balanced two-line system, where one hydraulic line induces the opening of the mother safety valve 200 and a second hydraulic line induces the closing of the mother safety valve 200. Alternatively, the mother safety valve 200 may utilize a gas dome system, where the hydraulic pressure from the control line 202 induces the opening of the mother safety valve 200 and a compressed gas inside a chamber functions as a gas spring to induce closing of the mother safety valve 200 analogously to compressed spring 214. The mother safety valve 200 of FIGURE 3 also depicts a flapper assembly 210; however, flapper assembly 210 may be substituted for any analogous assembly, for example, a ball assembly.

When a mother safety valve 200 fails, an insert safety valve may be inserted into the mother safety valve 200. The mother safety valve 200 may fail for a variety of reasons, for example, scale buildup. For the purposes of this disclosure, the reason for the failure of the mother safety valve 200 is irrelevant provided that such reason does not preclude the insertion of the insert safety valve (e.g., insert safety valve 300, as illustrated in FIGURE 4) and/or the puncture of the mother safety valve 200 such that the hydraulic fluid from the control line 202 is allowed to flow into the inner diameter 212 of the mother safety valve 200. FIGURE 4 is a cross-sectional view of a general configuration of an inset safety valve 300 coupled to a lock mandrel 302 that has been inserted into a generic mother safety valve 200. A key 304 is biased radially to lock with slot 306 once key 304 and slot 306 are aligned. Slot 306 is a space disposed along a surface of inner diameter 308 of mother safety valve 200. The key 304 locks the lock mandrel 302 and consequently the insert safety valve 300 into the mother safety valve 200. Although lock mandrel 302 depicts key 304 as the locking assembly used to secure lock mandrel 302 to a surface of the inner diameter 308 of mother safety valve 200, it is to be understood that key 304 may be substituted for any other sufficient locking assembly which may lock lock mandrel 302 into the inner diameter 308 of mother safety valve 200. Insert safety valve 300 may be coupled to lock mandrel 302 in any sufficient manner. In the illustrated example, lock mandrel 302 is coupled to insert safety valve 300 by spacer 310. Spacer 310 is a pipe with a threaded connection which is connected to both the insert safety valve 300 and the lock mandrel 302. Alternatively, a different coupling mechanism may be employed. In some alternative examples, insert safety valve 300 may be coupled directly to lock mandrel 302, and spacer 310 is not required. The coupling of insert safety valve 300 and lock mandrel 302 may provide a fluid and pressure tight seal. Once properly installed, production fluids circulating in production string 106 may flow through insert safety valve 300 and lock mandrel 302 and be produced at the surface.

Sealing assemblies 312 function to create a fluid and pressure tight seal on both sides of the sealing assemblies 312. The sealing assemblies 312 may comprise any sealable element sufficient to create a fluid and pressure tight seal. In the illustrated example, the sealing assembly is a packing stack. The sealing assemblies 312 may comprise any material sufficient for creating a fluid and pressure tight seal, for example, such materials may include, but are not limited to, elastomeric materials, non-elastomeric materials, synthetic rubbers, natural rubbers, metals, combinations thereof, or composites thereof. The sealing assemblies 312 should form a fluid and pressure tight seal that is pressure rated to withstand the pressure of the hydraulic fluid disposed in the fixed volume 314 created between the sealing assemblies 312 in the inner diameter 308 of the mother safety valve 200. The sealing assemblies 312 should form a fluid and pressure tight seal that is pressure rated to withstand the pressure of any wellbore fluids which may flow into or be present in the inner diameter 308 of the mother safety valve 200, such that the pressure of the wellbore fluids in the inner diameter 308 of the mother safety valve 200 do not rupture the fluid and pressure tight seal formed by the sealing assemblies 312, and consequently, no wellbore fluids may flow into fixed volume 314.

In the illustrated example, the top or uphole sealing assembly 312 is disposed about the exterior of the lock mandrel 302, and the bottom or downhole sealing assembly 312 is disposed about the exterior of the insert safety valve 300. In alternative examples, the sealing assemblies 312 may both be disposed on the exterior of the insert safety valve 300. As discussed above, the sealing assemblies 312 create and at least partially define a fixed volume 314. In examples, the fixed volume 314 is to be located adjacent to the puncture 316 in the inner surface of the inner diameter 308 of the mother safety valve 200. The puncture 316 may be created by any sufficient method. Generally, the tools used to create the puncture 316 comprise a wedge shaped core that mechanically forces a punch to exit the tool radially and puncture a thin walled portion of the mother safety valve 200. These tools may be deployed using wireline or E-line. These tools may also comprise a means of aligning the punch with the thin wall. Puncture 316 should be made in a surface of the inner diameter 308 of the mother safety valve 200 such that hydraulic fluid from control line 202 is able to flow into the fixed volume 314 of the inner diameter 308. Hydraulic fluid may flow through control line 202, past port 204, into the interior of mother safety valve 200 and through puncture 316 into the inner diameter of insert safety valve 300. The hydraulic fluid may then fill fixed volume 314 exerting a hydraulic pressure in the process. In the illustrated example, puncture 316 was made prior to insertion of lock mandrel 302 and insert safety valve 300. In some examples, puncture 316 may be made after insertion of lock mandrel 302 and insert safety valve 300 using a puncturing tool affixed to insert safety valve 300. Insert safety valve 300 may comprise a pressure sensor 318 disposed about the exterior of insert safety valve 300 and located such that pressure sensor 318 is capable of measuring the hydraulic pressure within the fixed volume 314.

Pressure sensor 318 may be any pressure sensor capable of measuring the hydraulic pressure in fixed volume 314. In some examples, pressure sensor 318 may also function as a pressure transducer. The measured hydraulic pressure may be used to induce actuation of insert safety valve 300 such that insert safety valve 300 is opened or closed as desired. As discussed above, the illustrated insert safety valve 300 of FIGURE 4 is a general configuration and is not intended to depict any specific configuration of the actuation of the opening or closing of the valve.

