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G01V 1/20 (2006.01)

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G1G GEEH

(56) Documents Cited:
GB 2396218 A **GB 2170161 A**
FR 002617284 A **US 5781510 A**
US 4689777 A

(58) Field of Search:
UK CL (Edition X) **G1G**
INT CL **G01V**
Other: **Online: WPI, EPODOC, JAPIO**

(54) Abstract Title: **Flexible body hydrophone**

(57) A hydrophone (20) includes an axially orientated body (22) formed of a flexible, plastic material. The body includes a plurality of channels (24) and each channel may have one or more wells (26) adapted to receive an active element (28) which includes mounting hardware. Each channel may have a chamfered edge to reduce wear on the outer shell of the hydrophone. The mounting hardware includes a soft, rubber grommet (38) or other means which suspends the active element, thereby permitting the flexing of the body (22) without introducing that motion to the active element (28). The grommet (38) may be held in place by a jaw formed from an upper (44, Fig 3) and lower plate (46, Fig 3) of the mounting assembly. The active element may be a piezoelectric element supported on a hollow box or an optical element. In a further embodiment the hydrophone may be mounted on a seismic streamer cable and have a means for isolating the active element from cable strain.

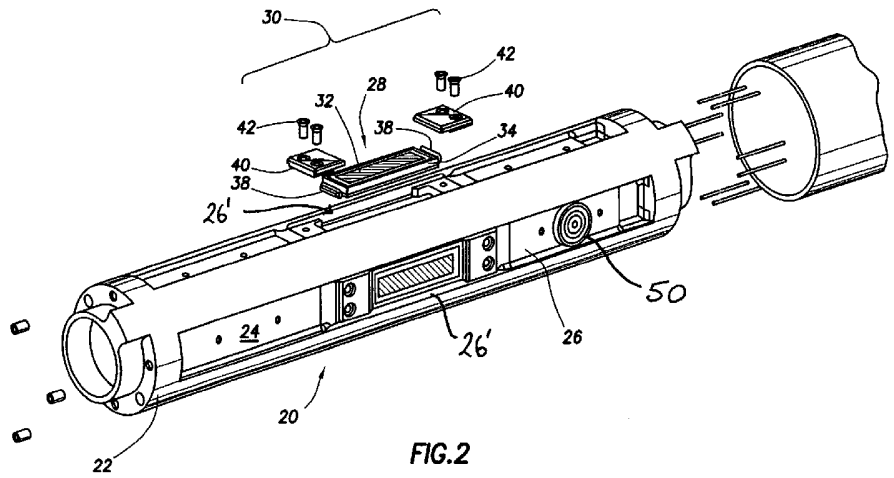

FIG.2

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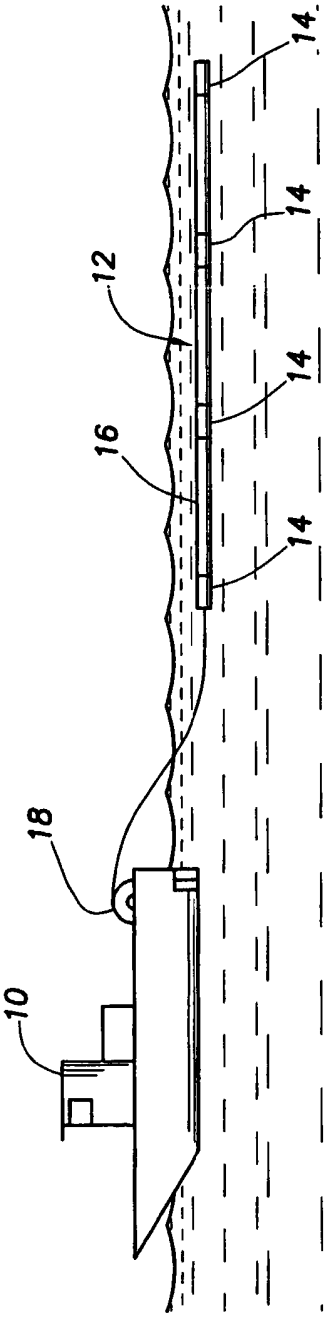


