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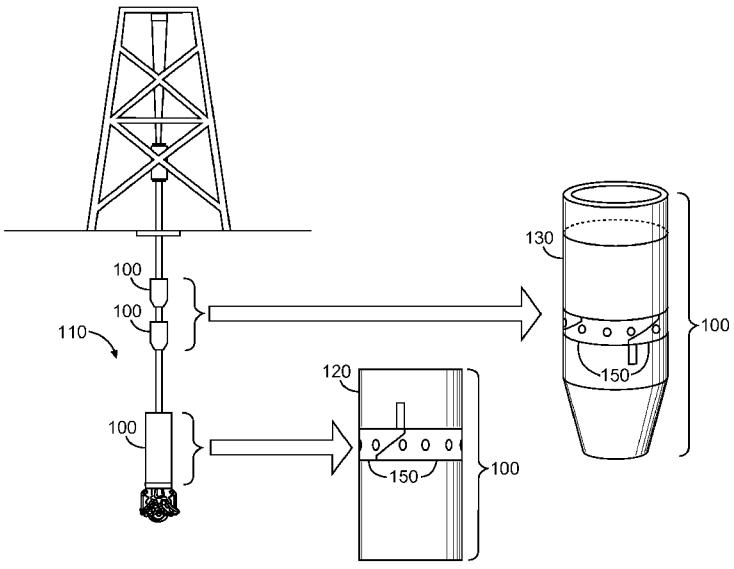


Fig. 1

(57) Abstract: In some embodiments, an apparatus and a system may include a tubular member; at least two interchangeable blades attached to the tubular member, the blades extendible radially outward to an extended position and retractable radially inward to a retracted position, wherein an outer surface of the blades is disposed at or below an outer surface of the tubular member when the blades are in the retracted position; and a plurality of sensors attached to the blades, the sensors to engage a circumferential portion of a borehole wall along the outer surface of the blades in an azimuthal direction when the blades are disposed downhole in the extended position, and to refrain from engaging the borehole wall when the blades are disposed downhole in the retracted position. Additional apparatus and systems, as well as methods, are disclosed.

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BLADE-MOUNTED SENSOR APPARATUS, SYSTEMS, AND METHODS

BACKGROUND

[0001] Understanding the structure and properties of geological formations may reduce the cost of drilling wells for oil and gas exploration. Measurements are typically performed in a borehole (i.e., downhole measurements) in order to attain this understanding. For example, the measurements may identify the composition and distribution of material that surrounds the measurement device downhole.

[0002] Measurement While Drilling (MWD) and Logging While Drilling (LWD) tools are often used to make such measurements, to help determine when hydrocarbon deposits are embedded in the surrounding formation. Temperature, pressure, and vibration may also be measured downhole, among other conditions. These measurements constitute data gathered by the MWD/LWD tool, and may be sent up to the surface in real time (e.g., in MWD), or retrieved at a later time (e.g., in LWD), after drilling operations are completed. Such measurements can be made using sensors or transducers, which may be fixed or movable, perhaps mounted along the MWD/LWD tool body, or on a probe that extends outwardly from the tool body. Sometimes these probes are expensive to manufacture, or difficult to replace.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. 1 illustrates a blade-mounted sensor apparatus employed in two locations on a drill string, according to various embodiments.

[0004] FIG. 2 provides perspective and top plan views of blades forming a part of a blade-mounted sensor apparatus, according to various embodiments.

[0005] FIG. 3 provides perspective and close-up views of a single blade, forming part of an apparatus, according to various embodiments.

[0006] FIG. 4 illustrates top and perspective views of an apparatus having four blades in retracted and extended positions, respectively, according to various embodiments.

[0007] FIG. 5 illustrates top and perspective views of an apparatus having two blades in retracted and extended positions, respectively, according to various embodiments.

[0008] FIG. 6 illustrates top and perspective views of an apparatus having three blades in retracted and extended positions, respectively, according to various embodiments.

[0009] FIG. 7 illustrates a side perspective view of a gear extension mechanism, and a top plan view, with a perspective view inset of a hydraulic actuator extension mechanism, according to various embodiments.

[0010] FIG. 8 illustrates a perspective view of an array of blade sets, according to various embodiments.

[0011] FIG. 9 illustrates side views of an apparatus, with blades in a retracted position, and an extended position to stabilize a drill string, respectively, according to various embodiments.

[0012] FIG. 10 is a block diagram of apparatus and systems according to various embodiments of the invention.

[0013] FIG. 11 is a flow chart illustrating several methods according to various embodiments of the invention.

[0014] FIG. 12 illustrates a wireline system, according to various embodiments of the invention.

[0015] FIG. 13 illustrates a drilling rig system, according to various embodiments of the invention.

DETAILED DESCRIPTION

[0016] Apparatus, systems, and methods are described herein that provide a new mechanism to mount sensors when making downhole measurements. For example, in some embodiments, the sensors can be attached to a drill collar and/or a crossover substitute (also known as a crossover sub to those of ordinary skill in the art). The sensors are mounted on blades that, upon activation, operate to extend radially outward toward the borehole wall, to come in contact with the surrounding formation. This mode of operation enhances the coupling effect between the sensors and the formation, often enhancing the accuracy of the

associated measurement. In some embodiments, multiple sensors are attached to a single blade to offer different sensing services at particular location. The details of various embodiments will now be described.

[0017] FIG. 1 illustrates a blade-mounted sensor apparatus 100 employed in two locations on a drill string, according to various embodiments. In the figure, a drill string 110 is shown to include an MWD/LWD collar 120 and a crossover sub 130. The apparatus 100, including blades 150 can be formed as part of the collar 120, as well as the crossover sub 130. As will be shown in later figures, the apparatus 100 may comprise two or more blades 150. In this figure, the apparatus 100 has four blades 150.

[0018] FIG. 2 provides perspective 120 and top plan views 220, 230 of blades forming a part of a blade-mounted sensor apparatus, according to various embodiments. These crescent-shaped blades 150 are shown in this figure to have a leading edge 240, and trailing edge 242. The leading edge 240 slopes downward (underneath the substantially flat table 260) along a downward sloping surface 268, toward a substantially flat base 250. The trailing edge 242 rises above the substantially flat base 250, upward along an upward sloping surface 264, toward a peak 254, which terminates at an edge of the substantially flat table 260. In many embodiments, the substantially flat table 260 and/or the downward sloping surface 268 include an aperture 270 that forms a point of rotation when the blade 150 is attached to a tubular member (not shown). The aperture 270 may be attached to the tubular member using a pin 274, for example.

[0019] In the figure, the top plan view 210 shows a set of four blades 150 in a retracted position, wherein the outer surfaces 272 of the blades 150 combine to form a circle that is, in many embodiments, the same diameter as the tubular member to which the blades 150 are attached. This feature enables the blades 150, when in the retracted position, to conform to the outer surface of the tubular member to which they are attached, by matching the outer circumference of a drilling collar or crossover sub, for example (e.g., see FIG. 1).

[0020] FIG. 3 provides perspective and close-up views of a single blade 150, forming part of an apparatus 100, according to various embodiments. Here it can

be seen that the apparatus 100, comprising a tubular member 300 and multiple blades 150, may be fabricated so that multiple sensors 310 are mounted to each blade. For example, in the close up view of the blade 150, three different sensor types are shown: an electrode E, a transducer T, and a coil C. Many other sensor types may be supported, such as temperature, vibration, etc.

[0021] As shown in the figure, the blades 150 are movable from the retracted position (not shown) to an extended position (shown). The blades 150 may also be constructed to as to be interchangeable, one for another. This allows a variety of sensing services to be provided with a single blade design. In some embodiments, as shown, the blades are also fabricated so as to be identical, making repair and substitution of the blades 150 relatively easy. Individual blades 150 may include wiring connections 320 on the inner surfaces 330 of the blades 150, providing electrical connectivity to the attached sensors 310. In this figure, it can also be seen how the outer surface 272 of the blades 150 does not conform to the outer surface 340 of the tubular member 300 when the blades are in the extended position.

[0022] FIG. 4 illustrates top 410, 420 and perspective views 430, 440 of an apparatus 100 having four blades 150 in retracted and extended positions, respectively, according to various embodiments. The operational modes of the blades 150 thus include the retracted position (shown in view 430) and, after the blades have moved radially outward to contact the borehole wall 450, the extended position (shown in view 440). In view 430, it can also be seen how the outer surface 272 of the blades 150 conforms to and completes the outer surface 340 of the tubular member 300 when the blades are in the retracted position.

[0023] In many embodiments, the tubular member 300 that forms part of an MWD/LWD tool will rotate during drilling operations, and then rotation will stop at some point. This may occur for a number of reasons, including to provide an opportunity to measure conditions in the borehole, such as formation pressure, seismic activity, etc. It is at this point that an extension mechanism will be activated, to move the blades 150 from the retraction position (see view 430) to the extended position (see view 440), so that the blades 150 are contacting the

borehole wall 450. Other numbers of blades 150 may be used in various embodiments.

[0024] For example, FIG. 5 illustrates top 510, 520 and perspective views 530, 540 of an apparatus 100 having two blades 150 in retracted and extended positions, respectively, according to various embodiments. The operational modes of the blades 150 again include the retracted position (shown in view 530) and, after the blades 150 have moved radially outward to contact the borehole wall 450, the extended position (shown in view 540).

[0025] In another example, FIG. 6 illustrates top 610, 620 and perspective views 630, 640 of an apparatus 100 having three blades 150 in retracted and extended positions, respectively, according to various embodiments. The operational modes of the blades 150 again include the retracted position (shown in view 630) and, after the blades 150 have moved radially outward to contact the borehole wall 450, the extended position (shown in view 640).

[0026] FIG. 7 illustrates a side perspective view 710 of a gear extension mechanism 715, and a top plan view, with a perspective view inset 730 of a hydraulic actuator extension mechanism 735, according to various embodiments. Thus, two possible extension mechanisms 715, 735, among many, can be used to extend and retract the blades 150 by urging the blades 150 radially outward, and rotating the blades 150 around the pins 274. In some embodiments, extension activity may cease when the blades 150 undergoing extension experience a sufficient counter-resistance force F, perhaps by coming into contact with a borehole wall, or a geological formation. Once contact is made, the sensors 310 can operate to provide measurement signals to other parts of a downhole measurement and data acquisition system.

[0027] FIG. 8 illustrates a perspective view of an array 800 of blade sets 810, according to various embodiments. This arrangement provides the flexibility of using different sensor groups 820', 820" arranged in an array configuration along the longitudinal direction Z of the tubular member 300. For example, the sensors in group 820' may be ultrasonic transducers, and the sensors in group 820" may be electrodes.

[0028] FIG. 9 illustrates side views 910, 920 of an apparatus 100, with blades in a retracted position, and an extended position to stabilize a drill string, respectively, according to various embodiments. In the first view 910, the blades of the apparatus 100 are shown in the retracted position. This position may be appropriate when drilling activity is ongoing in the borehole 930.

[0029] In the second view 920, the apparatus 100 is acting as a passive centralizer for the drill string 940. Thus, when the centerline 960 of the drill string 940 runs out from the centerline 970 of the borehole 930, the blades 150 can be activated to extend toward the toward the wall 950 of the borehole 930, in order to passively centralize the drill string 930 near the longitudinal location on the drill string 930 where the apparatus 100 is attached. Still further embodiments may be realized.

Apparatus and Systems

[0030] For example, FIG. 10 is a block diagram of apparatus 100 and systems 1000 according to various embodiments of the invention. Here, it can be seen that the system 1000 may include a controller 1025 specifically configured to interface with a controlled device 1070, such as an extension/retraction mechanism for the apparatus 100, a geosteering unit, and/or a user display or touch screen interface (in addition to displays 1055). The system 1000 may further include sensors 310, such as electromagnetic transmitters and receivers, transducers, etc. (see FIG. 3), attached to the blades of the apparatus 100. When configured in this manner, the system 1000 can receive measurements and other data (e.g., location and conductivity or resistivity information, among other data) to be processed according to various methods described herein.

[0031] A processing unit 1002 can be coupled to the apparatus 100 to obtain measurements from the sensors 310, and other components that may be attached to a housing 1004. Thus, in some embodiments, a system 1000 comprises a housing 1004 that can be attached to or used to house the apparatus 100, and perhaps the controlled device 1070, among other elements. The housing 1004 might take the form of a wireline tool body, or a downhole tool as described in more detail below with reference to FIGs. 12 and 13. The processing unit 1002 may be part of a surface workstation, or attached to the housing 1004.