As discussed above, the insert safety valve 300 may be preprogrammed to actuate its opening and closing assembly in response to measurements of the hydraulic pressure within the fixed volume 314 performed by pressure sensor 318. For example, insert safety valve 300 may be preprogrammed to open upon pressure sensor 318 registering a hydraulic pressure above a desired threshold. For example, if insert safety valve 300 is preprogrammed to open in the event that pressure sensor 318 measures a hydraulic pressure of greater than 5000 psi, an operator at the surface may open insert safety valve 300 by increasing the hydraulic pressure in the control line 202 such that the hydraulic pressure in the fixed volume 314 is greater than 5000 psi. Additionally, insert safety valve 300 may be preprogrammed to close upon pressure sensor 318 registering a hydraulic pressure below a desired threshold. For example, if insert safety valve 300 is preprogrammed to close in the event that pressure sensor 318 measures a hydraulic pressure of less than 5000 psi, an operator at the surface may close insert safety valve 300 by bleeding off the hydraulic pressure in the control line 202 such that the hydraulic pressure in the fixed volume 314 is less than 5000 psi. As another example, insert safety valve 300 may be preprogrammed to open or close upon the hydraulic pressure in the fixed volume 314 increasing or decreasing by a specific amount. For example, if the hydraulic pressure in the fixed volume 314 increases by 2000 psi, the insert safety valve 300 may open. As an additional example, the insert safety valve 300 may be preprogrammed to partially open or partially close in response to a pressure measurement performed by pressure sensor 318. For example, insert safety valve 300 may be preprogrammed to partially open in the event that pressure sensor 318 measures a hydraulic pressure of greater than 3000 psi; further, insert safety valve 300 may be preprogrammed to fully open in the event that pressure sensor 318 measures a hydraulic pressure of greater than 4000 psi. In the described examples, an operator is able to maintain and adjust the hydraulic pressure in the fixed volume 314 as desired using the control line 202. As such, insert safety valve 300 may be preprogrammed to respond to fluctuations in the hydraulic pressure within the fixed volume 314 in any manner desired by the operator.

FIGURE 5 is cross-sectional view of a lower (bottomhole) portion of an insert safety valve 300 in the closed position. FIGURE 5 depicts a specific type of insert safety valve 300 which may be used for deep-set operations. In the illustrated example, pressure sensor 318 is located uphole of bottom sealing assembly 312. Pressure sensor 318 may be used to measure the hydraulic pressure of the hydraulic fluid within the fixed volume (e.g., fixed volume 314 as illustrated in FIGURE 4) as described in FIGURE 4. The measurement may be conveyed as an electric signal to a processor 402. Processor 402 may be preprogrammed to open or close insert safety valve 300 upon registering a specific threshold of hydraulic pressure. For example, processor 402 may be preprogrammed to open insert safety valve 300 upon pressure sensor 318 measuring a hydraulic pressure of greater than 5000 psi. Continuing with this example, processor 402 may be preprogrammed to close insert safety valve 300 upon pressure sensor 318 measuring a hydraulic pressure of less than 4900 psi. As another example, processor 402 can be preprogrammed to open insert safety valve 300 upon registering a 1000 psi increase in the present pressure reading. Continuing with this example, processor 402 can be preprogrammed to close insert safety valve 300 upon registering a 1000 psi decrease in the present pressure reading.

With continued reference to FIGURE 5, when it is desirable to open insert safety valve 300, an operator may adjust the hydraulic pressure in the control line (e.g., control line 202, as illustrated in FIGURE 4) which may adjust the hydraulic pressure in the fixed volume (e.g.,. fixed volume 314, as illustrated in FIGURE 4) to a degree such that the measured hydraulic pressure crosses the preprogrammed threshold for processor 402 to induce opening of insert safety valve 300. Alternatively, when it is desirable to close insert safety valve 300, an operator may adjust the hydraulic pressure in the control line which may adjust the hydraulic pressure in the fixed volume to a degree such that the measured hydraulic pressure crosses the preprogrammed threshold for processor 402 to induce closing of insert safety valve 300.

If processor 402 is induced to actuate the opening or closing of insert safety valve 300, processor 402 may signal power source 404 to supply power to hydraulic pump 406 to pump a hydraulic fluid within reservoir 408 into hydraulic fluid line 410. Hydraulic fluid within hydraulic fluid line 410 may be used to actuate the valve actuation assembly, which is illustrated in FIGURE 5 as flow tube assembly 412. Flow tube assembly 412 may be used to move flow tube 414 lengthwise within the insert valve inner diameter 418. Flow tube 414 is coupled to ball 416 along an axis. Ball 416 comprises an orifice 420 through the center of ball 416. Ball 416 is able to be rotated to align orifice 420 within ball 416 to the desired opened or closed position. In the illustrated example, ball 416 is in the closed position. Ball 416 may comprise a boss machined into ball 416. The boss may be coupled to a complimentary hole or pocket within the exterior of flow tube 414. When flow tube 414 is moved lengthwise within the insert valve inner diameter 418, the ball 416 may be rotated to either the open or closed position. Flow tube assembly 412 may rotate ball 416 less than ninety degrees which would partially open insert safety valve 300, or flow tube assembly 412 may rotate ball 416 ninety degrees which would fully open insert safety valve 300. When opened, wellbore fluids may flow through orifice 420 and into insert valve inner diameter 418. These wellbore fluids may be produced if flow is allowed to continue to the surface.

Although the valve actuation assembly is illustrated as a flow tube assembly 412 in FIGURES 5 and 6, it is to be understood that any valve actuation assembly sufficient for use with the insert safety valve 300. For example, a motor and gearbox may be used to actuate a ball (e.g., ball 416 as illustrated in FIGURE 5) or a flapper (e.g., flapper 506 as illustrated in FIGURE 6). Any valve actuation assembly used in the safety valves may be used with the insert safety valve 300 provided such valve actuation assembly is able to be used with the smaller scale of the insert safety valve 300 and such valve actuation assembly is suitable for the depth at which the insert safety valve 300 is to be used.

