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(54) Title: ELECTRIC SUBMERSIBLE PUMP VIBRATION DAMPING

(57) Abstract: An electric submersible pump (ESP) can include a shaft; an electric motor configured to rotatably drive the shaft; a pump mechanism operatively coupled to the shaft; and a mechanism that includes at least one element that damps vibration.

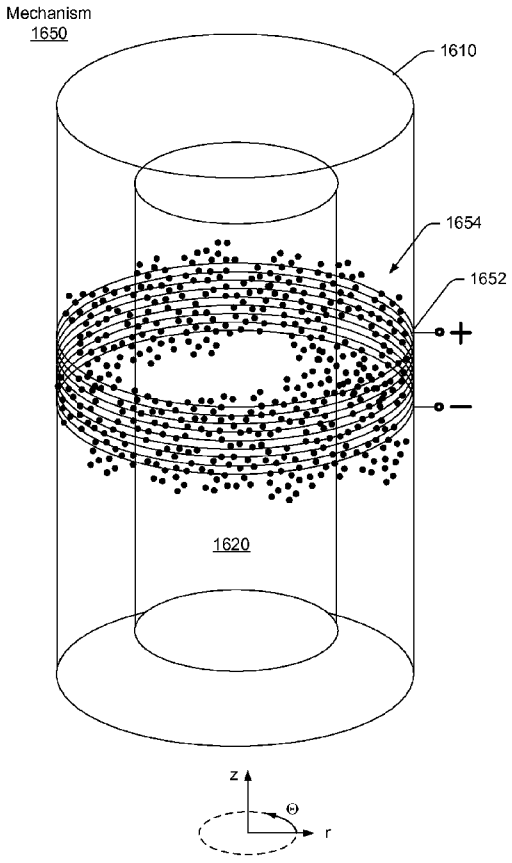


Fig. 16

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ELECTRIC SUBMERSIBLE PUMP VIBRATION DAMPING

BACKGROUND

[0001] As an example, an electric submersible pump (ESP) can include a stack of impeller and diffuser stages where the impellers are operatively coupled to a shaft driven by an electric motor. As an example, an electric submersible pump (ESP) can include a piston that is operatively coupled to a shaft driven by an electric motor, for example, where at least a portion of the shaft may include one or more magnets and form part of the electric motor.

SUMMARY

[0002] An electric submersible pump (ESP) can include a shaft; an electric motor configured to rotatably drive the shaft; a pump mechanism operatively coupled to the shaft; and a mechanism that includes at least one element that damps vibration. An electric submersible pump (ESP) can include a shaft that includes an axis; an electric motor configured to drive the shaft; a pump mechanism operatively coupled to the shaft; and a mechanism operatively coupled to the shaft where the mechanism includes an adjustable element that is adjustable to damp vibration of the shaft. An electric submersible pump (ESP) can include a shaft that includes an axis; a housing that includes a pump section and an electric motor section; an electric motor disposed in the electric motor section of the housing where the electric motor drives the shaft; a pump mechanism disposed in the pump section of the housing; and a mechanism operatively coupled to the housing that includes an actuatable element that applies force to the housing responsive to vibration. A system can include a vibration sensor; an electric submersible pump (ESP) that includes a shaft, a housing that includes a pump section and an electric motor section, an electric motor disposed in the electric motor section of the housing where the electric motor drives the shaft, a pump mechanism disposed in the pump section of the housing and operatively coupled to the shaft, and a mechanism that includes a vibration damping element; and a controller that controls at least the vibration damping element based at least in part on information sensed by the vibration sensor.

[0003] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to

identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Features and advantages of the described implementations can be more readily understood by reference to the following description taken in conjunction with the accompanying drawings.

[0005] Fig. 1 illustrates examples of equipment in geologic environments;

[0006] Fig. 2 illustrates an example of an electric submersible pump system;

[0007] Fig. 3 illustrates examples of equipment;

[0008] Fig. 4 illustrates an example of a system and examples of methods;

[0009] Fig. 5 illustrates an example of a system that includes one or more sensors;

[0010] Fig. 6 illustrates an example of a mechanism;

[0011] Fig. 7 illustrates an example of a mechanism;

[0012] Fig. 8 illustrates an example of a mechanism;

[0013] Fig. 9 illustrates an example of a mechanism;

[0014] Fig. 10 illustrates an example of a mechanism;

[0015] Fig. 11 illustrates examples of mechanisms;

[0016] Fig. 12 illustrates an example of a mechanism;

[0017] Fig. 13 illustrates an example of a method that includes operating mechanisms;

[0018] Fig. 14 illustrates an example of a mechanism;

[0019] Fig. 15 illustrates an example of a mechanism;

[0020] Fig. 16 illustrates an example of a mechanism;

[0021] Fig. 17 illustrates an example of a mechanism;

[0022] Fig. 18 illustrates an example of a mechanism;

[0023] Fig. 19 illustrates examples of mechanisms;

[0024] Fig. 20 illustrates an example of a method;

[0025] Fig. 21 illustrates an example of a system that includes one or more mechanisms;

[0026] Fig. 22 illustrates examples of equipment;

[0027] Fig. 23 illustrates examples of types of vibrations, examples of mechanisms and a table of vibration information; and

[0028] Fig. 24 illustrates example components of a system and a networked system.

DETAILED DESCRIPTION

[0029] The following description includes the best mode presently contemplated for practicing the described implementations. This description is not to be taken in a limiting sense, but rather is made merely for the purpose of describing the general principles of the implementations. The scope of the described implementations should be ascertained with reference to the issued claims.

[0030] Fig. 1 shows examples of geologic environments 120 and 140. In Fig. 1, the geologic environment 120 may be a sedimentary basin that includes layers (e.g., stratification) that include a reservoir 121 and that may be, for example, intersected by a fault 123 (e.g., or faults). As an example, the geologic environment 120 may be outfitted with any of a variety of sensors, detectors, actuators, etc. For example, equipment 122 may include communication circuitry to receive and to transmit information with respect to one or more networks 125. Such information may include information associated with downhole equipment 124, which may be equipment to acquire information, to assist with resource recovery, etc. Other equipment 126 may be located remote from a well site and include sensing, detecting, emitting or other circuitry. Such equipment may include storage and communication circuitry to store and to communicate data, instructions, etc. As an example, one or more satellites may be provided for purposes of communications, data acquisition, etc. For example, Fig. 1 shows a satellite in communication with the network 125 that may be configured for communications, noting that the satellite may additionally or alternatively include circuitry for imagery (e.g., spatial, spectral, temporal, radiometric, etc.).

[0031] Fig. 1 also shows the geologic environment 120 as optionally including equipment 127 and 128 associated with a well that includes a substantially horizontal portion that may intersect with one or more fractures 129. For example, consider a well in a shale formation that may include natural fractures, artificial fractures (e.g., hydraulic fractures) or a combination of natural and artificial fractures. As an example, a well may be drilled for a reservoir that is laterally extensive. In such an example, lateral variations in properties, stresses, etc. may exist where an assessment of such variations may assist with planning, operations, etc. to develop

the reservoir (e.g., via fracturing, injecting, extracting, etc.). As an example, the equipment 127 and/or 128 may include components, a system, systems, etc. for fracturing, seismic sensing, analysis of seismic data, assessment of one or more fractures, etc.

[0032] As to the geologic environment 140, as shown in Fig. 1, it includes two wells 141 and 143 (e.g., bores), which may be, for example, disposed at least partially in a layer such as a sand layer disposed between caprock and shale. As an example, the geologic environment 140 may be outfitted with equipment 145, which may be, for example, steam assisted gravity drainage (SAGD) equipment for injecting steam for enhancing extraction of a resource from a reservoir. SAGD is a technique that involves subterranean delivery of steam to enhance flow of heavy oil, bitumen, etc. SAGD can be applied for Enhanced Oil Recovery (EOR), which is also known as tertiary recovery because it changes properties of oil *in situ*.

[0033] As an example, a SAGD operation in the geologic environment 140 may use the well 141 for steam-injection and the well 143 for resource production. In such an example, the equipment 145 may be a downhole steam generator and the equipment 147 may be an electric submersible pump (e.g., an ESP).

[0034] As illustrated in a cross-sectional view of Fig. 1, steam injected via the well 141 may rise in a subterranean portion of the geologic environment and transfer heat to a desirable resource such as heavy oil. In turn, as the resource is heated, its viscosity decreases, allowing it to flow more readily to the well 143 (e.g., a resource production well). In such an example, equipment 147 (e.g., an ESP) may then assist with lifting the resource in the well 143 to, for example, a surface facility (e.g., via a wellhead, etc.). As an example, where a production well includes artificial lift equipment such as an ESP, operation of such equipment may be impacted by the presence of condensed steam (e.g., water in addition to a desired resource). In such an example, an ESP may experience conditions that may depend in part on operation of other equipment (e.g., steam injection, operation of another ESP, etc.).

[0035] Conditions in a geologic environment may be transient and/or persistent. Where equipment is placed within a geologic environment, longevity of the equipment can depend on characteristics of the environment and, for example, duration of use of the equipment as well as function of the equipment. Where equipment is to endure in an environment over an extended period of time, uncertainty may arise in one or more factors that could impact integrity or expected

lifetime of the equipment. As an example, where a period of time may be of the order of decades, equipment that is intended to last for such a period of time may be constructed to endure conditions imposed thereon, whether imposed by an environment or environments and/or one or more functions of the equipment itself.

[0036] Fig. 2 shows an example of an ESP system 200 that includes an ESP 210 as an example of equipment that may be placed in a geologic environment. As an example, an ESP may be expected to function in an environment over an extended period of time (e.g., optionally of the order of years). As an example, commercially available ESPs (such as the REDA™ ESPs marketed by Schlumberger Limited, Houston, Texas) may find use in applications that call for, for example, pump rates in excess of about 4,000 barrels per day and lift of about 12,000 feet or more.

[0037] In the example of Fig. 2, the ESP system 200 includes a network 201, a well 203 disposed in a geologic environment (e.g., with surface equipment, etc.), a power supply 205, the ESP 210, a controller 230, a motor controller 250 and a VSD unit 270. The power supply 205 may receive power from a power grid, an onsite generator (e.g., natural gas driven turbine), or other source. The power supply 205 may supply a voltage, for example, of about 4.16 kV.

[0038] As shown, the well 203 includes a wellhead that can include a choke (e.g., a choke valve). For example, the well 203 can include a choke valve to control various operations such as to reduce pressure of a fluid from high pressure in a closed wellbore to atmospheric pressure. Adjustable choke valves can include valves constructed to resist wear due to high-velocity, solids-laden fluid flowing by restricting or sealing elements. A wellhead may include one or more sensors such as a temperature sensor, a pressure sensor, a solids sensor, etc.

[0039] As to the ESP 210, it is shown as including cables 211 (e.g., or a cable), a pump 212, gas handling features 213, a pump intake 214, a motor 215, one or more sensors 216 (e.g., temperature, pressure, strain, current leakage, vibration, etc.) and optionally a protector 217.

[0040] As an example, an ESP may include a REDA™ HOTLINE™ high-temperature ESP motor. Such a motor may be suitable for implementation in a thermal recovery heavy oil production system, such as, for example, SAGD system or other steam-flooding system.

[0041] As an example, an ESP motor can include a three-phase squirrel cage with two-pole induction. As an example, an ESP motor may include steel stator laminations that can help focus magnetic forces on rotors, for example, to help reduce energy loss. As an example, stator windings can include copper and insulation.

[0042] In the example of Fig. 2, the well 203 may include one or more well sensors 220, for example, such as the commercially available OPTICLINE™ sensors or WELLWATCHER BRITEBLUE™ sensors marketed by Schlumberger Limited (Houston, Texas). Such sensors are fiber-optic based and can provide for real time sensing of temperature, for example, in SAGD or other operations. As shown in the example of Fig. 1, a well can include a relatively horizontal portion. Such a portion may collect heated heavy oil responsive to steam injection. Measurements of temperature along the length of the well can provide for feedback, for example, to understand conditions downhole of an ESP. Well sensors may extend thousands of feet into a well (e.g., 4,000 feet or more) and beyond a position of an ESP.

[0043] In the example of Fig. 2, the controller 230 can include one or more interfaces, for example, for receipt, transmission or receipt and transmission of information with the motor controller 250, a VSD unit 270, the power supply 205 (e.g., a gas fueled turbine generator, a power company, etc.), the network 201, equipment in the well 203, equipment in another well, etc.

[0044] As shown in Fig. 2, the controller 230 may include or provide access to one or more modules or frameworks. Further, the controller 230 may include features of an ESP motor controller and optionally supplant the ESP motor controller 250. For example, the controller 230 may include the UNICONN™ motor controller 282 marketed by Schlumberger Limited (Houston, Texas). In the example of Fig. 2, the controller 230 may access one or more of the PIPESIM™ framework 284, the ECLIPSE™ framework 286 marketed by Schlumberger Limited (Houston, Texas) and the PETREL™ framework 288 marketed by Schlumberger Limited (Houston, Texas) (e.g., and optionally the OCEAN™ framework marketed by Schlumberger Limited (Houston, Texas)).

[0045] In the example of Fig. 2, the motor controller 250 may be a commercially available motor controller such as the UNICONN™ motor controller. The UNICONN™ motor controller can connect to a SCADA system, the ESPWATCHER™ surveillance system, etc. The UNICONN™ motor controller can

perform some control and data acquisition tasks for ESPs, surface pumps or other monitored wells. The UNICONN™ motor controller can interface with the PHOENIX™ monitoring system, for example, to access pressure, temperature and vibration data and various protection parameters as well as to provide direct current power to downhole sensors (e.g., sensors of a gauge, etc.). The UNICONN™ motor controller can interface with fixed speed drive (FSD) controllers or a VSD unit, for example, such as the VSD unit 270.

[0046] For FSD controllers, the UNICONN™ motor controller can monitor ESP system three-phase currents, three-phase surface voltage, supply voltage and frequency, ESP spinning frequency and leg ground, power factor and motor load.

[0047] For VSD units, the UNICONN™ motor controller can monitor VSD output current, ESP running current, VSD output voltage, supply voltage, VSD input and VSD output power, VSD output frequency, drive loading, motor load, three-phase ESP running current, three-phase VSD input or output voltage, ESP spinning frequency, and leg-ground.

[0048] In the example of Fig. 2, the ESP motor controller 250 includes various modules to handle, for example, backspin of an ESP, sanding of an ESP, flux of an ESP and gas lock of an ESP. The motor controller 250 may include any of a variety of features, additionally, alternatively, etc.

[0049] In the example of Fig. 2, the VSD unit 270 may be a low voltage drive (LVD) unit, a medium voltage drive (MVD) unit or other type of unit (e.g., a high voltage drive, which may provide a voltage in excess of about 4.16 kV). As an example, the VSD unit 270 may receive power with a voltage of about 4.16 kV and control a motor as a load with a voltage from about 0 V to about 4.16 kV. The VSD unit 270 may include commercially available control circuitry such as the SPEEDSTAR™ MVD control circuitry marketed by Schlumberger Limited (Houston, Texas).

[0050] Fig. 3 shows cut-away views of examples of equipment such as, for example, a portion of a pump 320, a protector 370 and a motor 350 of an ESP. The pump 320, the protector 370 and the motor 350 are shown with respect to cylindrical coordinate systems (e.g., r, z, Θ). Various features of equipment may be described, defined, etc. with respect to a cylindrical coordinate system. As an example, a lower end of the pump 320 may be coupled to an upper end of the protector 370 and a

lower end of the protector 370 may be coupled to an upper end of the motor 350. As shown in Fig. 3, a shaft segment of the pump 320 may be coupled via a connector to a shaft segment of the protector 370 and the shaft segment of the protector 370 may be coupled via a connector to a shaft segment of the motor 350. As an example, an ESP may be oriented in a desired direction, which may be vertical, horizontal or other angle. Orientation of an ESP with respect to gravity may be considered as a factor, for example, to determine ESP features, operation, etc.

[0051] Fig. 4 shows an example of a system 400 and examples of methods 470, 480 and 490. As shown, the system 400 includes motorized equipment 410, vibration measurement equipment 430 and one or more vibration reduction mechanisms 450. As an example, the vibration measurement equipment 430 may be optional as, for example, one or more of the one or more vibration reduction mechanisms 450 may be self-adjusting (e.g., responsive to vibration to reduce vibration).

[0052] As shown, the method 470 includes an operation block 472 for operating a motor (e.g., of motorized equipment), a measurement block 474 for measuring vibration and a reduction block 476 for reducing vibration; the method 480 includes an operation block 482 for operating a motor (e.g., of motorized equipment) and a reduction block 486 for reducing vibration; and the method 490 includes an operation block 492 for operating a motor (e.g., of motorized equipment), a reduction block 494 for reducing vibration and a measurement block 496 for measuring vibration. As shown in the examples of Fig. 4, one or more control loops may exist within a method. For example, a loop may exist between operation of motorized equipment and reduction of vibration, a loop may exist between measurement of vibration and reduction of vibration, a loop may exist between reduction of vibration and measurement of vibration, a loop may exist between operation of motorized equipment and measurement of vibration, etc.

[0053] As an example, motorized equipment may include an electric motor operatively coupled to a shaft where operation of the electric motor rotates the shaft or, for example, reciprocates the shaft. As an example, an electric submersible pump (ESP) may be constructed to pump fluid via rotation of a shaft or may be constructed to pump fluid via reciprocation of a shaft (e.g., consider a plunger operatively coupled to a valve, etc.).

[0054] Vibration during operation of motorized equipment may lead to wear, degraded performance, etc. As an example, excessive vibration may lead to fatigue and possibly breakage of one or more components of motorized equipment (e.g., premature failure).

[0055] One type of vibration is shaft vibration such vibration can occur during rotation or reciprocation of the shaft as directly or indirectly coupled to an electric motor. Shaft vibration may lead to fatigue and breakage of a shaft or, for a multi-piece shaft, one or more pieces or connectors of the shaft. Vibration may also affect condition of one or more support bearings, which may lead to excessive wear and failure of a support bearing. Various components may perform at reduced capabilities while operating under vibration. For example, a shaft seal may experience leakage (e.g., an increased level of leakage). As another example, a thrust bearing may experience an increase in temperature, a reduction in load capacity, etc.

[0056] As an example, motorized equipment may include one or more sensors that can measure vibration (e.g., sense vibration). For example, an ESP may be fit with a sensor that can measure vibration in real-time. As an example, vibration information may be detectable via electronics associated with supply of power to an electric motor. For example, vibration of a rotor within a stator of an electric motor may be sensed via a change in load, energy demand, etc. (e.g., consider that vibration can “waste” energy and thus be modeled as an energy sink or energy leak).

[0057] As an example, a vibration reduction mechanism may affect a vibration regime in real-time and, for example, reduce vibration magnitude, alter vibration frequency, etc. As an example, a mechanism may compensate for vibration caused by unbalance, loading, bending, etc. of a body and/or a shaft. For example, consider an ESP housing as a body where the shaft passes through at least a portion of the ESP housing. In such an example, vibrations of a housing may effect a shaft and/or vibrations of a shaft may effect a housing. Further, a housing may vibration within a bore, which may be, for example, a cased bore (e.g., a bore fit with one or more casings).

[0058] As an example, a mechanism may operate in conjunction with vibration measurement equipment and adjust in real-time, for example, to achieve lower operational vibration. As an example, a mechanism may act to alter operational

vibration in type, character, etc. such that vibration that exists is less detrimental to equipment, performance, etc.

[0059] As an example, a mechanism may be an internal mechanism attached to a shaft (e.g., a rotary shaft, a reciprocating shaft, etc.). As an example, a mechanism may be an internal mechanism attached to a housing (e.g., that houses at least a portion of a shaft, etc.). As an example, a mechanism may be an external mechanism attached to a housing of motorized equipment or optionally other equipment that may experience undesirable vibration.

[0060] Vibration may be defined as a mechanical phenomenon whereby one or more mechanical components move, for example, as oscillations (e.g., oscillating movement). As an example, oscillations may occur about an equilibrium point. As an example, oscillations may be periodic or they may be random.

[0061] Vibration may be undesirable, desirable or neutral. For example, a type of vibration may aid with clearing debris from a fluid inlet (e.g., a screen, openings, etc.) and thus be considered desirable. Whereas, as mentioned, other types of vibration may be undesirable and shorten lifetime of equipment, compromise performance of equipment, etc. Yet other types of vibration may be considered to be neutral, for example, of a nature that do not particularly detriment or that do not particularly benefit longevity and/or operation of equipment.

[0062] As an example, vibration can generate noise (e.g., sound). In such an example, sound, or pressure waves, may be generated by one or more vibrating structures, which may induce vibration of one or more other structures. As an example, one or more mechanisms may operate in response to pressure waves. As an example, one or more sensors may measure vibration via pressure waves.

[0063] As an example, vibration may be modeled using one or more types of models. As an example, consider a mass–spring–damper model. As an example, a system may be modeled via a plurality of individual mass-spring-damper models. As an example, a mass–spring–damper model may represent a harmonic oscillator where, for example, equations such as those for an RLC circuit may be implemented.

