

July 2, 1968

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3,391,385

ELECTROMECHANICAL TRANSDUCER

Filed May 31, 1966

2 Sheets-Sheet 1

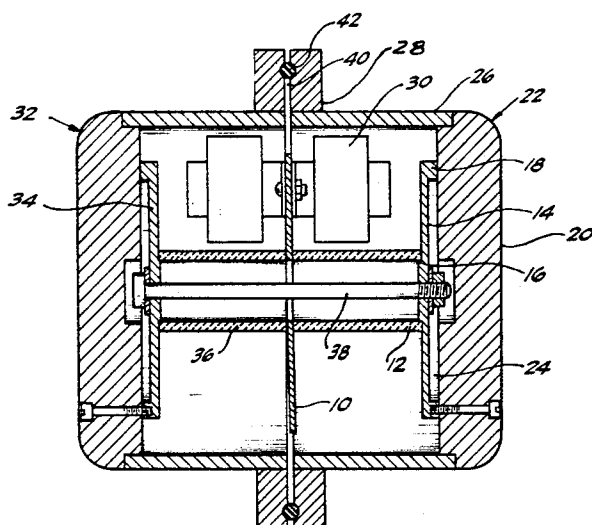


FIG 1

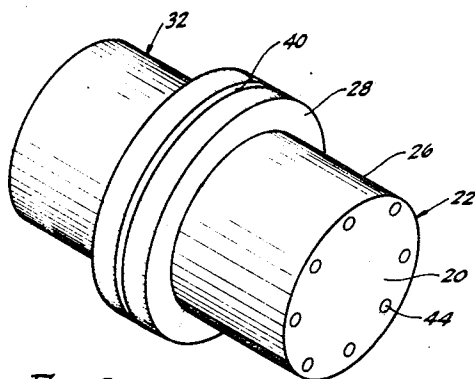


FIG 2

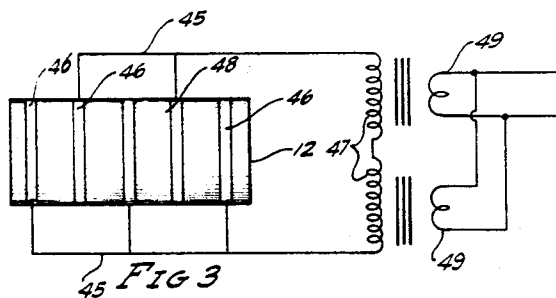


FIG 3

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2 Sheets-Sheet 2

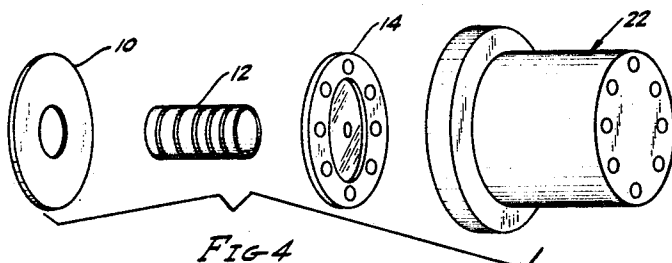


FIG 4

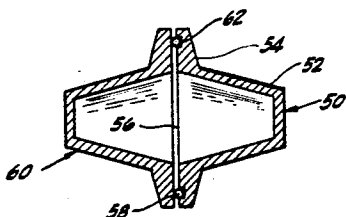


FIG 5

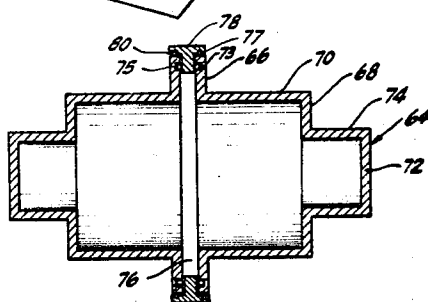


FIG 6

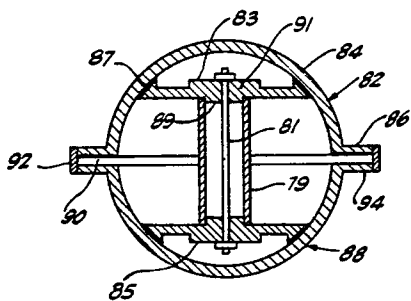


FIG 7

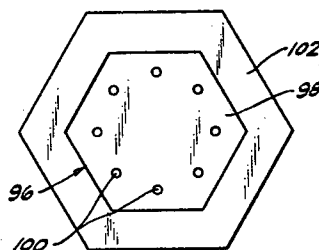


FIG 8

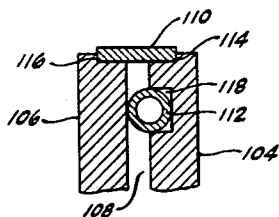


FIG 9

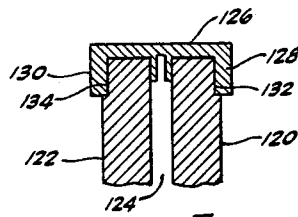


FIG 10

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ELECTROMECHANICAL TRANSDUCER