FIG.1

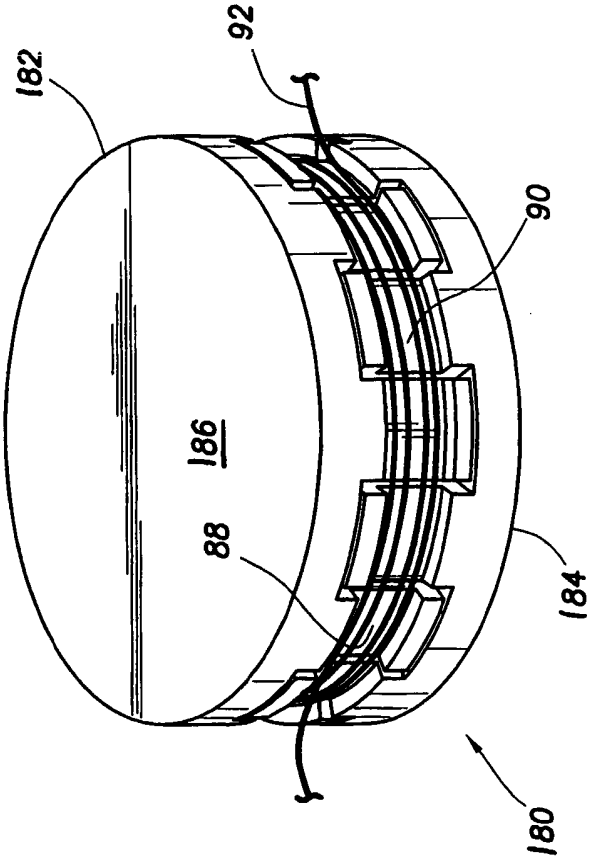


FIG.8

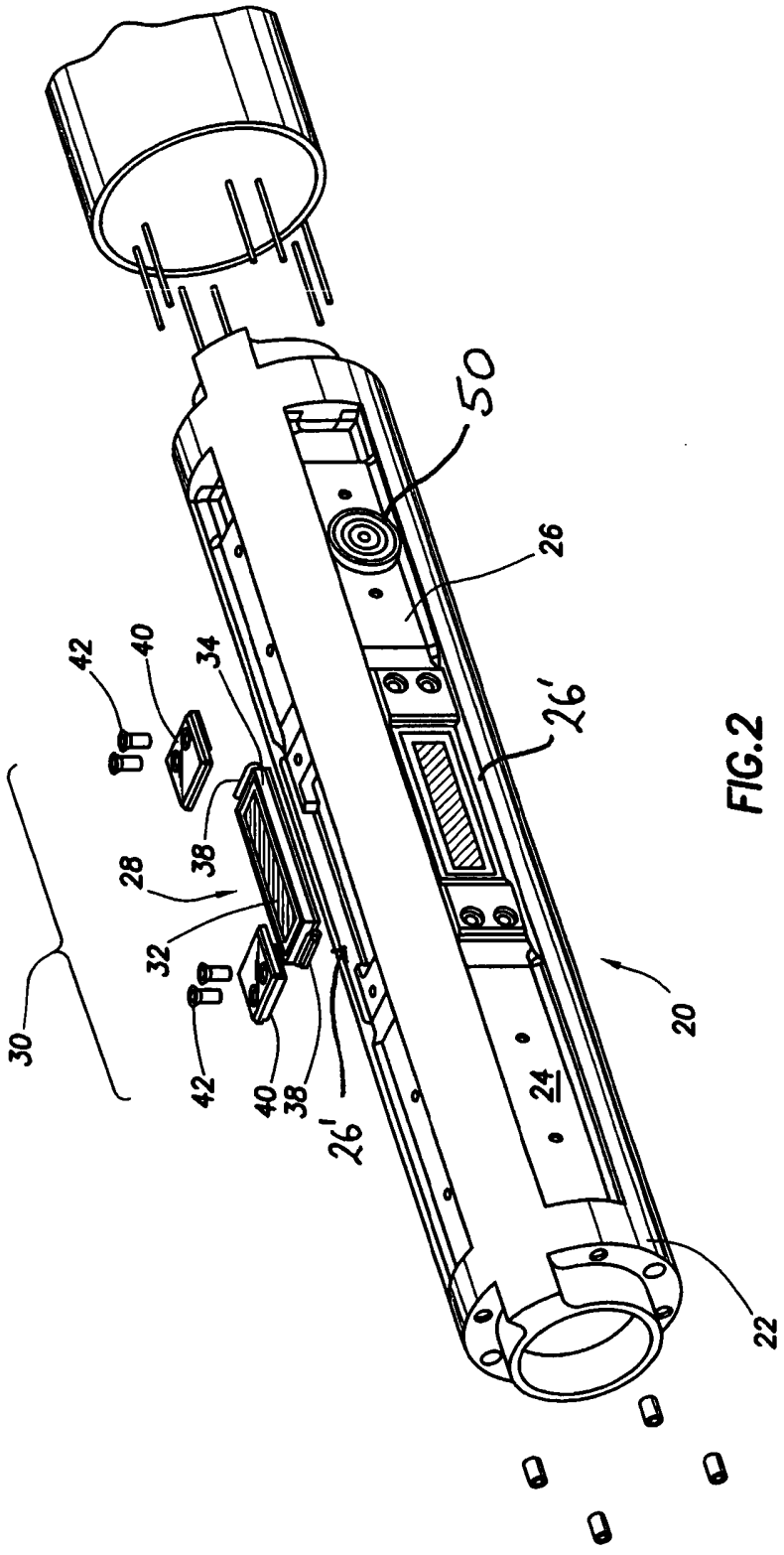


FIG.2

