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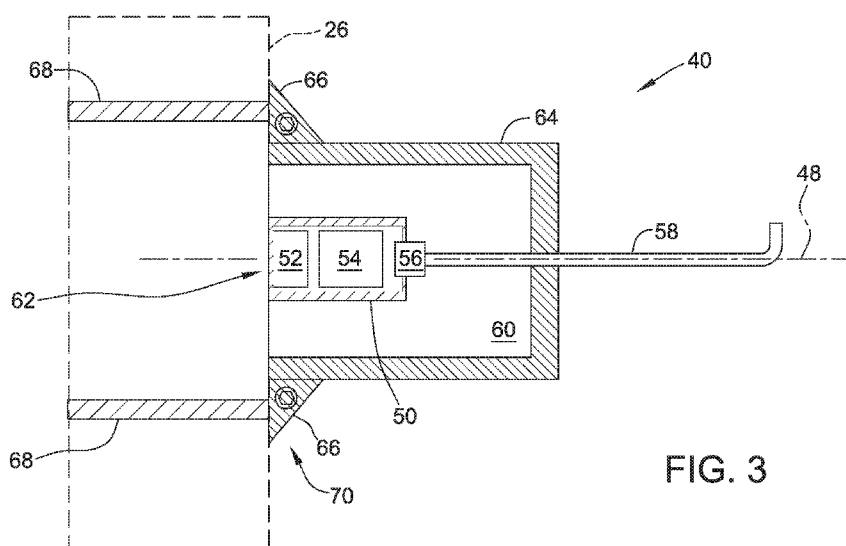


FIG. 3

(57) Abstract: An underwater acoustic sensor assembly includes a housing having an open end and an internal chamber. An acoustic sensor is positioned within the housing. The acoustic sensor includes a sensing end positioned adjacent to the open end of the housing. In addition, the underwater acoustic sensor includes an acoustic absorption layer coupled to the housing. The acoustic absorption layer extends between the housing and the acoustic sensor such that the acoustic sensor is substantially isolated from vibrations transmitted through the housing. The acoustic absorption layer includes an aperture formed adjacent to the housing open end. The sensing end of the acoustic sensor is positioned within the aperture.



SUBSEA MULTIFUNCTIONAL SENSOR

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/152,524 filed April 24, 2015, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Some subsea exploration and production operations, for example, oil and gas field operations, involve drilling, and operating, wells to locate and retrieve hydrocarbons. For many years, some drilling activities have increasingly expanded to subsea locations where drilling rigs are increasingly positioned at well sites in relatively deep water. Various types of equipment, e.g., drills, tubing, and pipes, are used at some well sites to explore the submerged reservoirs. The seafloor, however, is a harsh and remote environment, and, as such, many activities, such as, drilling operations, for example, may involve considerable risk of environmental contamination.

[0003] Accordingly, it is common to monitor the safety and efficiency of the drilling operations. However, it may be difficult to efficiently monitor such activities. In some operations, the exploration and production equipment is monitored by at least one sensor. However, because of the transmission of pressure waves in the water, such sensors may sense changes that are not associated with an area of interest or with the equipment to which they are intended to monitor. Furthermore, vibrations may be transmitted through the equipment such that a sensor placed remotely from the source of the vibration may sense a local vibration, thereby giving an extraneous reading.

BRIEF DESCRIPTION

[0004] In one aspect, an underwater acoustic sensor assembly is provided. The underwater acoustic sensor assembly includes a housing defining an internal chamber and having an open end. The underwater acoustic sensor assembly also includes an acoustic sensor positioned within the housing. The acoustic sensor includes a sensing end positioned adjacent to the housing open end. In addition, the underwater acoustic sensor assembly includes an acoustic absorption layer coupled to the housing. The acoustic

absorption layer extends between the housing and the acoustic sensor. The acoustic sensor is substantially isolated from vibrations transmitted through the housing. The acoustic absorption layer includes an aperture formed adjacent to the housing open end. The sensing end of the acoustic sensor is positioned within the aperture.

[0005] In another aspect, a system for monitoring subsea equipment is provided. The system includes a directional acoustic sensor assembly coupled to an outer surface of the subsea equipment. The directional acoustic sensor assembly includes a housing defining an internal chamber and having an open end and a first longitudinal axis. The directional acoustic sensor assembly also includes an acoustic sensor comprising a second longitudinal axis and a sensing end. The acoustic sensor is positioned within the housing internal chamber such that the second longitudinal axis is substantially parallel to the first longitudinal axis. In addition, the directional acoustic sensor assembly includes an acoustic absorption layer that extends between the housing and the acoustic sensor. The acoustic absorption layer is configured to substantially isolate the acoustic sensor from acoustic waves. The acoustic absorption layer includes an aperture formed adjacent to the housing open end and extending about the sensing end of the acoustic sensor. The aperture is configured to enable acoustic waves to be transmitted to the sensing end of the acoustic sensor. The system also includes a data processor coupled in electrical communication to the acoustic sensor assembly by a tether. The data processor is configured to receive and process data from the acoustic sensor assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0007] FIG. 1 is a schematic of an exemplary subsea drilling system for use in extracting natural gas and/or oil from an underground reservoir;

[0008] FIG. 2 is an enlarged view of an exemplary oil well blowout preventer (BOP) shown in FIG. 1, illustrating individual acoustic sensors coupled thereto;

[0009] FIG. 3 is an enlarged schematic section illustrating an exemplary individual acoustic sensor of FIG. 1 coupled to the BOP;

[0010] FIG. 4 is another embodiment of an exemplary individual acoustic sensor of FIG. 1, including an acoustically sensitive aperture that is spaced a predefined distance from the BOP such that a water layer is formed therebetween;

[0011] FIG. 5 is a schematic sectional view of another alternative individual acoustic sensor that may be used with the subsea drilling system shown in FIG. 1; and

[0012] FIG. 6 is a schematic sectional view of the individual acoustic sensor shown in FIG. 5, and including a cover having sound/vibration absorptive material extending over at least a portion of the BOP.

[0013] Unless otherwise indicated, the drawings provided herein are meant to illustrate features of embodiments of the disclosure. These features are believed to be applicable in a wide variety of systems comprising at least one embodiments of the disclosure. As such, the drawings are not meant to include all conventional features known by those of ordinary skill in the art to be required for the practice of the embodiments disclosed herein.

DETAILED DESCRIPTION

[0014] The subject matter disclosed herein relates generally to subsea industrial activities and, in particular, to a subsea multifunctional sensor for monitoring subsea exploration and production equipment.

[0015] In the following specification and the claims, reference will be made to a number of terms, which shall be defined to have the following meanings.

[0016] The singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise.