[0032] The system 1000 can include other electronic apparatus 1065, and a communications unit 1040. Electronic apparatus 1065 (e.g., electromagnetic sensors, current sensors, and other devices) can also be used in conjunction with the controller 1025 to perform tasks associated with taking measurements downhole. The communications unit 1040 can be used to handle downhole communications in a drilling operation. Such downhole communications can include telemetry.

[0033] The system 1000 can also include a bus 1027 to provide common electrical signal paths between the components of the system 1000. The bus 1027 can include an address bus, a data bus, and a control bus, each independently configured. The bus 1027 can also use common conductive lines for providing one or more of address, data, or control, the use of which can be regulated by the controller 1025 and/or the processing unit 1002.

[0034] The bus 1027 can include instrumentality for a communication network. The bus 1027 can be configured such that the components of the system 1000 are distributed. Such distribution can be arranged between downhole components such as the components attached to the housing 1004, and components that are located on the surface of a well. Alternatively, several of these components can be co-located, such as on one or more collars of a drill string or on a wireline structure.

[0035] In various embodiments, the system 1000 includes peripheral devices that can include displays 1055, additional storage memory, or other control devices that may operate in conjunction with the controller 1025 or the processing unit 1002. The displays 1055 can display diagnostic and measurement information for the system 1000, based on the signals generated according to embodiments described above.

[0036] In an embodiment, the controller 1025 can be fabricated to include one or more processors. The display 1055 can be fabricated or programmed to operate with instructions stored in the processing unit 1002 (for example in the memory 1006) to implement a user interface to manage the operation of the system 1000, including any one or more components distributed within the system 1000. This type of user interface can be operated in conjunction with the

communications unit 1040 and the bus 1027. Various components of the system 1000 can be integrated with a bottom hole assembly, if desired, which may in turn be used to house the apparatus 100, such that operation of the apparatus 100, and processing of the measurement data, identical to or similar to the methods discussed previously, and those that follow, can be conducted according to various embodiments that are described herein.

[0037] In some embodiments, a non-transitory machine-readable storage device can comprise instructions stored thereon, which, when performed by a machine, cause the machine to become a customized, particular machine that performs operations comprising one or more features similar to or identical to those described with respect to the methods and techniques described herein. A machine-readable storage device, as described herein, is a physical device that stores information (e.g., instructions, data), which when stored, alters the physical structure of the device. Examples of machine-readable storage devices can include, but are not limited to, memory 1006 in the form of read only memory (ROM), random access memory (RAM), a magnetic disk storage device, an optical storage device, a flash memory, and other electronic, magnetic, or optical memory devices, including combinations thereof.

[0038] The physical structure of stored instructions may be operated on by one or more processors such as, for example, the processing unit 1002. Operating on these physical structures can cause the machine to become a specialized machine that performs operations according to methods described herein. The instructions can include instructions to cause the processing unit 1002 to store associated data or other data in the memory 1006. The memory 1006 can store the results of measurements of formation parameters, to include gain parameters, calibration constants, identification data, sensor location information, sensor extension/retraction force information, etc. The memory 1006 can store a log of the measurement and location information provided by the system 1000. The memory 1006 therefore may include a database, for example a relational database. The processors 1030 can be used to process the data 1070 to form images of cement surrounding a well, or the formation itself.

[0039] Thus, referring to FIGs. 1-10, it can be seen that many embodiments may be realized. For example, an apparatus 100 may comprise a tubular member 300 attached to at least three mechanically interchangeable blades 150, with multiple sensors 310 mounted on the blades.

[0040] In some embodiments, an apparatus 100 comprises a tubular member 300 and at least two interchangeable blades 150 attached to the tubular member300. The blades 150 being extendible radially outward to an extended position, and retractable radially inward to a retracted position. The outer surface 272 of the blades 150 is disposed at or below an outer surface of the tubular member 300 when the blades 150 are in the retracted position. In some embodiments, a plurality of sensors 410 form a portion of the outer surface 272 of the blades 150, the sensors 310 engaging a circumferential portion of a borehole wall 450 along the outer surface 272 of the blades 150 in an azimuthal direction when the blades 150 are disposed downhole in the extended position. The sensors 310 refrain from engaging the borehole wall 450 when the blades 150 are disposed downhole in the retracted position.

[0041] The tubular member may take the form of a drilling collar, or a crossover substitute device, or crossover sub. Thus, in some embodiments, the tubular member 300 comprises one of a drilling collar 120 or a crossover sub 130.

[0042] The blades are often interchangeable, and may be identical. Thus, the interchangeable blades 150 comprise identical blades in some embodiments.

[0043] There may be three or four blades (or more) attached to the tubular member, occupying substantially equal portions of the circumferential distance around the outer surface of the tubular member. Thus, in some embodiments, the at least two interchangeable blades 150 comprise three or four interchangeable blades 150, each of the blades 150 occupying a substantially similar portion of a circumference of the tubular member 300 when the blades 150 are in the retracted position (see views 420, 520, 620 in FIGs. 4, 5, 6, respectively).

[0044] Each of the blades may overlap another blade when in the retracted position. In some embodiments, each blade overlaps two other blades. Thus, in some embodiments, each of the blades 150 overlap at least one other one of the

blades 150 along the circumference of the tubular member when the blades 150 are in the retracted position (see e.g., views 420 and 440 in FIG. 4).

[0045] Gears and/or a variety of actuators 735 may be used to extend and retract the blades. Thus, in some embodiments, gears, electromagnetic, piezoelectric, shape memory alloy, or hydraulic actuators are attached so as to couple the tubular member 300 to the blades 150 (see e.g., views 710 and 720, and breakout view of the different types of actuators 735, in FIG. 7).

[0046] Different sensor types may be attached to different blades, or the same blades. Thus, in some embodiments, the plurality of sensors 310 comprise at least two different sensor types arranged on one of the blades (see e.g., inset view of FIG. 3). In some embodiments, the blade sensors comprise one or more transducers (that provide a two-way conversion to and from electrical signals).

[0047] When in the retracted position, the ends of the blades may engage the ends of other blades, in a mirrored fashion. Thus, in some embodiments, each of the blades 150 includes end pieces that engage end pieces of other blades in a mirrored fashion (e.g., one end piece comprising the leading edge 240 and downward sloping surface 268 of one blade 150, and another end piece comprising the trailing edge 242 and upward sloping surface 264 of another blade 150) when the blades are in the retracted position.

[0048] When in the retracted position, the outer surfaces of the blades may meet the outer surface of the tubular member, to form a unified outer surface. Thus, in some embodiments, the outer surface 272 of the blades 150 substantially conforms to the outer surface 340 of the tubular member 300, to form a substantially continuous outer surface, when the blades 150 are in the retracted position (e.g., see view 430 in FIG. 4).

[0049] The blades may be attached to the tubular member using a rotating joint. Thus, in some embodiments, each of the blades 150 is attached to the tubular member 300 at a single point of rotation (e.g., using a pin 274).

[0050] The tubular member may be attached to a number of pins that retain the blades via an aperture formed in each blade. Thus, in some embodiments, the single point of rotation comprises an aperture 270 in the blade 150 extending in a

longitudinal direction of the tubular member 300 and located on an interlocking portion of the blade (e.g., the edge 240, and the downward sloping surface 268).

[0051] The blades may take a variety of forms, including that of a crescent. Thus, in some embodiments, each of the blades 150 is formed in a crescent shape (e.g., see blades 150 in view 230 of FIG. 2). Some sensors 310 operate best when a certain amount of standoff distance is maintained between the sensor face and the borehole wall. Other sensors operate best when in full contact between the sensor face and the borehole wall is maintained. The crescent shape can be useful in many embodiments precisely for this reason: there is the flexibility to mount sensors 310 on different locations of the outer surface 272 of the blade 150, depending on the usage of each individual sensor 310. Thus, when a particular crescent-shaped blade 150 is extended to engage the borehole wall, some sensors 310 mounted on the blade will be in direct contact with the wall, and other sensors will be provided with the proper standoff between the sensor face and the wall.

[0052] More than one set of blades may be installed along the length of the tubular member, to form an array of blade sets. Thus in some embodiments, and apparatus 100 comprises multiple sets 810 of the at least two interchangeable blades 150, each of the sets 810 attached to the tubular member 300 at a different longitudinal location (along the longitudinal axis Z).

[0053] A system 1000 may include a controller 1025 coupled to the multi-blade apparatus 100, similar to or identical to the apparatus 100 described previously. That is, in some embodiments the apparatus 100 is operatively coupled to the controller 1025, with the apparatus 100 comprising a tubular member 300 attached to at least two interchangeable blades 150. The blades 150 are extendible radially outward responsive to receiving an extend command issued by the controller 1025, to an extended position, and retractable radially inward responsive to receiving a retract command issued by the controller 1025, to a retracted position. An outer surface 272 of the blades 150 is disposed at or below an outer surface 340 of the tubular member 300 when the blades 150 are in the retracted position.

[0054] In some embodiments, the system 1000 further includes a plurality of sensors 310 attached to the blades 150. The sensors 310 may form a portion of the outer surface 272 of the blades 150. The sensors 310 are attached to the blades 150 so as to engage a circumferential portion of a borehole wall along the outer surface 272 of the blades 150 in an azimuthal direction when the blades 150 are disposed downhole in the extended position. The sensors 310 are also attached to the blades 150 so as to refrain from engaging the borehole wall when the blades 150 are disposed downhole in the retracted position. In some embodiments, a processing unit 1002 is coupled to the apparatus in lieu of the controller 1025, the processing unit 1002 programmed to issue the commands to extend and retract. In some embodiments, the system 1000 comprises both a processing unit 1002 and a controller 1025, with the controller 1025 receiving the extend and retract commands from the processing unit 1002, and the controller 1025 operating as an interface to a controlled device 1070 comprises extension/retraction mechanisms (e.g., gears, hydraulic actuators, etc.).

[0055] The multi-blade apparatus can operate as a passive stabilizer. Thus, in some embodiments, the tubular member 300 comprises a portion of a drill string 940, and the apparatus 100 operates as a passive stabilizer to centralize the drill string 940 when the blades 150 are in the extended position (e.g., see view 920 in FIG. 9).

[0056] When retracted, the outer surface of the blades may operate to form part of the outer surface of the tubular member. Thus, in some embodiments, the outer surface 272 of the blades 150 operate to complete the outer surface of the tubular member 300 when the blades are in the retracted position (e.g., see views 430, 530, 630 in FIGs. 4, 5, 6, respectively).

[0057] The apparatus 100, system 1000, and each of their elements may all be characterized as "modules" herein. Such modules may include hardware circuitry, and/or a processor and/or memory circuits, software program modules and objects, and/or firmware, and combinations thereof, as desired by the architect of the apparatus 100 and systems 1000, and as appropriate for particular implementations of various embodiments. For example, in some embodiments, such modules may be included in an apparatus 100 and/or system 1000 operation

simulation package, such as a software electrical signal simulation package, a power usage and distribution simulation package, a power/heat dissipation simulation package, a formation imaging package, an energy detection and measurement package, and/or a combination of software and hardware used to simulate the operation of various potential embodiments.

[0058] It should also be understood that the apparatus 100 and systems 1000 of various embodiments can be used in applications other than for logging operations, and thus, various embodiments are not to be so limited. The illustrations of apparatus 100 and systems 1000 are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein.

[0059] Applications that may include the novel apparatus and systems of various embodiments include electronic circuitry used in high-speed computers, communication and signal processing circuitry, modems, processor modules, embedded processors, data switches, and application-specific modules. Such apparatus and systems may further be included as sub-components within a variety of electronic systems, such as televisions, cellular telephones, personal computers, workstations, radios, vehicles, geothermal tools, and smart transducer interface node telemetry systems, among others. Some embodiments include a number of methods.

Methods

[0060] FIG. 11 is a flow chart illustrating several methods 1111 according to various embodiments of the invention. The methods 1111 may comprise processor-implemented methods, to execute on one or more processors that perform the methods. For example, one embodiment of the methods 1111 may begin at block 1121 with lowering the apparatus with retracted blades into a borehole, and extending the blades to engage the borehole wall at block 1125.

[0061] In some embodiments, a method 1111 begins at block 1121 with lowering a tubular member into a borehole while at least two interchangeable blades attached to the tubular member are in a retracted position, with the blades being retractable radially inward from an extended position to the retracted

position. When in the retracted position, the outer surface of each of the blades is disposed at or below the outer surface of the tubular member.

[0062] The method 1111 includes, in some embodiments, extending the blades radially outward into the extended position at block 1125 to engage, by the outer surface of each one of the blades and a plurality of sensors forming a portion of the outer surface of each one of the blades in an azimuthal direction, a circumferential portion of a wall of the borehole.