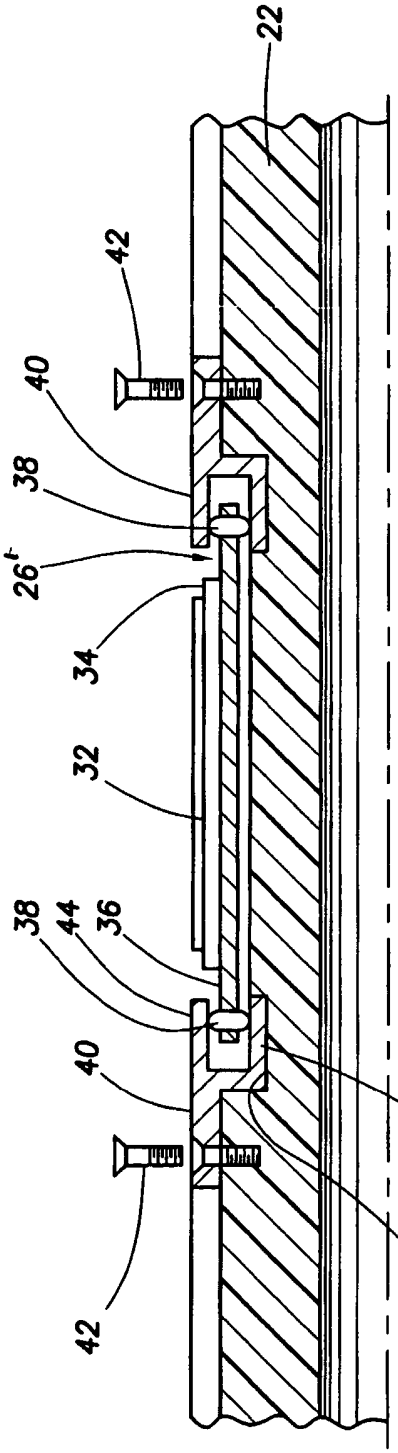


FIG.3

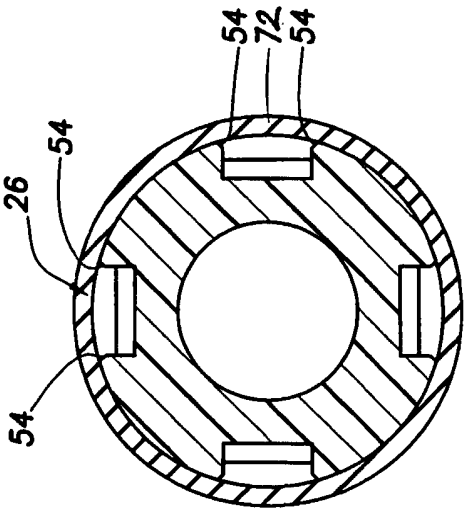
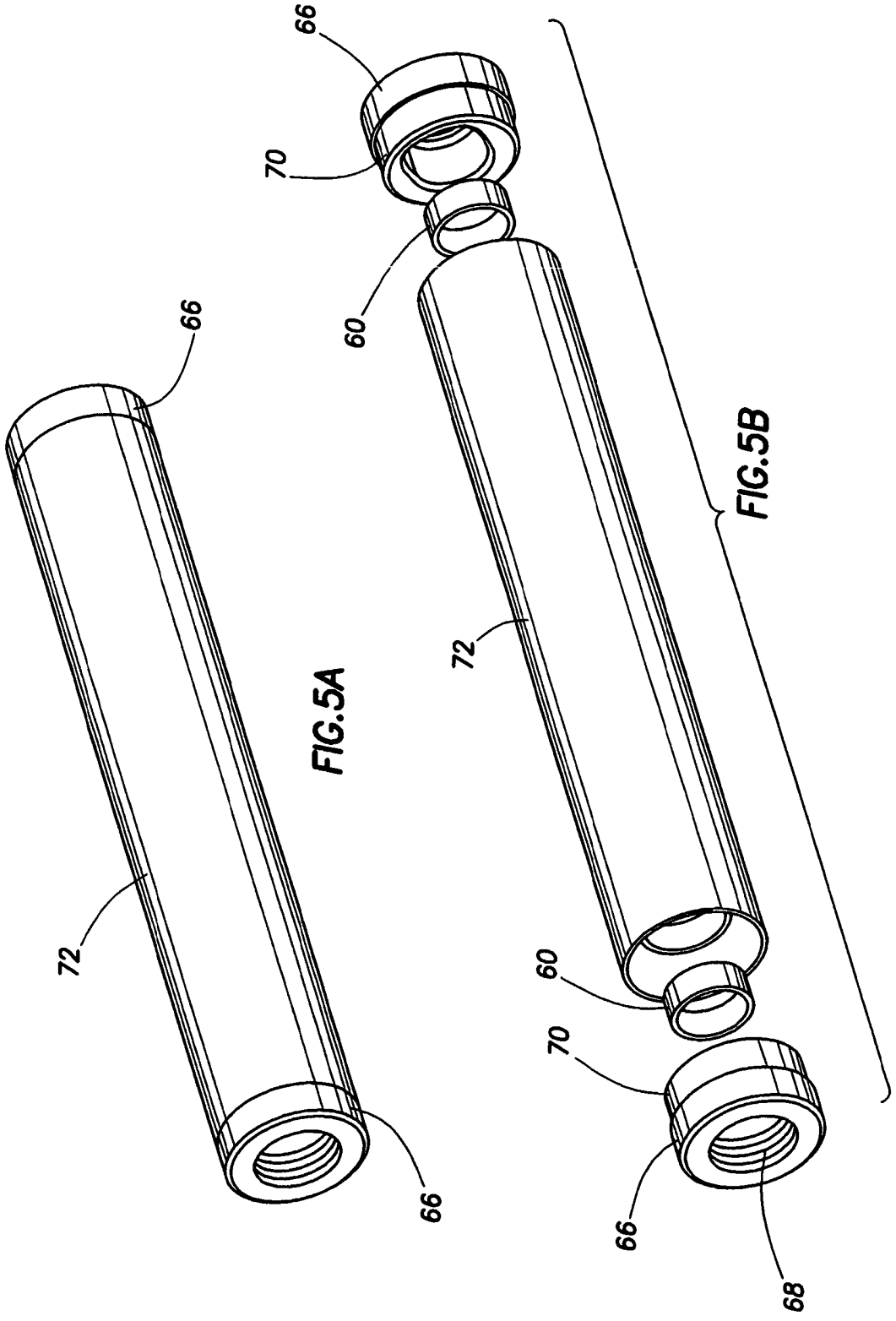