[0017] “Optional” or “optionally” means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where the event occurs and instances where it does not.

[0018] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about”, “approximately”, and “substantially”, are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Here and throughout the specification and claims, range limitations may be combined and/or interchanged; such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise.

[0019] Generally, the present disclosure provides techniques for monitoring subsea exploration and production operations. Many types of subsea exploration and production equipment are used during these exploration and production operations. To monitor the equipment during these subsea operations, various measurements may be obtained from the equipment using at least one sensor. Some of these sensors are acoustic sensors used to monitor the behavior, condition, and operations of the equipment located on the seafloor. As described more fully below, the disclosed subject matter relates to a subsea multifunctional sensor that senses acoustic pressure waves originating from a particular portion of the structure. The sensor converts the pressure waves into a corresponding electrical output signal. In one embodiment, the sensor is a directional sensor that is mounted such that its axis of maximum acoustic sensitivity is directed towards the sound source of interest. To facilitate discriminating the sound sources of interest, the sensor is encased in a sound/vibration absorptive material, except for an aperture that is open and is oriented towards the sound source of interest. Thus, the aperture enables the acoustic waves to pass to the sensor unobstructed, while the sound/vibration absorptive material around the other portions of the sensor prevents the transmission of the acoustic waves. In other embodiments, the sound/vibration absorptive material extends over the structure to facilitate providing a second degree of discrimination against sound sources originating from the same direction as the sound source of interest.

[0020] Although generally described herein with respect to a subsea multifunctional sensor or a hydrophone including a piezoelectric sensor element, the apparatus and systems described herein are applicable to any type or form of subsea multifunctional sensor. For example, and without limitation, subsea sensors may include

any sensor having any type of acoustic sensor element, such as, but not limited to, Langevin & mass loaded elements, piezoelectric composites, low frequency transducers, echosounder transducers, ultrasonic NDT transducers, and/or other acoustic sensor elements.

[0021] FIG. 1 is a schematic of an exemplary subsea drilling system 10 for use in extracting natural gas and/or oil from an underground reservoir 12. In the exemplary embodiment, a drill 14 is driven through a wellhead 16 on the seafloor 18 from a floating rig 20 floating at the sea surface 22. Drill 14 extends from floating rig 20 to wellhead 16 through a riser tube 24 that is used to capture the underground oil and/or gas (not shown). In the exemplary embodiment, an oil well blowout preventer (BOP) 26 is coupled to wellhead 16. The phrase “oil well blowout preventer” or “BOP”, as used herein, includes (but is not limited to) a piece of safety equipment used in subsea oil and/or gas drilling to prevent uncontrolled flow from a well (i.e., a blowout). In the exemplary embodiment, BOP 26 includes a vertical “stack” that sits atop wellhead 16 on seafloor 18. BOP 26 also includes a series of hydraulically-actuated shears (not shown) used to seal off wellhead 16 by force in the event of a blowout. It should be noted that BOP 26 is an exemplary underwater structure. However, the apparatus and systems described herein may be used with other underwater structures used in subsea exploration and production operations.

[0022] In the exemplary embodiment, subsea drilling system 10 includes a first acoustic sensor array 28 coupled to BOP 26. Also, as exemplary in FIG. 1, subsea drilling system 10 includes a second acoustic sensor array 30 positioned remotely from BOP 26 and a data processor 32 coupled in electrical communication with acoustic sensor arrays 28 and 30. Each acoustic sensor array 28 and 30 includes at least one individual acoustic sensor 40 coupled, for example, without limitation, together with arrays 28 and 30. As exemplary in FIG. 1, each acoustic sensor array 28 and 30 includes three individual acoustic sensors 40.

[0023] Data collected by arrays 28 and 30 is transmitted to data processor 32 through tethers 34 and 36 for signal processing and analysis. Data processor 32 provides operators with at least one monitoring capabilities, including, for example, without limitation: beam-forming, i.e., selective focusing on a desired portion of BOP 26 (even if no individual sensor is located at the desired portion); source localization, i.e., the

identification of an origin point of a detected sound; event identification, i.e., the association of a particular acoustic signal with a physical event; and trend identification, i.e., the identification of acoustic signal changes over time.

[0024] FIG. 2 is an enlarged view of BOP 26 including at least one individual acoustic sensors 40 coupled to an external surface 42 of BOP 26. More specifically, in the exemplary embodiment, BOP 26 includes first acoustic sensor array 28 coupled to external surface 42 and second acoustic sensor array 30 positioned remotely from BOP 26. Moreover, a data processor 44 is positioned anywhere along tethers 34 and 36, including at the site of the equipment being monitored (e.g., proximate to BOP 26) rather than on floating rig 20, as is shown in FIG. 1. In one embodiment, data processor 44 is coupled to BOP external surface 42. Alternatively, data processor 44 may be coupled against seafloor 18 (shown in FIG. 1) or to another piece of equipment (not shown) located proximate to BOP 26. In addition, in the embodiment shown in FIG. 2, a third acoustic sensor array 46 is coupled to data processor 44. Third acoustic sensor array 46, as well as any other acoustic sensor arrays that may be included, increase the data collected by first and second acoustic sensor arrays 28 and 30. In the exemplary embodiment, second acoustic sensor array 30 is suspended from BOP 26 and is coupled to data processor 44 via tether 36.

[0025] Moreover, in the exemplary embodiment, subsea drilling system 10 includes at least one individual acoustic sensor 40 (i.e., a sensor that is not part of an array) coupled to BOP external surface 42 at various locations of interest. In the exemplary embodiment, each individual acoustic sensor 40 is identical to the acoustic sensors used in each of acoustic sensor arrays 28, 30, and 46. Each individual acoustic sensor 40, and acoustic sensor arrays 28, 30, and 46 are coupled to BOP 26 in a variety of ways well known in the art. For example, and without limitation, in one suitable embodiment, individual acoustic sensor 40 is coupled to BOP external surface 42 using mechanical fasteners, such as bolts or magnets, and in such an embodiment, acoustic sensor 40 may function as a vibration sensor in addition to an acoustic sensor given its rigid attachment to BOP 26.

[0026] In the exemplary embodiment, individual sensors 40 are positioned adjacent to individual components or features (not shown) of BOP 26, such as, for example, adjacent to a valve, a bearing, and/or a seal, to provide localized detection of sound and/or vibration originating from the component and to facilitate better localization of sound origination (e.g., enabling discrimination between two seals that are located close to one another). In alternative embodiments, at least one individual acoustic sensor 40 may be positioned remotely from BOP 26 to provide additional input to data processor 44.