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ABSTRACT OF THE DISCLOSURE

An electromechanical transducer having broad band audio response for use as an underwater loudspeaker. The transducer includes an open-ended hollow piston having an electromechanical driving element positioned longitudinally in the interior of the piston with one end of the element rigidly supported and the other end being substantially unsupported and in contact with a compliance element on the inner end of the piston.

This invention relates to an electromechanical transducer. More particularly, this invention relates to an electromechanical transducer which is adapted for receiving or transmitting sonic energy from a body of liquid such as water.

Previously, considerable difficulty had been experienced in producing satisfactory underwater transducers having broadband audio response suitable for use as an underwater loudspeaker. In general, previous devices operated at too high a frequency for voice or music. Also, these previous devices were generally of excessive weight and size.

It is an object of this invention to provide an electromechanical transducer capable of operating in the range of from about 150 cycles to 4,000 cycles per second.

It is an object of this invention to provide a relatively lightweight electromechanical transducer capable of operating under water in the range of from about 150 cycles to 5,000 cycles per second with nearly uniform response.

Broadly, the electromechanical transducer of this invention comprises a stepped sonic energy radiating means which has a hollow interior, a closed end and an open end. An electromechanical transducer or driving element is rigidly supported in the hollow interior of the stepped sonic energy radiating means. A compliance element is positioned in contact with the interior surface of the closed end of the sonic energy radiating means. The opposite side of the compliance element is in contact with the transducer element.

In order to work effectively, men must be able to communicate with one another. In working under water, this is extremely difficult because normal speech is impossible. According to this invention, an electromechanical transducer is provided which serves both as a hydrophone and an underwater loudspeaker. This device is useful for audio communications underwater for training purposes, for safety purposes, for coordinating the efforts of workmen, for entertainment purposes, for experimentation with marine life and underwater acoustic measurement and calibration. The electromechanical transducer of this invention may be used as a high force driver, for example, to determine the resonance of a structure.

When desired, a number of electromechanical transducers of this invention may be employed together to increase the volume of sonic energy radiated or to increase the bandwidth of the radiation.

The use of a stepped sonic energy radiating means in the electromechanical transducer of this invention is particularly important in that this reduces the overall weight of the electromechanical transducer and aids in obtaining

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a broader operating bandwidth in the vicinity of the fundamental resonant frequency of the device.

For a more complete understanding of this invention, reference is made to the following drawings in which:

FIG. 1 is a cross-sectional view of an electromechanical transducer of this invention;

FIG. 2 is a perspective view of the exterior of the electromechanical transducer shown in FIG. 1;

FIG. 3 is a side elevation of a polycrystalline piezoelectric cylinder useful as the electromechanical transducer element used in this invention and a portion of a wiring diagram;

FIG. 4 is an exploded perspective view of an electromechanical transducer of this invention;

FIG. 5 is a cross-sectional view of two stepped sonic energy radiating means of this invention in which the steps are tapered;

FIG. 6 is a cross-sectional view of two sonic energy radiating means of this invention which have a plurality of steps;

FIG. 7 is a cross-sectional view of two sonic energy radiating means of this invention which have general hemispheric configurations with a piston step about the circumference of each thereof;

FIG. 8 is a plan view of a sonic energy radiating means which has hexagonal radiating surfaces;

FIG. 9 is an enlarged cross-sectional view of a sealing and energy absorbing means between the mating surfaces of two piston steps;

FIG. 10 is an enlarged cross-sectional view of a sealing and energy absorbing means between the mating surfaces of two piston steps.

Referring particularly to FIG. 1 there is shown an electromechanical transducer of this invention which is symmetrical about node plate 10. An elongated piezoelectric cylinder 12 is positioned axially between node plate 10 and compliance element 14. Piezoelectric cylinder 12 is bounded to node plate 10 and is securely positioned on the inward face of compliance element 14 by shoulder 16. Compliance element 14 has a generally disc shaped configuration and is provided at its periphery with an outwardly extending flange 18 which contacts the inward face of piston end 20 of a stepped piston indicated generally at 22. Stepped piston 22 serves as a sonic energy radiating means. Compliance element 14 is separated from the interior face of piston end 20 by gap 24 except at flange 18.