FIG.4


66
72
66
FIG.5A
66
70
60
72
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70
66
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FIG.5B

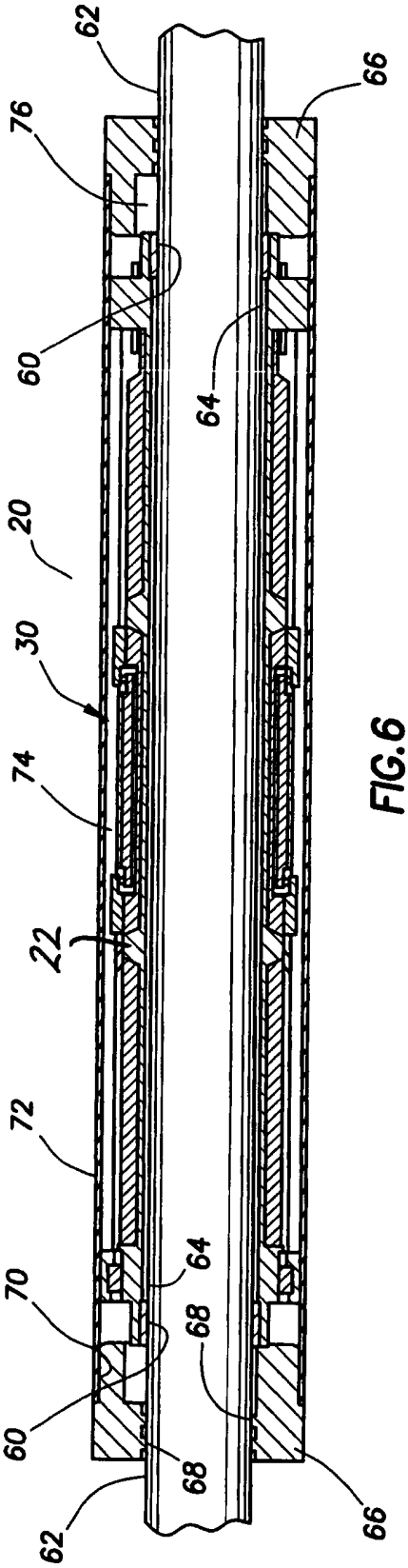
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FIG.6