[0027] FIG. 3 is an enlarged schematic section illustrating acoustic sensor assembly 40 coupled to BOP 26. In the exemplary embodiment, acoustic sensor 40 has a longitudinal axis 48 extending the length of the sensor. Acoustic sensor 40 includes a sensor unit 50 having a sensing end or an acoustic sensor element 52 that is adjacent to an open end or a first end 70 of sensor 40. In the exemplary embodiment, sensor element 52 is a piezoelectric element. Alternatively, sensor element 52 may be any sensor element that enables acoustic sensor 40 to function as described herein. For example, and without limitation, sensor element 52 may be a Langevin & mass loaded element, a piezoelectric composite, a low frequency transducer, an echosounder transducer, an ultrasonic (NDT) transducer, and/or other acoustic sensor element. In the exemplary embodiment, acoustic sensor element 52 is electrically coupled to signal conditioning/digitizing electronics, or to signal processing component 54. Signal processing component 54 processes the raw signal (not shown) sensed by acoustic sensor element 52 before transmitting it to data processor 32 and/or 44. It is contemplated that, in some embodiments, signal processing component 54 may be omitted from individual acoustic sensor 40, and therefore, the signal sensed by acoustic sensor element 52 may be transmitted directly to data processor 32 and/or 44.

[0028] In the exemplary embodiment, sensor unit 50 includes a cable entry or electrical penetrator 56 and a cable 58, which in combination enable sensor unit 50 to be electrically coupled to data processor 32 and/or 44. Cable 58 may include, for example, and without limitation, traditional copper (or other conductive metal) wiring or fiber-optic cabling. Alternatively, cable 58 may be of any construction that enables the sensed signal to be transmitted to data processor 32 and/or 44.

[0029] In the exemplary embodiment, sensor unit 50 is encased in a sound/vibration absorptive material 60 that facilitates isolating sensor unit 50 from acoustical waves and vibrations emanating from sound sources that are not of interest. To facilitate discriminating sound sources of interest, sound/vibration absorptive material 60 includes an acoustically-sensitive aperture 62 located near first end 70 of individual acoustic sensor 40, such that acoustic sensor element 52 is uncovered by sound/vibration absorptive material 60 at aperture 62. For example, in one embodiment, aperture 62 is substantially aligned with sensor first end 70. In an alternative embodiment, sound/vibration absorptive material 60 may extend from first end 70 of acoustic sensor 40 a predetermined distance. For example, in one embodiment, material extends between about 5 millimeters (mm) to about 20 mm from end 70, such that aperture 62 is spaced from acoustic sensor first end 70.

[0030] In the exemplary embodiment, sound/vibration absorptive material 60 is an acoustic absorber material, such as, for example, and without limitation, a syntactic foam material. Known syntactic foam materials include a micro-sphere or micro-balloon filled material, such as a cast polyurethane and/or a rubber compound mixture including small, heavy particles. Alternatively, sound/vibration absorptive material 60 may be any other acoustic absorber material that enables individual acoustic sensor 40 to function as described herein.

[0031] Moreover, in the exemplary embodiment, acoustic sensor 40 includes a rigid outer housing 64 that defines an internal chamber sized and oriented to receive sensor unit 50 and sound/vibration absorptive material 60 therein. As illustrated in FIG. 3, sensor unit 50 is substantially centered in outer housing 64, sharing the longitudinal axis 48, such that sound/vibration absorptive material 60 is generally evenly distributed therein. Also as shown, sensor unit 50 is located adjacent to first end 70 such that acoustic sensor element 52 is substantially aligned with aperture 62. In an alternative embodiment, sensor unit 50 may extend from aperture 62 a distance of between about 1 mm to about 10 mm.

[0032] During operation, sound/vibration absorptive material 60 facilitates isolating sensor unit 50 from sounds and vibrations emanating from locations that are not generally axially aligned with sensor unit 50 and aperture 62. Without sound/vibration

absorptive material 60, acoustic pressure waves originating from other sound sources would couple to sensor unit 50, and propagate as acoustical and/or mechanical waves in sensor unit 50, thereby causing a motion or acoustic signal output of sensor unit 50. However, sound/vibration absorptive material 60 and acoustically sensitive aperture 62 cooperate to dampen or discriminate those signals not axially aligned with aperture 62 and sensor unit 50. This enables acoustic sensor 40 to be precisely positioned to sense sounds and or vibrations from a specific area of interest on BOP 26.

[0033] As shown in FIG. 3, individual acoustic sensor 40 is coupled to BOP 26. Outer housing 64 includes at least one flanges 66 used to fasten individual acoustic sensor 40 to various structures, such as BOP 26. For example, in one embodiment, acoustic sensor 40 is coupled to BOP 26 using at least one strap 68 extending from outer housing 64, for example, at flanges 66. In the exemplary embodiment, acoustic sensor 40 is coupled against BOP 26 such that sensor unit 50 is positioned adjacent to BOP 26. This enables acoustic sensor 40 to dampen or discriminate sounds and vibrations emanating from portions of BOP 26 other than those portions directly across from and/or axially aligned with aperture 62.

[0034] FIG. 4 is an exemplary embodiment of an alternate individual acoustic sensor 72, including an acoustically-sensitive aperture 62 and an end portion of sound/vibration absorptive material 60 that is spaced from BOP 26 such that a cavity 74 is defined. Water extends within cavity 74, between BOP 26 and sensor unit 50/sound/vibration absorptive material 60. In the exemplary embodiment, components of acoustic sensor 74 that are identical to components of acoustic sensor 40 (shown in FIG. 3) are referenced using the same reference numerals used in FIG. 3. By extending outer housing 64 outward beyond a plane of aperture 62, only outer housing 64 is rigidly coupled to BOP 26 and sensor unit 50 is spaced from BOP 26. Moreover, unit 50 is only coupled to BOP 26 via the water extending within the cavity 74 and sound/vibration absorptive material 60. As such, water filled cavity 74 facilitates reducing acoustic sensor 72 from being influenced by, i.e., responding to and/or coupling to, shear waves propagating along BOP 26, as water cannot couple to shear waves.

[0035] FIG. 5 is a schematic sectional view of another alternative acoustic sensor 80 that may be used with subsea drilling system 10 shown in FIG. 1. Corresponding reference characters indicate corresponding parts throughout the several views of FIGS. 3–5. In the exemplary embodiment, acoustic sensor 80 includes longitudinal axis 48 extending the length of the sensor. Acoustic sensor 80 includes sensor unit 50 having an acoustic sensor element 52 that is adjacent to first end 70 of acoustic sensor 80. In the exemplary embodiment, sensor element 52 is electrically coupled to signal processing component 54. In addition, acoustic sensor 80 includes a motion sensor 82 that senses motion of acoustic sensor 80. Motion sensor 82 includes, for example, and without limitation, an accelerometer, a velocity sensor, a geophone, and/or other motion sensors.