[0063] To extend the blades, a geared mechanism or an actuator can be used. Thus, in some embodiments, the activity at block 1125 further comprises rotating a geared mechanism or activating an electromagnetic, piezoelectric, shape memory alloy, or hydraulic actuator attached to the blades.

[0064] The blades can be extended until a certain preselected amount of resistive counter-force is measured with respect to one or more of the blades, or until a substantially equal counter-force is measured on each blade. Thus, in some embodiments, the activity at block 1125 further comprises measuring a resistance force encountered by one or more of the blades, and ceasing to extend the blades when a preselected amount of the resistance force is measured.

[0065] Sensor data can be acquired from different sensor types. Thus, in some embodiments, the method 1111 comprises, at block 1129, acquiring sensor data from the plurality of sensors, wherein at least two different sensor types are located on at least one of the blades.

[0066] The blades can be retracted to enable drilling operations, and then the blades can be extended to stabilize the tubular member, as well as the attached drill string. Thus, in some embodiments, the method 1111 includes retracting the blades radially inward into the retracted position at block 1131, and drilling into a geological formation surrounding the borehole at block 1133, to extend the length of the borehole, using a drill string that includes the tubular member.

[0067] In some embodiments, the method 1111 may return to block 1125, to include extending the blades radially outward into the extended position to stabilize the drill string within the borehole. In some embodiments, the method 1111 may continue from block 1133 to return to 1121, to repeat the activities designated therein, as well as in the other blocks of the method 1111.

[0068] It should be noted that the methods described herein do not have to be executed in the order described, or in any particular order. Moreover, various activities described with respect to the methods identified herein can be executed in iterative, serial, or parallel fashion. The various elements of each method (e.g., the methods shown in FIG. 11) can be substituted, one for another, within and between methods. Information, including parameters, commands, operands, and other data, can be sent and received in the form of one or more carrier waves.

[0069] Upon reading and comprehending the content of this disclosure, one of ordinary skill in the art will understand the manner in which a software program can be launched from a computer-readable medium in a computer-based system to execute the functions defined in the software program. One of ordinary skill in the art will further understand the various programming languages that may be employed to create one or more software programs designed to implement and perform the methods disclosed herein.

[0070] For example, the programs may be structured in an object-orientated format using an object-oriented language such as Java or C#. In another example, the programs can be structured in a procedure-orientated format using a procedural language, such as assembly or C. The software components may communicate using any of a number of mechanisms well known to those of ordinary skill in the art, such as application program interfaces or interprocess communication techniques, including remote procedure calls. The teachings of various embodiments are not limited to any particular programming language or environment. Thus, other embodiments may be realized.

Wireline and Drilling Systems

[0071] For example, FIG. 12 illustrates a wireline system 1264, according to various embodiments of the invention. FIG. 13 illustrates a drilling rig system 1364, according to various embodiments of the invention. Therefore, the systems 1264, 1364 may comprise portions of a wireline logging tool body 1270 as part of a wireline logging operation, or of a downhole tool 1324 as part of a downhole drilling operation. The systems 1264 and 1364 may include any one or more elements of the apparatus 100 and systems 1000 shown in FIGs. 1-10.

[0072] Thus, FIG. 12 shows a well during wireline logging operations. In this case, a drilling platform 1286 is equipped with a derrick 1288 that supports a hoist 1290.

[0073] Drilling oil and gas wells is commonly carried out using a string of drill pipes connected together so as to form a drilling string that is lowered through a rotary table 1210 into a wellbore or borehole 1212. Here it is assumed that the drilling string has been temporarily removed from the borehole 1212 to allow a wireline logging tool body 1270, such as a probe or sonde, to be lowered by wireline or logging cable 1274 into the borehole 1212. Typically, the wireline logging tool body 1270 is lowered to the bottom of the region of interest and subsequently pulled upward at a substantially constant speed.

[0074] During the upward trip, at a series of depths, various instruments included in the tool body 1270 may be used to perform measurements (e.g., made by sensors 310 attached to the apparatus 100 shown in FIG. 3) on the subsurface geological formations 1214 adjacent the borehole 1212 (and the tool body 1270). The borehole 1212 may represent one or more offset wells, or a target well. The blades in the apparatus 100 may be extended and retracted as desired, perhaps to secure the position of the tool body 1270 in a more centralized position in the borehole 1212.

[0075] The measurement data can be communicated to a surface logging facility 1292 for processing, analysis, and/or storage. The logging facility 1292 may be provided with electronic equipment for various types of signal processing, which may be implemented by any one or more of the components of the system 1000 in FIG. 10. Similar formation evaluation data may be gathered and analyzed during drilling operations (e.g., during logging while drilling operations, and by extension, sampling while drilling).

[0076] In some embodiments, the tool body 1270 is suspended in the wellbore by a wireline cable 1274 that connects the tool to a surface control unit (e.g., comprising a workstation 1254). The tool may be deployed in the borehole 1212 on coiled tubing, jointed drill pipe, hard wired drill pipe, or any other suitable deployment technique.

[0077] Turning now to FIG. 13, it can be seen how a system 1364 may also form a portion of a drilling rig 1302 located at the surface 1304 of a well 1306. The drilling rig 1302 may provide support for a drill string 1308. The drill string 1308 may operate to penetrate the rotary table 1210 for drilling the borehole 1212 through the subsurface formations 1214. The drill string 1308 may include a Kelly 1316, drill pipe 1318, and a bottom hole assembly 1320, perhaps located at the lower portion of the drill pipe 1318.

[0078] The bottom hole assembly 1320 may include drill collars 1322, a downhole tool 1324, and a drill bit 1326. The drill bit 1326 may operate to create the borehole 1212 by penetrating the surface 1304 and the subsurface formations 1214. The downhole tool 1324 may comprise any of a number of different types of tools including MWD tools, LWD tools, and others.

[0079] During drilling operations, the drill string 1308 (perhaps including the Kelly 1316, the drill pipe 1318, and the bottom hole assembly 1320) may be rotated by the rotary table 1210. Although not shown, in addition to, or alternatively, the bottom hole assembly 1320 may also be rotated by a motor (e.g., a mud motor) that is located downhole. The drill collars 1322 may be used to add weight to the drill bit 1326. The drill collars 1322 may also operate to stiffen the bottom hole assembly 1320, allowing the bottom hole assembly 1320 to transfer the added weight to the drill bit 1326, and in turn, to assist the drill bit 1326 in penetrating the surface 1304 and subsurface formations 1214.

[0080] During drilling operations, a mud pump 1332 may pump drilling fluid (sometimes known by those of ordinary skill in the art as "drilling mud") from a mud pit 1334 through a hose 1336 into the drill pipe 1318 and down to the drill bit 1326. The drilling fluid can flow out from the drill bit 1326 and be returned to the surface 1304 through an annular area between the drill pipe 1318 and the sides of the borehole 1212. The drilling fluid may then be returned to the mud pit 1334, where such fluid is filtered. In some embodiments, the drilling fluid can be used to cool the drill bit 1326, as well as to provide lubrication for the drill bit 1326 during drilling operations. Additionally, the drilling fluid may be used to remove subsurface formation cuttings created by operating the drill bit 1326.

[0081] In light of the foregoing discussion, it may be seen that in some embodiments, the system 1364 may include a drill collar 1322 and/or a downhole tool 1324 to house one or more systems 1000, including some or all of the components thereof. Thus, for the purposes of this document, the term "housing" may include any one or more of a drill collar 1322, or a crossover sub (see FIG. 1), or a downhole tool 1324 (each having an outer wall, to enclose or attach to blades to which magnetometers, sensors, fluid sampling devices, pressure measurement devices, transmitters, receivers, fiber optic cable, acquisition and processing logic, and data acquisition systems, are attached). Many embodiments may thus be realized.

[0082] Thus, referring now to FIGs. 1-10 and 12-13, it may be seen that in some embodiments, the systems 1264, 1364 may include a drill collar 1322, a crossover sub (see FIG. 1) as part a downhole tool 1324, and/or a wireline logging tool body 1270 to house one or more apparatus 100, similar to or identical to the apparatus 100 described above and illustrated in the figures. Any and all components of the system 1000 shown in FIG. 10 may also be housed by the tool 1324 or the tool body 1270.

[0083] The tool 1324 may comprise a downhole tool, such as an LWD tool or an MWD tool. The wireline tool body 1270 may comprise a wireline logging tool, including a probe or sonde, for example, coupled to a logging cable 1274. Many embodiments may thus be realized, and a list of some of them follows.

Additional Example Embodiments

[0084] In some embodiments, an apparatus comprises a tubular member and at least two interchangeable blades attached to the tubular member. The blades are extendible radially outward to an extended position and retractable radially inward to a retracted position. The outer surface of the blades is disposed at or below an outer surface of the tubular member when the blades are in the retracted position.

[0085] In some embodiments, the apparatus further comprise a plurality of sensors forming a portion of the outer surface of the blades, wherein the sensors are used to engage a circumferential portion of a borehole wall along the outer surface of the blades in an azimuthal direction when the blades are disposed

downhole in the extended position. The sensors are attached to the blades so as to refrain from engaging the borehole wall when the blades are disposed downhole in the retracted position.

[0086] In some embodiments, the tubular member comprises one of a drilling collar, a crossover sub, or a bottom hole assembly.

[0087] In some embodiments, the at least two interchangeable blades comprise identical blades. In some embodiments, some of the interchangeable blades comprise identical blades, and some of the interchangeable blades do not comprise identical blades.

[0088] In some embodiments, the at least two interchangeable blades comprise three or four interchangeable blades. In some embodiments, each of the blades occupies a substantially similar portion of a circumference of the tubular member when the blades are in the retracted position.

[0089] In some embodiments, each of the blades overlap at least one other one of the blades along the circumference of the tubular member when the blades are in the retracted position. In some embodiments, each of the blades overlap at least two other blades along the circumference of the tubular member when the blades are in the retracted position.

[0090] In some embodiments, gears, electromagnetic, piezoelectric, shape memory alloy, and/or hydraulic actuators are used to couple the tubular member to the blades.

[0091] In some embodiments, the plurality of sensors comprise at least two different sensor types arranged on one of the blades. In some embodiments, the plurality of sensors on each blade are identical. In some embodiments, the sensors comprise one or more transducers. In some embodiments, the transducers are attached to a single blade. In some embodiments, each transducer is attached to a different blade.

[0092] In some embodiments, each of the blades includes end pieces that engage end pieces of other blades in a mirrored fashion when the blades are in the retracted position.

[0093] In some embodiments, the outer surface of the blades substantially conforms to the outer surface of the tubular member, to form a substantially

complete and continuous outer surface, when the blades are in the retracted position.

[0094] In some embodiments, one or more (or all) of the blades is attached to the tubular member at a single point of rotation. In some embodiments, the single point of rotation comprises an aperture in the blade extending in a longitudinal direction of the tubular member and located on an interlocking portion of the blade.

[0095] In some embodiments, each of the blades is formed in a crescent shape. Some embodiments comprise multiple sets of the at least two interchangeable blades, each of the sets attached to the tubular member at a different longitudinal location. The sets may be arranged to form an array of sonic transducers, or antennas, for example.

[0096] In some embodiments, a system comprises a controller and an apparatus operatively coupled to the controller. In some of these embodiments, the apparatus comprises a tubular member attached to at least two interchangeable blades, the blades being extendible radially outward responsive to receiving an extend command issued by the controller, to an extended position, and retractable radially inward responsive to receiving a retract command issued by the controller, to a retracted position. The outer surface of the blades is disposed at or below an outer surface of the tubular member when the blades are in the retracted position. In some embodiments, the outer surface of the blades operate to complete the outer surface of the tubular member when the blades are in the retracted position.

[0097] In some embodiments, the system comprises a plurality of sensors forming a portion of the outer surface of the blades, wherein the sensors are to engage a circumferential portion of a borehole wall along the outer surface of the blades in an azimuthal direction when the blades are disposed downhole in the extended position, and to refrain from engaging the borehole wall when the blades are disposed downhole in the retracted position.

[0098] In some embodiments, the tubular member comprises a portion of a drill string, wherein the apparatus operates as a passive stabilizer to centralize the drill string when the blades are in the extended position. This centralizing

operation may occur when the tubular member is used in a wireline operation, or a drilling operation, among others.

[0099] In some embodiments, a method comprises lowering a tubular member into a borehole while at least two interchangeable blades attached to the tubular member are in a retracted position. The blades are retractable radially inward from an extended position to the retracted position, wherein an outer surface of each of the blades is disposed at or below an outer surface of the tubular member when the blades are in the retracted position.