Processor 402 may be any processor sufficient for performing any desired calculations and pulling appropriate power from the power source 404 to supply the valve actuation assembly, for example, flow tube assembly 412. Processor 402 may be programmable as described above and is configured to perform the various arithmetic operations and logic functions necessary to determine when and to what degree to actuate the valve actuation assembly if the pressure sensor 318 measures a hydraulic pressure in the fixed volume (e.g.,. fixed volume 314, as illustrated in FIGURE 4) that has crossed a preprogrammed threshold. In some examples, processor 402 may comprise a transmitter and receiver configured to allow an operator on the surface to receive data about the insert safety valve 300 such as the status of the insert safety valve 300. The transmitter may also transmit data measurements from any sensors of the insert safety valve 300. The receiver may receive signals from an operator. The signals may comprise override commands or adjusts made to any preprogrammed thesholds.

Power source 404 may be any such power source sufficient for powering the valve actuation assembly, for example, flow tube assembly 412. Power source 404 may include, but should not be limited to, a battery, a battery pack, a capacitor (including supercapacitors, ultracapacitors, etc.), a generator, and combinations thereof. In some examples, power source 404 may comprise an electrical cable connected to the surface.

Flow tube assembly 412 may be any such assembly for moving a flow tube 414 within the insert valve inner diameter 418. In the illustrated configuration, hydraulic fluid line 410, hydraulic pump 406, and reservoir 408 are a closed system that is not in fluid communication with the hydraulic fluid supplied from the surface via control line 202. As such, the system does not rely on hydraulic pressure from control line 202 to power the valve actuation assembly. In the illustrated configuration, the hydraulic fluid line 410 is coupled to flow tube assembly 412 at two points such that hydraulic fluid pumped via hydraulic fluid line 410 to the first point may actuate the flow assembly 412 to move the flow tube 414 in a first direction, whereas hydraulic fluid pumped via hydraulic fluid line 410 to the second point may actuate the flow tube assembly 412 to move the flow tube 414 in a second direction. In the illustrated configuration, the flow tube assembly 412 is able to move flow tube 414 into the opened or closed position by rotating ball 416. Flow tube assembly 412 is able to move flow tube 414 into the opened or closed position so long as electrical power is supplied.

FIGURE 6 is cross-sectional view of a lower (bottomhole) portion of an insert safety valve 300 in the open position. FIGURE 6 depicts a specific type of insert safety valve 300 which may be used for deep-set operations. In the illustrated example, pressure sensor 318 is located uphole of bottom sealing assembly 312. Pressure sensor 318 may be used to measure the hydraulic pressure of the hydraulic fluid within the fixed volume (e.g., fixed volume 314 as illustrated in FIGURE 4) as described in FIGURE 4. The measurement may be conveyed as an electric signal to a processor 402. As discussed above, processor 402 may be preprogrammed to open or close insert safety valve 300 upon registering a specific threshold of hydraulic pressure.

With continued reference to FIGURE 6, when it is desirable to open insert safety valve 300, an operator may adjust the hydraulic pressure in the control line (e.g., control line 202, as illustrated in FIGURE 4) which may adjust the hydraulic pressure in the fixed volume (e.g., fixed volume 314, as illustrated in FIGURE 4) to a degree such that the measured hydraulic pressure crosses the preprogrammed threshold for processor 402 to induce opening of insert safety valve 300. Alternatively, when it is desirable to close insert safety valve 300, an operator may adjust the hydraulic pressure in the control line which may adjust the hydraulic pressure in the fixed volume 314 to a degree such that the measured hydraulic pressure crosses the preprogrammed threshold for processor 402 to induce closing of insert safety valve 300.

If processor 402 is induced to actuate the opening or closing of insert safety valve 300, processor 402 may pull appropriate power from the power source 404 to supply the hydraulic pump 406 to pump a hydraulic fluid within reservoir 408 into hydraulic fluid line 410. Hydraulic fluid within hydraulic fluid line 410 may be used to actuate the valve actuation assembly, which is illustrated in FIGURE 6 as flow tube assembly 412. Flow tube assembly 412 may be used to move flow tube 414 lengthwise within the insert valve inner diameter 418. Flapper 506 is illustrated as disposed within slot 508, which allows wellbore fluids to flow through insert valve inner diameter 418. The wellbore fluids may be produced if their flow is allowed to continue to the surface. Flapper 506 is biased radially outwards into the insert valve inner diameter 418 through any sufficient biasing means. If flow tube 414 is moved into the position illustrated in FIGURE 6, flow tube 414 will force flapper 506 into slot 508. If flow tube 414 is moved away from flapper 506, flapper 506 will swing at a hinge into the insert valve inner diameter 418 and block fluid flow through insert valve inner diameter 418.

In the illustrated configuration, hydraulic fluid line 410, hydraulic pump 406, and reservoir 408 are a closed system that is not in fluid communication with the hydraulic fluid supplied from the surface via control line 202. As such, the system does not rely on hydraulic pressure from control line 202 to power the valve actuation assembly. In the illustrated configuration, the hydraulic fluid line 410 is coupled to flow tube assembly 412 at two points such that hydraulic fluid pumped via hydraulic fluid line 410 to the first point may actuate the flow assembly 412 to move the flow tube 414 in a first direction, whereas hydraulic fluid pumped via hydraulic fluid line 410 to the second point may actuate the flow tube assembly 412 to move the flow tube 414 in a second direction. In the illustrated configuration, the flow tube assembly 412 is able to move flow tube 414 into the opened or closed position by forcing flapper 506 into recessed slot 508 or allowing the biased flapper to close insert valve inner diameter 418. Flow tube assembly 412 is able to move flow tube 414 into the opened or closed position so long as electrical power is supplied.