[0064] As an example, a mechanism may be a damping mechanism. As an example, a mechanism may be an alteration mechanism. As an example, a mechanism may be both a damping mechanism and an alteration mechanism. To understand damping and alteration mechanisms, consider a vibrating guitar string

where placing a flat hand over the string quickly damps its motion; whereas, placing a finger over a fret acts to change the length of the string and hence its frequency of motion. Without intervention, a vibrating guitar string will eventually stop moving due to frictional damping, for example, viscous damping due to air (e.g., metal strings), internal damping (e.g., nylon strings), etc. A vibration that is damped may be characterized, for example, via a decay rate. A decay rate may provide information as to one or more types of damping mechanism, types of materials undergoing vibration, etc. As an example, an alteration mechanism may act to damp a particular vibration and, in such an example, be considered to be a damping mechanism.

[0065] As an example, one or more mechanisms may be dynamic in their response to vibration. For example, a mechanism may respond to vibration to damp and/or alter the vibration (e.g., directly and/or indirectly).

[0066] As an example, a mechanism that can dynamically modify vibration of motorized equipment may be operatively coupled to control logic of the motorized equipment. For example, a mechanism may be operatively coupled to a motor controller for an ESP. In such an example, the controller may receive one or more vibration measurements form sensors (e.g., internal, external, etc.) and, in turn, trigger one or more adjustments to a vibration-reduction mechanism (e.g., damping, alteration, damping and alteration, etc.). As an example, a closed loop may be formed to achieve real-time vibration reduction.

[0067] As an example, a system may include multiple vibration-reduction mechanisms of one or more types, for example, located at one or more axial locations of an ESP. As mentioned, a mechanism may be internal to an ESP and attached to a rotational shaft assembly (e.g., or a reciprocating shaft assembly), internal to an ESP and attached to a housing (e.g., a non-motor driven component such as a component intended to be “stationary”), or external to an ESP and attached to an ESP housing. As an example, a system may include a combination of mechanisms of one or more types.

[0068] Fig. 5 shows an example of an electric motor assembly 500 that includes a shaft 550, a housing 560 with an outer surface 565 and an inner surface 567, stator windings 570, stator laminations 580, rotor laminations 590 and rotor windings 595. As shown, the rotor laminations 590 are operatively coupled to the shaft 550 such that rotation of the rotor laminations 590, with the rotor windings 595 therein, can rotate the shaft 550. As mentioned, a shaft may be reciprocating, for

example, where a shaft includes one or more magnets (e.g., permanent magnets) that respond to current that passes through stator windings. As an example, the housing 560 may define a cavity via its inner surface 567 where the cavity may be hermetically sealed. As an example, such a cavity may be filled at least partially with dielectric oil. As an example, dielectric oil may be formulated to have a desired viscosity and/or viscoelastic properties, etc.

[0069] Fig. 5 also shows examples of sensors 532 and 534, where a system may include one or more of the sensors 532 and/or one or more of the sensors 534 (e.g., and/or optionally one or more other types of sensors). In Fig. 5, filled circles represent some example sensor locations.

[0070] As an example, a sensor may be integrated into one or more of the stator windings 570 and/or into one or more of the stator laminations 580. As an example, a sensor may be integrated into one or more of the rotor windings 595 and/or into one or more of the rotor laminations 590.

[0071] As an example, one or more sensors may be disposed within a space defined by the housing 560 of the electric motor assembly 500. As an example, a sensor may be an accelerometer (e.g., a single or multi-axis accelerometer) that can sense movement. As an example, the housing 560 of the electric motor assembly 500 may be at least partially filled with a fluid (e.g., dielectric fluid, etc.) where a sensor may sense pressure waves that pass through the fluid. In such an example, pressure waves may be sensed that are due to vibration, which may be undesirable vibration. As an example, circuitry may filter pressure waves associated with rotational operation of an electric motor from pressure waves associated with vibration of one or more components of the electric motor (e.g., a housing, a shaft, etc.). As an example, a sensor may include one or more piezo-elements that respond to stress and/or strain. As an example, a sensor may detect movement of one component with respect to another component.

[0072] As shown in Fig. 5, the sensor 532 may include circuitry for speed and/or vibration sensing and the sensor 534 may include circuitry for axial displacement sensing. As an example, sensors may include one or more of an impeller vane sensor configured for vane pass speed and/or vane wear sensing, a hydraulic seal sensor configured for leakage and/or wear sensing, a diffuser sensor configured for separation sensing, a bellows sensor configured for expansion and/or contraction sensing, a shaft seal sensor configured for separation, wear and/or

skipping sensing and/or a thrust bearing sensor configured for lift sensing. As an example, one or more sensors may be part of equipment such as equipment that can be deployed in a downhole environment. As an example, one or more sensors may be a proximity sensor.

[0073] Fig. 6 shows cutaway views of a system 600 that includes at least one of the sensor 632 and/or at least one of the sensor 634. As shown the system 600 includes an end cap 602 and an end cap 604 that are fit to ends of a housing 610 that houses various components of a pump such as a shaft 606, impellers 620-1 to 620-N and diffusers 640-1 to 640-N. The end caps 602 and 604 may be employed to protect the system 600, for example, during storage, transport, etc.

[0074] In the example of Fig. 6, rotation of the shaft 606 (e.g., about a z-axis) can rotate the impellers 620-1 to 620-N to move fluid upwardly where such fluid is guided by the diffusers 640-1 to 640-N. As an example, a pump stage may be defined as an impeller and a diffuser, for example, the impeller 620-1 and the diffuser 640-1 may form a pump stage. In the example of Fig. 6, flow in each stage may be characterized as being mixed in that flow is both radially and axially directed by each of the impellers 620-1 to 620-N and each of the diffusers 640-1 to 640-N (see, e.g., the r, z coordinate system).

[0075] As an example, the sensor 632 may be mounted in an opening of the housing 610 and include an end directed toward the shaft 606. As shown, the sensor 632 includes circuitry 633 such as, for example, emitter/detector circuitry, power circuitry and communication circuitry. As an example, power circuitry may include power reception circuitry, a battery or batteries, power generation circuitry (e.g., via shaft movement, fluid movement, etc.), etc. As an example, communication circuitry may include an antenna or antennas, wires, etc. As an example, communication circuitry may be configured to communication information (e.g., receive and/or transmit) via wire (e.g., conductor or conductors) or wirelessly.

[0076] As an example, the shaft 606 may include a marker 607-1 that can reflect energy emitted by an emitter of the sensor 632 where such reflected energy may be detected by a detector of the sensor 632. For example, an emitter may be an electromagnetic energy emitter that can emit energy at one or more wavelengths (e.g., IR, VIS, UV, etc.). As an example, an emitter may be an LED, a laser or other emitter. As an example, a detector may be an electromagnetic energy detector that can detect energy at one or more wavelengths (e.g., IR, VIS, UV, etc.). As an

example, the shaft 606 may be fit with a reflector strip as the marker 607-1 such that rotation of the shaft 506 may allow the sensor 632 to sense rotation of the shaft 606 by passage of the reflector strip in front of an emitter/detector of the shaft sensor 612. For example, where the shaft 606 of the system 600 (e.g., without the end caps 602 and 604) is operatively coupled to a motor, rotational speed of the shaft 606 may be sensed via the sensor 632, deviations indicative of vibrations of the shaft 606 may be sensed via the sensor 632, etc.

[0077] As an example, the circuitry 633 of the sensor 632 may include vibration sensing circuitry. For example, the circuitry 633 may include a detector array that can sense spatial deviations in reflected energy over time while the shaft 606 is rotating. Such a detector array may be a linear array or a matrix array and may interact with one or more markers 607-2 of the shaft 606. As an example, in absence of vibration, reflected energy may be detected as having a peak with respect to one or more detector elements of the array; whereas, in presence of vibration, reflected energy may be detected as having a peak or peaks that move with respect to the detector elements. In such an example, greater movement of peak reflected energy with respect to time may indicate larger amplitude vibrations. Further, a frequency analysis of detected energy with respect to time with respect to one or more detector elements may indicate one or more vibration frequencies.

[0078] As to control, where shaft vibration is detected at a particular rotational speed of the shaft 606, power to a motor operatively coupled to the shaft 606 may be adjusted to alter the rotational speed, for example, in an effort to reduce the shaft vibration. In such an example, the sensor 632 may be part of a feedback control loop. In such an example, vibration reduction may improve pump performance, pump longevity, etc.

[0079] As an example, one or more mechanisms may act to reduce or damp vibrations of a shaft during operation, as driven by an electric motor. Such one or more mechanisms may operate independent of sensed information (e.g., vibration measurement) and/or may operate based at least in part on sensed information (e.g., vibration measurement and optionally other information, etc.).

[0080] As to the sensor 634, it can include circuitry 635 such as, for example, emitter/detector circuitry, power circuitry and communication circuitry. As an example, the shaft 606 may include a marker that can be tracked by the shaft sensor 634 to sense axial movement of the shaft 606 (e.g., along the z-axis). Such

information may be germane to positions of one or more of the impellers 620-1 to 620-N with respect to positions of one or more of the diffusers 640-1 to 640-N.

[0081] As an example, where a shaft is supported by one or more bearings, walking, shifting, etc. of the shaft with respect to the one or more bearings may be related to rotational speed, load, etc. For example, a shaft may "walk up" (e.g., ride up, ride down, etc.) with respect to a bearing in a manner dependent on shaft rotational speed. As an example, a shaft may seat in a bearing in a manner that depends on one or more operational conditions (e.g., shaft rotational speed, fluid properties, load, etc.). In such an example, a shaft may change in its radial position, axial position or radial and axial position with respect to a bearing. As an example, a shaft displacement sensor may be configured to sense one or more of axial and radial position of a shaft. In such an example, where a change in shaft speed occurs, a change in axial and/or radial position of the shaft (e.g., optionally with respect to a bearing, etc.) may be used to determine axial and/or radial displacement of the shaft.

[0082] As to control, where shaft axial movement is detected at a particular rotational speed of the shaft 606, power to a motor operatively coupled to the shaft 606 may be adjusted to alter the rotational speed, for example, in an effort to reduce the axial shaft movement. In such an example, the sensor 634 may be part of a feedback control loop. In such an example, reduction of axial movement of the shaft 506 may improve pump performance, pump longevity, etc.

[0083] As shown in Fig. 6, the system 600 may include one or more sensors such as one or more of the sensors 632 (e.g., 632-1, 632-2, etc.) and/or one or more of the sensors 634 (e.g., 634-1, 634-2, etc.).

[0084] As an example, a marker or markers may be characterized by shape, orientation, material of construction, etc. As an example, consider the marker 607 which includes a plurality of marker elements arranged in a pattern that has a different profile for clockwise and counter-clockwise rotations. As an example, a marker may be constructed from a magnetic material, for example, to interact with a proximity sensor that can detect movement of a magnetic field, presence of a magnetic field, proximity of a magnetic field, etc. As an example, a magnet moving in space may induce a current in a detector of a sensor. In such an example, a sensor may act as a detector without emitting energy. As an example, where a fluid may carry ferromagnetic particles, a magnetic marker may be configured with a

relatively weak magnetic field, for example, where gravity, force of fluid flow, etc. may overcome magnetic attraction between such particles and the magnetic marker such that the particles do not collect on the magnetic marker.

[0085] As an example, a sensor may emit energy that is affected by presence of a marker, proximity of a marker, movement of a marker, etc. As an example, a marker may be made of or include a conductive material, a non-conductive material or a combination of conductive and non-conductive material.

[0086] As an example, a marker may be part of a shaft or other rotating component where the mass of the marker is negligible, where markers are positioned to balance the shaft or component, etc. For example, consider a shaft with three markers positioned at 120 degree intervals, which may act to balance a shaft where the markers are approximate equal in mass.

[0087] As an example, a proximity sensor may be configured to detect presence of an object without direct contact with the object (e.g., a non-contact sensor). In such an example, an object may be a component, a marker or other object. As an example, a proximity sensor may detect a clearance (e.g., a gap) between objects or, for example, adjacent to an object. As an example, a sensor may employ a contact mechanism to determine proximity or, for example, lack thereof, with respect to an object. For example, consider a strain gauge that can measure strain with respect to two components where the strain depends on proximity of one of the components with respect to the other one of the components.

[0088] As another example, an electrical contact strip may break where proximity is lost. For example, an electrical contact strip may be mounted to two components with or without slack such that loss of proximity (e.g., gap formation, etc.) between the components causes the electrical contact strip to break (e.g., where the gap exceeds strain tolerated by the strip, slack of the strip, etc.). As an example, a series of electrical contact strips may be employed, optionally with different values of resistance (e.g., ohms). In such an example, a current that passes through the strips may change as one or more of the strips breaks (e.g., consider resistors in parallel). For example, a circuit may be formed using electrical contact strips of different lengths and resistances (e.g., resistance per unit length, etc.) where the circuit is coupled to or across two components. In such an example, as the two components move away from each other individual strips may break successively to alter resistance in the circuit where one or more measurements

using the circuit may infer or determine how large of a gap exists between the two components.

[0089] Fig. 7 shows an example of a mechanism 750 that includes a body 752 that operatively couples to a shaft 720. The body 752 of the mechanism 750 includes a distributed mass array that can shift closer to or farther away from a rotational center (e.g., the rotational axis of the shaft 720). As an example, a mass array can be a single mass or a plurality of masses. As shown, individual masses 753 may move radially with respect to a rotational axis. As an example, masses can initially be located closer to a center of a shaft or initially located further away from a center of a shaft (e.g., prior to making one or more adjustments). As shown in the example of Fig. 7, the body 752 can protrude radially outwards from an outer diameter of the shaft 720. As an example, a mechanism may be at least in part within a shaft. For example, a mechanism may include one or more masses that can move radially within a span that is less than an outer diameter of a shaft.

[0090] As an example, a mechanism may include one or more of motors, springs, solenoids, hydraulic circuits, etc. that adjust a position of one or more movable masses. As an example, a mass may move responsive to one set of threads rotating with respect to another set of matching threads. As an example, a mass may move responsive to movement of a piston. In such an example, a piston may be a movable mass. As an example, a mechanism may include one or more levers that can adjust mass distribution. As an example, a mechanism may include one or more articulated beams that can adjust mass distribution.

[0091] Fig. 8 shows an example of a mechanism 850 that includes a component 852 that operatively couples to a shaft 820 where elements 854-1 to 854-N extend radially outwardly from the component 852. As shown in the example of Fig. 8, the elements 854-1 to 854-N may be configured as a distributed blade array that can shift rotational angles, for example, responsive to vibration, responsive to a control signal, etc.

[0092] As an example, an element may include circuitry that can respond to vibration (e.g., variations in force, etc.). For example, in response to vibration, an element may re-orient itself (e.g., via translation, rotation, bending, etc.). As an example, an element may include a piezoelectric material that can sense vibration (e.g., via stress and/or strain) and cause the element to change its orientation and/or shape with respect to a shaft (e.g., a shaft of motorized equipment). As an example,

elements may be independently adjustable and/or dependently adjustable (e.g., in a coordinated manner).

[0093] As an example, the component 852 may include sensing circuitry that can sense vibration and, in response, cause one or more of the elements 854-1 to 854-N to adjust (e.g., via orientation adjustment and/or shape adjustment).

[0094] As an example, a mechanism may include one or more blades that are adjustable. In such an example, consider adjustments that may twist and turn longitudinal, vertical, horizontal or axial angles of one or more individual blades to modify the vibrational behavior of a shaft (e.g., the shaft 820).

[0095] As an example, an element may be powered via a power source that is directly coupled to an element (e.g., wired), an element may be powered via its own power generation circuit (e.g., that generates power based on rotation of a shaft), and/or an element may be powered wirelessly via an energy transmission technique (e.g., consider a transmitter coil and a receiver coil).

[0096] Fig. 9 shows an example of a mechanism 950 that includes a plurality of elements 954-1 to 954-N that are operatively coupled to a shaft 920. One or more of the elements 954-1 to 954-N may include circuitry that can generate tension and/or compression in the shaft 920. For example, an element may expand axially to generate tension force or an element may contract axially to generate compression force. Such forces may alter properties of the shaft 920 in a manner that reduces vibration and/or that alters vibration of the shaft 920 (e.g., to a neutral vibration, a desirable vibration, to a lesser undesirable vibration, etc.). As shown in the example of Fig. 9, one or more of the elements 954-1 to 954-N may change shape so as to apply an inwardly or outwardly bending force, which may, in turn, alter properties of the shaft 920.

[0097] As an example, an element may include a piezoelectric circuit. Such a circuit may respond to vibrational energy by altering its shape in a manner that applies force to a shaft (e.g., the shaft 920). As an example, such an element may include a feedback loop that acts to minimize vibrational energy. For example, where an element changes its shape and vibration increases, the element may respond by changing its shape in another manner (e.g., opposite geometrically) in an effort to reduce vibration.

[0098] As an example, an element may be powered via a power source that is directly coupled to an element (e.g., wired), an element may be powered via its own

power generation circuit (e.g., that generates power based on rotation of a shaft), and/or an element may be powered wirelessly via an energy transmission technique (e.g., consider a transmitter coil and a receiver coil).

[0099] Fig. 10 shows an example of a mechanism 1050 that includes a component 1052 operatively coupled to a shaft 1020 and another component 1054 operatively coupled to a housing 1010. As shown in cross-section, the component 1052 includes a tapered end while the component 1054 includes a tapered recess. In such an example, radial movement of the shaft 1020 causes the tapered portions of the component 1052 and 1054 to interact, for example, via coulomb friction. Such friction may act to damp radial movement as associated with vibration and, for example, to limit magnitude of vibration. As an example, a clearance may exist that corresponds to an activation displacement of the shaft 1020 with respect to the housing 1010. For example, an activation displacement may be of the order of about a millimeter (e.g., depending on configuration, operational parameters, etc.; see, e.g., table 2380 of Fig. 23).

[00100] Fig. 11 shows examples of mechanisms 1150 that provide for viscous friction engagement between a shaft 1120 and housing 1110 for damping vibration. As an example, radial movement of a component or components may be resisted by one or more viscous friction elements, which may, for example, alter one or more dimensions of space that includes a viscous fluid. As an example, a viscous fluid may be provided in a space between a housing and a shaft that has rheopectic properties such that the fluid may increase in viscosity in response to shearing forces. In such an example, a mechanism may be adjustable to control an amount of shearing, optionally in a time dependent manner. For example, a mechanism may adjust one or more dimensions of an annular space that is at least partially bound by a surface of a rotating shaft, which can impart force that shears fluid in the annular space.

[00101] As shown in Fig. 11, a mechanism 1154 can extend axially to increase an axial length of an annular space such that viscous effects of fluid in the annular space may introduce more drag, for example, as an outer surface the rotating shaft 1120 contacts a fluid that is in the annular space as defined by an inner surface of the mechanism 1154. As an example, the inner surface of the mechanism 1154 may include a surface roughness that introduces drag (e.g., the surface may be rough rather than smooth and polished).

[00102] As shown in Fig. 11, a mechanism 1156 can extend radially to decrease an annular dimension of an annular space such that viscous effects of fluid in the annular space may introduce more drag, for example, as an outer surface of the rotating shaft 1120 contacts a fluid that is in the annular space as defined by an inner surface of the mechanism 1156. As an example, the inner surface of the mechanism 1156 may include a surface roughness that introduces drag (e.g., the surface may be rough rather than smooth and polished). Fig. 11 also shows an example of the mechanism 1156 where an eccentric annulus may be formed, which may introduce forces that may reduce a type of vibration or types of vibration.

[00103] As an example, depending on speed of the shaft, viscosity of fluid, axial flow, etc., various types of flow may develop in an annular space (e.g., Couette types of flow developed via motion of a wall bounding a viscous liquid, etc.).

[00104] As an example, a mechanism may provide for axially adjusting an annular space and/or may provide for radially adjusting an annular space. As an example, a mechanism may include nested elements that can extend axially. As an example, a mechanism may include a mechanical iris, a pressurized bladder, etc. that can increase and/or decrease radius of a wall, optionally asymmetrically (e.g., to form an eccentric annulus).

[00105] Fig. 12 shows an example of a mechanism 1250 that may be positioned internal to an ESP and attached to a housing 1210 of the ESP through which a shaft 1220 passes. As shown in the example of Fig. 12, the mechanism 1250 includes dampers 1254-1 to 1254-N, which may each apply a biasing force to the shaft 1220 where the force acts to damp vibration of the shaft 1220.

[00106] Fig. 13 shows an example of a mechanism 1350 that may be positioned internal to an ESP and attached to a housing 1310 of the ESP through which a shaft 1320 passes. As shown in the example of Fig. 13, the shaft 1320 receives a key 1321 that may couple the shaft to a bearing sleeve 1322 that has a radial clearance with respect to a bearing bushing 1324.

[00107] In the example of Fig. 13, the mechanism 1350 includes elements 1354-1 to 1354-N that are attached to the housing 1310 and that include contact skids or brushes that can apply force to the shaft 1320 (e.g., directly or via one or more features associated with the shaft 1320). In such an example, via such force(s), at one or more axial locations, vibration of the shaft 1320 can be reduced.

[00108] As an example, one or more elements may be co-located with a shaft radial bearing (see, e.g., the bearing 1322). As an example, elements may be constructed to exert both pushing and pulling. As an example, the mechanism 1350 may act to radially adjust the bearing bushing 1354 in a manner that can alter the vibration regime of the shaft 1320. As an example, one or more of the elements 1354-1 to 1354-N may exert a twisting (e.g., torsion) force to the shaft 1320, the bearing 1322 and/or the bearing bushing 1324.