[0036] In the exemplary embodiment, motion sensor 82 is rigidly coupled to outer housing 64. As illustrated in FIG. 5, motion sensor 82 is encased in sound/vibration absorptive material 60, other than at the connection location between outer housing 64 and motion sensor 82. Because outer housing 64 is rigidly coupled to BOP 26, any motion of BOP 26 is sensed by motion sensor 82. Thus, mechanical motion of BOP 26 is registered by acoustic sensor 80. While motion sensor 82 is capable of registering lateral motion and/or resolving motion in three perpendicular directions, the bandwidth of motion sensor 82 is limited in comparison to the bandwidth of sensor unit 50. Thus, the combination of sensor unit 50 and motion sensor 82 in acoustic sensor 80 facilitates providing increased overall registration of movements of BOP 26.

[0037] In the exemplary embodiment, due to prolonged underwater submergence, acoustic sensor 80 includes a hermetically sealed electrical penetrator 56. Electrical penetrator 56 is a glass to metal seal and is coupled to a pressure balanced, oil-filled (PBOF) coupling 84 configured to couple to PBOF cable 58. The PBOF cable arrangement facilitates increasing cable life due to individual strands of the cable being soaked in oil to reduce pressure against adjacent strands. It is noted that PBOF cable 58 may couple a plurality of acoustic sensors together into acoustic sensor arrays 28 and 30, and may operate as tethers 34 and 36. In the exemplary embodiment, motion sensor 82 includes a hermetically sealed electrical penetrator (not shown) and is coupled to PBOF coupling 84 via a PBOF cable 86. PBOF cable 86 facilitates flexibly coupling sensor unit 50 to motion sensor 82.

[0038] The sensor embodiments illustrated in FIGS. 3–5 facilitate reducing the sensing of acoustic pressure waves to those pressure waves originating from locations that are generally axially aligned with the sensor unit and the aperture. The alternative embodiment illustrated in FIG. 6, however, further reduces the sensing of acoustic pressure waves.

[0039] FIG. 6 is a schematic sectional view of acoustic sensor 80 for use with subsea drilling system 10 shown in FIG. 1. Acoustic sensor 80 includes a cover 88 having sound/vibration absorptive material 60 extending over at least a portion of BOP 26. While exemplary with individual acoustic sensor 80, it is understood that cover 88 may be used with each of the embodiments of the individual acoustic sensor described herein.

[0040] In the exemplary embodiment, cover 88 is coupled to, and extends about, at least a portion of BOP 26 to facilitate isolating sensor unit 50 from acoustic waves and vibration emanating away from the area of interest on BOP 26. Housing 88 includes sound/vibration absorptive material 60 therein and is configured to couple rigidly against BOP 26 and individual acoustic sensor 80. This facilitates providing an additional level of damping or discrimination of acoustic pressure waves originating in the same axial direction as the sound source of interest. In particular, providing housing 88 with sound/vibration absorptive material 60 extending over BOP 26 facilitates enclosing sensor unit 50 and an area of interest of BOP 26 in a sound absorbing sheath, thereby reducing acoustic pressure waves and/or vibrations from being sensed by sensor unit 50 other than those acoustic pressure waves emanating from area of interest of BOP 26 and axially aligned with the aperture 62.

[0041] The apparatus and systems described herein enable acoustic pressure waves originating from localized mechanical structures to be sensed and converted into corresponding electrical output signals. Sources of sound emanating from areas not of interest are damped or discriminated by isolating the acoustic sensor and focusing its sensing area via an acoustically sensitive aperture. To facilitate discriminating the sound sources of interest, the acoustically sensitive portion of the sensor is encased in a sound/vibration absorptive material, except for an aperture oriented towards the sound source of interest. Moreover, extending the sound/vibration absorptive material over the structure containing the sound source of interest and the sensor facilitates providing a

second degree of discrimination against sound sources originating from the same direction as the sound source of interest. This facilitates focusing the sensing of acoustic waves to a particular area of interest while minimizing sensed acoustic waves emanating from other portion of the structure.

[0042] The apparatus and systems described herein are not limited to the specific embodiments described herein. For example, components of each system may be utilized independently and separately from other components described herein. For example, the systems may also be used in combination with other acoustic sensing systems, and are not limited to practice only with the oil and gas industry as described herein. Rather, the exemplary embodiment may be implemented and utilized in connection with many other applications and industries.

[0043] Although specific features of various embodiments of the disclosure may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the disclosure, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

[0044] This written description uses examples to disclose the systems described herein, including the best mode, and also to enable any person skilled in the art to practice the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

[0045] While the disclosure has been described in terms of various specific embodiments, those skilled in the art will recognize that the disclosure may be practiced with modification within the spirit and scope of the claims.

WHAT IS CLAIMED IS:

1. An underwater acoustic sensor assembly comprising:

a housing defining an internal chamber and comprising an open end and an internal surface;

an acoustic sensor positioned in said housing internal chamber and
5 comprising a sensing end adjacent to said housing open end; and

an acoustic absorption layer coupled to said internal surface and to said acoustic sensor, said acoustic absorption layer extends between said housing and said acoustic sensor such that said acoustic sensor is substantially isolated from vibrations transmitted through said housing, said acoustic absorption layer comprising an aperture
10 formed adjacent to said housing open end, said sensing end of said acoustic sensor is within said aperture.
2. The underwater acoustic sensor assembly in accordance with Claim 1, wherein said acoustic sensor comprises one of a piezoelectric element, a mass loaded element, a low frequency transducer, an echosounder transducer, and an ultrasonic transducer.
3. The underwater acoustic sensor assembly in accordance with Claim 1 further comprising a signal processing component positioned in said housing and electrically coupled to said acoustic sensor.
4. The underwater acoustic sensor assembly in accordance with Claim 1, wherein said housing further comprises a flange configured to couple said underwater acoustic sensor assembly to a second component.
5. The underwater acoustic sensor assembly in accordance with Claim 1, wherein said acoustic absorption layer aperture is substantially aligned with said housing open end.
6. The underwater acoustic sensor assembly in accordance with Claim 1, wherein said acoustic absorption layer extends outward from said internal chamber a predetermined distance beyond said housing open end.

7. The underwater acoustic sensor assembly in accordance with Claim 1, wherein said acoustic absorption layer is spaced inwardly from said housing open end a predetermined distance in said internal chamber defining a cavity between said housing open end and said acoustic absorption layer.

8. The underwater acoustic sensor assembly in accordance with Claim 1 further comprising a motion sensor configured to sense motion of said underwater acoustic sensor assembly.

9. The underwater acoustic sensor assembly in accordance with Claim 8, wherein said motion sensor is positioned within said internal chamber and is rigidly coupled to said housing.