FIGURES 5 and 6 depict configurations of insert safety valve 300 which may be used in deep-set operations, i.e., operations at depths exceeding 10,000 feet. As such, these configurations do not rely on springs to actuate the opening or closing of the insert safety valve 300 and are powered by an electrical source, for example, power source 404, to actuate the opening and closing of the insert safety valve 300. In alternative examples, the insert safety valve 300 may be electrically powered by an electrical cable run from the surface. In further alternative examples, the insert safety valves may be used for operations which are not deep-set and may comprise components or configurations other than those illustrated in FIGURES 5 and 6 in order to actuate the opening and closing of the insert safety valve 300. It is to be understood that FIGURES 5 and 6 are merely illustrative of potential opening and closing assemblies for the insert safety valve 300, and that this disclosure is not to be limited to any specific type of opening or closing assembly for the insert safety valve 300.

With reference to FIGURE 4, in some examples, insert safety valve 300 may be removed and replaced with another insert safety valve 300. For example, in configurations of insert safety valve 300 which comprise a power source (e.g., power source 404, as illustrated in FIGURES 5 and 6), when the power source dies, lock mandrel 302 may be unlocked from mother safety valve 200 by unlatching key 304 from slot 306. Lock mandrel 302 and insert safety valve 300 may then be retrieved using a wireline or any other suitable retrieval method. Once retrieved, a new insert safety valve 300 may be inserted into mother safety valve 200 if desired. Alternatively, power source 404 may be removed and replaced, and the same insert safety valve 300 may be reinserted into the mother safety valve 200.

In optional examples, insert safety valve 300 may comprise sensors within the inner diameter of insert safety valve 300. These sensors may be able to measure the fluid properties of any fluids flowing through insert safety valve 300 when insert safety valve 300 is opened. Examples of sensors may include, but are not limited to, temperature sensors, flow rate sensors, pressure sensors, and the like. Insert safety valve 300 may be preprogrammed to autonomously actuate based on the measured fluid properties. For example, if a temperature sensor measuring the temperature of a fluid flowing through the inner diameter of insert safety valve 300 measures a spike in temperature sufficient to cross a predetermined threshold, actuation of insert safety valve 300 may be induced, and insert safety valve 300 may be closed to block the flow of the fluid through insert safety valve 300. Analogous automation may be performed with other sensor types. For example, a flow rate sensor measuring an increase in flow rate of the fluid flowing through insert safety valve 300 may induce actuation of insert safety valve 300 to close insert safety valve 300 and block the flow of the fluid through insert safety valve 300.

Well systems comprising insert safety valves for use in subterranean formations are provided. An example well system comprises a mother safety valve and an insert safety valve. The mother safety valve comprises an inner diameter. The insert safety valve is disposed within the inner diameter of the mother safety valve. The insert safety valve comprises a pressure sensor on an exterior surface of the insert safety valve. The well system may further comprise a control line configured to pump hydraulic fluid to the mother safety valve. The mother safety valve may further comprise a puncture in a surface of its inner diameter such that hydraulic fluid from the interior of the mother safety valve is capable of flowing into the inner diameter of the mother safety valve. The insert safety valve may further comprise a sealing element on its exterior. The insert safety valve may be coupled to a lock mandrel. The lock mandrel may comprise a sealing element on its exterior. The sealing element on the exterior of the insert safety valve and the sealing element on the exterior of the lock mandrel may at least partially define a fixed volume. The pressure sensor of the insert safety valve may be adjacent to the fixed volume. The insert safety valve may comprise a valve actuation assembly for opening and closing the insert safety valve. The valve actuation assembly may be electrically powered by a power source. The insert safety valve may be preprogrammed to open or close in response to pressure measurements taken by the pressure sensor crossing preprogrammed pressure measurement thresholds. The insert safety valve may further comprise an inner diameter and wherein a surface of the inner diameter comprises a sensor selected from the group consisting of a pressure sensor, a temperature sensor, and a flow rate sensor.

An apparatus for use in subterranean formations is provided. The apparatus comprises an insert safety valve and a lock mandrel. The insert safety valve comprises a pressure sensor on its exterior. The lock mandrel is coupled to the insert safety valve. The apparatus may be disposed within the inner diameter of the mother safety valve. A control line may be configured to pump hydraulic fluid to the mother safety valve. The mother safety valve may further comprise a puncture in a surface of its inner diameter such that hydraulic fluid from the interior of the mother safety valve is capable of flowing into the inner diameter of the mother safety valve. The insert safety valve may further comprise a sealing element on its exterior. The lock mandrel may comprise a sealing element on its exterior. The sealing element on the exterior of the insert safety valve and the sealing element on the exterior of the lock mandrel may at least partially define a fixed volume. The pressure sensor of the insert safety valve may be adjacent to the fixed volume. The insert safety valve may comprise a valve actuation assembly for opening and closing the insert safety valve. The valve actuation assembly may be electrically powered by a power source. The insert safety valve may be preprogrammed to open or close in response to pressure measurements taken by the pressure sensor crossing preprogrammed pressure measurement thresholds. The insert safety valve may further comprise an inner diameter and wherein a surface of the inner diameter comprises a sensor selected from the group consisting of a pressure sensor, a temperature sensor, and a flow rate sensor.