[00100] In some embodiments, a method comprises extending the blades radially outward into the extended position to engage, by the outer surface of each one of the blades and a plurality of sensors attached to the blades in an azimuthal direction, a circumferential portion of a wall of the borehole. In some embodiments, the plurality of sensors form a portion of the outer surface of at least some of the blades in the azimuthal direction.

[00101] In some embodiments, extending the blades further comprises rotating a geared mechanism or activating an electromagnetic, piezoelectric, shape memory alloy, or hydraulic actuator attached to the blades.

[00102] In some embodiments, a method comprises measuring a resistance force encountered by one or more of the blades. The method may further include ceasing to extend the blades when a preselected amount of the resistance force is measured.

[00103] In some embodiments, a method comprises acquiring sensor data from the plurality of sensors, wherein at least two different sensor types are located on at least one of the blades. In some embodiments, the same sensors types are located on each of the blades.

[00104] In some embodiments, a method comprises retracting the blades radially inward into the retracted position. In some embodiments, the method may further include drilling into a geological formation surrounding the borehole, to extend a length of the borehole, using a drill string that includes the tubular member. In some embodiments, the method may further include extending the blades radially outward into the extended position to stabilize the drill string within the borehole. After reading the information disclosed herein,

those of ordinary skill in the art will realize that many other embodiments may be realized, but in the interest of brevity, these are not listed here.

Conclusion

[00105] In summary, the apparatus, systems, and methods disclosed herein differ from conventional sensor mounting apparatus in that the sensor-mounted structures may be fabricated as two, three, or four (or more) blades which are crescent-shaped. Multiple sensors can be located on each blade to provide different sensing services at any given circumferential location around the wall of the borehole. The blades are interchangeable, so that repairs are relatively inexpensive (e.g., a single blade can be replaced, instead of an entire collar), and changes in sensing service can be made relatively easily as well.

[00106] Another difference in most embodiments is the mechanism used to couple the sensors to the borehole wall. Due to the crescent shape of the blades, circumferential coupling is provided, rather than point coupling. This enhances the connection between the sensor and the formation. The proximity of the sensor to the borehole wall enable the acquisition of more accurate data, reducing noise created by the tools and surrounding environment. In short, the overall construction of the various embodiments provides great flexibility, at relatively low cost. As a result, the value of services provided by an operation/exploration company may be significantly enhanced.

[00107] The accompanying drawings that form a part hereof, show by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[00108] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term “invention” merely for

convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[00109] The Abstract of the Disclosure is provided to comply with 37 C.F.R. §1.72(b), requiring an abstract that will allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

Claims

What is claimed is:

1. An apparatus, comprising:

a tubular member;

at least two interchangeable blades attached to the tubular member, the blades extendible radially outward to an extended position and retractable radially inward to a retracted position, wherein an outer surface of the blades is disposed at or below an outer surface of the tubular member when the blades are in the retracted position; and

a plurality of sensors attached to the blades, the sensors to engage a circumferential portion of a borehole wall along the outer surface of the blades in an azimuthal direction when the blades are disposed downhole in the extended position, and to refrain from engaging the borehole wall when the blades are disposed downhole in the retracted position.

2. The apparatus of claim 1, wherein the tubular member comprises one of a drilling collar or a crossover sub.

3. The apparatus of claim 1, wherein the at least two interchangeable blades comprise identical blades.

4. The apparatus of claim 1, wherein the at least two interchangeable blades comprise three or four interchangeable blades, each of the blades occupying a substantially similar portion of a circumference of the tubular member when the blades are in the retracted position.

5. The apparatus of claim 1, wherein each of the blades overlap at least one other one of the blades along the circumference of the tubular member when the blades are in the retracted position.

6. The apparatus of claim 1, further comprising:

gears, electromagnetic, piezoelectric, shape memory alloy, or hydraulic actuators to couple the tubular member to the blades.

7. The apparatus of claim 1, wherein the plurality of sensors comprise at least two different sensor types arranged on one of the blades.

8. The apparatus of claim 1, wherein each of the blades includes end pieces that engage end pieces of other blades in a mirrored fashion when the blades are in the retracted position.

9. The apparatus of claim 1, wherein the outer surface of the blades substantially conforms to the outer surface of the tubular member, to form a substantially continuous outer surface, when the blades are in the retracted position.

10. The apparatus of claim 1, wherein each of the blades is attached to the tubular member at a single point of rotation.

11. The apparatus of claim 10, wherein the single point of rotation comprises an aperture in the blade extending in a longitudinal direction of the tubular member and located on an interlocking portion of the blade.

12. The apparatus of claim 1, wherein the sensors comprise at least one transducer.

13. The apparatus of claim 1, wherein each of the blades is formed in a crescent shape.

14. The apparatus of claim 1, further comprising:

multiple sets of the at least two interchangeable blades, each of the sets attached to the tubular member at a different longitudinal location.

15. The apparatus of claim 1, wherein at least some of the plurality of sensors form a portion of the outer surface of the blades.

16. A system, comprising:

a controller; and

an apparatus operatively coupled to the controller, the apparatus comprising a tubular member attached to at least two interchangeable blades, the blades extendible radially outward responsive to receiving an extend command issued by the controller, to an extended position, and retractable radially inward responsive to receiving a retract command issued by the controller, to a retracted position, wherein an outer surface of the blades is disposed at or below an outer surface of the tubular member when the blades are in the retracted position; and a plurality of sensors attached to the blades, the sensors to engage a circumferential portion of a borehole wall along the outer surface of the blades in an azimuthal direction when the blades are disposed downhole in the extended position, and to refrain from engaging the borehole wall when the blades are disposed downhole in the retracted position.

17. The system of claim 16, wherein the tubular member comprises a portion of a drill string, and wherein the apparatus operates as a passive stabilizer to centralize the drill string when the blades are in the extended position.

18. The system of claim 16, wherein the outer surface of the blades operate to complete the outer surface of the tubular member when the blades are in the retracted position.

19. A method, comprising:

lowering a tubular member into a borehole while at least two interchangeable blades attached to the tubular member are in a retracted position, the blades retractable radially inward from an extended position to the retracted position, wherein an outer surface of each of the blades is disposed at or below

an outer surface of the tubular member when the blades are in the retracted position; and

extending the blades radially outward into the extended position to engage, by the outer surface of each one of the blades and a plurality of sensors attached to the blades in an azimuthal direction, a circumferential portion of a wall of the borehole.

20. The method of claim 19, wherein extending the blades further comprises:

rotating a geared mechanism or activating an electromagnetic, piezoelectric, shape memory alloy, or hydraulic actuator attached to the blades.

21. The method of claim 19, further comprising:

measuring a resistance force encountered by one or more of the blades; and

ceasing to extend the blades when a preselected amount of the resistance force is measured.

22. The method of claim 19, further comprising:

acquiring sensor data from the plurality of sensors, wherein at least two different sensor types are located on at least one of the blades.

23. The method of claim 19, further comprising:

retracting the blades radially inward into the retracted position;

drilling into a geological formation surrounding the borehole, to extend a length of the borehole, using a drill string that includes the tubular member; and

extending the blades radially outward into the extended position to stabilize the drill string within the borehole.