[00109] As an example, a mechanism can include an array of skids at different radial locations surrounding a shaft to accomplish discrete loading from different directions (e.g., azimuthal angles in a cylindrical coordinate system). As an example, a skid may be configured such that it can contact a shaft (e.g., or associated component such as the bearing 1322, the bearing bushing 1324, etc.) without interfering with its rotational function.

[00110] As an example, an element can include a skid end and an opposing end that may be attached directly or indirectly to a housing. As an example, a skid end of an element may be actuated via one or more techniques, for example, consider a motor, a spring, a solenoid, a hydraulic circuit, etc. As an example, a mechanism may include one or more of screws, pistons, levers, articulated beams, etc.

[00111] Fig. 14 shows an example of cooperating mechanisms 1450 and example of a method 1470. As shown in Fig. 14, the cooperating mechanisms 1450 can include a shaft mounted mechanism 1452 and a housing mounted mechanism 1454. The method 1470 includes a provision block 1472 for providing a shaft mechanism (e.g., the mechanism 1452) and a housing mechanism (e.g., the mechanism 1454), an operation block 1474 for operating a motor (e.g., of motorized equipment) and an interaction block 1476 for interacting between the shaft mechanism and the housing mechanism.

[00112] As an example, a mechanism may be a hybrid mechanism that includes a shaft mounted mechanism that cooperates with a housing mounted mechanism. In such an example, the mechanism may be housed within a housing of an ESP.

[00113] As an example, a shaft mounted mechanism can include a mass array that actuates to reduce vibration of a shaft and a housing mounted mechanism may actuate to apply force to a shaft to reduce vibration of the shaft. As an example, a

housing mounted mechanism may interact with a shaft mounted mechanism to move masses in an array, for example, via contact or contactless (e.g., via magnetic forces, etc.).

[00114] Fig. 15 shows an example of a mechanism 1550 that includes a plurality of elements 1554-1 to 1554-N that are operatively coupled to a housing 1510 that houses at least a portion of a shaft 1520. One or more of the elements 1554-1 to 1554-N may include circuitry that can generate tension and/or compression in the housing 1510. For example, an element may expand axially to generate tension force or an element may contract axially to generate compression force. Such forces may alter properties of the housing 1510 in a manner that reduces vibration and/or that alters vibration of the housing 1510 (e.g., to a neutral vibration, a desirable vibration, to a lesser undesirable vibration, etc.). As shown in the example of Fig. 15, one or more of the elements 1554-1 to 1554-N may change shape so as to apply an inwardly or outwardly bending force, which may, in turn, alter properties of the housing 1510.

[00115] As an example, an element may include a piezoelectric circuit. Such a circuit may respond to vibrational energy by altering its shape in a manner that applies force to a housing (e.g., the housing 1510). As an example, such an element may include a feedback loop that acts to minimize vibrational energy. For example, where an element changes its shape and vibration increases, the element may respond by changing its shape in another manner (e.g., opposite geometrically) in an effort to reduce vibration.

[00116] As an example, an element may be powered via a power source that is directly coupled to an element (e.g., wired), an element may be powered via its own power generation circuit (e.g., that generates power based on rotation of a shaft), and/or an element may be powered wirelessly via an energy transmission technique (e.g., consider a transmitter coil and a receiver coil).

[00117] Fig. 16 shows an example of a mechanism 1650 associated with a housing 1610 and a shaft 1620. As shown in the example of Fig. 16, the mechanism 1650 includes a coil 1652 and an electro-rheological fluid 1654.

[00118] As an example, an electro-rheological (ER) fluid may change in apparent viscosity in a manner that depends on its exposure to an electric field. For example, an ER fluid may be disposed between plates where a field may be imposed and optionally controlled via one or more of the plates. Such a fluid may

exhibit an electric field dependent shear yield stress. As an example, an activated ER fluid may behave as a Bingham plastic, for example, with a yield point determined by electric field strength. In such an example, after a yield point is reached, the ER fluid may shear as a fluid (e.g., incremental shear stress proportional to the rate of shear).

[00119] As an example, an ER fluid, subject to an electric field, may change in consistency from that a liquid to that of a gel, and back, with a response time of the order of milliseconds. As an example, a waveform may be applied to conductors to generate an electric field that causes an ER fluid to change in its consistency, for example, in a manner that acts to damp vibrations of one or more components (e.g., a shaft, a housing, etc.). As an example, a sensor may measure one or more characteristics of vibration and circuitry may generate an electric field (e.g., control an electric field) based at least in part on the one or more characteristics to thereby alter properties of one or more ER fluids in one or more chambers of an ESP, for example, to damp or otherwise alter vibration.

[00120] As an example, a mechanism may include an ER fluid and one or more electrically conductive plates, coils or components that can establish an electric field. As an example, a method can include generating an electric field and exposing an ER fluid to the electric field. In such an example, the electric field may be adjusted to alter shear yield stress of the ER fluid. As an example, an ER fluid may be altered by an electric field in a manner that causes vibration of one or more components that may be in contact with the field to be damped or otherwise altered. As an example, an electric field may be adjusted to alter an ER fluid's resistance to motion. For example, an electric field may alter an ER fluid's resistance to motion of a shaft where the shaft is disposed at least in part in a housing (e.g., where a fluid chamber exists in a region defined by the shaft and the housing).

[00121] As an example, an ER fluid may include urea coated nanoparticles of barium titanium oxalate suspended in silicone oil. Such a fluid may exhibit a desired yield strength, for example, due to the dielectric constant of the particles, the small size of the particles and the urea coating. As an example, an ER fluid may exhibit a relationship between electrical field strength and yield strength that is non-linear and/or linear. For example, the aforementioned ER fluid that includes urea coated nanoparticles of barium titanium oxalate suspended in silicone oil may exhibit a

relatively linear relationship between electrical field strength and yield strength for electric field levels at and above about 1 kV/mm.

[00122] As an example, a circuitry may be included in a mechanism that can sense position of a shaft. As an example, circuitry may sense vibration of a shaft and control a field that can, in turn, control viscosity of a fluid in a space adjacent to a surface of the shaft. For example, in the mechanism 1650 of Fig. 16, a coil or coils may sense rotation and/or vibration of the shaft 1620 and generate a field or fields that can control viscosity of a fluid. In such an example, the shaft 1620 may include a magnetic marker or markers that may generate fields that can be sensed by one or more coils. Different types of vibration of the shaft 1620 and/or the housing 1610 may result in particular signals, which may be analyzed, classified, etc. to determine a vibration damping strategy (e.g., type of field or fields to generate, etc.).

[00123] As an example, a power supply to an electric motor may include a tap that is electrically connected to a mechanism such as the mechanism 1650 of Fig. 16. As an example, the power supply to an electric motor may be of the order of thousands of volts. As an example, circuitry may be included to adjust a power supply voltage to a level suitable for use in a mechanism such as the mechanism 1650 of Fig. 16. As an example, the mechanism 1650 may be implemented in a pump portion, a motor potion, a protector portion and/or another portion of an ESP.

[00124] As an example, a combination of mechanisms may be employed to damp vibration. For example, a mechanism may be in part physical (e.g., moving masses, blades, etc.) and in part electro-rheological. For example, blades may be oriented in fluid which may be electro-rheological where the blades and/or the fluid may be adjusted to achieve a damping effect as to one or more types of vibration.

[00125] Fig. 17 shows an example of a mechanism 1750 that is disposed at least in part in a space defined by a housing of an ESP and a casing 1705. As shown, the mechanism 1750 includes elements 1754-1 to 1754-N. As an example, one or more of the elements 1754-1 to 1754-N may be attached to an exterior of an ESP. As an example, the housing 1710 may include features that can operatively couple to the elements 1754-1 to 1754-N, for example, to maintain axial position of the elements 1754-1 to 1754-N.

[00126] As an example, the elements 1754-1 to 1754-N may be extendable from the housing 1710. For example, the elements 1754-1 to 1754-N may be disposed in recesses of the housing 1710 and extendable in response to a signal

(e.g., operation of a motor, etc.), interaction with a tool, etc. As an example, one or more of the elements 1754-1 to 1754-N may, upon actuation, extend radially outwardly from the housing 1710 and contact a surface of the casing 1705.

[00127] As an example, the elements 1754-1 to 1754-N may be extendable from the casing 1705. For example, the elements 1754-1 to 1754-N may seat in recesses of the casing 1705 and may be extendable upon response to a signal, interaction with a tool, presence of the housing 1710, etc. As an example, the housing 1710 may be rotatable such that ends of the elements 1754-1 to 1754-N are received in slots, etc. that may be formed in an outer surface of the housing 1710. As an example, an ESP may be positioned in bore of a casing and rotated to "lock" in ends of elements that extend radially inwardly from the casing. As an example, where elements extend from an ESP, the ESP may be rotated to "lock" in ends of elements with respect to slots or other features of a casing. As an example, a mechanism may include elements that extend from a casing and elements that extend from a housing of an ESP.

[00128] As an example, elements may have properties that act to damp or otherwise alter vibration of an ESP within a bore of a casing. As an example, elements may be or include springs that can act to damp vibration of an ESP within a bore of a casing. As an example, springs may be relatively linear with respect to their displacement (e.g., consider Hooke's law) or, for example, non-linear. As an example, elements may differ in one or more characteristics in a manner that act to avoid, damp, or alter vibration of an ESP in a bore of a casing.

[00129] As an example, a mechanism can include elements attached to an exterior of a housing of an ESP where such elements can interact with a well casing. In such an example, the mechanism can include extension elements that push against the well casing causing the housing of the ESP to flex and modify its vibration regime. Such an approach may be used to reduce operational vibration and, for example, to reduce an amount of bend (e.g., consider a dogleg path) of an ESP when installed in a wellbore.

[00130] As an example, a mechanism can include an array of pushing elements at different radial locations surrounding a housing where such elements may operate to provide discrete loading from each of the different directions.

[00131] As an example, an element may be actuated via a motor, a spring, a solenoid, a hydraulic circuit, etc. As an example, an element may be a screw

element, for example, that can rotate to extend or to retract. As an example, an element may be a piston or driven by a piston, for example, to extend or to retract (e.g., or to apply a biasing force). As an example, an element may be a lever. As an example, an element may be an articulated beam.

[00132] Fig. 18 shows an example of a mechanism 1850 that includes a component 1852 operatively coupled to a housing 1810 and another component 1854 operatively coupled to a casing 1805. As shown in cross-section, the component 1852 includes a tapered end while the component 1854 includes a tapered recess. In such an example, radial movement of the housing 1810 causes the tapered portions of the component 1852 and 1854 to interact, for example, via coulomb friction. Such friction may act to damp radial movement as associated with vibration and, for example, to limit magnitude of vibration.

[00133] Fig. 19 shows an example of a mechanism 1950 that provides viscous friction engagement between a housing 1910 and a casing 1905 for damping (radial movement is resisted by viscous friction elements).

[00134] Fig. 19 shows examples of mechanisms 1950 that provide for viscous friction engagement between a housing 1910 and a casing 1905 for damping vibration. As an example, radial movement of a component or components may be resisted by one or more viscous friction elements, which may, for example, alter one or more dimensions of space that includes a viscous fluid. As an example, a mechanism may adjust one or more dimensions of an annular space through which fluid may flow or be in a relatively stationary state.

[00135] As shown in Fig. 19, a mechanism 1954 can extend axially to increase an axial length of an annular space such that viscous effects of fluid in the annular space may introduce more drag. As an example, the inner surface of the mechanism 1954 may include a surface roughness that introduces drag (e.g., the surface may be rough rather than smooth and polished).

[00136] As shown in Fig. 19, a mechanism 1956 can extend radially to decrease an annular dimension of an annular space such that viscous effects of fluid in the annular space may introduce more drag. As an example, the inner surface of the mechanism 1956 may include a surface roughness that introduces drag (e.g., the surface may be rough rather than smooth and polished). Fig. 19 also shows an example of the mechanism 1956 where an eccentric annulus may be formed, which may introduce forces that may reduce a type of vibration or types of vibration.

[00137] As an example, a mechanism may provide for axially adjusting an annular space and/or may provide for radially adjusting an annular space. As an example, a mechanism may include nested elements that can extend axially. As an example, a mechanism may include a mechanical iris, a pressurized bladder, etc. that can increase and/or decrease radius of a wall, optionally asymmetrically (e.g., to form an eccentric annulus).

[00138] Fig. 20 shows an example of a method 2000 that includes a vibration measurement block 2010, a control block 2030 and a driver correction block 2050. As an example, the method 2000 may be implemented to achieve at least some amount of active vibration control (e.g., damping of vibration of one or more ESP components).

[00139] As an example, the vibration measurement block 2010 may include receiving information from one or more accelerometers (e.g., single or multi-axis). As an example, the control block 2030 may include circuitry that can amplify and invert signals from one or more accelerometers and, for example, control logic (e.g., one or more of proportional, integral and derivative control, etc.) that can control one or more active elements (e.g., driver elements), for example, elements that can receive output of the driver adjustment block 2050.

[00140] As an example, the driver correction block 2050 may act to adjust a driver of one or more electric motors of an ESP and/or may act to adjust one or more actively driven elements that can damp or otherwise alter vibration of one or more components of an ESP. For example, the driver correction block 2050 may provide output to the controller 230, the ESP motor controller 250 and/or the VSD unit 270 of the ESP system 200 of Fig. 2 and/or the driver correction block 2050 may provide output to one or more of the mechanisms 750 of Fig. 7, 850 of Fig. 8, 950 of Fig. 9, 1050 of Fig. 10, 1150 of Fig. 11 (e.g., 1151 and/or 1152), 1250 of Fig. 12, 1350 of Fig. 13, 1450 of Fig. 14, 1550 of Fig. 15, 1650 of Fig. 16, 1750 of Fig. 17, 1850 of Fig. 18 and 1950 of Fig. 19 (e.g., 1951 and/or 1952).

[00141] As an example, a mechanism may include one or more active drivers. As an example, an active driver may be driven electrically, hydraulically, pneumatically, piezo-electrically, etc. As an example, a driver may be driven fluidically, for example, via fluid pumped by an ESP. As an example, a driver may be driven electrically, for example, via a power cable that supplies power to an electric motor of an ESP. As an example, a driver may be driven via power generated

downhole, for example, via fluid flow, heat energy, electro-magnetic energy (e.g., rotation of one or more magnets with respect to a coil or coils), etc.

[00142] As an example, the control block 2030 may implement an adaptive control algorithm. For example, if vibration is periodic, the control block 2030 may include analyzing signals from the vibration measurement block 2010 as to the periodic vibration such that the driver correction block 2050 can tailor output to one or more active elements to avoid, damp, etc., the periodic vibration.

[00143] As an example, a method can include acquiring vibration measurements form an ESP and transmitting measurement data to control logic (e.g., surface and/or downhole) for processing which may aim to process the measurement data to provide a signal that includes opposing vibration characteristics. In such an example, the method may include feeding the signal to drive circuitry that can drive an electric motor of an ESP, for example, to modify the power transmitted to an electric motor of an ESP. In such an example, the detected vibration (e.g., per the vibration measurements) may be "balanced" (e.g., counter-acted) by vibration generated via the fed signal. For example, a drive signal to an electric motor of an ESP may be summed with a signal that aims to reduce vibration that may be occurring for the drive signal by itself. Such an approach may result in reduced ESP vibration. As an example, a method may include implementing closed-loop control in real-time to reduce vibration of one or more components of an ESP.

[00144] As an example, a controller may process vibration measurements and decide whether adjustments are to be made to a motor controller and/or to one or more mechanism controllers that may, for example, control one or more elements (e.g., active elements). In such an example, the controller may receive further information as to movement (e.g., vibration) and determine whether the control strategy may be adjusted. For example, a controller may effectively damp vibration at an axial location of an electric motor of an ESP while vibration may still exist at an axial location of a stack of impellers/diffusers of the ESP. In such an example, one or more elements may be in place adjacent to a housing that houses the stack of impellers/diffuser and controllable to damp vibrations of the housing.

[00145] As an example, a method can include adjusting an ESP electric motor controller output (e.g., power input to the ESP electric motor) to affect a vibration signature of the electric motor. In such an example, the method can include gathering vibration data and processing at least a portion of such data to modify the

ESP electric motor controller output in such a way that the electric motor generates vibration in a controlled, relatively opposite direction, which may act to effectively cancel out operational vibration (e.g., to reduce vibration). As an example, a vibration measurement and adjustment method may operate in a closed-loop manner and, for example, in real-time.

[00146] As an example, the method 2000 of Fig. 20 may help to reduce risk of failure of one or more individual components, for example, based at least in part on identification of one or more associated "characteristic" vibrations and outputting signals that aim to reduce such one or more vibrations. As an example, the method 2000 of Fig. 20 may be implemented to make an ESP more vibration tolerant, which may, for example, enhance ESP run life.

[00147] As mentioned, the method 2000 of Fig. 20 may operate via control of power supplied to an electric motor of an ESP and/or via control of one or more mechanisms of an ESP. Once an ESP is positioned downhole, various noise factors may or may not be controllable. For example, consider as examples of factors that may affect vibration, shape of a bore (e.g., consider a dogleg, etc.) (e.g., cave-in, fracturing, etc.), an amount of particulate matter in pumped fluid (e.g., sand, etc.), and/or temperature, pressure, gas, etc.

[00148] An ESP system may operate in a more robust manner when it includes one or more mechanisms that can allow an ESP to tolerate or "deal" with vibrations. An ESP system may be configured to include components that may act to reduce vibration (e.g., self-centering bearings, etc.) and/or to include one or more mechanisms that act to reduce vibration.

[00149] Fig. 21 shows an example of the ESP system 200 as including one or more features of a system 2101. As shown, the ESP system 200 may include the ESP 201 with a rotating shaft driven by an electric motor or an ESP 2102 with a reciprocating shaft 2104 driven by an electric motor (e.g., linear permanent magnet motor, etc.); noting that the shaft 2104 may be part of the motor (e.g., include one or more permanent magnets). The ESP system 200 may include one or more of the sensors 532, 534, 632, and 634 and/or optionally one or more other sensors. As an example, the ESP system 200 may include one or more of the mechanisms 750 of Fig. 7, 850 of Fig. 8, 950 of Fig. 9, 1050 of Fig. 10, 1150 of Fig. 11, 1250 of Fig. 12, 1350 of Fig. 13, 1450 of Fig. 14, 1550 of Fig. 15, 1650 of Fig. 16, 1750 of Fig. 17, 1850 of Fig. 18 and 1950 of Fig. 19 and/or optionally one or more other mechanisms.

As an example, a mechanism may be internal, external and/or internal and external to a housing of the ESP 201 or the ESP 2102.

[00150] Fig. 22 shows an example of an ESP 2210 that includes a shaft 2212 that includes an axis; an electric motor 2214 configured to drive the shaft 2212; a pump mechanism 2216 operatively coupled to the shaft 2212; and a mechanism 2218 operatively coupled to the shaft 2212 where the mechanism includes an adjustable element that is adjustable to damp vibration of the shaft 2212. As an example, the shaft 2212 may be a rotating shaft or a reciprocating shaft. As an example, the pump mechanism 2216 may be a pump mechanism driven by a rotation shaft or may be a pump mechanism driven by a reciprocating shaft.

[00151] Fig. 22 also shows an example of an ESP 2230 that includes a shaft 2232 that includes an axis; a housing 2233 that may include a pump section and an electric motor section; an electric motor 2234 disposed in the housing 2233 (e.g., a electric motor section) where the electric motor 2234 drives the shaft 2232; a pump mechanism 2236 disposed in the housing 2233 (e.g., a pump section); and a mechanism 2238 operatively coupled to the housing 2233 that includes an actuatable element that applies force to the housing 2233 responsive to vibration. As an example, the shaft 2232 may be a rotating shaft or a reciprocating shaft. As an example, the pump mechanism 2236 may be a pump mechanism driven by a rotation shaft or may be a pump mechanism driven by a reciprocating shaft.

[00152] Fig. 22 further shows an example of a system 2250 that includes one or more vibration sensors 2251; an electric submersible pump (ESP) 2255 that includes a shaft, a housing that includes a pump section and an electric motor section, an electric motor disposed in the electric motor section of the housing where the electric motor drives the shaft, a pump mechanism disposed in the pump section of the housing and operatively coupled to the shaft, and a mechanism that includes a vibration damping element; and a controller 2257 that controls at least the vibration damping element based at least in part on information sensed by the vibration sensor. As an example, the shaft of the ESP 2255 may be a rotating shaft or a reciprocating shaft. As an example, the pump mechanism of the ESP 2255 may be a pump mechanism driven by a rotation shaft or may be a pump mechanism driven by a reciprocating shaft.

[00153] Fig. 23 shows various types of vibration 2300, which include axial vibration 2302, lateral or transverse vibration 2306 and torsional vibration 2306. As

an example, a mechanism may respond to a type or types of vibration. For example, Fig. 23 shows a mechanism 2320 that can respond to a change in axial displacement of a component or components (e.g., as associated with axial vibration), a mechanism 2340 that can respond to a change in lateral displacement of a component or components (e.g., as associated with lateral vibration) and a mechanism 2360 that can respond to a change in torsion of a component or components (e.g., as associated with torsional vibration). As an example, a mechanism may respond to a change in shaft speed of a shaft of an ESP, which may experience torsional vibration when undergoing the change in shaft speed. In such an example, a mechanism may adjust to damp torsional vibration, for example, automatically or in response to a control signal and/or a sensor signal (e.g., as may be associated with an increase in shaft speed).