Methods of using an insert safety valve in a subterranean formation are provided. An example method comprises puncturing a hole in a surface of the inner diameter of a mother safety valve such that the hole allows hydraulic fluid from a control line connected to the mother safety valve to flow into the inner diameter of the mother safety valve. The method further comprises inserting a lock mandrel coupled to an insert safety valve in the inner diameter of the mother safety valve, wherein the lock mandrel comprises a sealing element and the insert safety valve comprises a sealing element. The method further comprises securing the lock mandrel in the inner diameter of the mother safety valve and sealing the sealing elements on the lock mandrel and the insert safety valve to define a fixed volume with a surface of the inner diameter of the mother safety valve, and wherein the hole in the surface of the inner diameter of the mother safety valve is disposed adjacent to the fixed volume. The insert safety valve may comprise a pressure sensor on its exterior, and wherein the pressure sensor is adjacent to the fixed volume. The hydraulic fluid from a control line coupled to the mother safety valve may be pumped into the fixed volume. The insert safety valve may be actuated in response to a measurement of the hydraulic pressure of the hydraulic fluid within the fixed volume. The actuation may be electrically powered.

Therefore, the disclosed systems and methods are well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the teachings of the present disclosure may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined, or modified, and all such variations are considered within the scope of the present disclosure. The systems and methods illustratively disclosed herein may suitably be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein.

Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the following claims.

WHAT IS CLAIMED IS:

1. A well system in a subterranean formation, comprising:

a mother safety valve comprising an inner diameter;

an insert safety valve disposed within the inner diameter of the mother safety valve, wherein the insert safety valve comprises a pressure sensor on an exterior surface of the insert safety valve.

2. The well system of claim 1 further comprising a control line configured to pump hydraulic fluid to the mother safety valve.

3. The well system of claim 1, wherein the mother safety valve comprises a puncture in a surface of its inner diameter such that hydraulic fluid from the interior of the mother safety valve is capable of flowing into the inner diameter of the mother safety valve.

4. The well system of claim 1, wherein the insert safety valve comprises a sealing element on its exterior.

5. The well system of claim 1, wherein the insert safety valve is coupled to a lock mandrel.

6. The well system of claim 5, wherein the lock mandrel comprises a sealing element on its exterior.

7. The well system of claim 1, wherein the insert safety valve comprises a sealing element on its exterior, wherein the insert safety valve is coupled to a lock mandrel, wherein the lock mandrel comprises a sealing element, wherein the sealing element on the exterior of the insert safety valve and the sealing element on the exterior of the lock mandrel at least partially define a fixed volume.

8. The well system of claim 7, wherein the pressure sensor of the insert safety valve is adjacent to the fixed volume.

9. An apparatus comprising:

an insert safety valve, wherein the insert safety valve comprises a pressure sensor on its exterior;

a lock mandrel, wherein the lock mandrel is coupled to the insert safety valve.

10. The apparatus of claim 9, wherein the insert safety valve comprises a sealing element on its exterior.

11. The apparatus of claim 9, wherein the lock mandrel comprises a sealing element on its exterior.

12. The apparatus of claim 9, wherein the insert safety valve comprises a sealing element on its exterior and the lock mandrel comprises a sealing element on its exterior and the pressure sensor is disposed between the sealing element on the exterior of the insert safety valve and the sealing element on the exterior of the lock mandrel.

13. The apparatus of claim 9, wherein the insert safety valve comprises a valve actuation assembly for opening and closing the insert safety valve, and wherein the valve actuation assembly is electrically powered by a power source.

14. The apparatus of claim 9, wherein the insert safety valve is preprogrammed to open or close in response to pressure measurements taken by the pressure sensor crossing preprogrammed pressure measurement thresholds.

15. The apparatus of claim 9, wherein the insert safety valve further comprises an inner diameter and wherein a surface of the inner diameter comprises a

sensor selected from the group consisting of a pressure sensor, a temperature sensor, and a flow rate sensor.

16. A method of using an insert safety valve, comprising:

puncturing a hole in a surface of the inner diameter of a mother safety valve such that the hole allows hydraulic fluid from a control line connected to the mother safety valve to flow into the inner diameter of the mother safety valve,

inserting a lock mandrel coupled to an insert safety valve in the inner diameter of the mother safety valve, wherein the lock mandrel comprises a sealing element and the insert safety valve comprises a sealing element,

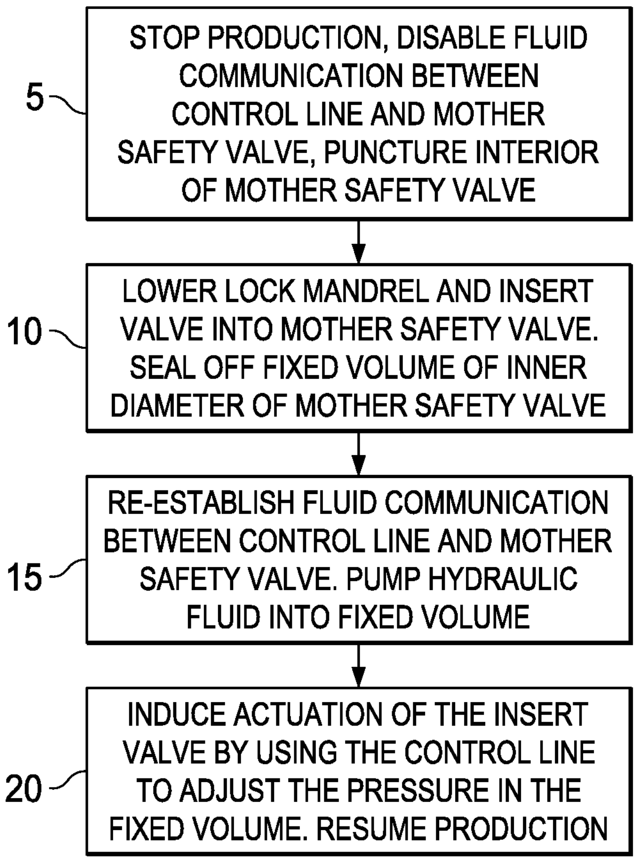
securing the lock mandrel in the inner diameter of the mother safety valve and sealing the sealing elements on the lock mandrel and the insert safety valve to define a fixed volume with a surface of the inner diameter of the mother safety valve, and wherein the hole in the surface of the inner diameter of the mother safety valve is disposed adjacent to the fixed volume.