10. A system for monitoring subsea equipment, said system comprising:

a directional acoustic sensor assembly coupled to an outer surface of the subsea equipment, said directional acoustic sensor assembly comprising:

5 a housing defining an internal chamber and comprising an open end and a first longitudinal axis;

an acoustic sensor positioned in said housing internal chamber and comprising a second longitudinal axis and a sensing end, wherein said second longitudinal axis is substantially parallel to said first longitudinal axis; and

10 an acoustic absorption layer that extends between said housing and said acoustic sensor, said acoustic absorption layer configured to substantially isolate said acoustic sensor from acoustic waves, said acoustic absorption layer comprising an aperture formed adjacent to said housing open end and extending about said acoustic sensor sensing end, said aperture configured to enable acoustic waves to be transmitted to said sensing end of said acoustic sensor; and

15 a data processor coupled in electrical communication to said acoustic sensor assembly by a tether, said data processor configured to receive and process data received from said directional acoustic sensor assembly.

11. The system for monitoring subsea equipment in accordance with Claim 10, wherein said directional acoustic sensor assembly is coupled to the outer surface of the subsea equipment using at least one of the following: mechanical fasteners, magnetic coupling, and straps.

12. The system for monitoring subsea equipment in accordance with Claim 10, wherein said directional acoustic sensor assembly further comprises a signal processing component positioned within said housing and electrically coupled to said acoustic sensor.

13. The system for monitoring subsea equipment in accordance with Claim 10, wherein said directional acoustic sensor assembly further comprises a pressure balanced, oil-filled coupling.

14. The system for monitoring subsea equipment in accordance with Claim 13, wherein said acoustic sensor further comprises a hermetically sealed electrical penetrator coupled to said pressure balanced, oil-filled coupling.

15. The system for monitoring subsea equipment in accordance with Claim 13, wherein said tether is a pressure balanced, oil-filled cable coupled to said data processor and said pressure balanced, oil-filled coupling.

16. The system for monitoring subsea equipment in accordance with Claim 10, wherein said directional acoustic sensor assembly further comprises a motion sensor configured to sense motion of said directional acoustic sensor assembly.

17. The system for monitoring subsea equipment in accordance with Claim 16, wherein said motion sensor is positioned within said housing internal chamber and is rigidly coupled to said housing.

18. The system for monitoring subsea equipment in accordance with Claim 16, wherein said motion sensor is coupled in electrical communication to a pressure balanced, oil-filled coupling of said directional acoustic sensor assembly.

19. The system for monitoring subsea equipment in accordance with Claim 10, wherein said acoustic sensor comprises one of a piezoelectric element, a mass loaded element, a low frequency transducer, an echosounder transducer, and an ultrasonic transducer.

20. The system for monitoring subsea equipment in accordance with Claim 10, wherein said housing further comprises a flange configured to couple said directional acoustic sensor assembly to the subsea equipment.