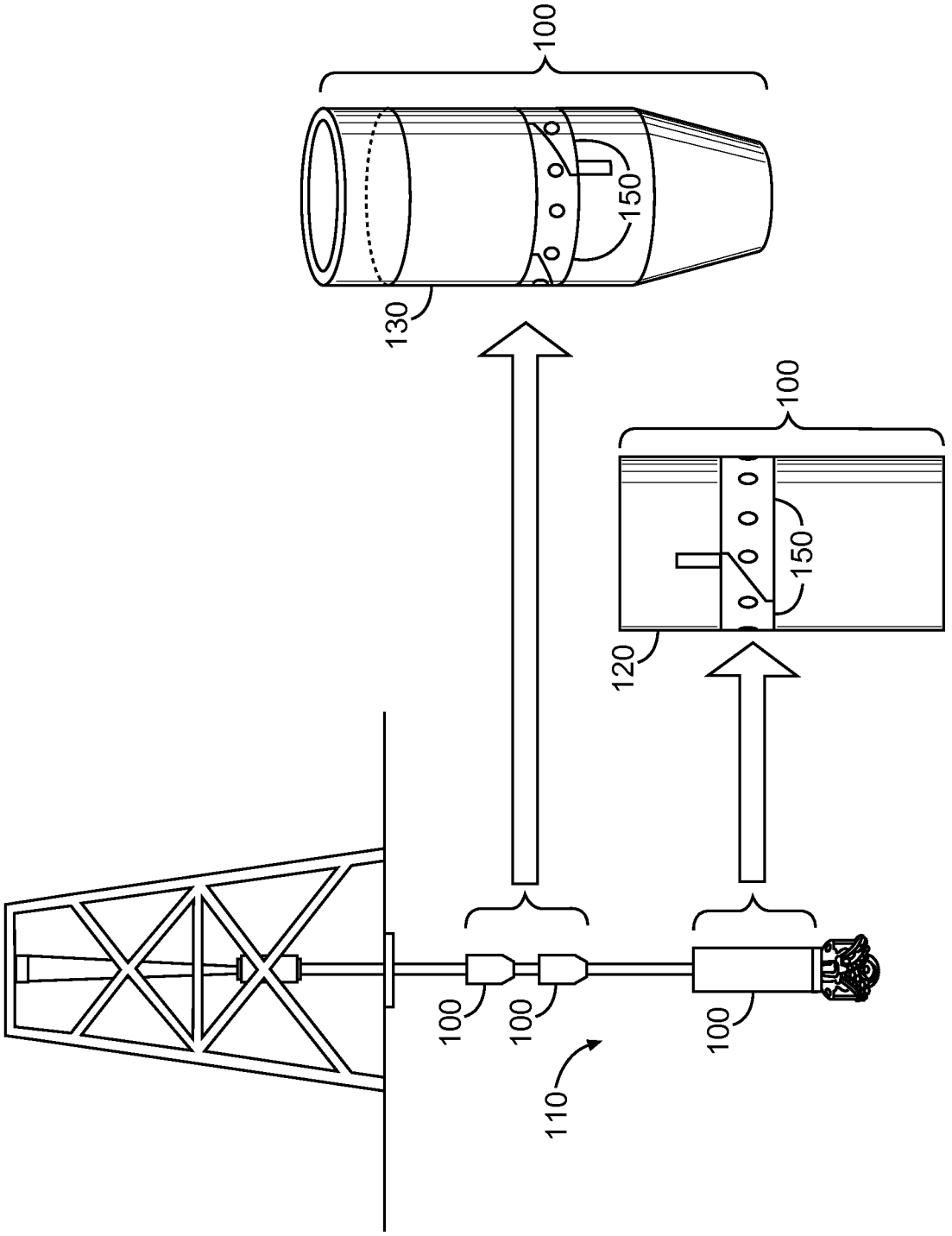


Fig. 1

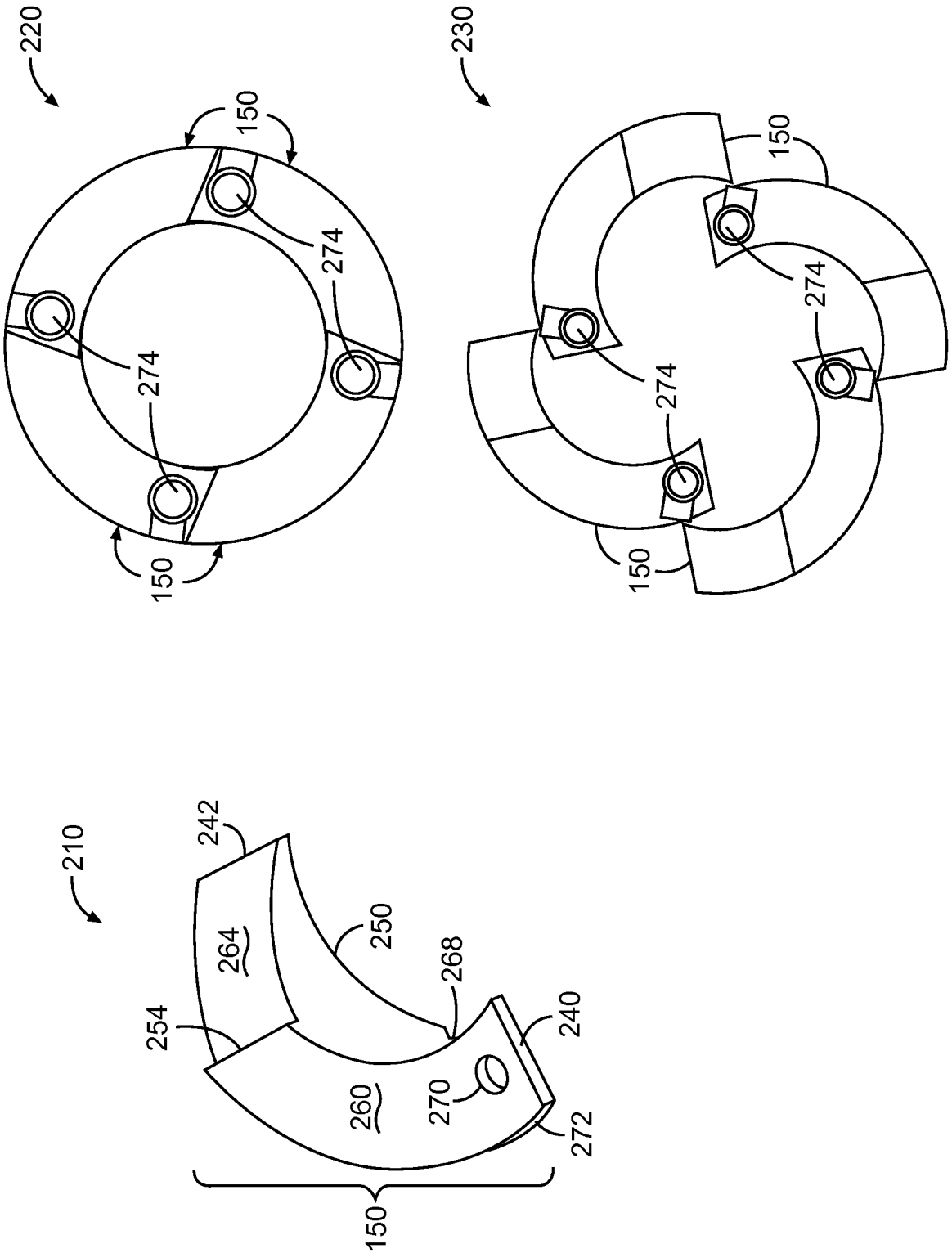

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Fig. 2

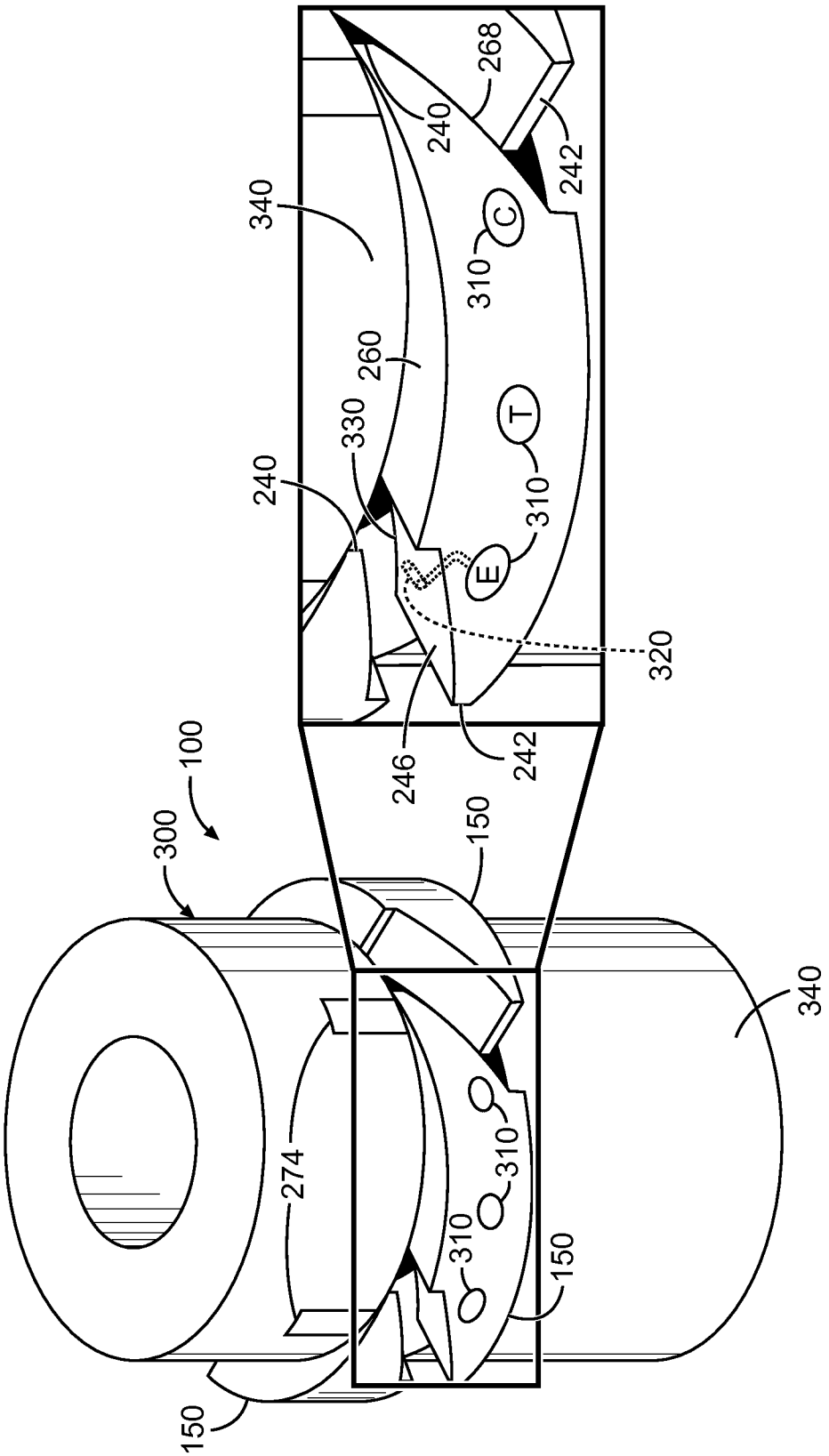

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Fig. 3

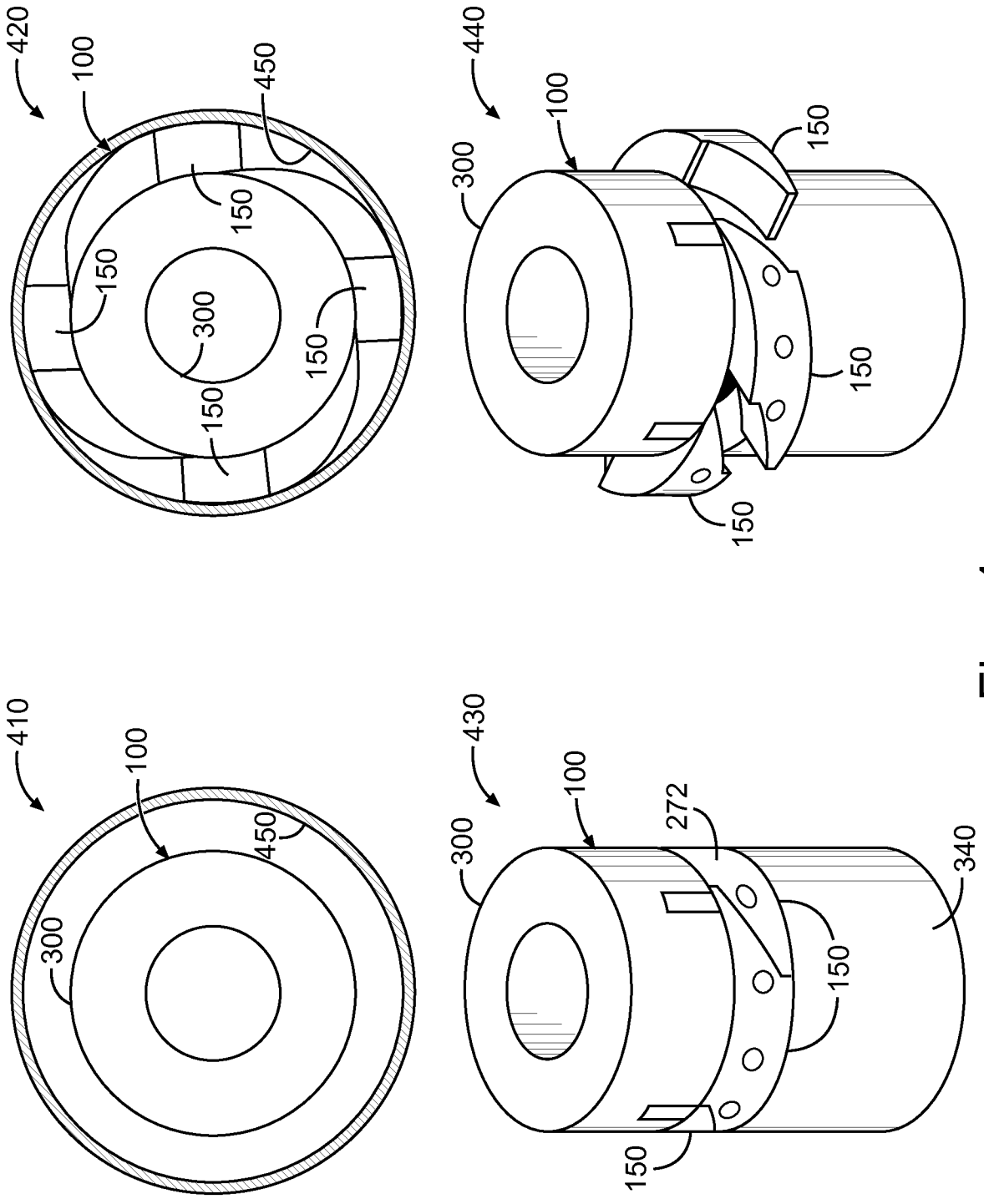

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Fig. 4

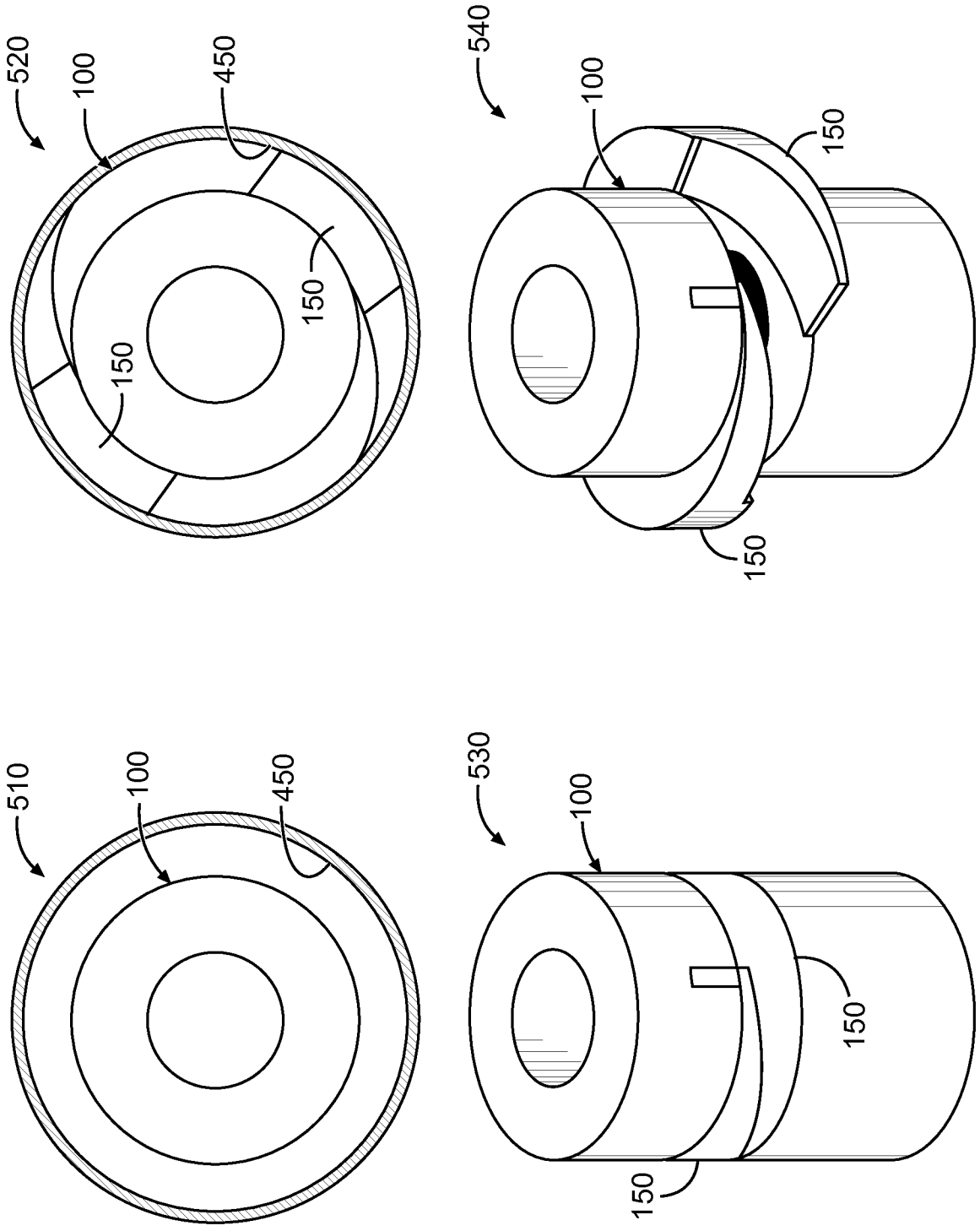


Fig. 5

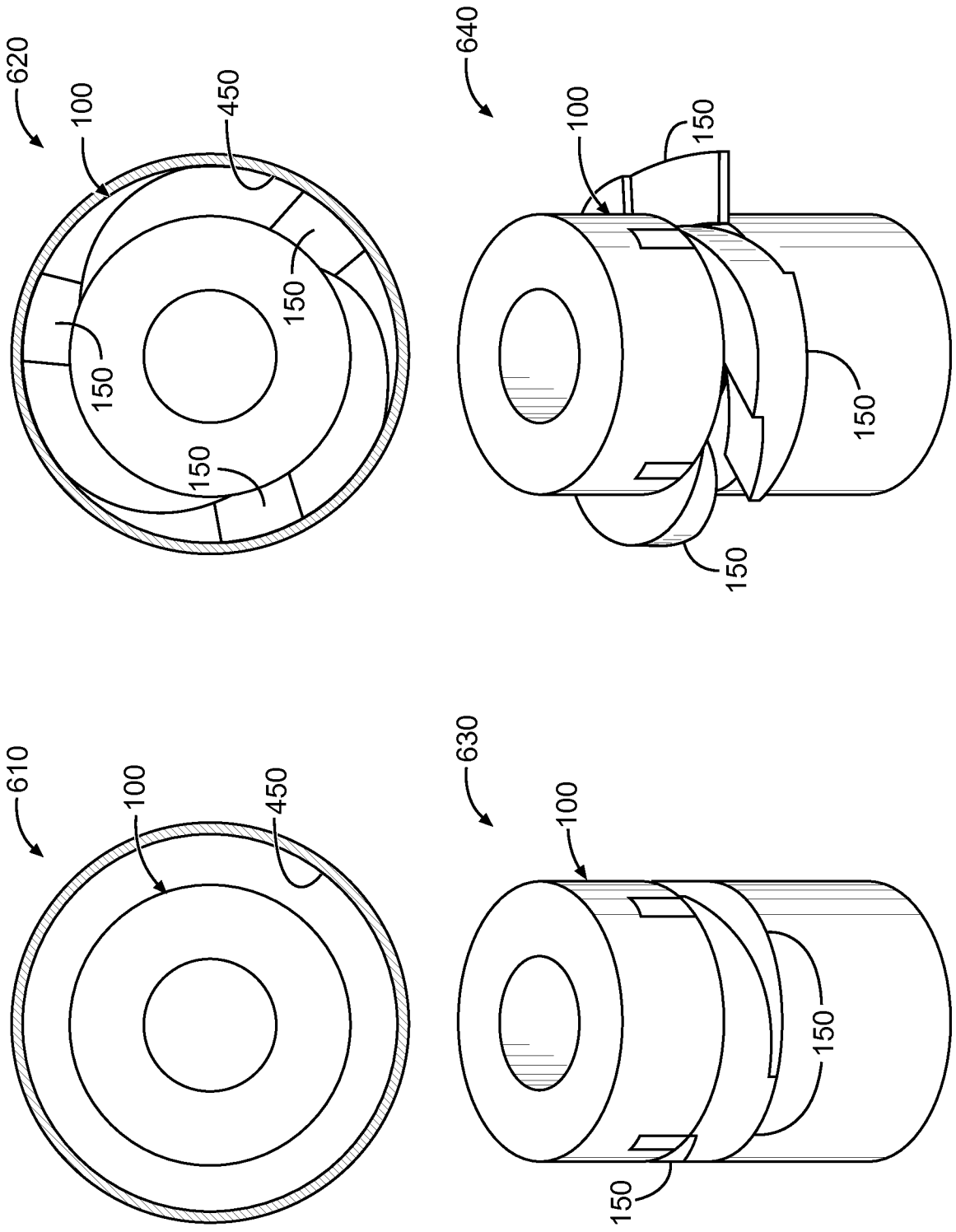

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Fig. 6