17. The method of claim 16, wherein the insert safety valve comprises a pressure sensor on its exterior, and wherein the pressure sensor is adjacent to the fixed volume.

18. The method of claim 17, wherein hydraulic fluid from a control line coupled to the mother safety valve is pumped into the fixed volume.

19. The method of claim 18, wherein the insert safety valve is actuated in response to a measurement of the hydraulic pressure of the hydraulic fluid within the fixed volume.

20. The method of claim 19, wherein the actuation is electrically powered.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STOP PRODUCTION, DISABLE FLUID COMMUNICATION BETWEEN CONTROL LINE AND MOTHER SAFETY VALVE, PUNCTURE INTERIOR OF MOTHER SAFETY VALVE
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LOWER LOCK MANDREL AND INSERT VALVE INTO MOTHER SAFETY VALVE. SEAL OFF FIXED VOLUME OF INNER DIAMETER OF MOTHER SAFETY VALVE
15
RE-ESTABLISH FLUID COMMUNICATION BETWEEN CONTROL LINE AND MOTHER SAFETY VALVE. PUMP HYDRAULIC FLUID INTO FIXED VOLUME
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INDUCE ACTUATION OF THE INSERT VALVE BY USING THE CONTROL LINE TO ADJUST THE PRESSURE IN THE FIXED VOLUME. RESUME PRODUCTION