[00154] Fig. 23 also shows a table 2380 that includes vibration information from ISO 2732, 1974. The table 2380 includes velocity information and displacement information as well as qualitative indicators as to vibration at about 3,600 rpm. As an example, an electric motor of an ESP may rotate a shaft at speeds of about tens of rpm to thousands of rpms (e.g., 3,600 rpm or more). As an example, an electric motor of a reciprocating submersible pump may reciprocate a shaft, for example, along a longitudinal axis of the shaft (e.g., from a few cycles per minute to a cycle per second or more). As an example, one or more mechanisms may be dimensioned with respect to a vibration type, vibration displacement, vibration velocity, vibration frequency, vibration acceleration, etc.

[00155] As an example, a diameter of a pump housing may be less than about 30 cm (e.g., about one foot). As an example, a diameter of an ESP housing may be less than about 15 cm (e.g., about 6 inches). As an example, a casing inner diameter may provide a clearance for an outer diameter of an ESP housing (e.g., a casing inner diameter larger than an outer diameter of an ESP housing). As an example, consider an ESP housing outer diameter of about 10 cm and a casing inner diameter of about 14 cm (e.g., or more). In such an example, a mechanism may be disposed at least in part between the outer diameter of the ESP housing and the inner diameter of the casing.

[00156] As an example, a housing of an ESP may be made of carbon steel, an alloy, etc. As an example, consider a housing made of a chrome alloy (e.g., 9 Cr:1 Mo). As an example, a shaft of an ESP may be a single piece shaft or a multiple

piece shaft. As an example, a shaft may be made of a material such as MONEL™, INCONEL™ (e.g., INCONEL™ 718, etc.), etc. As an example, a shaft may be of a diameter of the order of centimeters. For example, consider a shaft with a diameter of about 2 cm (e.g., less than about an inch). As an example, a shaft may be rated with respect to power (e.g., HP of an electric motor). As mentioned, a shaft may include magnets such that the shaft can reciprocate in response to a field generated by one or more coils (e.g., within an ESP housing).

[00157] As an example, an electric submersible pump (ESP) can include a shaft that includes an axis; an electric motor configured to drive the shaft; a pump mechanism operatively coupled to the shaft; and a mechanism operatively coupled to the shaft where the mechanism includes an adjustable element that is adjustable to damp vibration of the shaft. In such an example, the adjustable element can include a movable mass, for example, with respect to the axis of the shaft, a radially movable mass. As an example, a mechanism may include a body that includes a plurality of movable masses.

[00158] As an example, an adjustable element of a mechanism may be or include a movable blade (e.g., or blades). For example, consider one or more of a rotatable blade, a translatable blade, a rotatable and translatable blade, etc.

[00159] As an example, an adjustable element of a mechanism may be a contractable element and/or an expandable element. For example, consider a piezeo-electric element that can contract and/or expand.

[00160] As an example, a mechanism can include a power source and an adjustable element can include a piezeo-electric element (e.g., a piezo-electric circuit) that can apply force to a shaft responsive to receipt of power from the power source. In such an example, the piezo-electric element may be controlled to apply a tension force or a compression force to the shaft.

[00161] As an example, an electric submersible pump (ESP) can include a shaft that includes an axis; a housing that includes a pump section and an electric motor section; an electric motor disposed in the electric motor section of the housing where the electric motor drives the shaft; a pump mechanism disposed in the pump section of the housing; and a mechanism operatively coupled to the housing that includes an actuatable element that applies force to the housing responsive to vibration. In such an example, the actuatable element can extend radially inwardly from the housing, for example, to directly contact the shaft and/or, for example, a

bearing may be disposed about the shaft and a bearing bushing disposed about the bearing where the actuatable element contacts the bearing bushing.

[00162] As an example, an actuatable element can include an actuated state where the actuatable element extends radially outwardly from a housing for contacting a casing. As an example, a housing can include a recess that receives an actuatable element in an unactuated state. In such an example, an ESP may be disposed in a bore and the element actuated such that the element moves at least in part out of the recess to contact another component or components (e.g., a shaft, a bearing bushing, a casing, etc.).

[00163] As an example, a system can include a vibration sensor; an electric submersible pump (ESP) that includes a shaft, a housing that includes a pump section and an electric motor section, an electric motor disposed in the electric motor section of the housing where the electric motor drives the shaft, a pump mechanism disposed in the pump section of the housing and operatively coupled to the shaft, and a mechanism that includes a vibration damping element; and a controller that controls at least the vibration damping element based at least in part on information sensed by the vibration sensor. In such an example, the controller can control power to the electric motor based at least in part on information sensed by the vibration sensor. As an example, the mechanism of such a system can be operatively coupled to the pump section of the housing.

[00164] As an example, one or more methods described herein may include associated computer-readable storage media (CRM) blocks. Such blocks can include instructions suitable for execution by one or more processors (or cores) to instruct a computing device or system to perform one or more actions. As an example, a computer-readable storage medium may be a storage device that is not a carrier wave (e.g., a non-transitory storage medium that is not a carrier wave).

[00165] Fig. 24 shows components of a computing system 2400 and a networked system 2410. The system 2400 includes one or more processors 2402, memory and/or storage components 2404, one or more input and/or output devices 2406 and a bus 2408. According to an embodiment, instructions may be stored in one or more computer-readable media (e.g., memory/storage components 2404). Such instructions may be read by one or more processors (e.g., the processor(s) 2402) via a communication bus (e.g., the bus 2408), which may be wired or wireless. The one or more processors may execute such instructions to implement (wholly or

in part) one or more attributes (e.g., as part of a method). A user may view output from and interact with a process via an I/O device (e.g., the device 2406). According to an embodiment, a computer-readable medium may be a storage component such as a physical memory storage device, for example, a chip, a chip on a package, a memory card, etc.

[00166] According to an embodiment, components may be distributed, such as in the network system 2410. The network system 2410 includes components 2422-1, 2422-2, 2422-3, . . ., 2422-N. For example, the components 2422-1 may include the processor(s) 2402 while the component(s) 2422-3 may include memory accessible by the processor(s) 2402. Further, the component(s) 2402-2 may include an I/O device for display and optionally interaction with a method. The network may be or include the Internet, an intranet, a cellular network, a satellite network, etc.

Conclusion

[00167] Although only a few examples have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the examples. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words “means for” together with an associated function.

CLAIMS

What is claimed is:

1. An electric submersible pump (ESP) comprising:
a shaft that comprises an axis;
an electric motor configured to drive the shaft;
a pump mechanism operatively coupled to the shaft; and
a mechanism operatively coupled to the shaft wherein the mechanism comprises an adjustable element that is adjustable to damp vibration of the shaft.

2. The ESP of claim 1 wherein the adjustable element comprises a movable mass.

3. The ESP of claim 2 wherein the movable mass comprises, with respect to the axis of the shaft, a radially movable mass.

4. The ESP of claim 2 wherein the mechanism comprises a body that comprises a plurality of movable masses.

5. The ESP of claim 1 wherein the adjustable element comprises a movable blade.

6. The ESP of claim 5 wherein the movable blade comprises a rotatable blade.

7. The ESP of claim 5 wherein the movable blade comprises a translatable blade.

8. The ESP of claim 1 wherein the adjustable element comprises a contractable element.

9. The ESP of claim 1 wherein the adjustable element comprises an expandable element.

10. The ESP of claim 1 wherein the mechanism comprises a power source and wherein the adjustable element comprises a piezeo-electric element that applies force to the shaft responsive to receipt of power from the power source.

11. The ESP of claim 10 wherein the piezo-electric element applies a tension force or a compression force to the shaft.

12. An electric submersible pump (ESP) comprising:

a shaft that comprises an axis;

a housing that comprises a pump section and an electric motor section;

an electric motor disposed in the electric motor section of the housing wherein the electric motor drives the shaft;

a pump mechanism disposed in the pump section of the housing; and

a mechanism operatively coupled to the housing that comprises an actuatable element that applies force to the housing responsive to vibration.

13. The ESP of claim 12 wherein the actuatable element extends radially inwardly from the housing.

14. The ESP of claim 13 wherein the actuatable element directly contacts the shaft.

15. The ESP of claim 13 further comprising a bearing disposed about the shaft and a bearing bushing disposed about the bearing wherein the actuatable element contacts the bearing bushing.

16. The ESP of claim 12 wherein the actuatable element comprises an actuated state wherein the actuatable element extends radially outwardly from the housing for contacting a casing.

17. The ESP of claim 13 wherein the housing comprises a recess that receives the actuatable element in an unactuated state.

18. A system comprising:

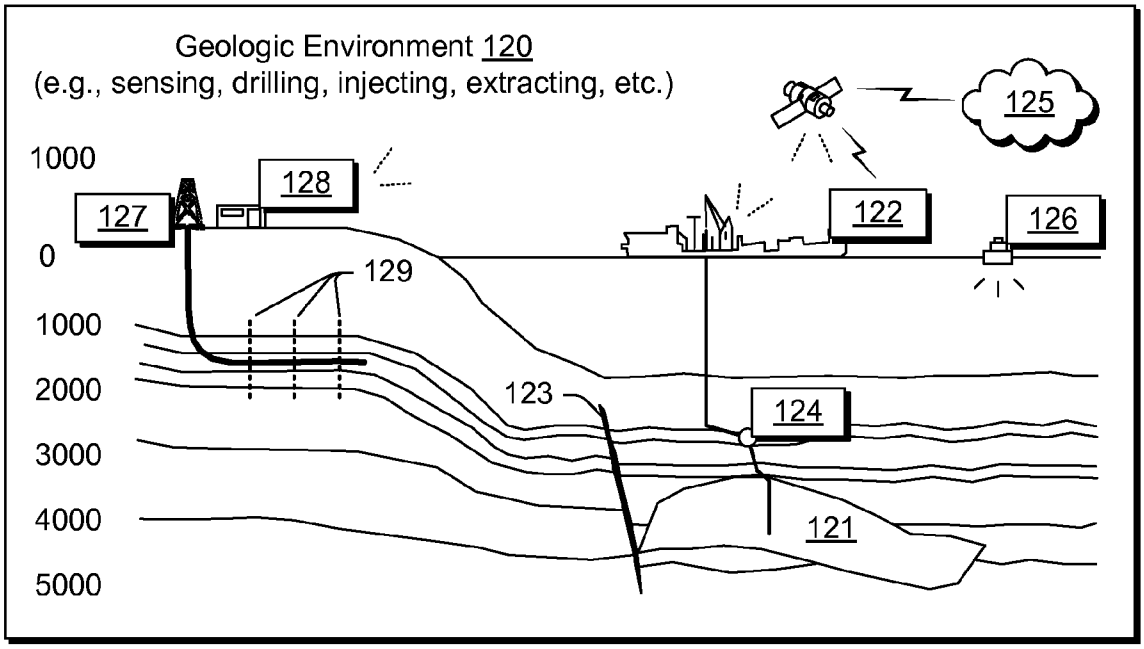
a vibration sensor;

an electric submersible pump (ESP) that comprises a shaft, a housing that comprises a pump section and an electric motor section, an electric motor disposed in the electric motor section of the housing wherein the electric motor drives the shaft, a pump mechanism disposed in the pump section of the housing and operatively coupled to the shaft, and a mechanism that comprises a vibration damping element; and

a controller that controls at least the vibration damping element based at least in part on information sensed by the vibration sensor.

19. The system of claim 18 wherein the controller controls power to the electric motor based at least in part on information sensed by the vibration sensor.

20. The system of claim 18 wherein the mechanism is operatively coupled to the pump section of the housing.


Geologic Environment 120
(e.g., sensing, drilling, injecting, extracting, etc.)
1000
0
1000
2000
3000
4000
5000
127
128
129
123
124
121
122
125
126

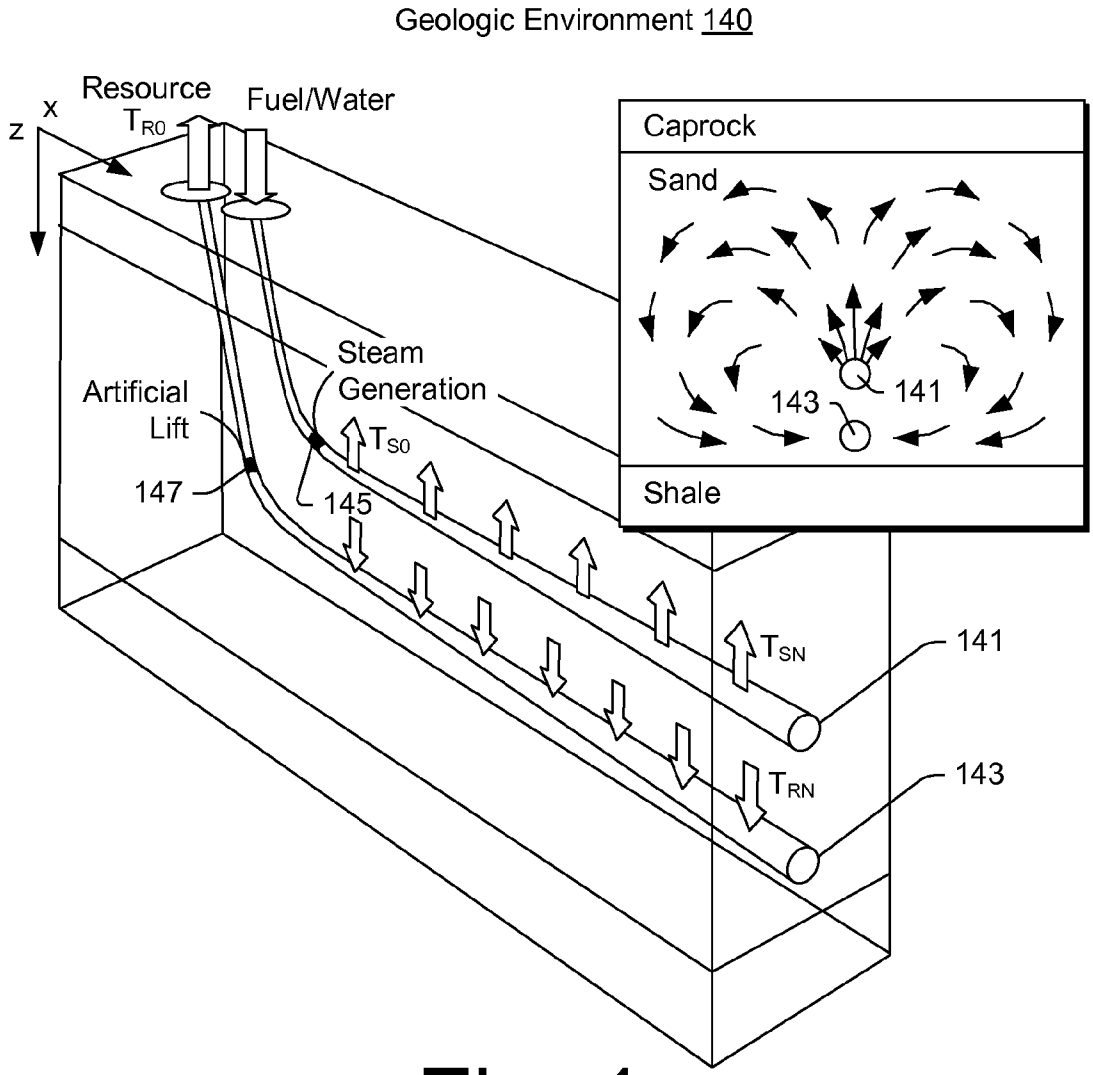

Geologic Environment 140
Resource
Fuel/Water
x
z
T_{R0}
Caprock
Sand
Shale
Steam
Generation
Artificial
Lift
147
145
T_{S0}
143
141
T_{SN}
T_{RN}

Fig. 1

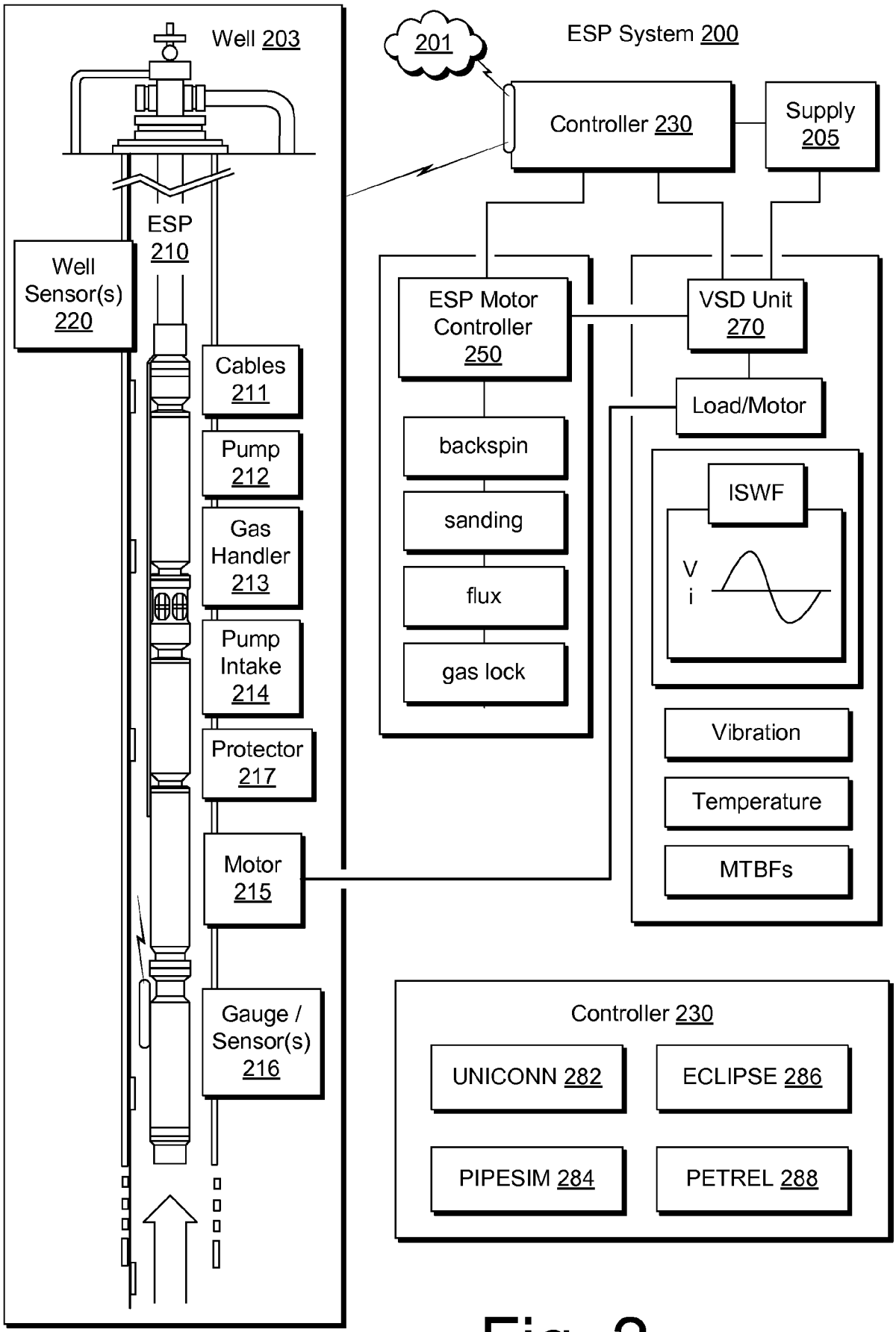

Well 203
201
ESP System 200
Controller 230
Supply 205
ESP 210
Well Sensor(s) 220
Cables 211
Pump 212
Gas Handler 213
Pump Intake 214
Protector 217
Motor 215
Gauge / Sensor(s) 216
ESP Motor Controller 250
VSD Unit 270
Load/Motor
backspin
sanding
flux
gas lock
ISWF
V
i
Vibration
Temperature
MTBFs
Controller 230
UNICONN 282
ECLIPSE 286
PIPESIM 284
PETREL 288