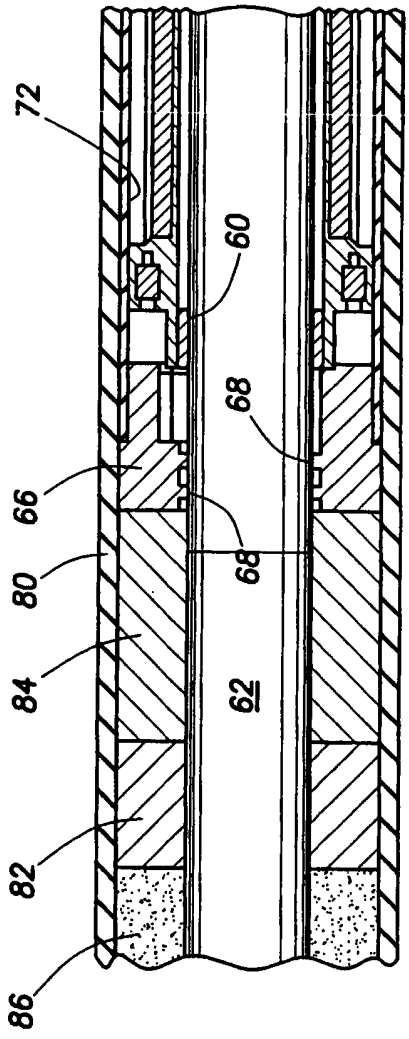
72
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FIG.7

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FLEXIBLE HYDROPHONE

The present invention relates generally to the field of seismic streamers which are towed through water behind vessels for seismic exploration, and, more particularly, to the field of non-fluid filled seismic streamers. Even more particularly, the present invention relates to a hydrophone comprising a hydrophone body which retains a plurality of active elements, wherein the body of the hydrophone is formed of a pliable or flexible material.

In modern marine seismic streamer systems, a vessel tows a long cable supporting a large number of sensors. Recent developments in such systems have simultaneously focused on making such cables light, durable, and easy to manufacture and maintain, as well as sensitive to the acoustic signals of interest while remaining relatively immune to noise. These developments lead to improvements disclosed in U.S. No. 6,128,251, in which a structure of a solid marine seismic cable was disclosed which included an interior cable, a surrounding woven strength member, an overlying foam floatation layer, and an enclosing jacket. One or more elongate channels were formed in the overlying floatation layer, and one or more piezoelectric elements were mounted in the channel(s). The elongate form of the channel enlarges the acoustic aperture for improved reception of seismic signals.

Further testing of the structure disclosed in that patent proved the efficacy of the structure disclosed therein, and has resulted in certain improvements and refinements, which are the focus of the present application. Many drawbacks then known in the art were solved by the structure disclosed in U.S. Patent No. 6,853,604, incorporated herein by reference. However, the improvements and refinements have continued.

More particularly, it has been found that previous solid marine seismic cables suffer extreme stresses at the ends of the hydrophone body when the cables are reeled onto a cable reel aboard a vessel. This is due in large part to the fact that the body is rigid and the cable forms a sharp bend at each end of the body when it is wrapped around the reel. These extreme stresses have been found to result in premature failure of the cables.

The present invention is directed to solving these and other drawbacks in the art of solid marine seismic streamers by providing a hydrophone whose body is formed of a flexible, plastic material. As used herein, the term "flexible" means a material that, when formed

as described herein, bends to conform to the radius of curvature of a cable reel aboard a vessel conducting seismic operations at sea.

However, in developing the new flexible hydrophone, a number of new problems have been noted. These new problems involved strain isolation of the active elements of the hydrophone from the strength members of the cable, and isolation of noise from both the streamer and surrounding environment of the cable.

The present invention addresses these and other problems in the art by providing at least three levels of strain and motion isolation from the flexible hydrophone body which retains the sensor element. The first such level of strain and motion isolation relates to the mounting of the active element on the hydrophone body.

The flexible hydrophone includes a plurality of channels, preferably four such channels, with one or more active elements in each channel. The channels are adapted to receive active elements which are mounted upon mounting hardware. The mounting hardware may include a soft, rubber grommet which suspends the active element, thereby permitting the flexing of the hydrophone without introducing that motion to the active element. The grommet also eliminates extensional waves and transverse waves from the body to the active element. Instead of a grommet, an open-ended boot or a self-molded mounting flange may be provided on the mount for the active element on which to suspend the active element in the channel.

The flexible hydrophone of the present invention also includes open cell foam within the channels in order to reduce sloshing of a fluid which is used to fill the channels. Sloshing of the fluid within the channel tends to create an additional noise component that may be received by the active elements. Finally, the active element is precisely positioned at a center point in the channel so that the active element resides at a null point for axial pressure waves within the hydrophone channel.

The second level of isolation relates to isolating the hydrophone body from the cable. The flexible hydrophone body is separated from the underlying cable by a space which is filled with a closed cell foam. The body also rides on a soft seal ring to further dampen vibration from the cable to the body. Finally, a plug is positioned at each end of the body to maintain the radial and axial position of the body, and the plug has a pair of integrally formed ribs to maintain minimal contact area between the cable and the body.