FIG. 1

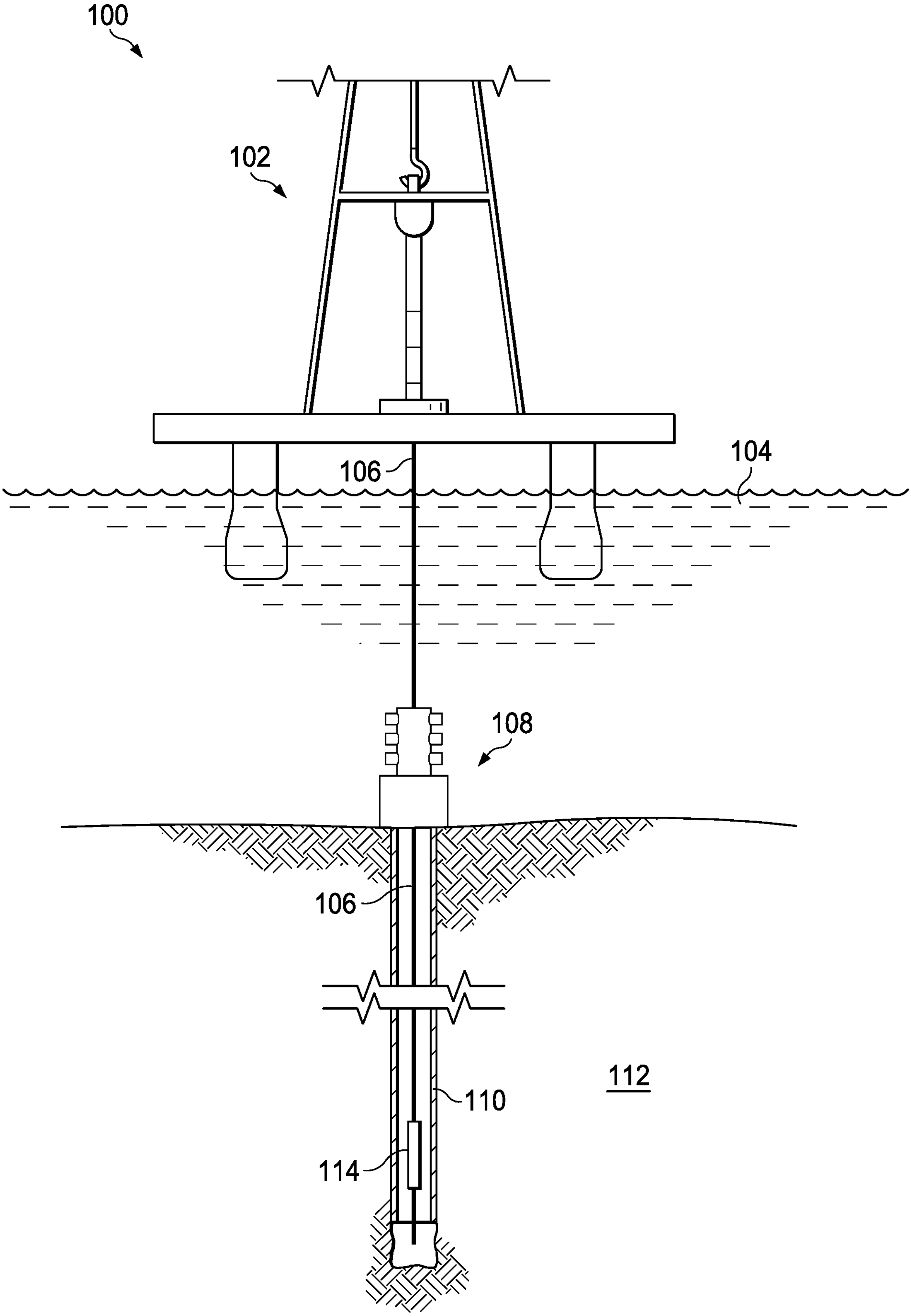

FIG. 2

FIG. 3

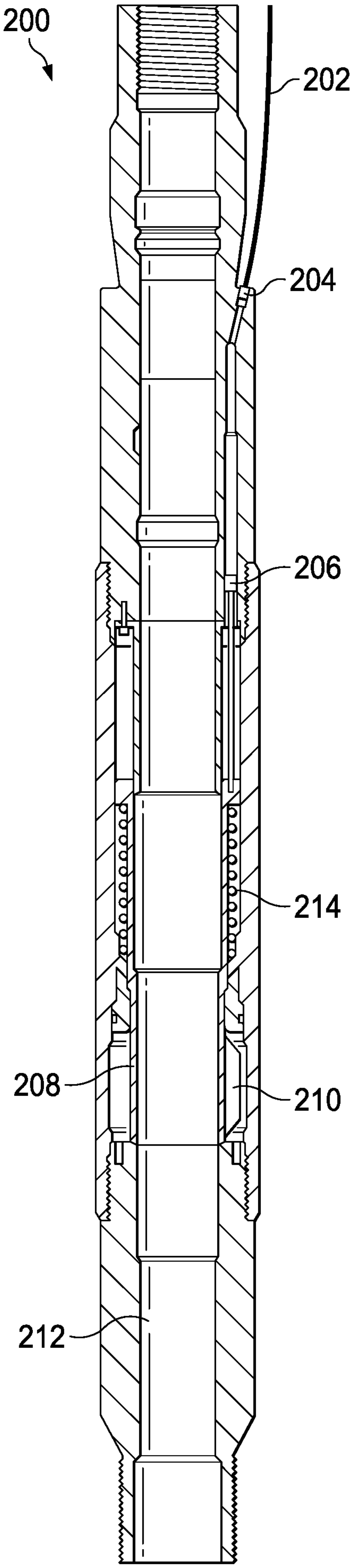
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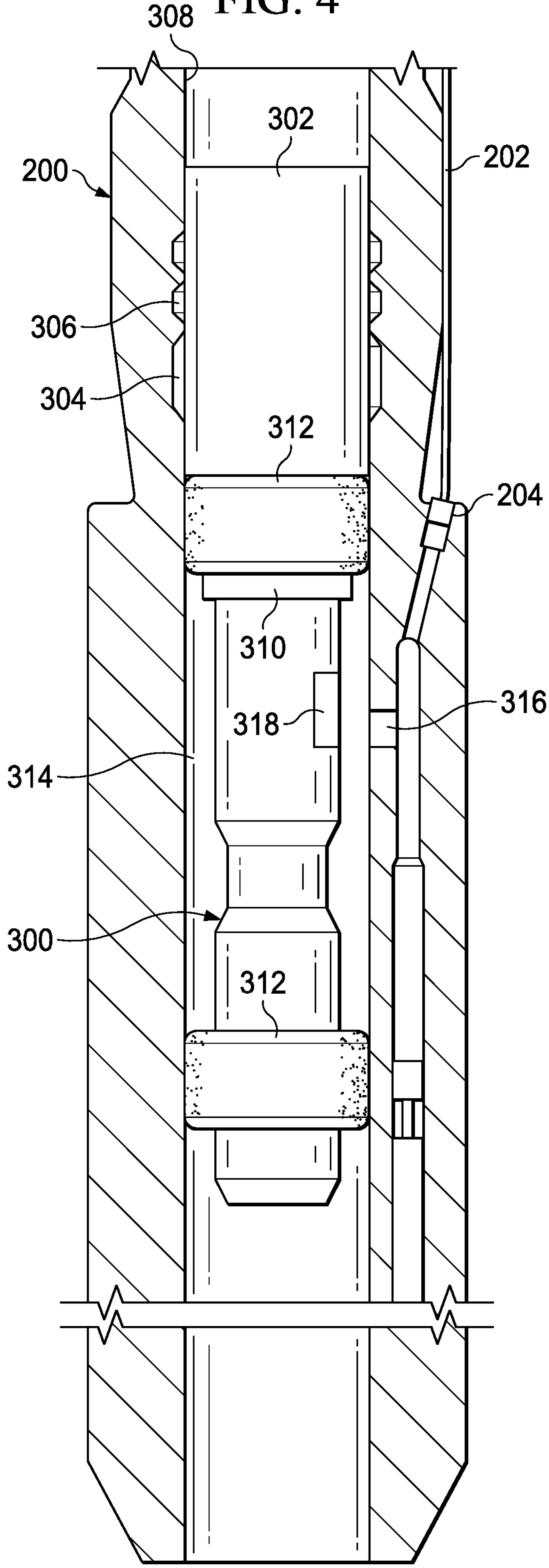
FIG. 4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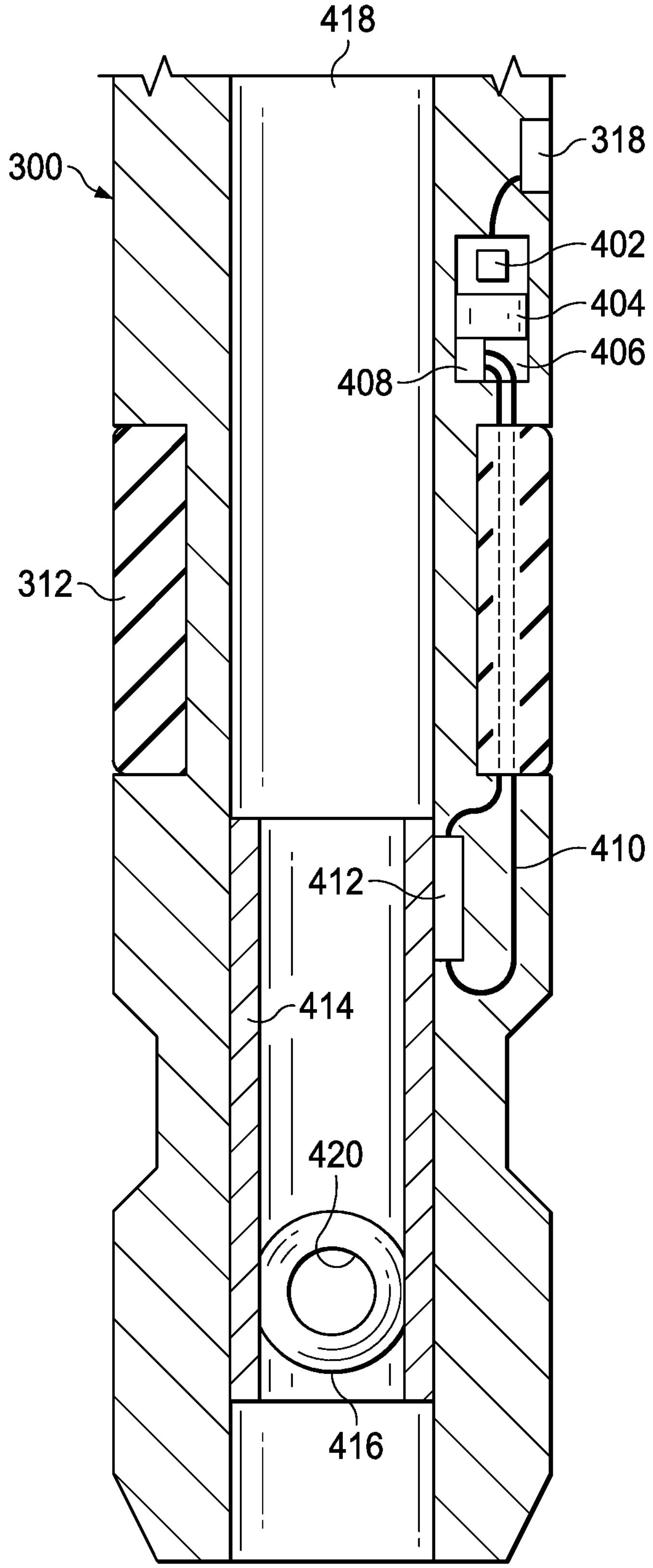