Fig. 2

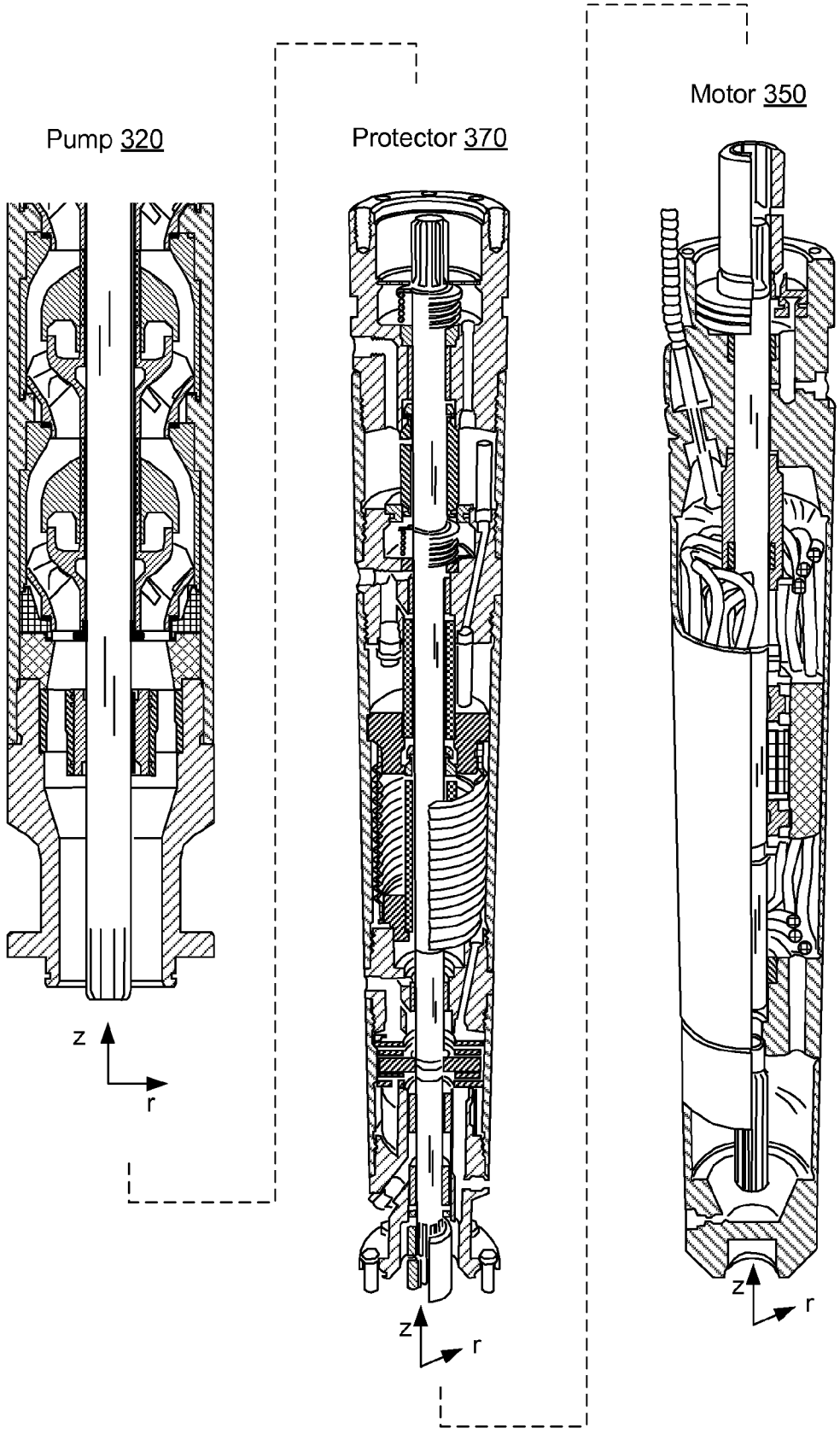


Fig. 3

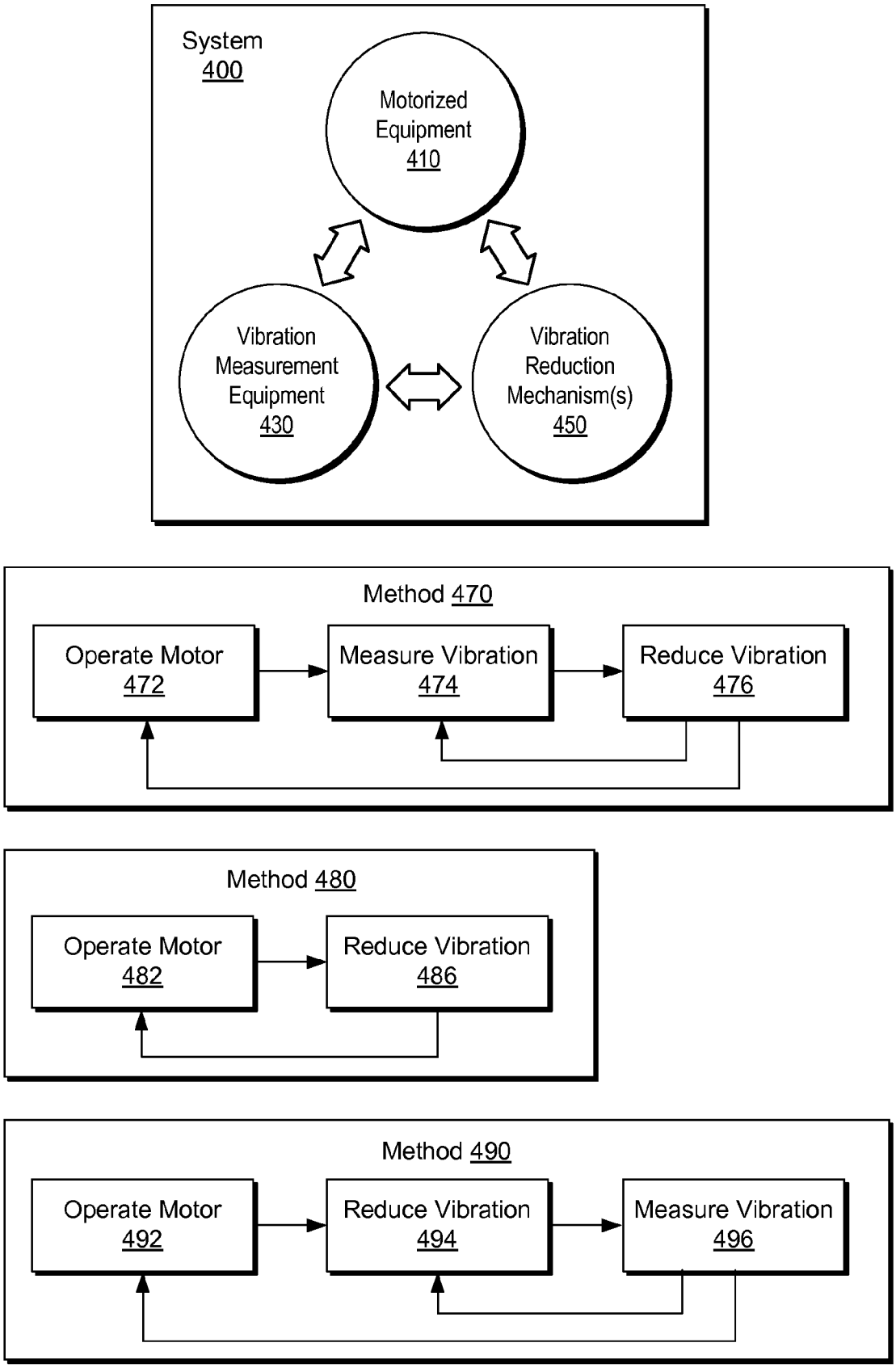

System
400
Motorized Equipment
410
Vibration Measurement Equipment
430
Vibration Reduction Mechanism(s)
450
Method 470
Operate Motor
472
Measure Vibration
474
Reduce Vibration
476
Method 480
Operate Motor
482
Reduce Vibration
486
Method 490
Operate Motor
492
Reduce Vibration
494
Measure Vibration
496

Fig. 4

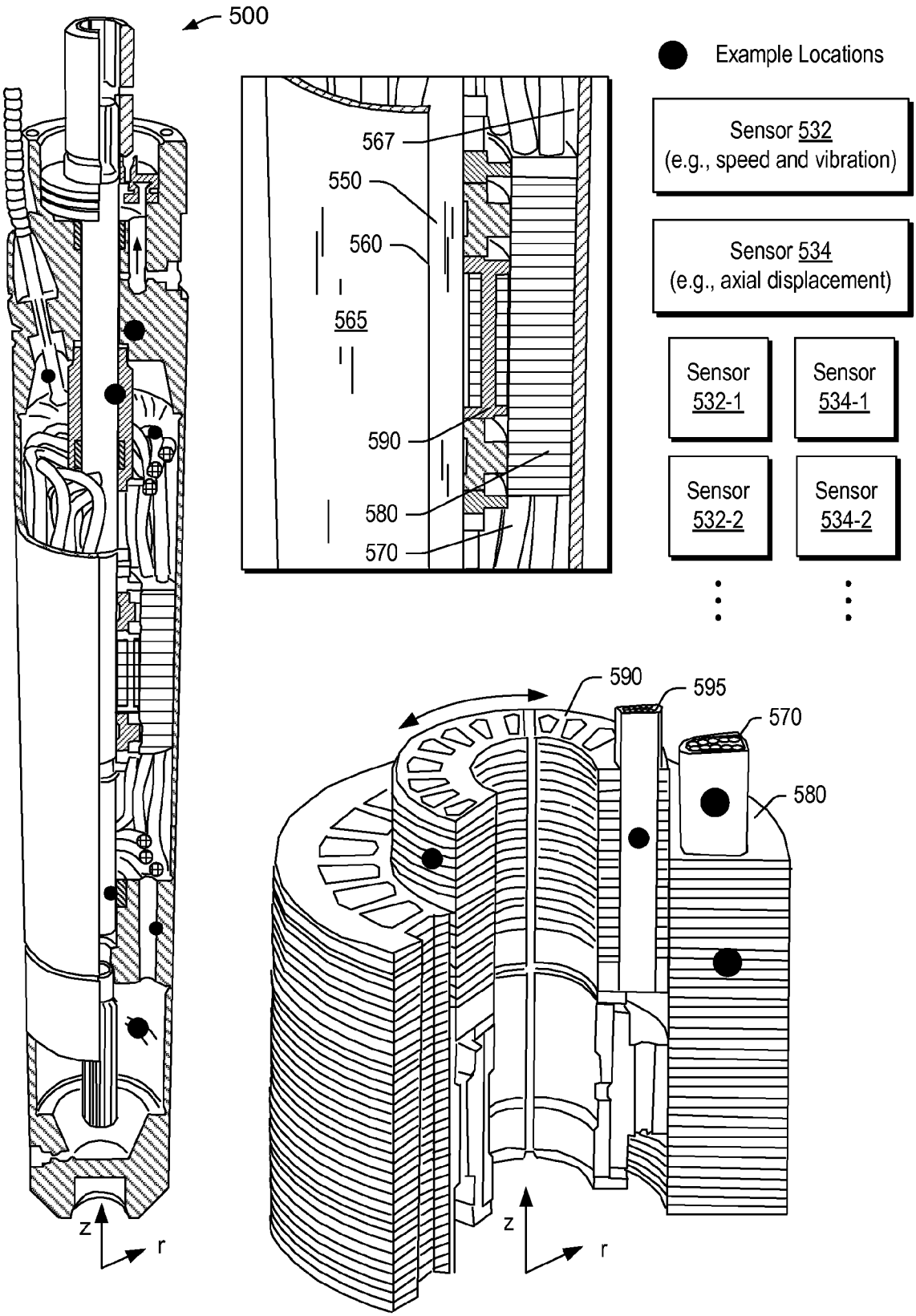

500
Example Locations
Sensor 532
(e.g., speed and vibration)
Sensor 534
(e.g., axial displacement)
Sensor 532-1
Sensor 534-1
Sensor 532-2
Sensor 534-2
567
550
560
565
590
580
570
590
595
570
580
z
r
z
r

Fig. 5

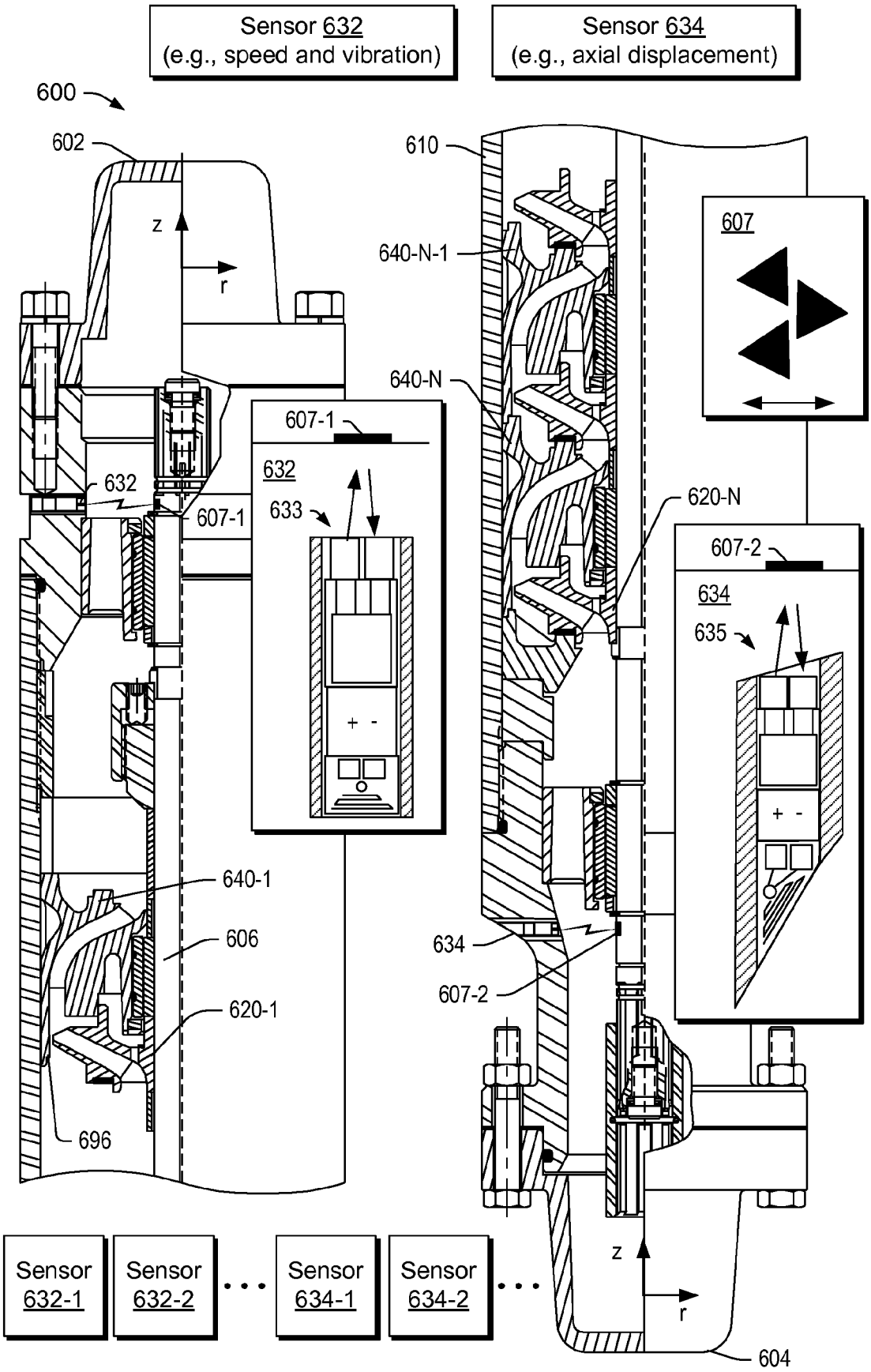

Sensor 632
(e.g., speed and vibration)
Sensor 634
(e.g., axial displacement)
600
602
610
z
r
607
640-N-1
640-N
607-1
632
633
607-1
620-N
607-2
634
635
640-1
606
620-1
634
607-2
696
Sensor 632-1
Sensor 632-2
Sensor 634-1
Sensor 634-2
z
r
604