The third level of isolation of the active elements from strain and noise relates to the carrying of noise from the flotation foam and the outer jacket of the streamer into the active element. An anchor is molded to the cable and a split ring is movably attached to the cable between the anchor and the body. The outer surface of the split ring is not bonded to the inner surface of the jacket. The anchor and the soft split ring act such that noise and vibration from the flotation foam and the outer jacket are absorbed, and do not substantially pass on to the flexible body or to the active elements.

These and other features, objects, and advantages of the present invention will be readily apparent to those of skill in the art from a review of the following detailed description of embodiments of the invention which are illustrated in the appended drawings; in which:

FIG. 1 is an overall schematic illustration of a marine seismic system wherein the present invention may find application;

FIG. 2 is a perspective view of an embodiment of the flexible hydrophone of the present invention;

FIG. 3 is a longitudinal cross-section of a portion of the hydrophone body shown in Fig. 2, depicting the mounting of an active element in the body;

FIG. 4 is a transverse cross-section of the body at a well in which an active element is mounted;

FIG. 5A is a perspective view of an assembled hydrophone, while FIG. 5B is a perspective, exploded view of the hydrophone, illustrating a strain isolation feature of the invention;

FIG. 6 is a longitudinal cross-section view of the body, illustrating the elements of the hydrophone assembled onto a streamer cable;

FIG. 7 is an enlarged scale detail of part of the section view of Fig. 6 the region of the streamer between the flotation foam and the flexible body; and

FIG. 8 is a presently preferred embodiment of an optical element which may find application in the hydrophone of this invention.

FIG. 1 depicts a basic marine system including a vessel 10 towing a streamer 12. The streamer has a number of pieces of auxiliary equipment, such as depth control devices, associated with it that are not shown in order to simplify FIG. 1.

The streamer 12 also includes a number of hydrophones 14 spaced apart along the streamer. As used herein, the term "hydrophone" refers to active elements which are sensitive to seismic signals and a supporting body (or structure) which retains the active elements. Active elements typically comprise piezoelectric elements, but may also include optical elements, micro-machined electro-mechanical sensor elements, and the like.

The hydrophones 14 and a buoyant material are sealed within an outer jacket 16, preferably made of polyurethane, to present a smooth profile, thereby minimizing flow noise. During seismic operations, the streamer 12 is deployed from a cable reel 18 and, once operations are complete, the streamer 12 is reeled back onto the cable reel 18.

Each hydrophone 14 typically includes a body to support the active elements and the body is made of a rigid material, such as aluminum or hard, glass-stiffened plastic. Thus, the body cannot bend when the cable is reeled onto a cable reel aboard a vessel and large stresses are imposed on the cable at either end of the hydrophone 14. The present invention solves this problem by providing a plastic, flexible hydrophone body. However, because the hydrophone body is made of a plastic, flexible material, certain noise effects become significant.

The flexible hydrophone 20 of this invention is depicted in FIG. 2 (corresponding to each hydrophone 14 of FIG. 1). The hydrophone 20 preferably comprises a molded plastic body 22, although other techniques of forming the body may be used. The body 22 includes a plurality of axially oriented channels 24, and each channel may define one or more wells 26. A well 26', which is the center-most of the wells 26, retains an active element 28 suspended therein. As shown in FIG. 2, the hydrophone 20 preferably includes four axially oriented channels. Preferably, one well 26' is provided, centrally positioned along each channel, although more wells 26 may be provided if desired.

Further, an active element 28 is radially positioned at each of the four quadrants precisely centrally positioned on the body 22.

Referring now to FIG. 2 and FIG. 3, mounted within each well 26' is an active element mounting assembly 30 which includes the active element 28. The active element 28 may comprise a piezoelectric material 32 glued to an enclosed, six-sided, hollow box 34, in a manner like that shown and described in U.S. Patent No. 6,853,604. The active element 28 may also comprise an optical element (see for example FIG. 8), a micro-machined, electro-mechanical transducer as shown and described in U.S. Patent No. 5,956,292, or other means which is responsive to a seismic signal. Further, the active element mounting plate may serve as the top of the box 34.

The box 34 is in turn mounted upon a mounting plate 36, seen best in FIG. 3. A soft, rubber grommet 38 is removably placed near each end of the plate 36. In place of the grommet, an open-ended boot or a self molded flange near the end of the plate 36 may be used to the same effect. Whether a grommet as shown in FIG. 3 or the other means, the present invention provides a "non-rigid" mounting for the active element which isolates the active element 28 from strain and vibration in the hydrophone body. As used herein, the term "non-rigid" refers to the fact that the active element is permitted to move relative to the body (*i.e.* is not rigidly attached) yet is still mounted (in contrast to known elements which are permitted to float within a fluid volume). Thus, a feature of the present invention resides in the fact that the active element is supported on a relatively thick, rigid plate 36 which is flexibly held by the grommet or other support, so that vibration and noise caused by the flexing of the streamer cable is not carried through the mount to the active element.