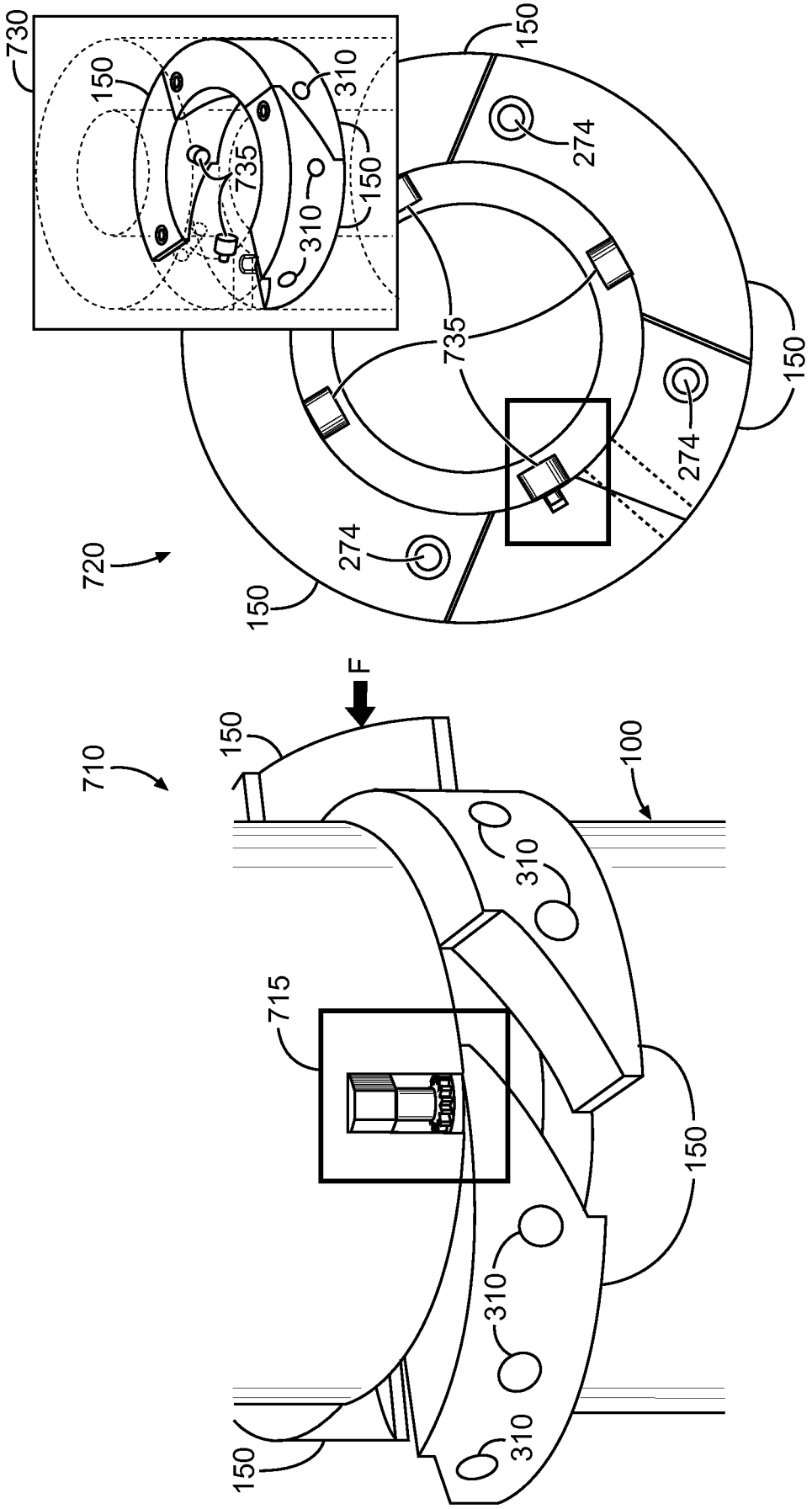

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Fig. 7

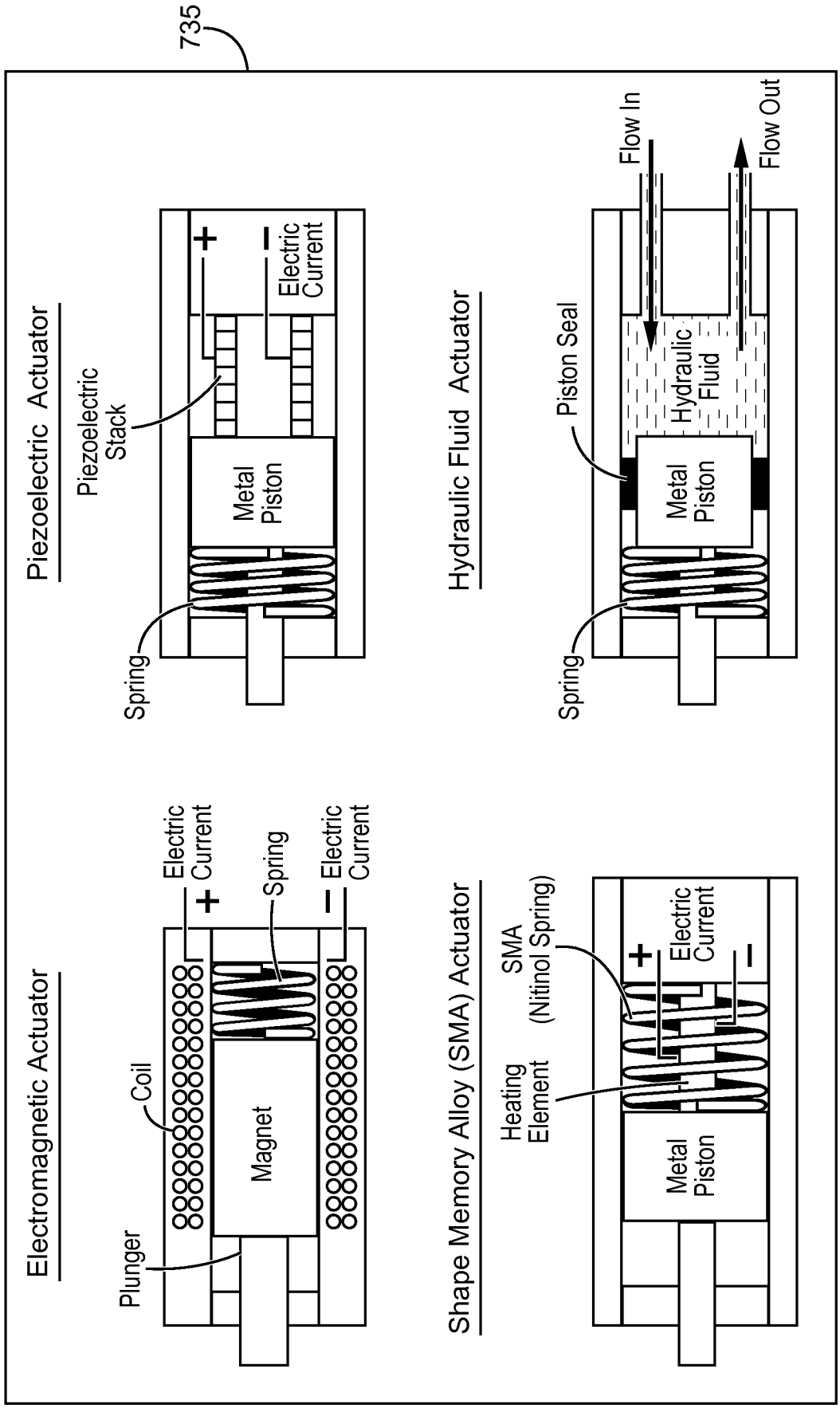

735
Piezoelectric Actuator
Piezoelectric Stack
Metal Piston
Spring
+
−
Electric Current
Hydraulic Fluid Actuator
Flow In
Flow Out
Piston Seal
Hydraulic Fluid
Metal Piston
Spring
Electromagnetic Actuator
Plunger
Coil
Magnet
Spring
Electric Current
Electric Current
Shape Memory Alloy (SMA) Actuator
Heating Element
SMA (Nitinol Spring)
Metal Piston
Electric Current