Fig. 6

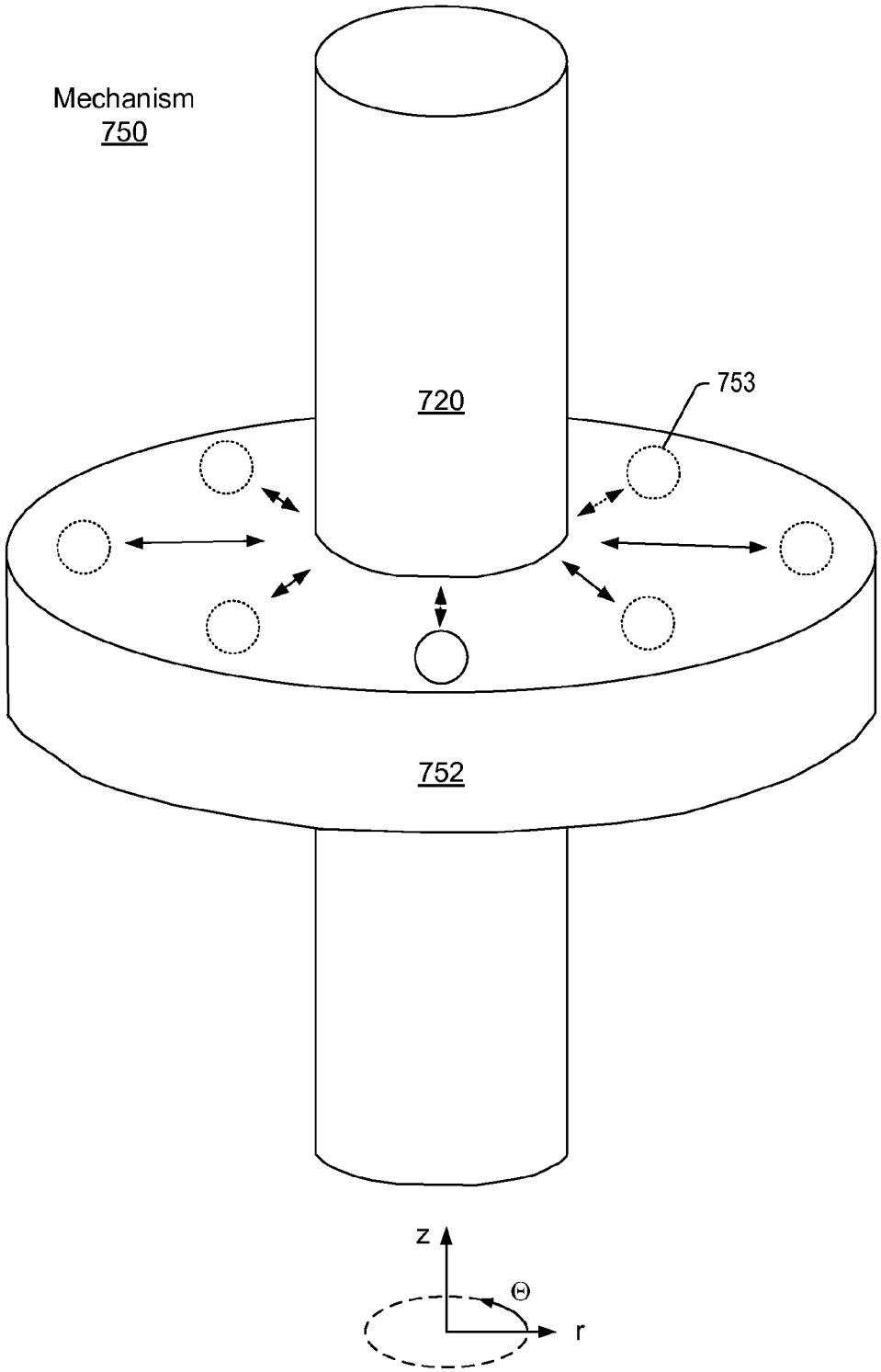


Fig. 7

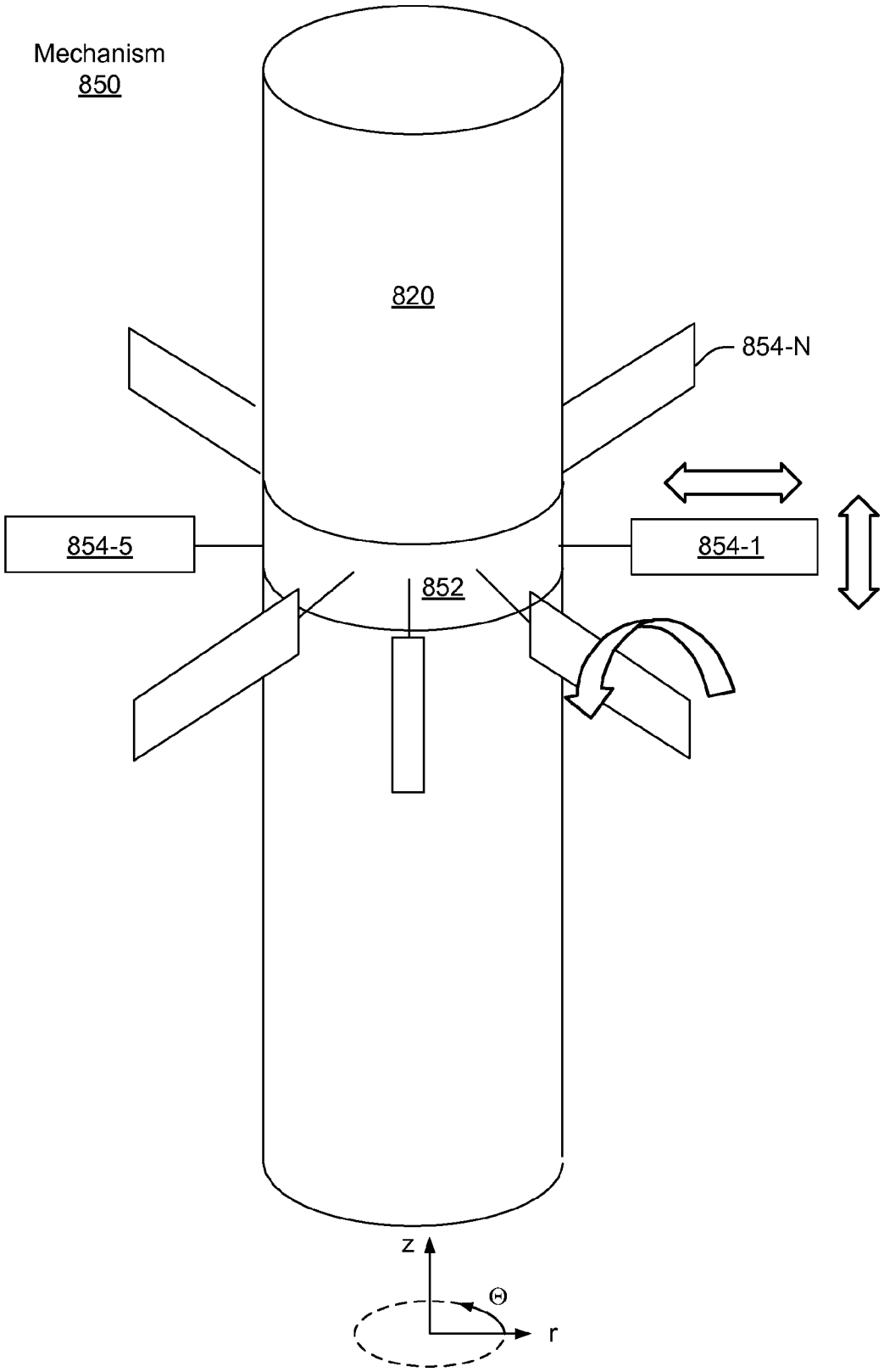


Fig. 8

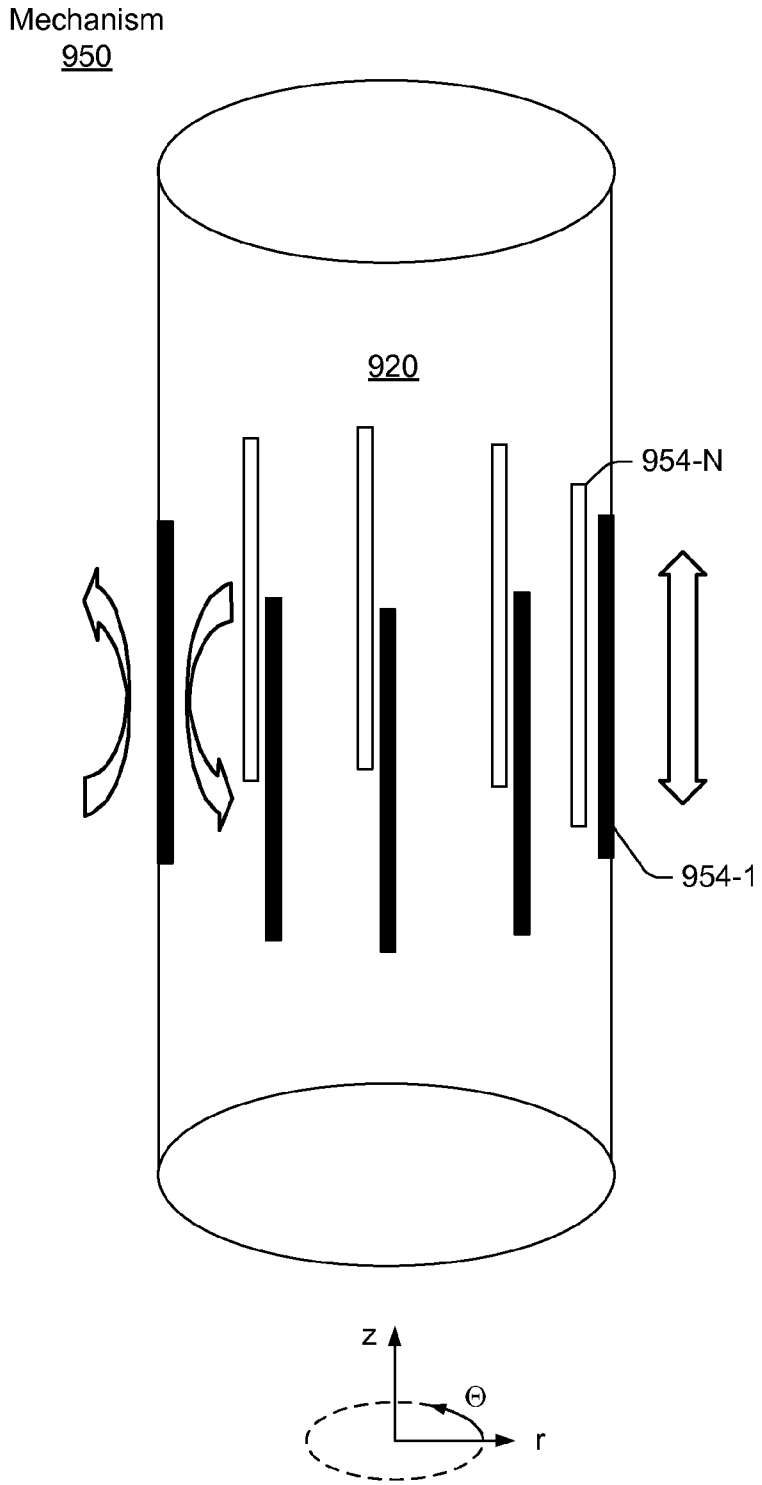


Fig. 9

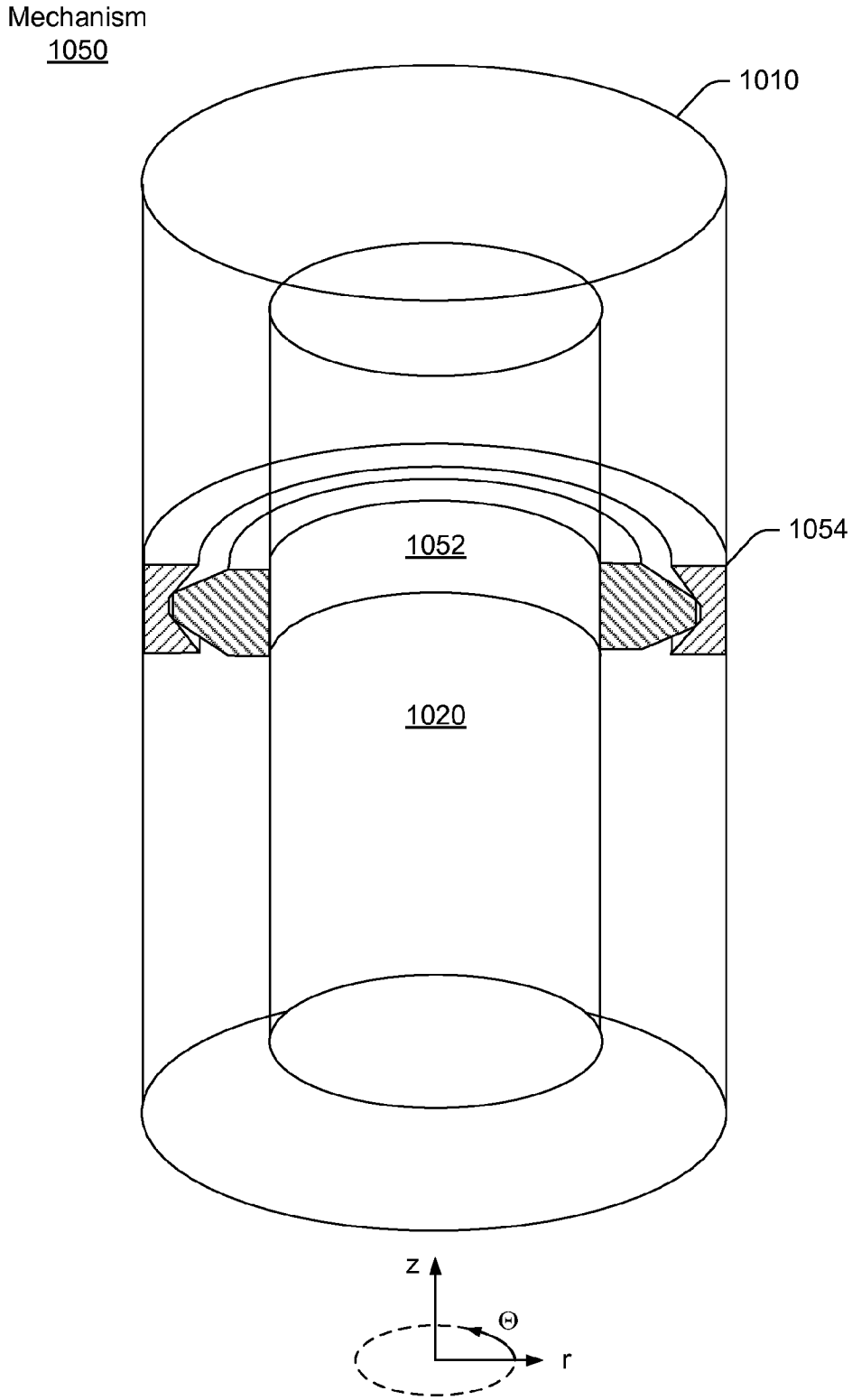


Fig. 10

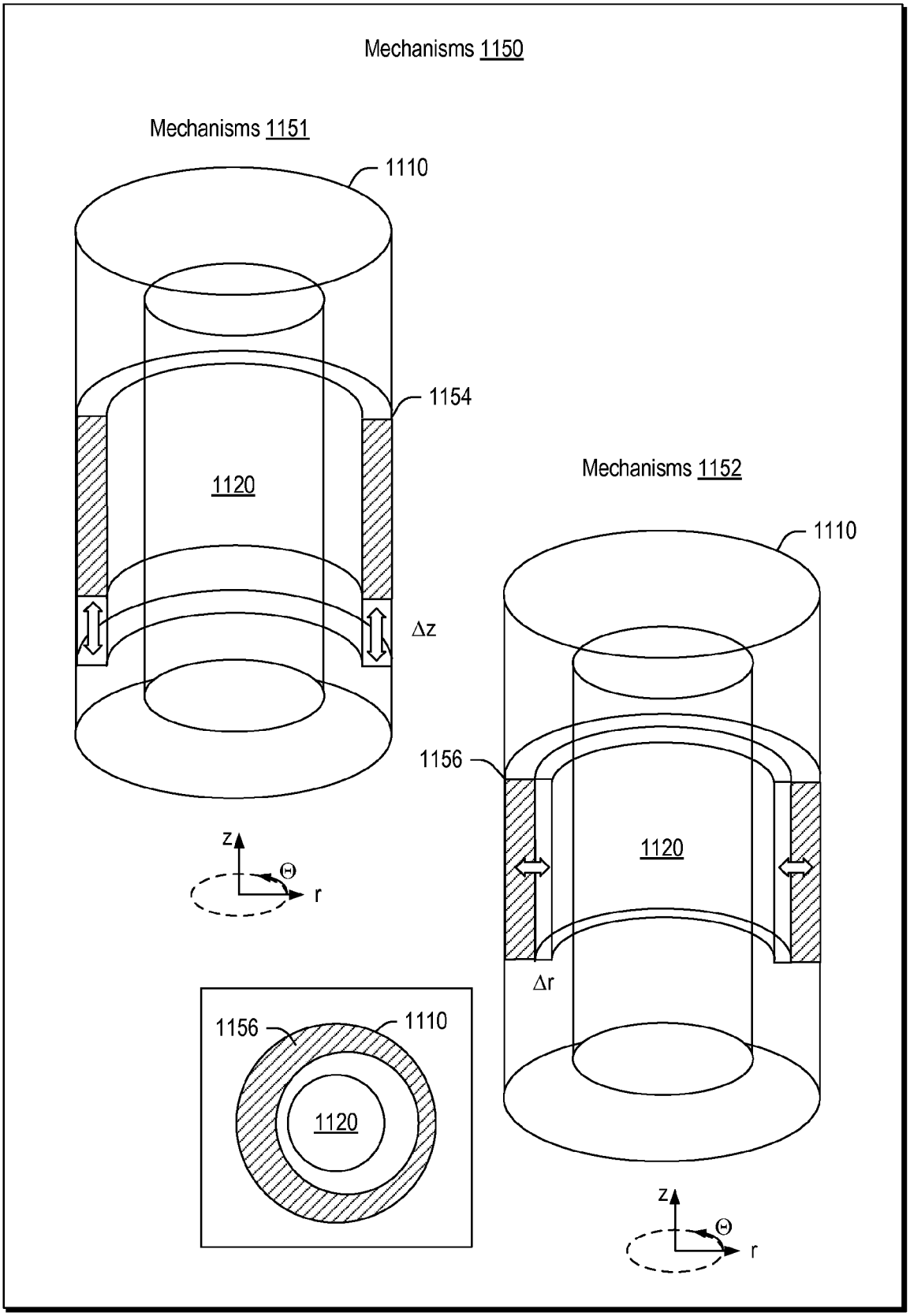

Mechanisms 1150
Mechanisms 1151
1110
1154
1120
Δz
z
Θ
r
Mechanisms 1152
1110
1156
1120
Δr
1156
1110
1120
z
Θ
r

Fig. 11

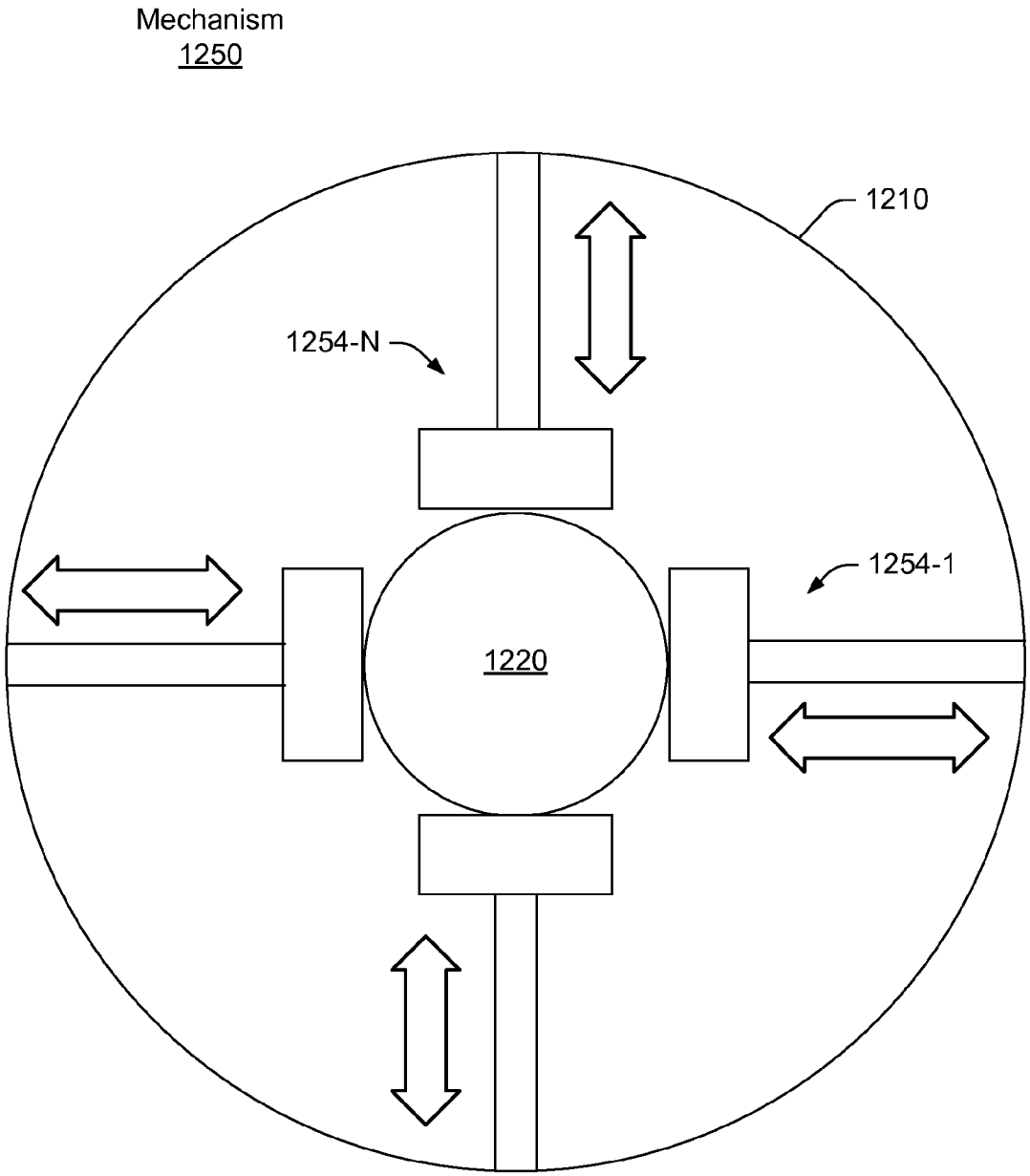


Fig. 12

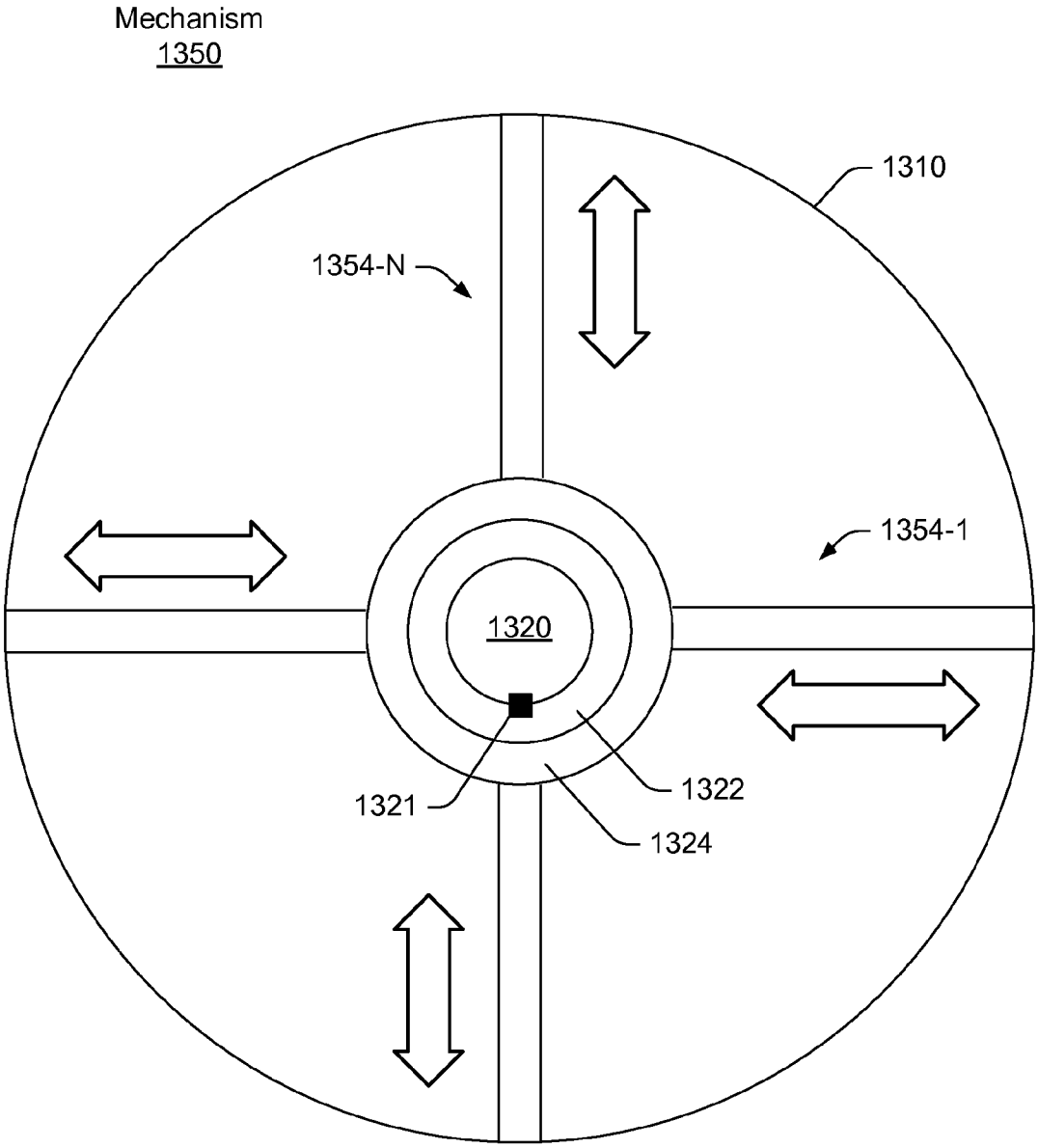


Fig. 13

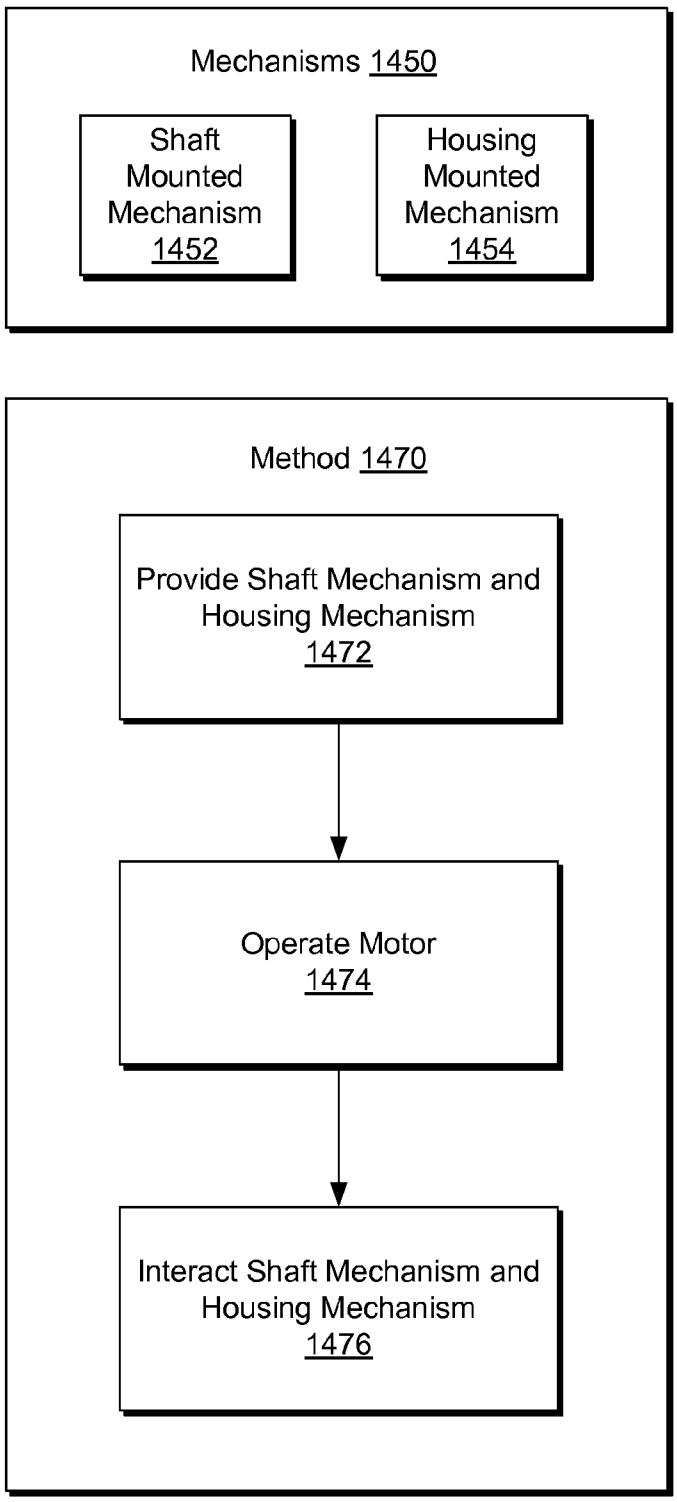

Mechanisms 1450
Shaft Mounted Mechanism 1452
Housing Mounted Mechanism 1454
Method 1470
Provide Shaft Mechanism and Housing Mechanism 1472
Operate Motor 1474
Interact Shaft Mechanism and Housing Mechanism 1476