In addition to piston end 20, stepped piston 22 is provided with piston side wall 26 and piston step 28. Preferably, piston end 20, piston side wall 26 and piston step 28 are welded together or cast as one integral unit. Element 30 is an electrical transformer for stepping up the voltage applied, to piezoelectric element 12. The other half of the electromechanical transducer is substantially identical to the half just described. A stepped piston indicated generally at 32 is connected at its inward face to a compliance element 34 which is in turn connected to piezoelectric element 36 which is bonded to node plate 10. Compliance elements 14 and 34 are secured together by stress bolt 38. A space 40 is provided between coaxially aligned stepped pistons 22 and 32. Space 40 is sealed with an energy absorbing seal 42. Seal 42 serves to seal the interior of stepped pistons 22 and 32 as well as providing an energy absorbing member between these two pistons. Piston end 20 and the exterior surface of piston step 28, which surface is parallel to said piston end 20, are the radiating surfaces for stepped piston 22. Very little sonic energy radiates from side wall 26.

Referring particularly to FIG. 2 there is illustrated a perspective view of the exterior of the electromechanical transducer shown in section in FIG. 1. In FIG. 2 the ends

of the recessed bolts 44 are shown in piston end 20. Recessed bolts 44 hold piston end 20 and flange 18 together.

Referring particularly to FIG. 3 there is shown one embodiment of piezoelectric element 12, shown in situ in FIG. 1 in which silver stripes 46 are shown on the bare surface 48 of this polycrystalline piezoelectric element. Alternate silver stripes 46 are connected in parallel by flexible electric wires 45. Flexible wires 45 are connected to the secondaries 47 of a step-up transformer. The primary windings 49 are connected to an amplifier, not shown. If more than one polycrystalline piezoelectric element is employed, flexible wires 45 are also connected to the additional polycrystalline piezoelectric elements.

Referring now particularly to FIG. 4, there is illustrated an exploded perspective view of the node plate 10, piezoelectric element 12, compliance element 14, and stepped piston 22 of this invention. These elements are shown assembled in FIG. 1.

Referring particularly to FIG. 5 there is illustrated an embodiment of this invention in which the stepped piston indicated generally at 50 has a tapered side wall 52, and a tapered piston step 54. Space 56 is sealed by a hollow O ring 58 which is positioned between stepped piston 50 and stepped piston 60. The hollow O ring 58 sets in a recess 62, in piston step 54. Adequate sealing is provided by the single groove in stepped piston 50, no corresponding groove is necessary in stepped piston 60. The exterior surface of the end of the piston and the exterior surface of the piston step 54 are the same energy radiating surfaces of this piston. Very little sonic energy radiates from side wall 52.

Referring particularly to FIG. 6 there is illustrated a stepped piston indicated generally at 64 which has a plurality of piston steps. Piston steps 66 and 68 are joined to one another through piston side wall 70 and piston step 68 is joined to piston end 72 by piston side wall 74. Piston end 72 and piston steps 66 and 68 provide the radiating surfaces for this piston. The space 76 between the two pistons is sealed with a center member or support flange 78 which has energy absorbing hollow O rings 73 and 75 on either side thereof set in recesses in the mating surfaces of each of the piston steps and liquid seals 77 and 80 set in recesses in support flange 78. Support flange 78 may be affixed to a suitable mounting means not shown.

Referring particularly to FIG. 7 there is illustrated an embodiment of this invention in which the sonic energy radiating means are in the form of stepped hemispheres. Stepped piston 82 has a continuous hemispherical wall 84 which serves in different portions as both the piston side wall and piston end. Hemispherical wall 84 terminates in piston step 86. Hemispherical stepped pistons indicated generally at 82 and 88 are separated from one another by space 90 and the opening provided by space 90 is sealed with an energy absorbing seal 92. Seal 92 is a resilient flexible elastomeric ring extending around the circumference of the piston steps 86 and 94. A single electromechanical driving element 79 is secured by stress bolt 81 between first compliance element 83 and second compliance element 85. Compliance elements 84 and 85 are of identical configuration. The configuration of compliance element 83 will be described and it will be understood that this description applies equally to compliance element 85. Compliance element 83 is provided with an annular mating surface 87 which rests against and conforms to the shape of the inner surface of hemispherical wall 84. The open end of driving element 79 fits over and is securely positioned in place by a generally disc-shaped projection 89 which is formed in the inward facing side of compliance element 83, concentrically with annular surface 87. The outwardly facing surface of compliance element 83 is provided with a generally disc-shaped stiffener 91 which projects outwardly from the surface and is concentric with annular surface 87. Stiffener 91 inhibits the bending of compliance element 83 in the region where it contacts driving element 79, thus con-

tributing to the maintenance of good contact between elements 79 and 83. Annular surface 87 may be secured to stepped piston 82 by means not shown, including, for example, mechanical fasteners such as screws and bolts, bonding agents, adhesives and the like.