The grommet 38 fits within the jaws of a mounting bracket 40 at each end of the active element 28. A set of screws 42 secure the active element assembly 30 to the body 22. An outer sleeve 72 is installed on the hydrophone body 22 (see FIG. 6) and then each entire channel 24 with the active element(s) 28 installed is filled with a fluid or potting material. Preferably, an open cell foam fills the channel 24 on either side of the active element assembly 30. This feature of the invention reduces the sloshing of the fluid which may create noise applied to the active element.

Note that the mounting bracket 40 includes an upper plate 44 and a lower plate 46, which together define the jaws referred to above which retain the grommet 38. The

lower plate 46 rests snugly within a recess 48 formed in the bottom of the well 26. Note also that the grommet 38 isolates the active element 28 from strain and vibration which is passed along the body 22, while leaving the active element 28 free to respond to sound signals within the water surrounding the streamer.

The body may also include a depth limiting button 50. As pressure increases on the outside of the cable, the depth limiting button is compressed. At a predetermined depth, the ambient pressure collapses the button 50, thereby shorting the signal conductors of the hydrophone, and the hydrophone will no longer function.

FIG. 4 depicts a cross-section of the body 22 in the region of a well 26. As previously described, the body includes four channels 24, each channel having up to three wells 26. The entire hydrophone is covered by a hydrophone sleeve 72. However, at the points at which the sleeve 72 meets a channel 24, we have found that a self-noise phenomenon is present, created by a vibration of the sleeve at the edge of the channel. To eliminate this self-noise, the edge should include a chamfer 54 in every instance. Further, the sleeve is preferably thermally welded to the body 22 between the channels 24.

As previously described, the present invention also isolates the strain of the streamer cable from the hydrophone elements. This feature of the present invention is best illustrated in FIGs. 5A, 5B, and 6.

FIG. 6 shows a side section view of the hydrophone 20 with an active element 28 mounted therein. The body 22 rides upon a soft and highly pliable seal ring 60 on each end and the seal ring maintains a space 64 between the hydrophone 20 and a cable bundle 62. The space 64 is filled with a soft, dry, closed cell foam to exclude all fluids from the space and to buffer strain and vibration from the cable bundle 62 to the hydrophone body 20. The closed cell foam may comprise a sheet of foam which is cut to size and wrapped around the cable bundle 62. Alternatively, the foam in the space 64 may be developed *in situ* by the injection of the constituent chemicals into the space 64 wherein the reaction occurs to generate the foam.

The cable bundle 62 comprises power and data conductors, one or more strength members, and filler material in a manner well known in the art. The body 22 is also held both radially and longitudinally in place by a pair of thermoplastic rubber plugs 66. The plugs 66 define a pair of annular rings 68 which are in abutting contact with cable bundle

62. This feature provides a solid mounting for the body 22, while maintaining a minimum contact area for the conduction of vibration and noise from the cable bundle 62 to the body 22 of the hydrophone 20.

The plugs 66 also define a reduced diameter step 70. The step receives the hydrophone sleeve 72 which encloses the active element assembly 30 within a channel volume 74. This channel volume 74 is, in turn, partially filled with the open cell baffle foam previously described to reduce sloshing of a fluid filling the baffle foam. A splice void 76 is also defined between the end of the body and the plug to provide a region in which to splice the electrical conductors from the hydrophone 20 into the cable bundle 62. The splice void is then filled with a hydrophobic gel to prevent the migration of sea water between the body 22 and the cable bundle 62 in the event of outer jacket damage.

FIG. 7 illustrates another noise isolation feature of the present invention. As previously described, a plug 66 retains the body 22 at a desired radial and axial position relative to the underlying cable bundle 62. A minimal contact area between the plug and the cable bundle is maintained by providing a pair of annular contact rings 68. The plug also supports the end of the hydrophone sleeve 72. The entire arrangement is enclosed within an outer jacket 80, which is the smooth outer surface of the streamer cable.

An anchor 82 is molded to the cable bundle 62 and is rigidly affixed thereto. Furthermore, the outer jacket 80 is bonded to the anchor 82. A soft split-ring 84 rides on the cable bundle between the anchor 82 and the plug 66. The split ring 84 is not bonded to the cable bundle 62 or the jacket 80. Vibrations and axial strain traveling through the flotation foam 86 and the outer jacket 80 are reduced by the fixed anchor 82. The soft split-ring 84 then acts as a vibration absorber further reducing the vibrations and strain that would otherwise pass through to the hydrophone body 20.

Finally FIG. 8 depicts a perspective view of a presently preferred optical element 180 which may be used in the active element of the present invention, and which was shown and described in U.S. Patent 6,049,511 and incorporated herein by reference. The optical element includes a top diaphragm member 182 and a bottom diaphragm member 184. The top diaphragm member 182 includes a diaphragm 186 and a plurality of tabs 88 which define an annular groove 90 to receive a winding of optical fiber 92.