Fig. 14

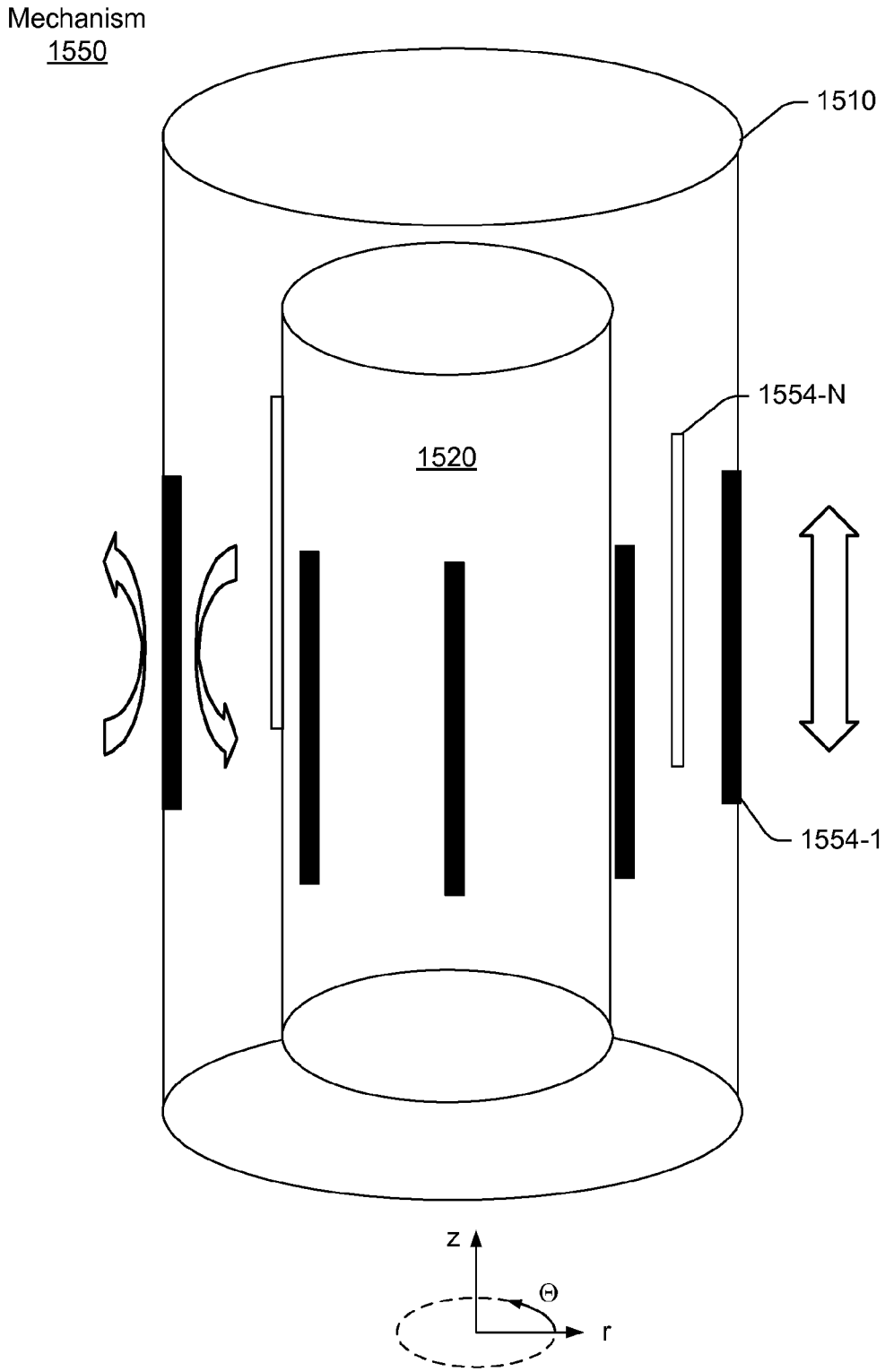


Fig. 15

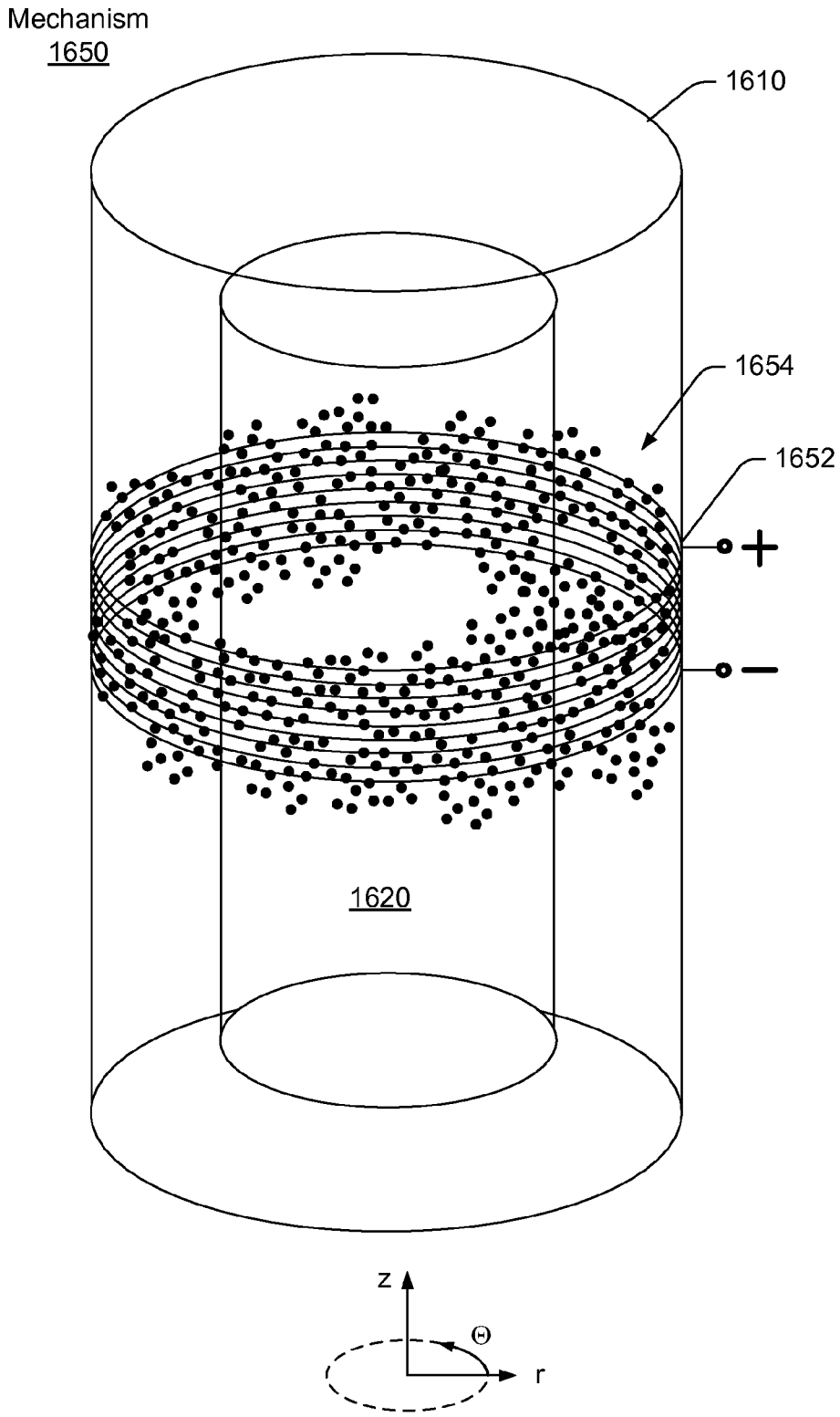


Fig. 16

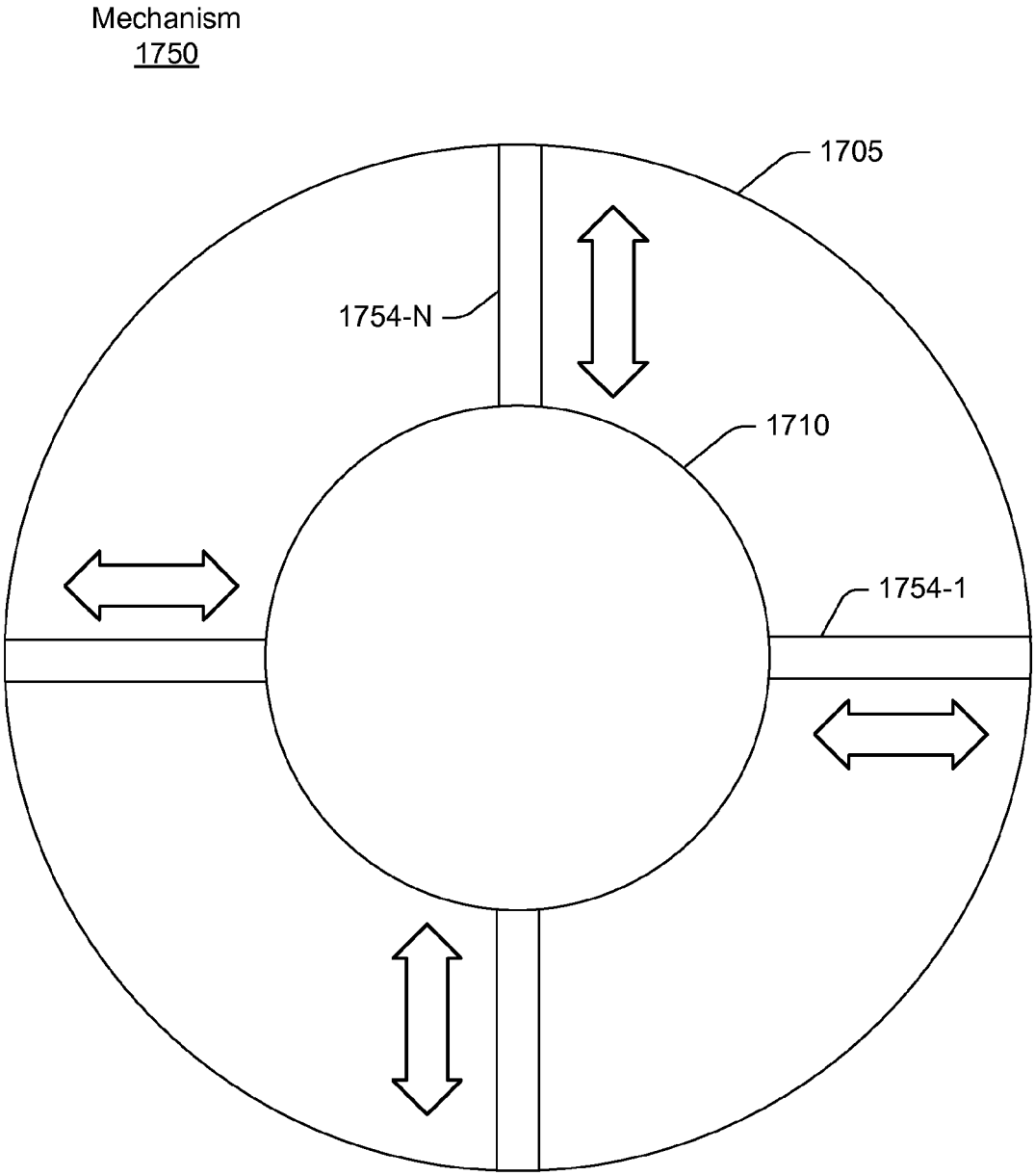


Fig. 17

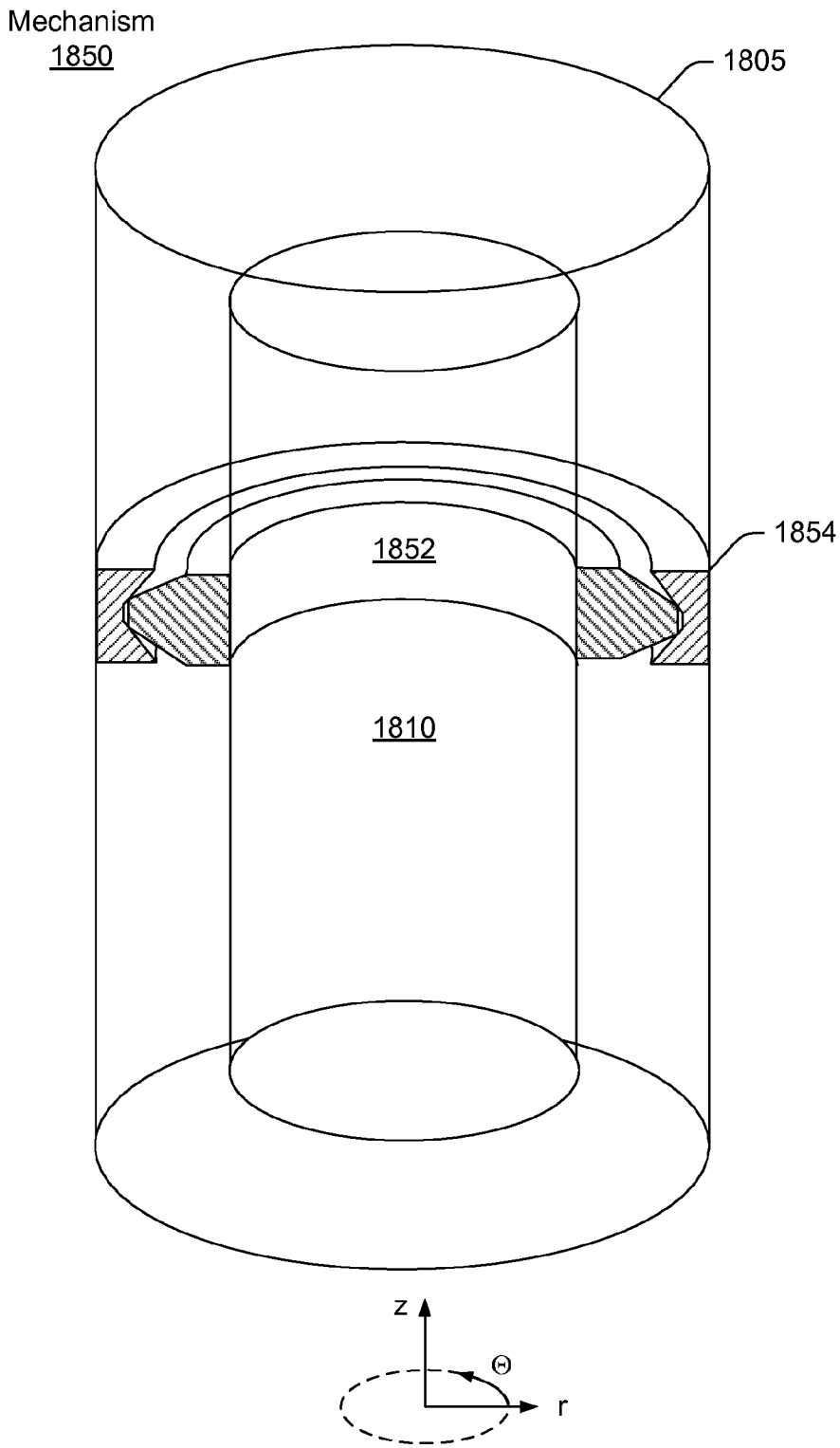


Fig. 18

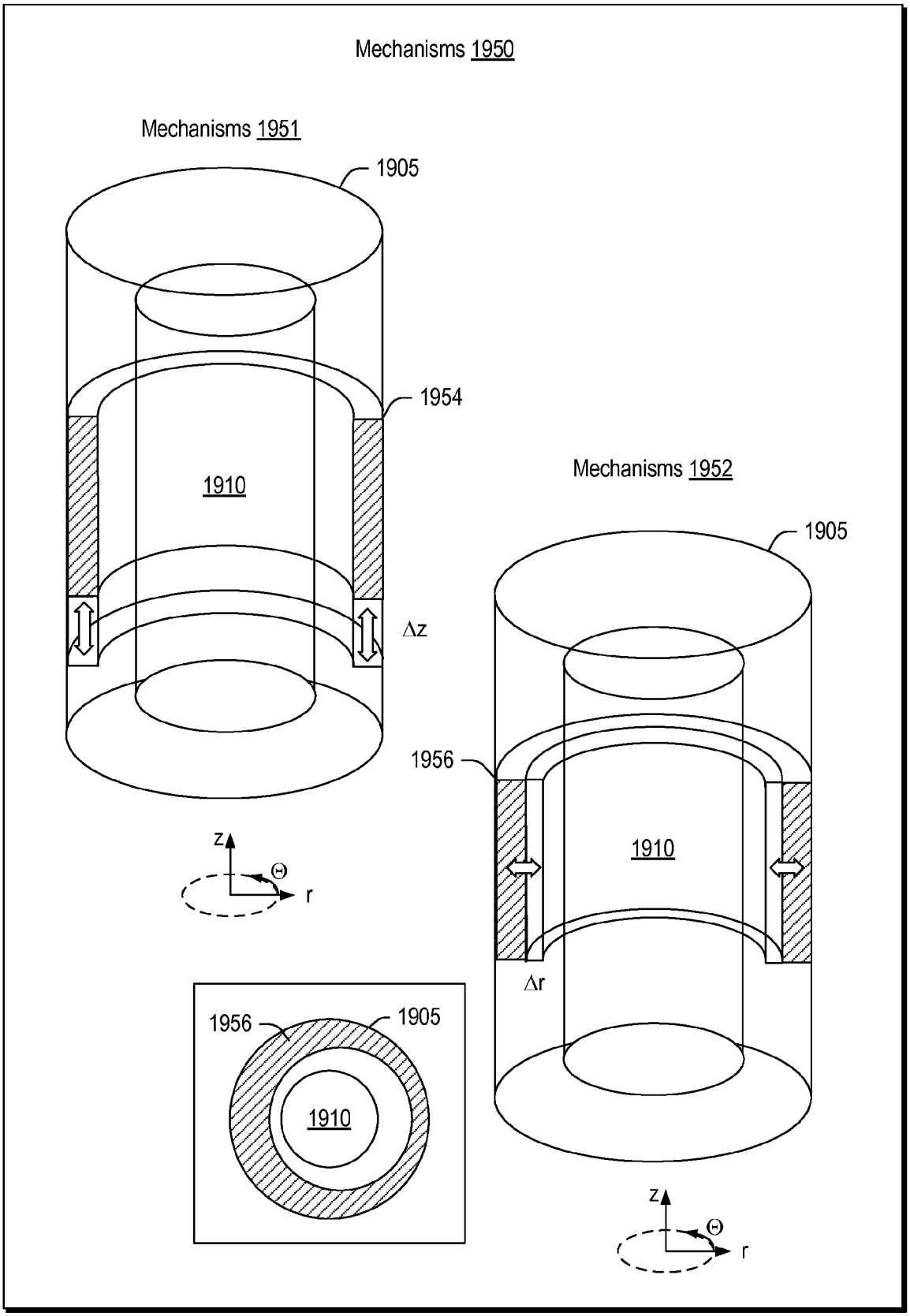

Mechanisms 1950
Mechanisms 1951
1905
1954
1910
Δz
z
Θ
r
1956
1905
1910
Mechanisms 1952
1905
1956
1910
Δr
z
Θ
r