Referring particularly to FIG. 8 there is illustrated an embodiment of this invention in which the stepped piston 96 has a hexagonal configuration. The stepped piston is shown as viewed axially from the exterior of the piston. The recessed bolts by which piston end 98 is connected to a compliance element are clearly shown at 100. The hexagonal configuration is also carried by piston step 102.

Referring particularly to FIG. 9 there is illustrated a preferred embodiment of an energy absorbing seal in enlarged cross-section. Piston steps 104 and 106 are spaced apart from one another by space 108, which space is sealed by the resilient band 110 and the hollow resilient O ring 112. Resilient band 110 is set in recesses 114 and 116 of piston steps 104 and 106, respectively. The hollow O ring 112 is set in recess 118 in piston step 104.

Referring particularly to FIG. 10 there is illustrated a seal between piston steps 120 and 122 sealing space 124 between these piston steps. An elastomeric band 126 having in general an E-shaped cross-section completely surrounds the periphery of piston steps 120 and 122. Legs 128 and 130 of elastomeric band 126 are set in recesses 132 and 134 in piston steps 120 and 122, respectively.

In general, the radiating surfaces are those exterior surfaces of the sonic energy radiating means which are generally perpendicular to the direction of vibration of the electromechanical transducer element. The sonic energy radiating means should be rigid enough to insure that all of the radiating surfaces move in unison. The use of stepped sonic energy radiating means improves the radiation loading with a minimum addition of vibratory mass, overall weight and size. In general, the several elements of the total radiating surface of the sonic energy radiating means should have approximately equal area and be displaced from one another by a distance comparable to the diameter of the outermost surface. In general, such distance should be from about 0.5 to 1.5 times such diameter and the area of one step may vary as much as about 0.5 and 1.5 times the area of the other step. For the transducer shown in FIG. 1, the addition of step 28 to piston end 20 increases the radiating area by a factor of about 1.8. This change increases the radiation resistance by a factor of about 3.2. Also, the stepped piston exhibits approximately half the radiation mass expected of a simple piston in an infinite baffle.

Since in general the largest step on the sonic energy radiating means is positioned adjacent the open end, the interior surface of this step provides a convenient location for the placement of a seal or energy absorbing means. Sealing between two sonic energy radiating means is conveniently accomplished by the use of hollow rubber O rings. These hollow O rings allow the sonic energy radiating means to pulsate over a considerable range of travel without breaking the seal and with a minimum of energy required to deform the rings. When desired, the hollow rings may be so constructed that they also serve as energy absorbing devices.

When it is desired to dampen the resonance of the electromechanical transducer element, this can be conveniently accomplished by coating the transducer element with energy absorbing material. When the electromechanical transducer element is a hollow piezoelectric cylinder, the interior of the cylinder may be filled with energy absorbing material if desired. Suitable energy absorbing materials include, for example, rubber, cork, polyurethane compounds and the like.

As illustrated in the drawings, the electromechanical transducer or driving element is an elongated piezoelectric cylinder. This invention is not limited to any particular electromechanical transducer or driving element, for example, piezoelectric cylinder 12 can be replaced by any

driving element which has an electrical response reflecting longitudinal stress fluctuations therein. Suitable electromechanical driving elements include for example, magnetostrictive devices, stacked piezoelectric crystal elements, motor-driven devices and the like.

When it is desired to use only one sonic energy radiating means, node plate 10 (see FIG. 4) is replaced by a heavy rigid structure, often referred to as a backing mass, and only one stepped piston is used with a mechanical transducer element in the interior thereof. The stepped piston is sealed to the rigid structure with a resilient seal such as that shown, for example, in FIG. 5. One end of the electromechanical transducer element is rigidly attached to the backing mass while the other end is affixed to the stepped piston through a compliance element. The stepped piston is resiliently mounted so that it can fluctuate in response to the stress fluctuations in the transducer element. The backing mass may be recessed in the area of the transducer element to permit the use of a longer element.

When first and second sonic energy radiating means are employed, each having an electromechanical transducer element in the interior thereof, the two electromechanical transducer elements are balanced against a node plate, so that only the outer ends of the elements are free to transmit fluctuations to the pistons. Because they are balanced each transducer element is rigidly supported by the node plate.