As the diaphragm 186 flexes down under the influence of a pressure increase, the tabs 88 rotate outwardly, stretching the fiber 92. This action provides mechanical advantage for the lever action, stretching the fiber for a given movement of the diaphragm. Stretching the fiber in this way increases the optical path length of the light through the optical fiber, and this action modulates the seismic signal impressed on the optical element. It should be appreciated that other forms and modes of active elements may be used within the scope of this invention.

The principles, preferred embodiment, and mode of operation of the present invention have been described in the foregoing specification. This invention is not to be construed as limited to the particular forms disclosed, since these are regarded as illustrative rather than restrictive. Moreover, variations and changes may be made by those skilled in the art without departing from the scope of the invention.

CLAIMS

1. A hydrophone comprising an axially oriented, flexible plastic body and at least one active element supported by the body and sensitive to a seismic signal.

2. A hydrophone as claimed in claim 1, further comprising a plurality of channels in the body.

3. A hydrophone as claimed in claim 2, wherein an active element is disposed within each of the plurality of channels.

4. A hydrophone as claimed in claim 2, wherein a plurality of active elements is disposed within each of the plurality of channels.

5. A hydrophone as claimed in claim 3 or claim 4, further comprising an open cell foam in the or each channel adjacent the or each active element.

6. A hydrophone as claimed in any preceding claim, wherein the or each active element comprises a piezoelectric element, a hollow box supporting the piezoelectric element, a mounting plate supporting the hollow box, the mounting plate having opposing ends, a grommet on each of the opposing ends of the mounting plate, and a mounting bracket adjacent each end of the mounting plate and grasping the grommet on each end of the plate.

7. A hydrophone as claimed in claim 6, wherein the mounting bracket includes an upper plate and a lower plate to define a set of jaws to grasp the grommet.

8. A hydrophone as claimed in claim 7, further comprising a recess in each well to receive the lower plate of the mounting bracket.

9. A hydrophone as claimed in any preceding claim, wherein the or each active element comprises an optical element.

10. A hydrophone as claimed in any preceding claim, wherein the or each active element comprises a micro-machined electro-mechanical pressure sensing element.

11. A hydrophone as claimed in any of claims 2 to 5, wherein each channel is defined by an edge and has a chamfer on the edge.

12. A hydrophone as claimed in any preceding claim, wherein the body is mounted on a cable, and further comprising a closed cell foam between the body and the cable.

13. A hydrophone as claimed in claim 12, further comprising a plug on each end of the body to maintain radial and axial positioning of the body on the cable.

14. A hydrophone as claimed in claim 13, wherein the plug maintains minimal contact between the body and the cable.

15. A hydrophone as claimed in any of claims 12 to 14, further comprising a seal ring between each end of the body and the cable.

16. A seismic streamer cable having a plurality of hydrophones positioned therealong at intervals, each of the plurality of hydrophones being as defined in any preceding claim.

17. A hydrophone on a seismic streamer cable, the hydrophone comprising an axially oriented, flexible plastic body, at least one active element supported by the body and sensitive to a seismic signal, and means for isolating strain from the streamer cable to the active element.

18. A hydrophone as claimed in claim 17, wherein the means for isolating strain comprises a non-rigid mount coupling the active element to the body.

19. A hydrophone as claimed in claim 18, wherein the active element comprises a piezoelectric element supported by a mounting plate having opposing ends, and wherein the means for isolating strain includes a grommet on each of the opposing ends of the mounting plate and a mounting bracket adjacent each end of the mounting plate and grasping the grommet on each end of the plate.

20. A hydrophone as claimed in claim 17, wherein the means for isolating strain comprises a closed cell foam between the body and the cable.

21. A hydrophone substantially as hereinbefore described with reference to and as illustrated by any of Figures 2 to 7 of the accompanying drawings.

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Application No:	GB0613611.3	**Examiner:**	Nigel Hanley
Claims searched:	1-20	**Date of search:**	29 September 2006

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 12-17 & 20	GB 2396218 A SCHLUMERGER - See whole document especially Figs 3-7b and Page 18 Line 7-23. Note the use of a flexible body of a hydrophone in order that a cable containing the sensor can be wound on a reel for easy deployment.
X	1, 12, 16 & 17	FR 2617284 A REGNAULT - See whole document especially Abstract and Page 3 Line 3-6. Note the construction of a hydrophone having a flexible body made of plastics material.
A		US 5781510 A INPUT/OUTPUT- Note the arrangements for mounting sensors on a seismic streamer.
A		US 4689777 A SHELL - Note arrangement for mounting a hydrophone on a streamer cable.
A		GB 2170161 A STC - Note construction of a flexible hydrophone from a plurality of smaller components.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

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G1G

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G01V

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC, JAPIO