Fig. 19

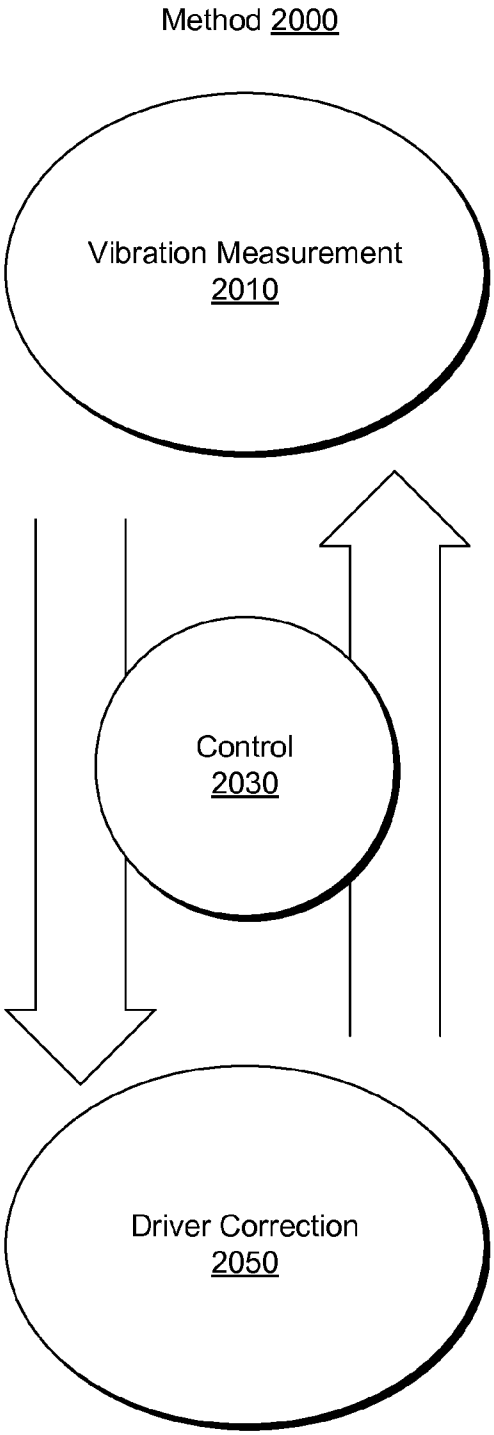

Method 2000
Vibration Measurement
2010
Control
2030
Driver Correction
2050

Fig. 20

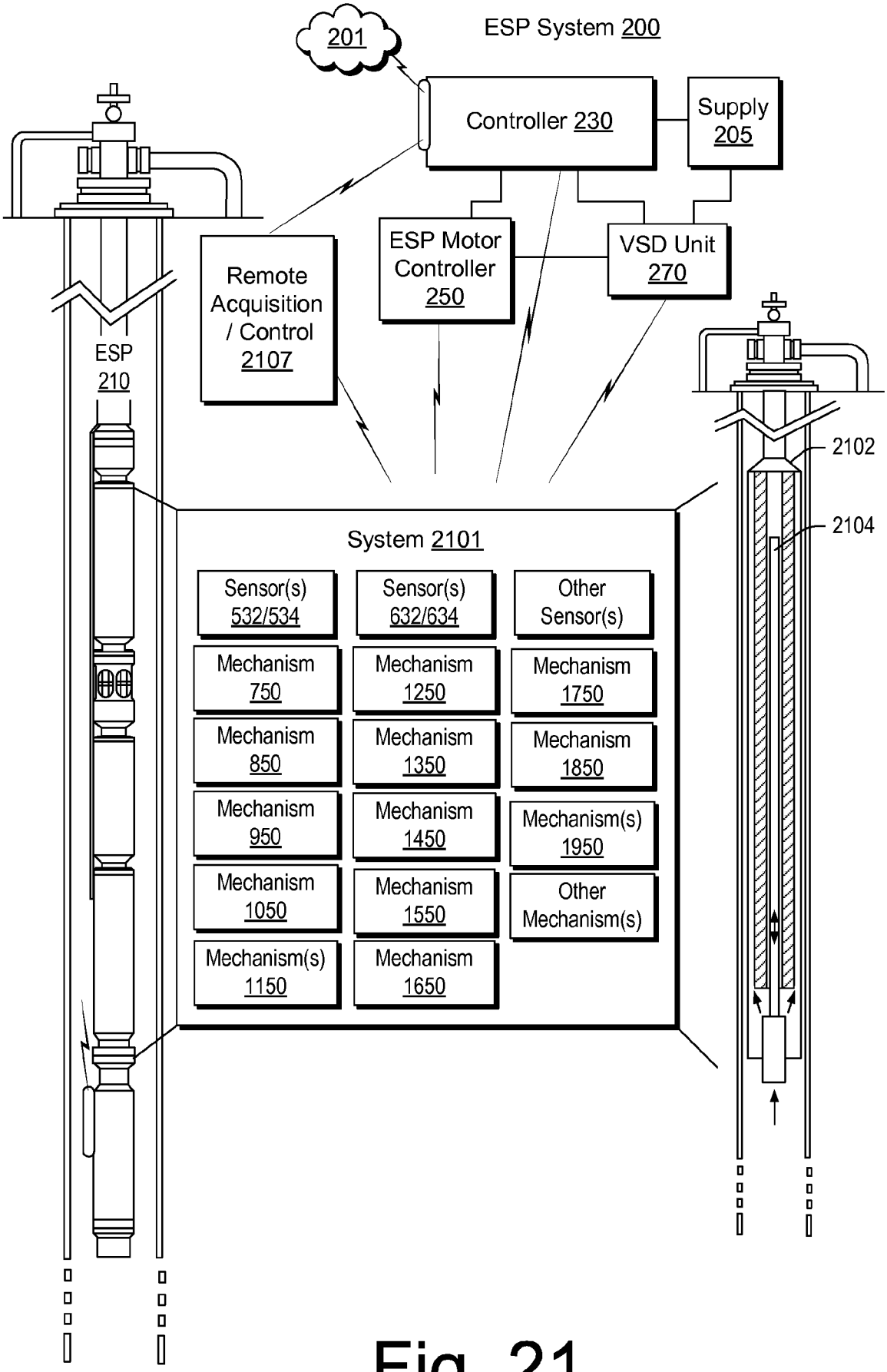

201
ESP System 200
Controller 230
Supply 205
ESP Motor Controller 250
VSD Unit 270
Remote Acquisition / Control 2107
ESP 210
2102
2104
System 2101
Sensor(s) 532/534
Sensor(s) 632/634
Other Sensor(s)
Mechanism 750
Mechanism 1250
Mechanism 1750
Mechanism 850
Mechanism 1350
Mechanism 1850
Mechanism 950
Mechanism 1450
Mechanism(s) 1950
Mechanism 1050
Mechanism 1550
Other Mechanism(s)
Mechanism(s) 1150
Mechanism 1650

Fig. 21

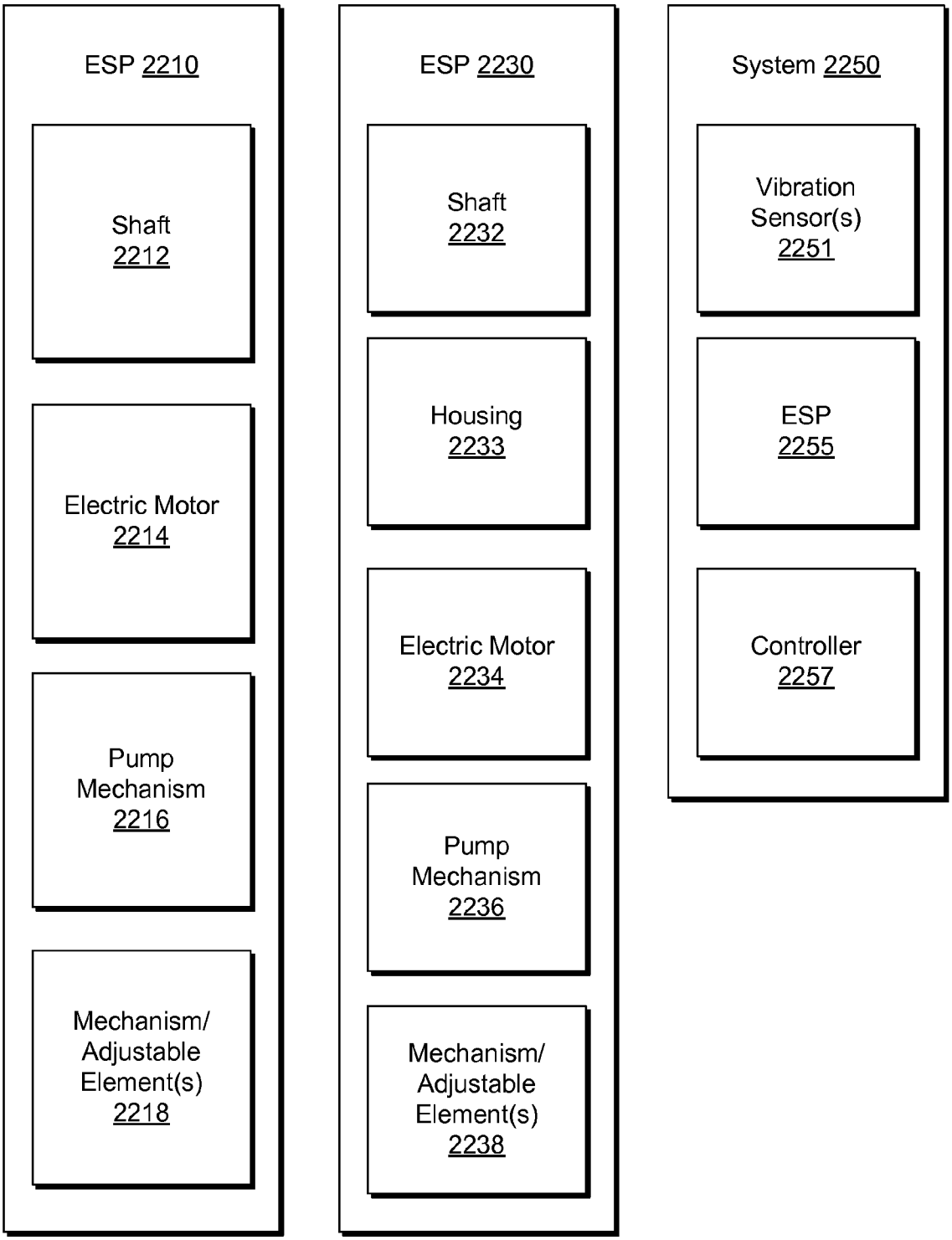

ESP 2210
Shaft 2212
Electric Motor 2214
Pump Mechanism 2216
Mechanism/ Adjustable Element(s) 2218
ESP 2230
Shaft 2232
Housing 2233
Electric Motor 2234
Pump Mechanism 2236
Mechanism/ Adjustable Element(s) 2238
System 2250
Vibration Sensor(s) 2251
ESP 2255
Controller 2257

Fig. 22

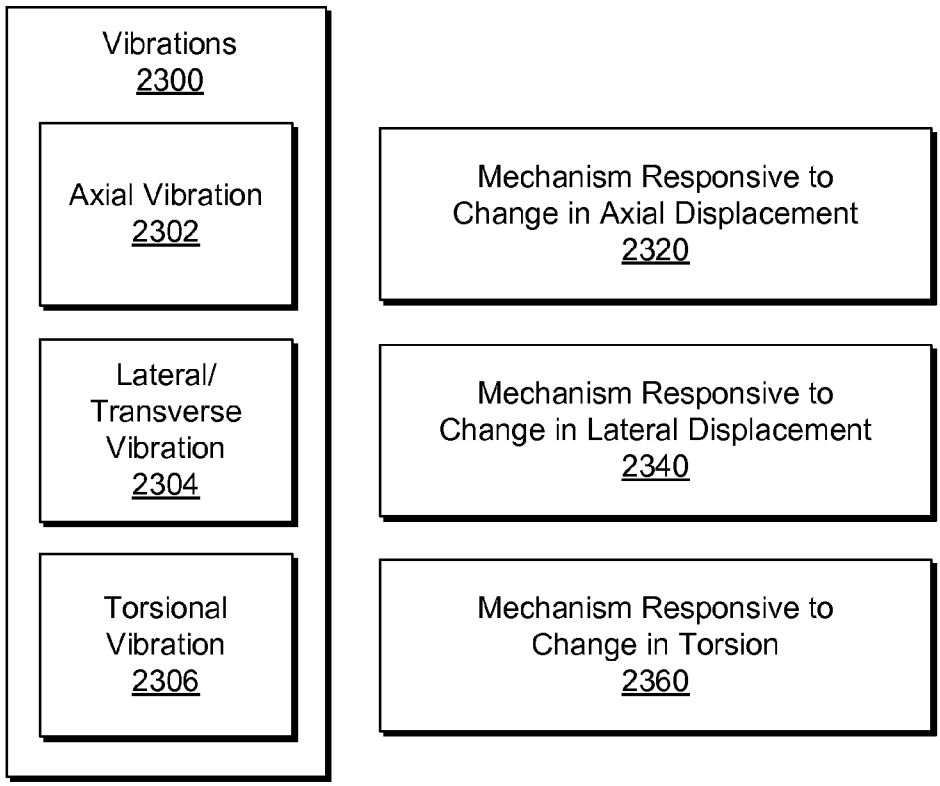
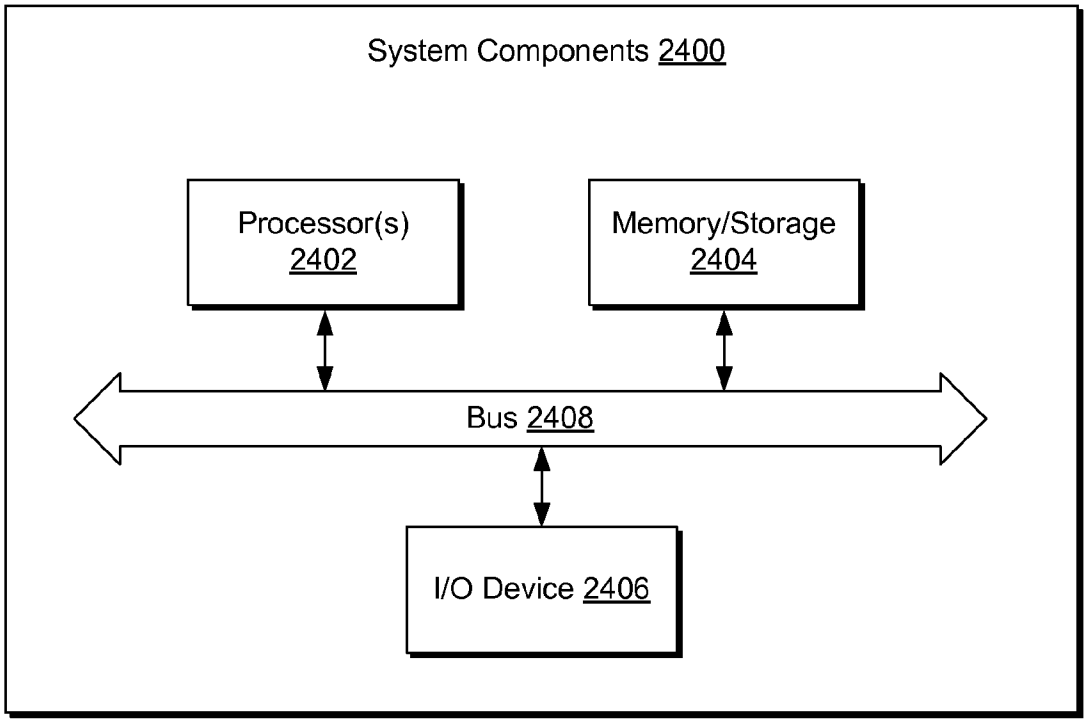


Table 2380
Vibration Severity Criteria (ISO IS 2372,1974)

Peak velocity ranges of vibration severity		Vibration Severity	Peak-to-peak displacement amplitude @ 3,600 rpm	
(in/sec)	(cm/sec)		(mils)	(mm)
<0.014	<0.036	Extremely smooth	<0.074	<0.0019
0.028	0.071	Very smooth	0.148	0.0038
0.042	0.107	Smooth	0.233	0.0057
0.057	0.145	Very good	0.302	0.0077
0.099	0.251	Good	0.525	0.0133
0.156	0.396	Fair	0.828	0.0210
0.255	0.648	Slightly rough	1.353	0.0344
0.396	1.006	Rough	2.101	0.0534
0.622	1.580	Very rough	3.300	0.0838
>0.622	>1.580	Extremely rough	>3.300	>0.0838

Fig. 23


System Components 2400
Processor(s) 2402
Memory/Storage 2404
Bus 2408
I/O Device 2406

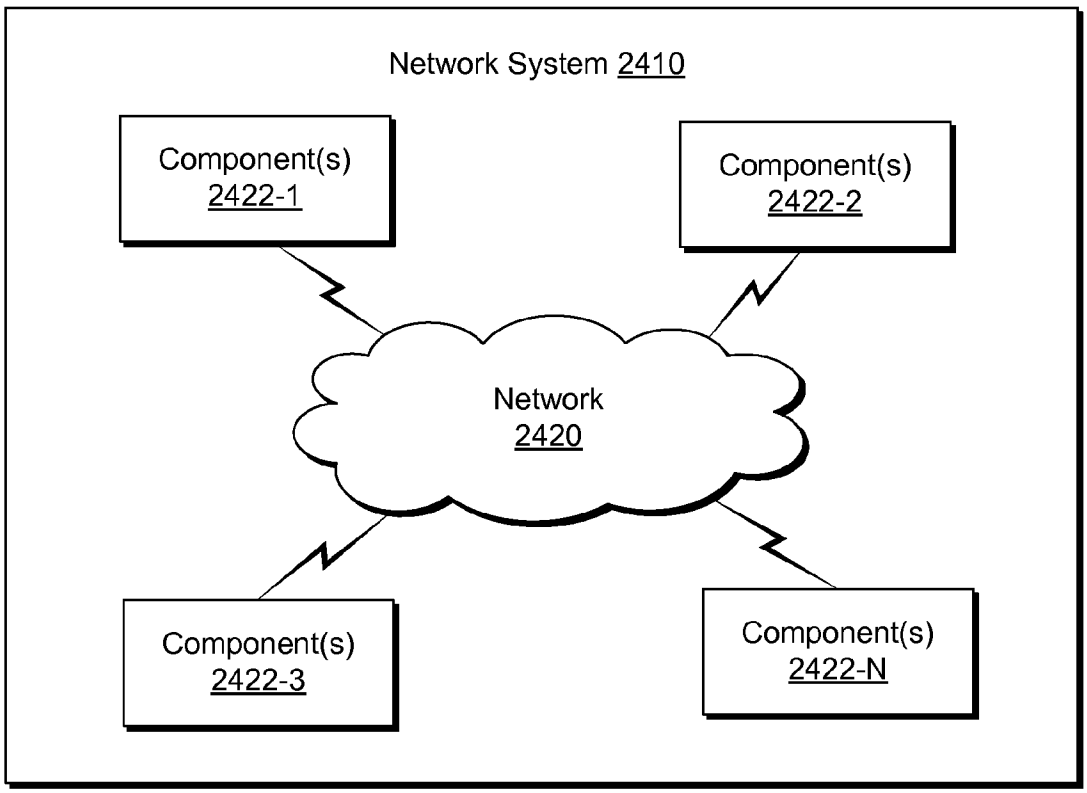

Network System 2410
Component(s) 2422-1
Component(s) 2422-2
Network 2420
Component(s) 2422-3
Component(s) 2422-N

Fig. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/022146

A. CLASSIFICATION OF SUBJECT MATTER

F04D 29/66(2006.01)i, F04D 13/08(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)
F04D 29/66; F04B 49/06; F16C 3/00; F16F 15/00; F04B 35/04; F16F 15/02; F16F 15/18; F04D 29/04; B23P 15/00; F04D 13/08

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: electric submersible pump, vibration, damper, bearing, extendable, blade, mass, actuator, and balance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0058797 A1 (PRIETO et al.) 07 March 2013 See paragraphs [0024]-[0026], [0031] and figures 1, 9-11.	18-20
Y		1-17
Y	US 2013-0298724 A1 (JUSTAK et al.) 14 November 2013 See paragraphs [0022]-[0026] and figures 5-7.	1-17
A	US 2011-0182535 A1 (PRIETO, CARLOS A.) 28 July 2011 See paragraphs [0021]-[0025] and figure 1.	1-20
A	US 2012-0251362 A1 (FORSBERG, MICHAEL A.) 04 October 2012 See paragraphs [0021]-[0024] and figures 4-5.	1-20
A	US 4963804 A (GEIGER, THOMAS L.) 16 October 1990 See column 8, line 15 - column 9, line 50 and figures 4-5.	1-20

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

☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"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
15 December 2015 (15.12.2015)	**18 December 2015 (18.12.2015)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2015/022146

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		WO 2012-134639 A3	13/12/2012
US 4963804 A	16/10/1990	None	