Fig. 7

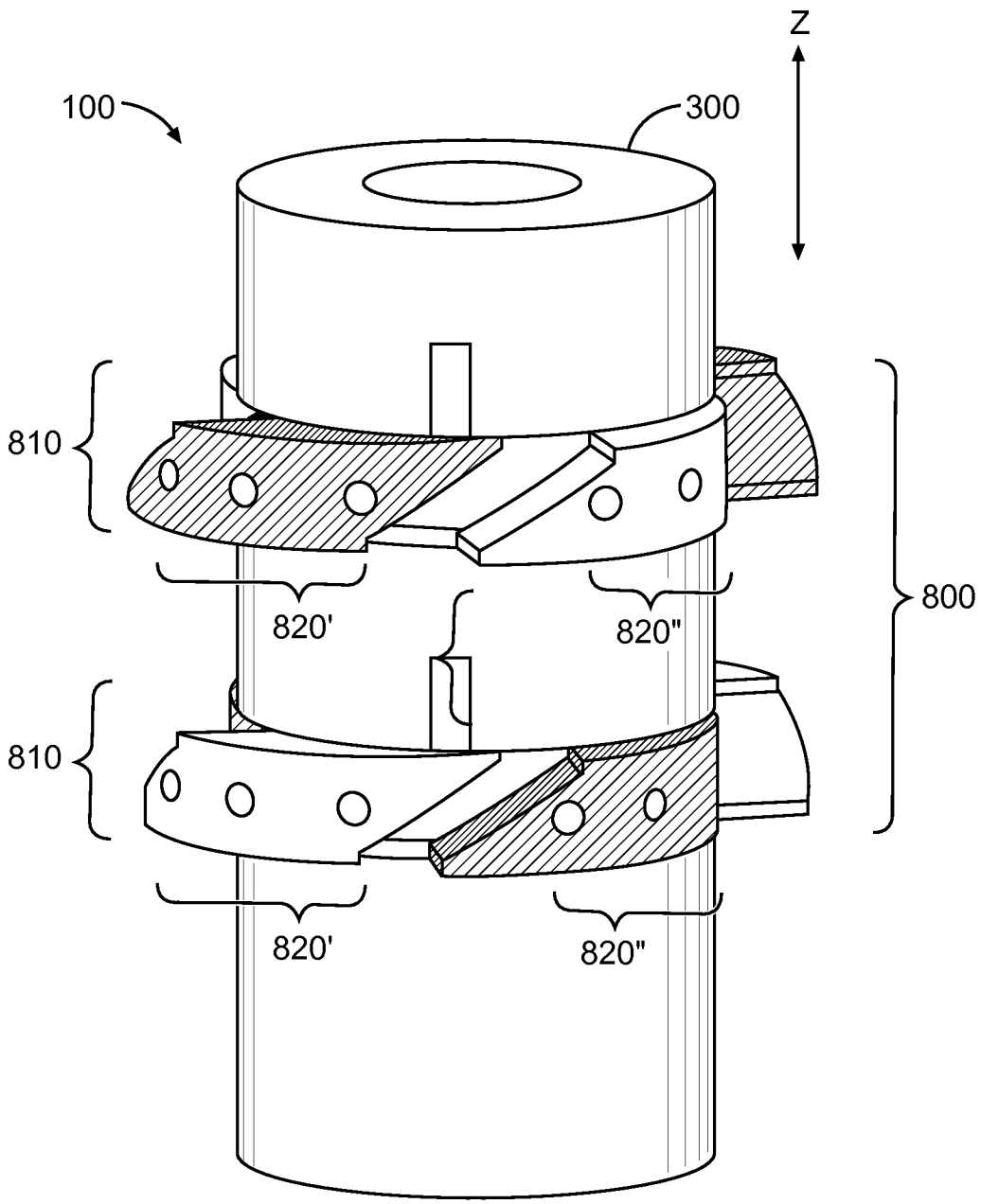


Fig. 8

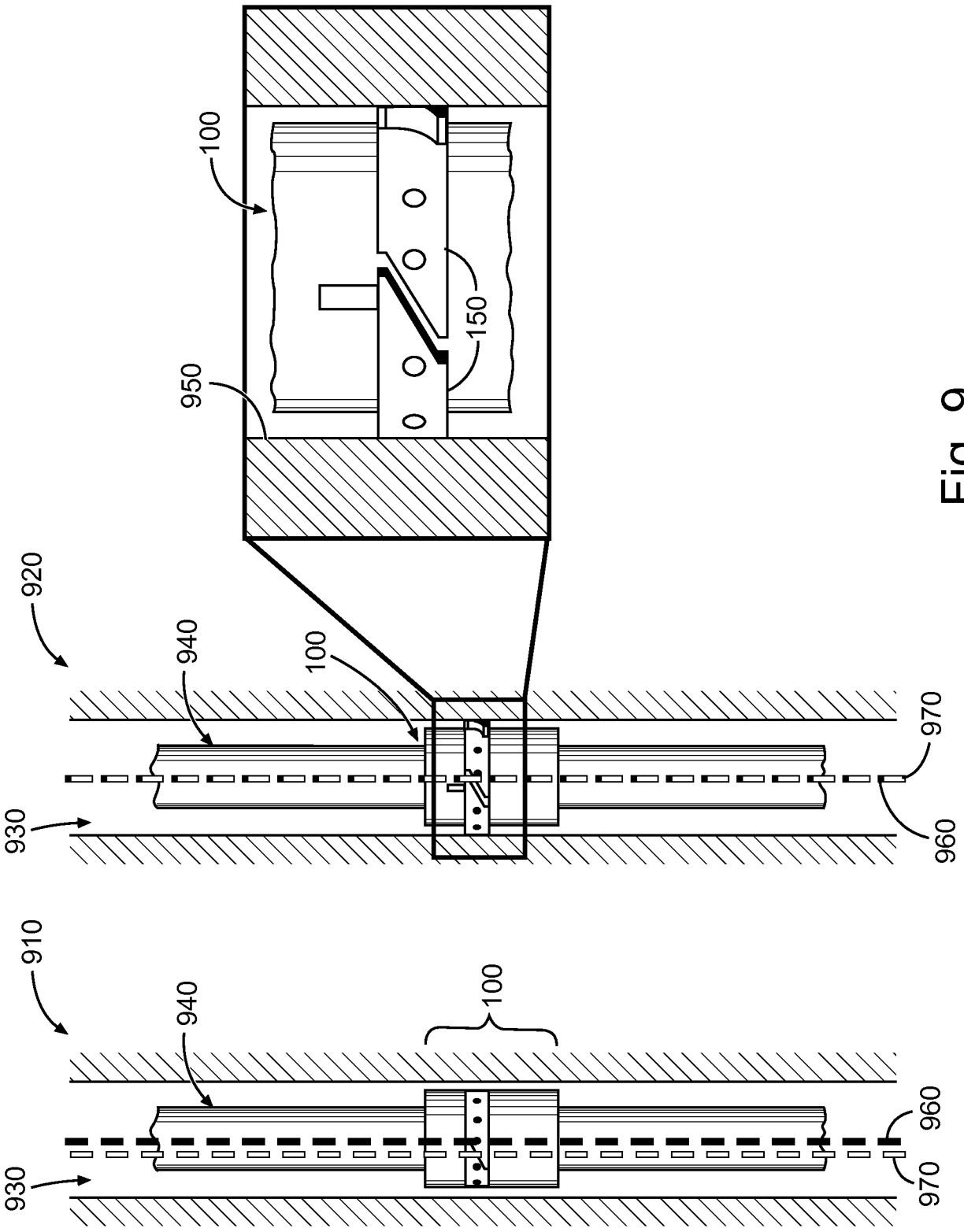


Fig. 9

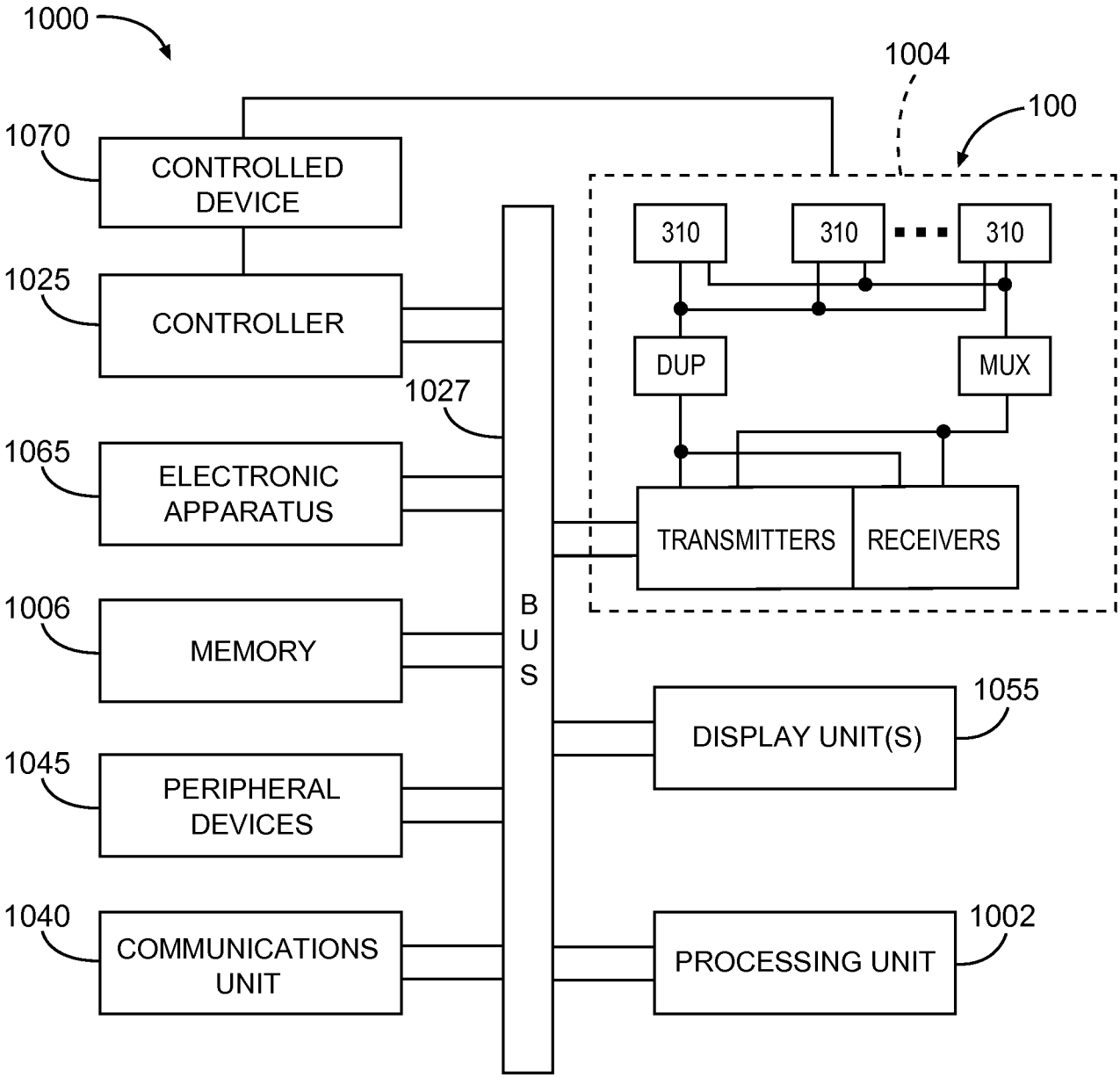

1000
1004
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1070
CONTROLLED DEVICE
1025
CONTROLLER
1027
1065
ELECTRONIC APPARATUS
1006
MEMORY
1045
PERIPHERAL DEVICES
1040
COMMUNICATIONS UNIT
BUS
310
310
310
DUP
MUX
TRANSMITTERS
RECEIVERS
1055
DISPLAY UNIT(S)
1002
PROCESSING UNIT