FIG. 5

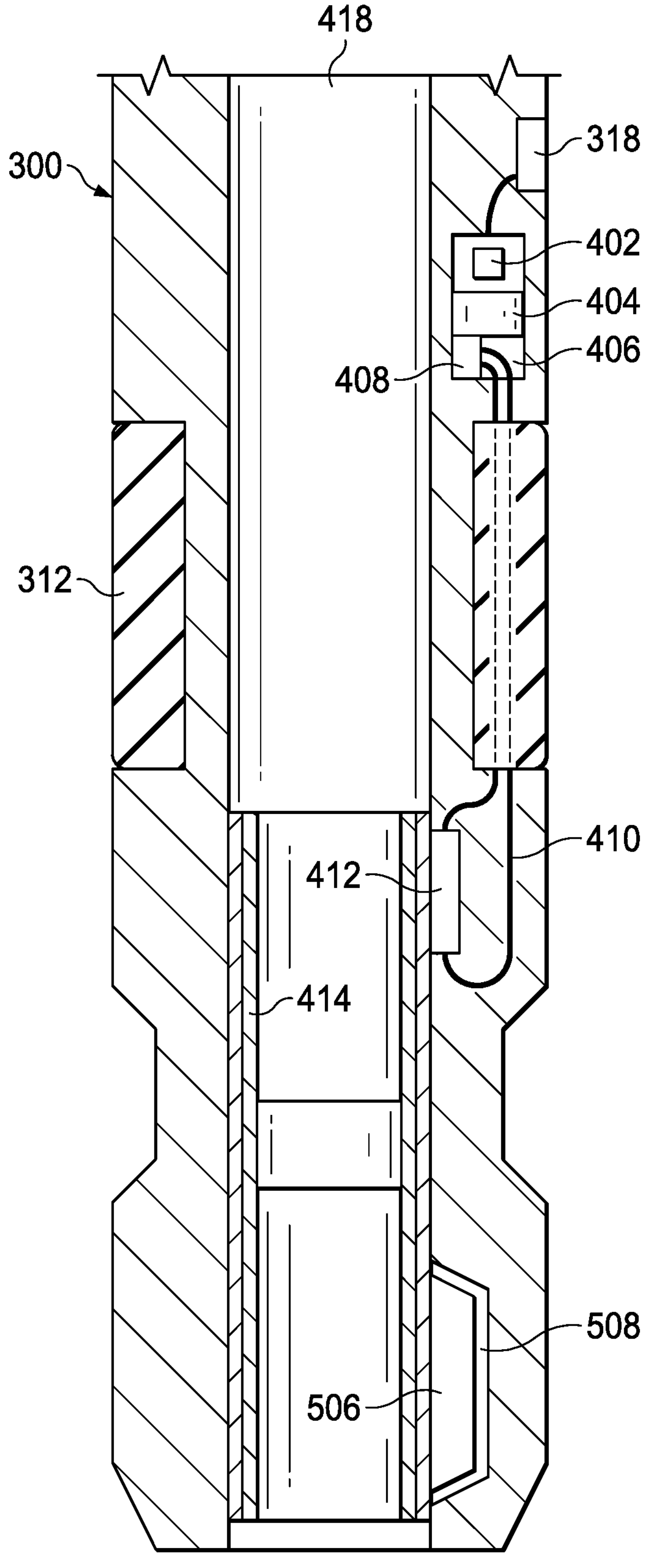

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/034221

A. CLASSIFICATION OF SUBJECT MATTER

E21B 34/06(2006.01)i, E21B 34/10(2006.01)i, E21B 17/00(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 34/06; E21B 43/04; E21B 34/00; E21B 34/12; E21B 34/14; E21B 23/00; E21B 34/10; E21B 17/00

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: insert safety valve, mother safety valve, sealing element, pressure sensor, lock mandrel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013-0032355 A1 (SCOTT et al.) 07 February 2013 See paragraphs [0021]-[0040], [0096] and figures 1-3.	1-20
Y	US 2012-0012312 A1 (WHITSITT et al.) 19 January 2012 See paragraphs [0029]-[0045] and figures 1, 4, 15-16.	1-20
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☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"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	Date of mailing of the international search report
17 February 2017 (17.02.2017)	**20 February 2017 (20.02.2017)**

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