The use of a compliance element causes the transducer to resonate at a lower frequency and also increases the power output of some versions of the transducer by improving the loading of the driving element. Preferably, the compliance element is in the general form of a disc which has a flange extending outwardly from the first face of the disc. In general, this flange should be at or about the periphery of the disc. This flange is adapted to contact the interior side of a radiating surface of the sonic energy radiating means. Preferably, the outwardly extending flange is radially disposed as far from the center of the compliance element as the interior dimensions of the sonic energy radiating means will permit. In general, only the flange portion of the compliance element contacts the sonic energy radiating means.

The second side of the generally disc shaped compliance element is adapted to contact the electromechanical transducer element. When the transducer element is a piezoelectric cylinder, the diameter of the cylinder is preferably substantially less than that of the outwardly extending flange. The outwardly extending flange on the compliance elements supports the interior side of a radiating surface as would a larger piezoelectric cylinder.

Compliance elements in the form of discs may be slotted for higher compliance if desired. Several discs can be used in tandem as compliance elements. The compliance elements can be made integral with the sonic energy radiating means if desired. In general, in order to obtain a low resonant frequency, a wide bandwidth response and an overall lightweight structure, the area of the sonic energy radiating means should be maximized and the length of the piezoelectric element, when piezoelectric cylinders or slabs are used, should be relatively long and of small cross-section. In general, the ratio of the cross-sectional area of the actual material of the piezoelectric cylinders or slabs, measured in a direction parallel to the radiating surfaces, to the exterior area of the radiating surfaces ranges from about 20 to 200 and preferably from about 100 to 200.

As will be understood by those skilled in the art, what has been described are preferred embodiments of this invention; however, changes and modifications may be made therein without departing from the spirit and scope of the accompanying claims.

What is claimed is:

1. An electromechanical transducer comprising:
a piston having an open end, a closed end, and a hollow interior;

an electromechanical driving element positioned in said hollow interior of said piston, one end of said element being adapted to be rigidly supported and the other end being substantially unsupported;

a force-transmitting compliance element in contact with the interior surface of said closed end and said unsupported end of said driving element.

2. The electromechanical transducer of claim 1 wherein said piston is a stepped piston.

3. The electromechanical transducer of claim 1 wherein said compliance element has a generally disc-shaped configuration with an outwardly extending flange at about the periphery thereof, said compliance element being in contact with said interior surface of said closed end only through said flange.

4. The electromechanical transducer of claim 1 wherein said piston is of hemispherical configuration provided with piston steps adjacent said open end.

5. The electromechanical transducer of claim 1 wherein said piston is a stepped piston with the largest diameter step positioned adjacent said open end, said open end being positioned adjacent a backing mass;

a resilient seal adapted to be positioned between said open end and said backing mass to seal said hollow interior.

6. The electromechanical transducer of claim 1 wherein said hollow interior is sealed with a resilient seal, which seal comprises a hollow O ring retained in a groove in a surface at the open end of said piston.

7. An electromechanical transducer comprising:

a first stepped piston having an open end, a closed end, and a hollow interior;

a second stepped piston having an open end, a closed end, and a hollow interior, said stepped pistons being positioned coaxially with, and slightly apart from one another with the open ends facing one another;

a resilient seal between said open ends;

a first electromechanical driving element positioned in said hollow interior of said first stepped piston;

a second electromechanical driving element positioned in said hollow interior of said second stepped piston; and

a node plate positioned between said open ends, said first and second electromechanical driving elements being balanced against said node plate.

8. The electromechanical transducer of claim 7 including a center member positioned between said stepped pistons and a resilient seal between each of said open ends and said center member.

9. The electromechanical transducer of claim 7 including:

a first compliance element in contact with the interior surface of the closed end of said first stepped piston and said first driving element; and

a second compliance element in contact with the interior surface of the closed end of said second stepped piston and said second driving element.

10. An electromechanical transducer comprising:
a first stepped piston having an open end, a closed end, and a hollow interior;

a second stepped piston having an open end, a closed end, and a hollow interior, said step pistons being positioned coaxially with and slightly apart from one another with the open ends facing one another;

a first compliance element in contact with the interior surface of the closed end of said first stepped piston; and

a second compliance element in contact with the interior surface of the closed end of said second stepped piston;

a resilient seal between said open ends;

an electromechanical driving element positioned in said hollow interiors of said first and second stepped pistons, one end of said driving element being in contact with said first compliance element and the

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other end of said driving element being in contact
with said second compliance element.

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