Fig. 10

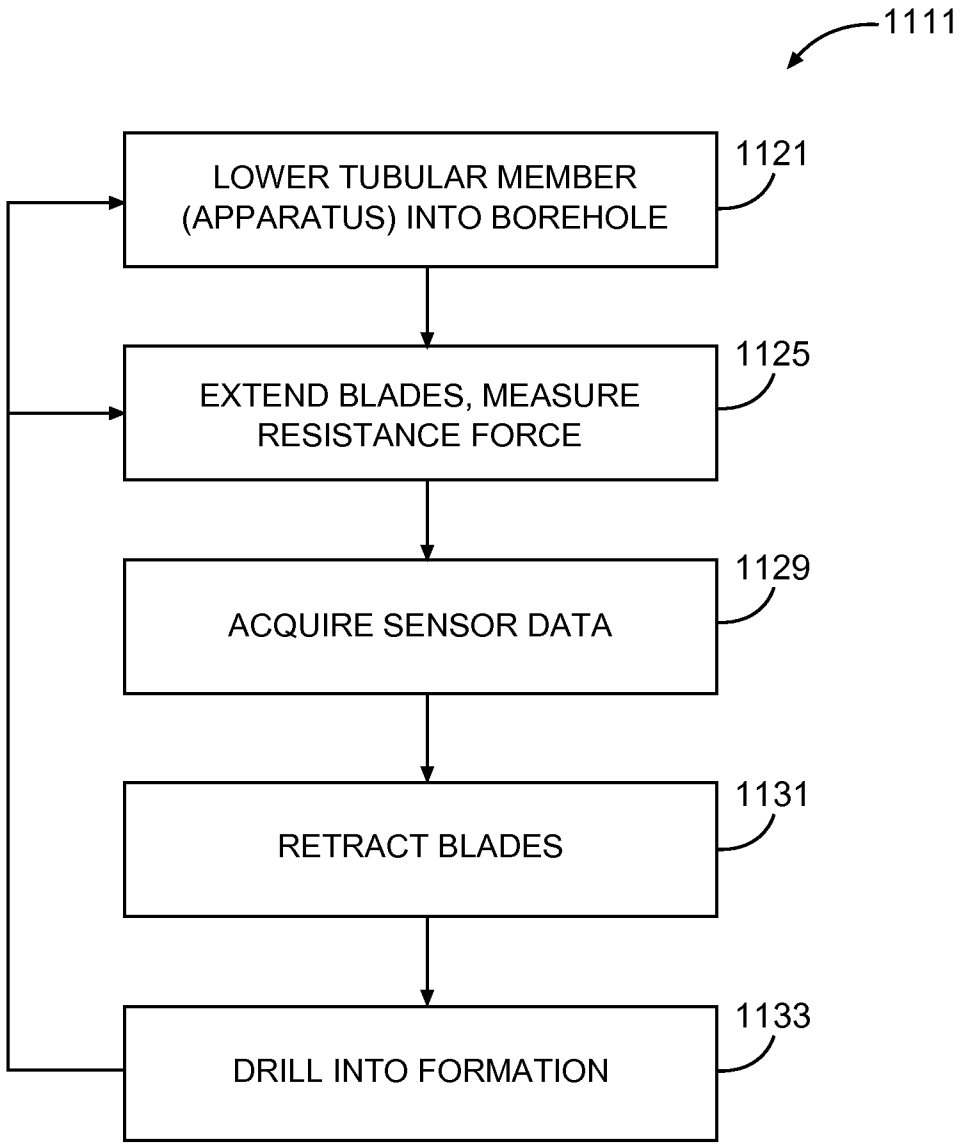

1111
LOWER TUBULAR MEMBER (APPARATUS) INTO BOREHOLE
1121
EXTEND BLADES, MEASURE RESISTANCE FORCE
1125
ACQUIRE SENSOR DATA
1129
RETRACT BLADES
1131
DRILL INTO FORMATION
1133

Fig. 11

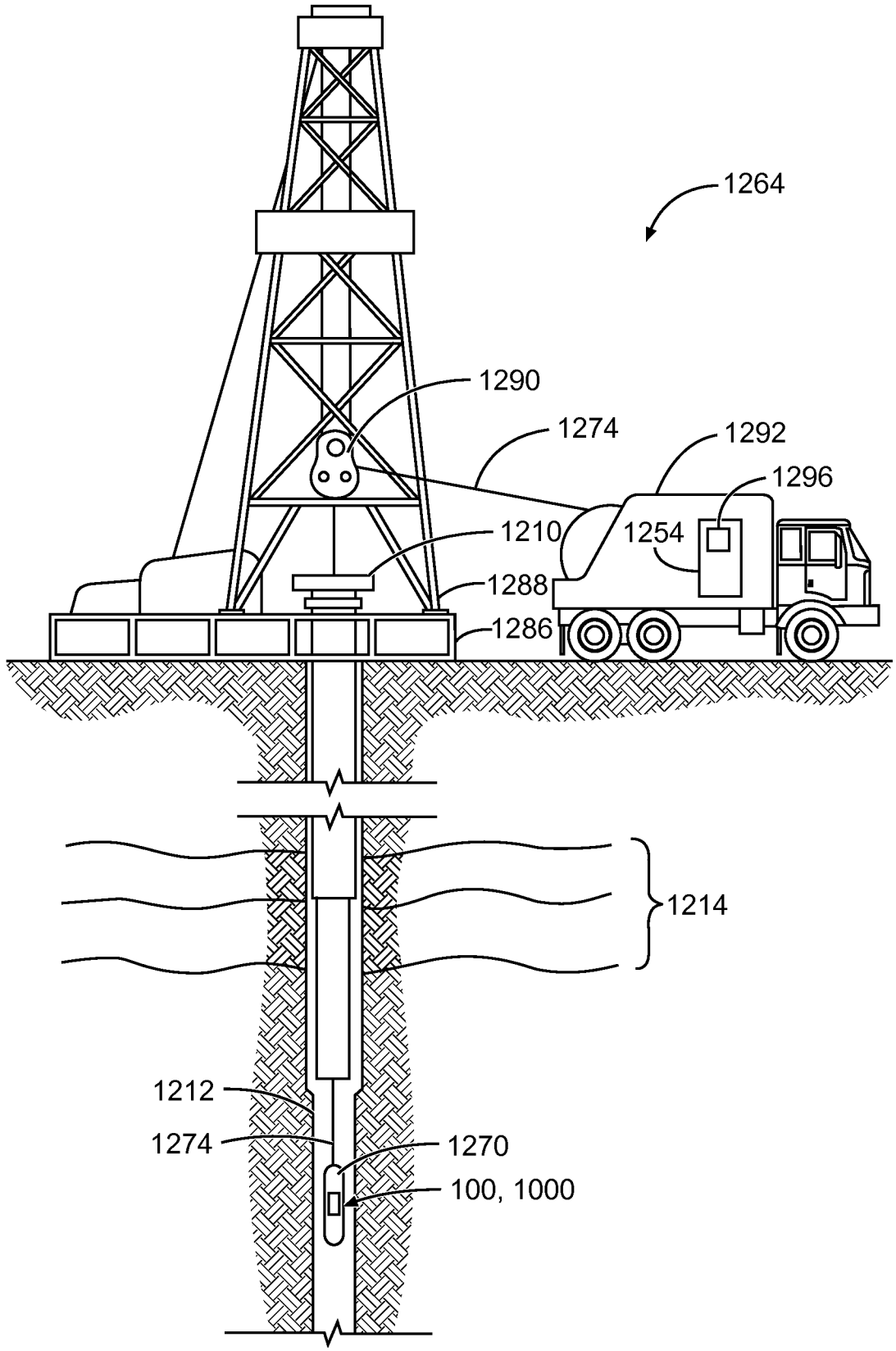

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100, 1000

Fig. 12

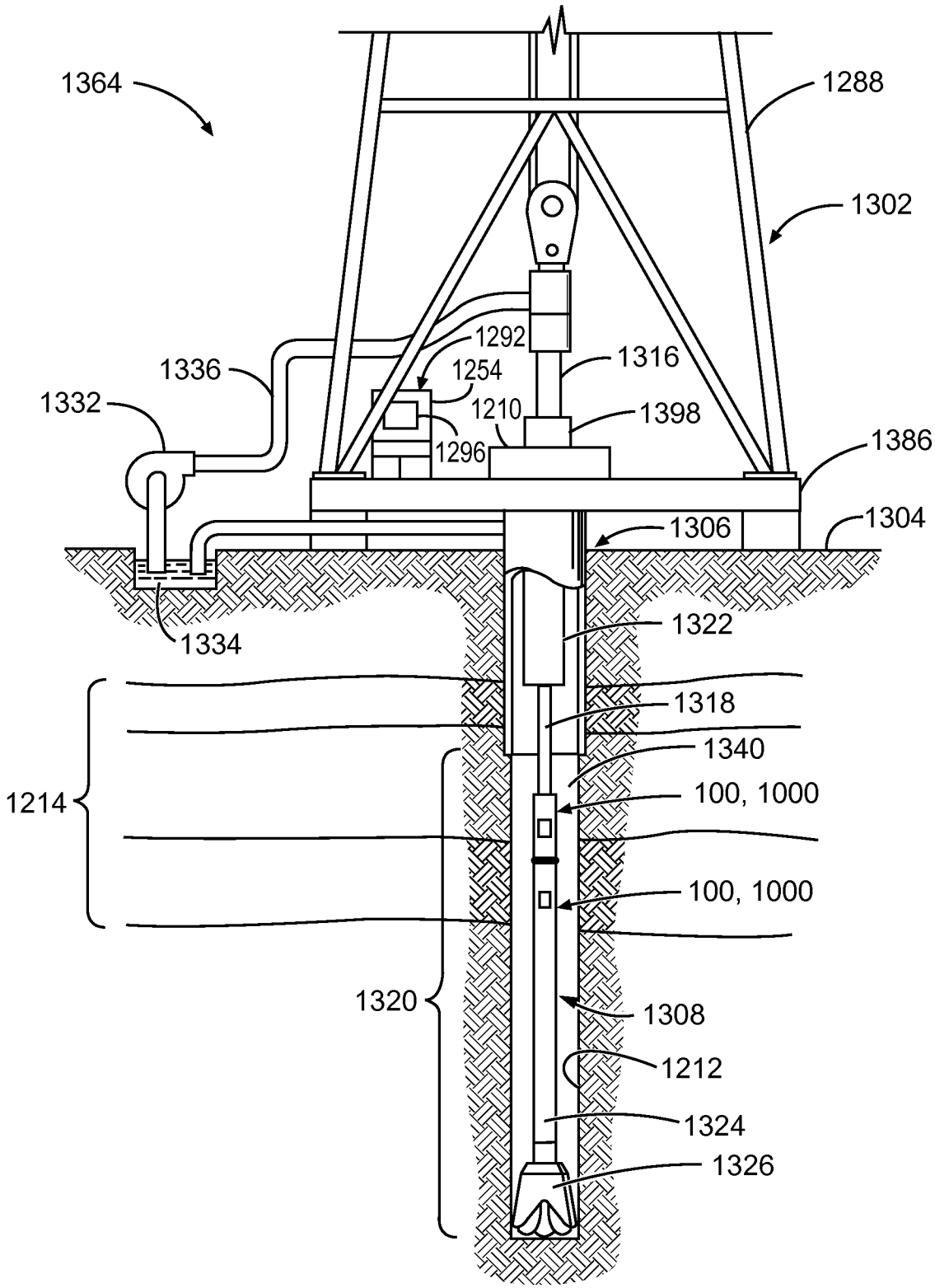

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1214
100, 1000
100, 1000
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Fig. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/018498

A. CLASSIFICATION OF SUBJECT MATTER

E21B 47/013(2012.01)i, E21B 47/06(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 47/013; E21B 47/00; E21B 47/01; E21B 44/00; E21B 47/16; E21B 47/022; G01V 1/40; E21B 7/04; E21B 47/06; 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: wellbore, logging tool, tubular member, interchangeable blade, sensor, extend, retract, and stabilizer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011-0286307 A1 (WANG, TSILI) 24 November 2011 See paragraphs [0028], [0032]-[0047], [0053] and figures 3, 5.	1-23
Y	US 2011-0048702 A1 (JACOB, GREGOIRE) 03 March 2011 See paragraphs [0058]-[0059] and figure 2A.	1-23
A	US 2002-0062992 A1 (FREDERICKS et al.) 30 May 2002 See paragraphs [0035]-[0041] and figures 2, 3A.	1-23
A	US 2014-0352422 A1 (PAULSSON, BJORN N.) 04 December 2014 See paragraphs [0027]-[0043] and figure 4.	1-23
A	US 2010-0126770 A1 (SUGIURA, JUNICHI) 27 May 2010 See abstract and claims 1, 13.	1-23

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
12 November 2015 (12.11.2015)	**13 November 2015 (13.11.2015)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2015/018498

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