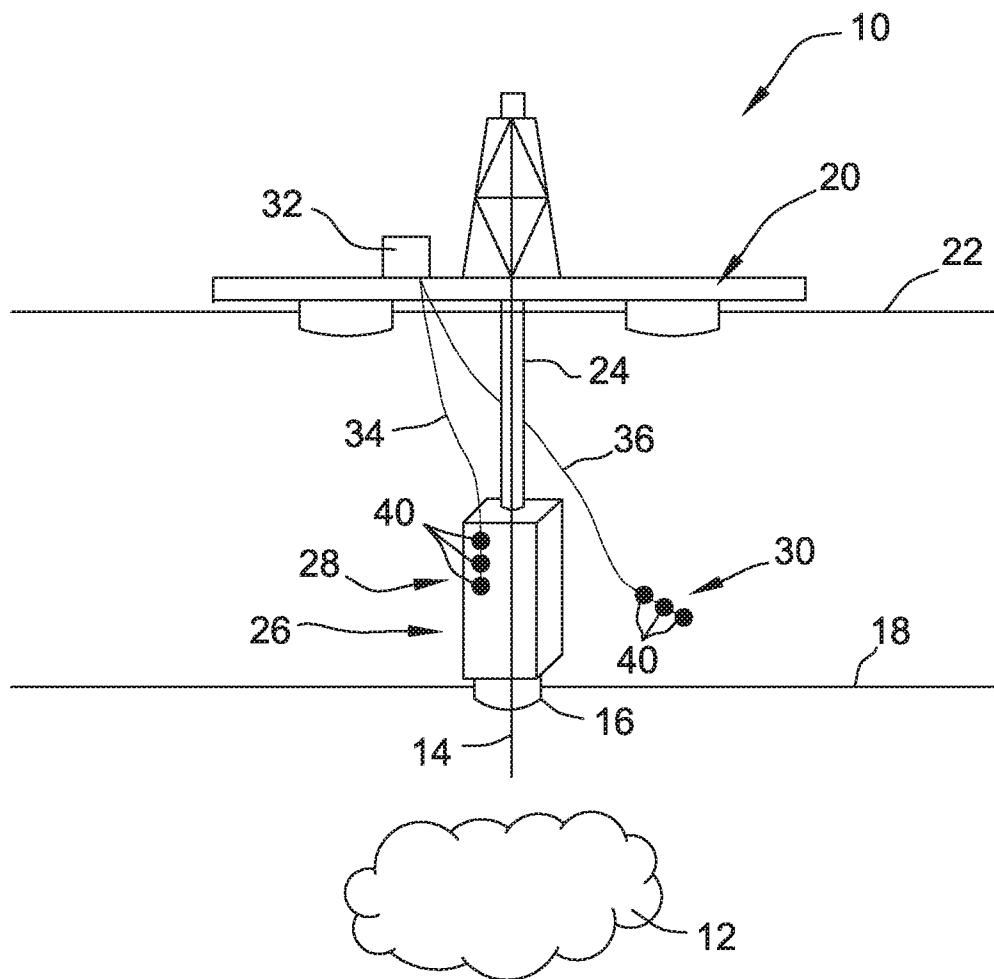


FIG. 1

2/6

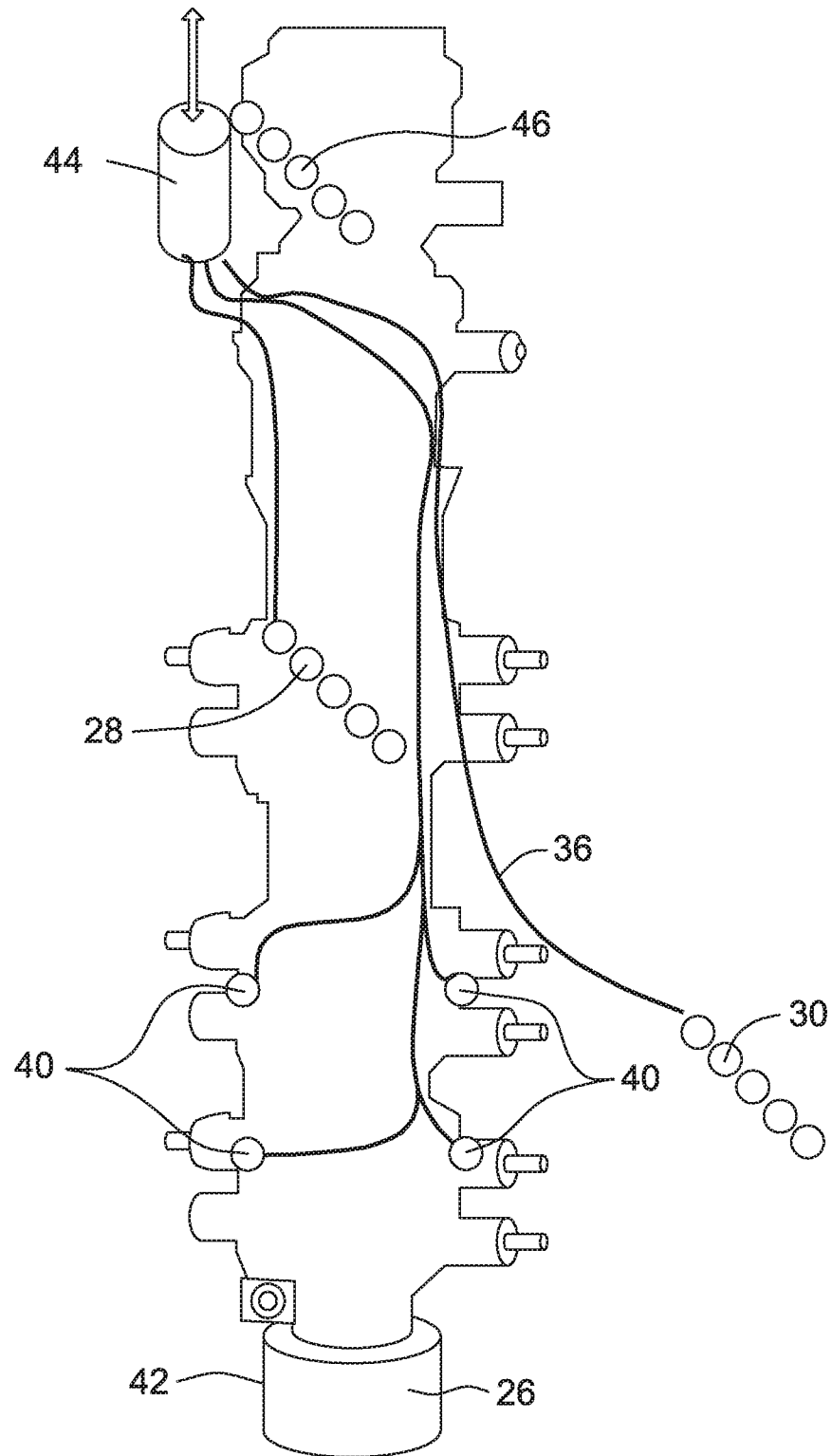
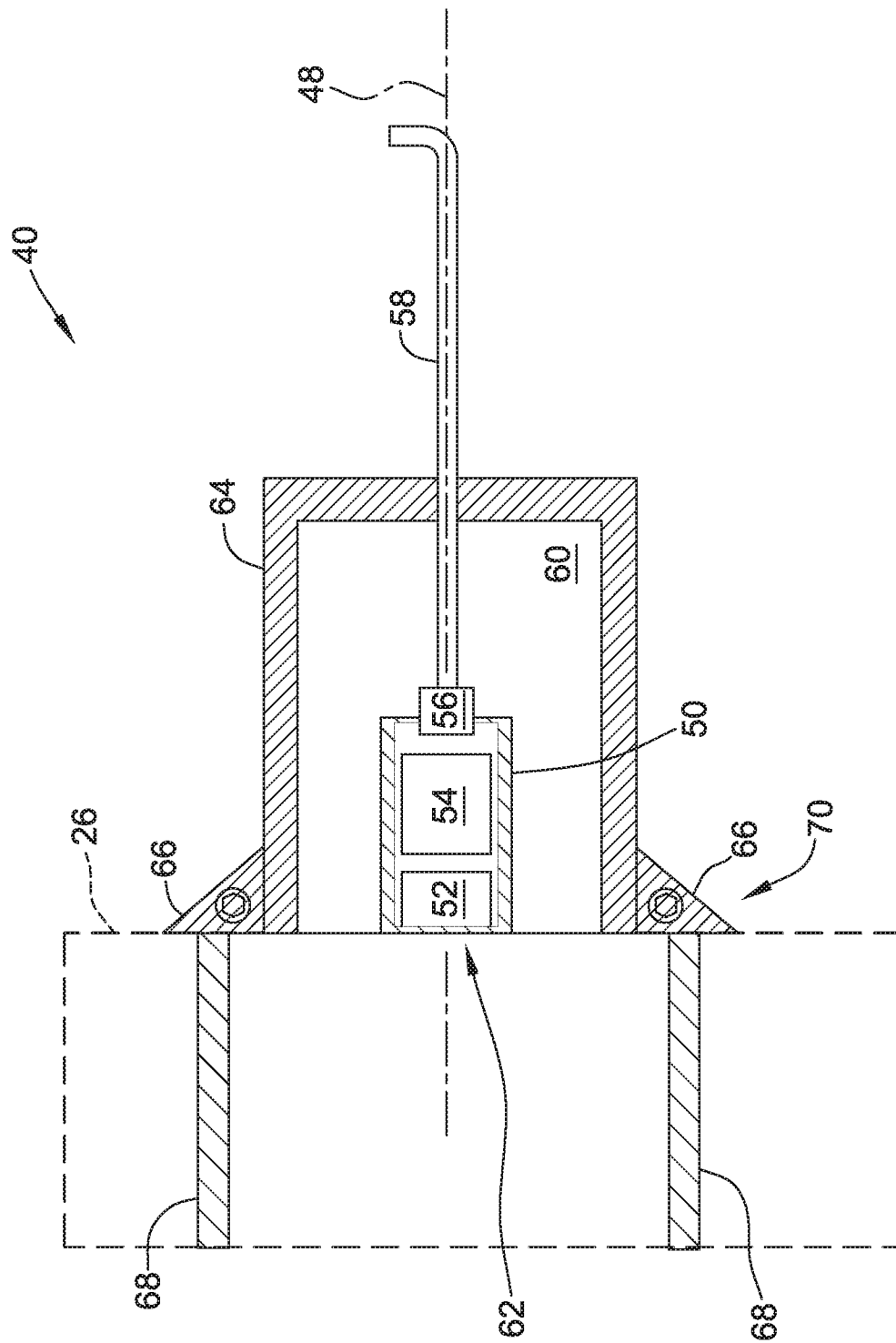


FIG. 2



மேல்

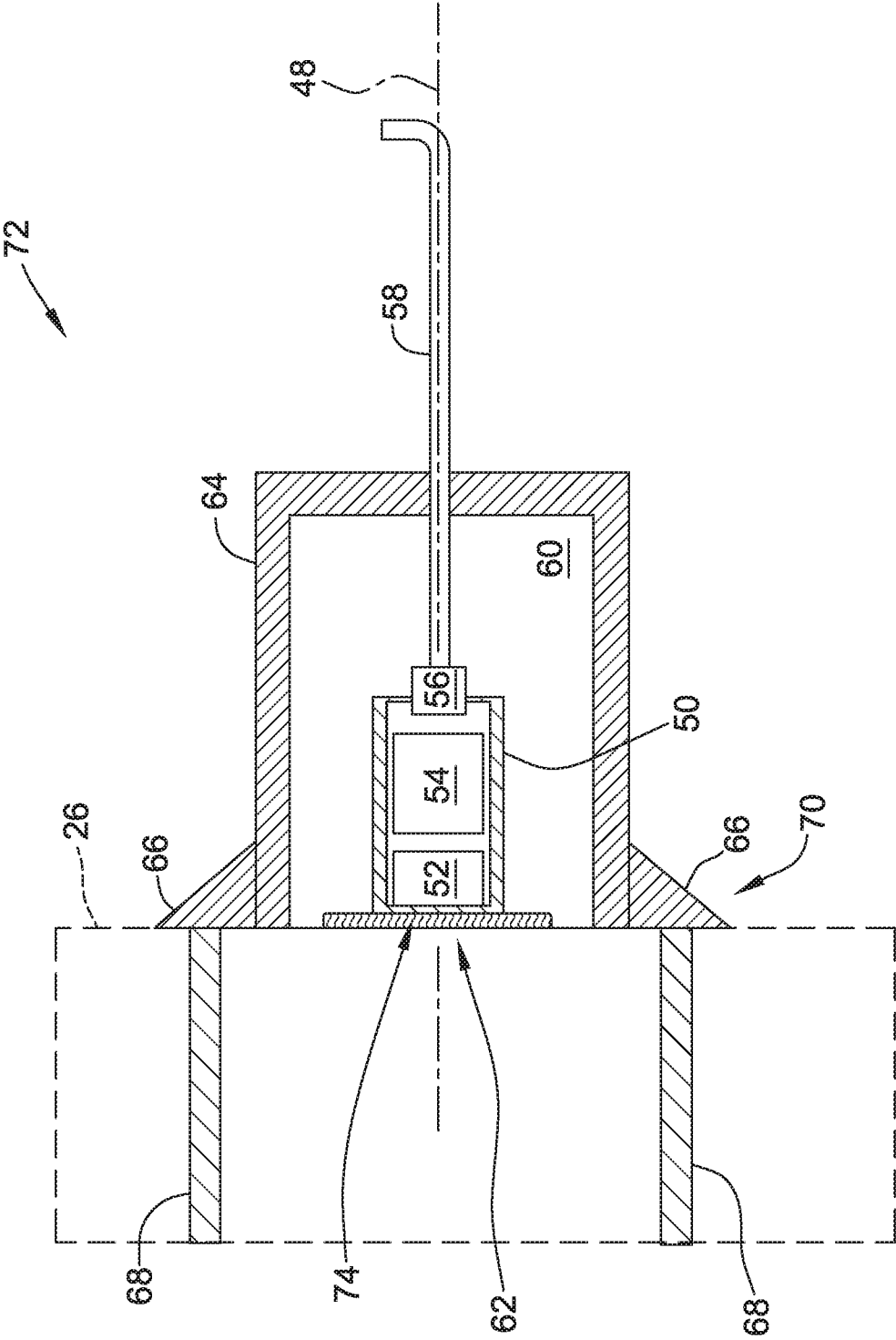


FIG. 4

5/6

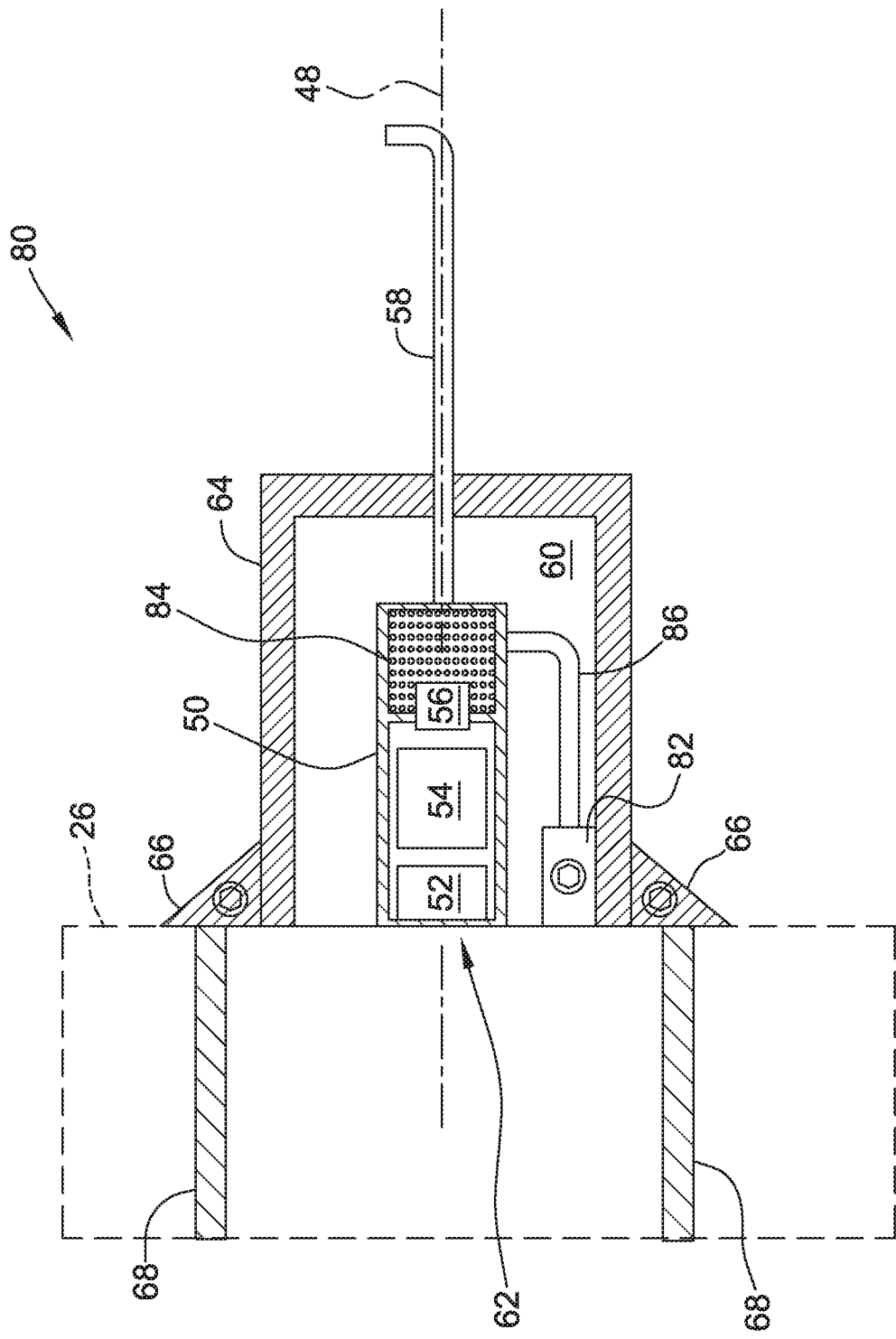


FIG. 5

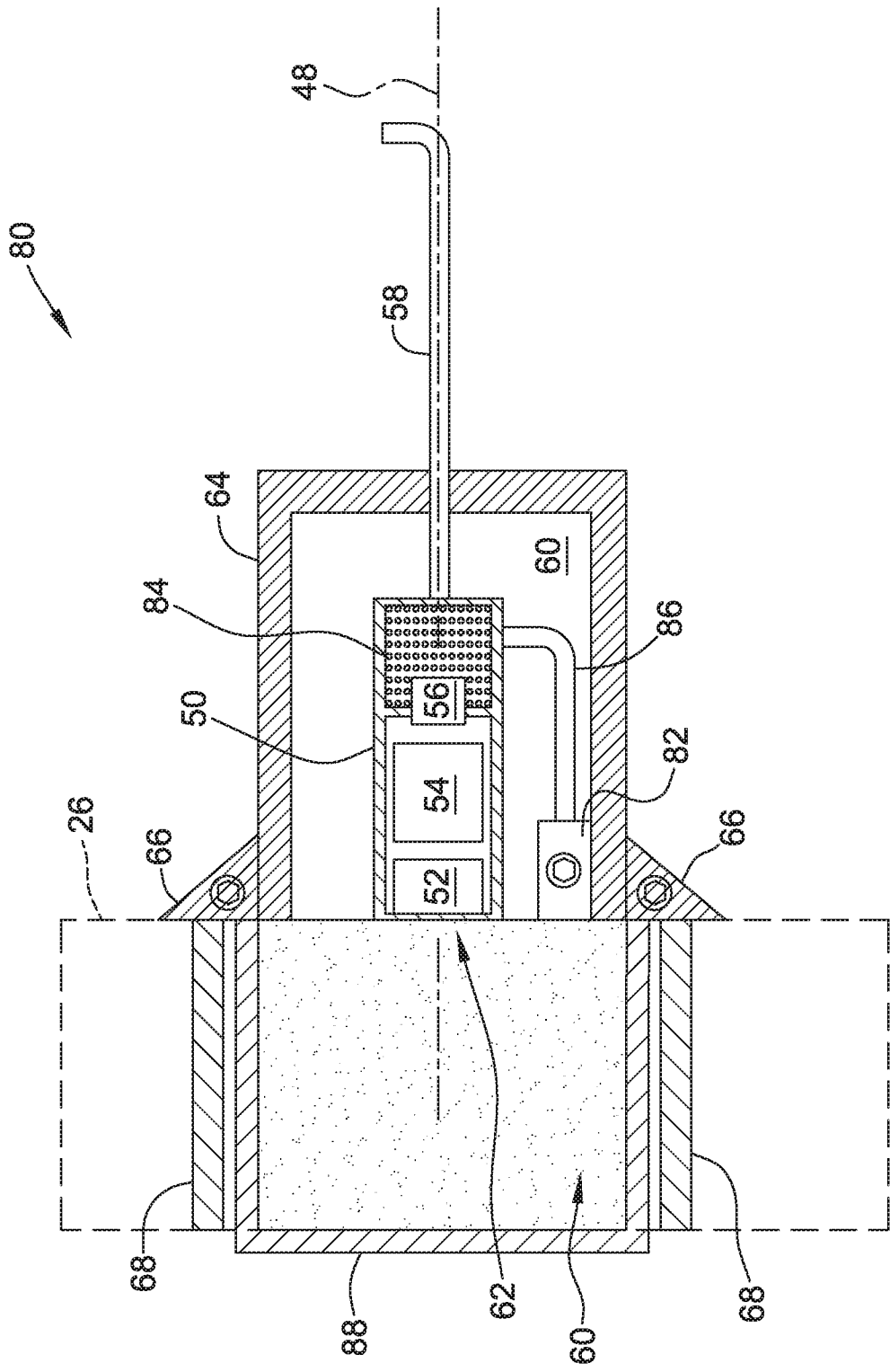


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/028373

A. CLASSIFICATION OF SUBJECT MATTER

INV. G10K11/00 G01H1/00 G01H3/00
ADD.

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)

G10K G01H E21B G01N

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 104 314 111 A (ZHANG SICHENG; YU FANGMING; LEI HAIFENG) 28 January 2015 (2015-01-28)	1,2,4,5, 10,11, 19,20
Y	figure 1 claim 1	3,12
Y	GB 2 082 324 A (REDDING ROBERT JAMES) 3 March 1982 (1982-03-03) page 2, column 1, line 2 - line 11 figures 2,3	3,12



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

11 July 2016

Date of mailing of the international search report

09/09/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Tympe1, Jens

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/028373

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

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

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

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

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

see additional sheet

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

1-5, 10-12, 19, 20

Remark on Protest

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/028373

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
CN 104314111	A	28-01-2015	NONE	

GB 2082324	A	03-03-1982	NONE	

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-5, 10-12, 19, 20

improving the underwater acoustic sensor assembly in general

1.1. claims: 2, 19

providing alternative sensor types

1.2. claims: 3, 12

reducing the bandwidth usage of the monitoring system,

2. claims: 6, 7

improving the isolation of the acoustic sensor from
undesired sound sources

3. claims: 8, 9, 16-18

increasing the overall registration of system movements

4. claims: 13-15

a pressure balanced oil-filled coupling
