



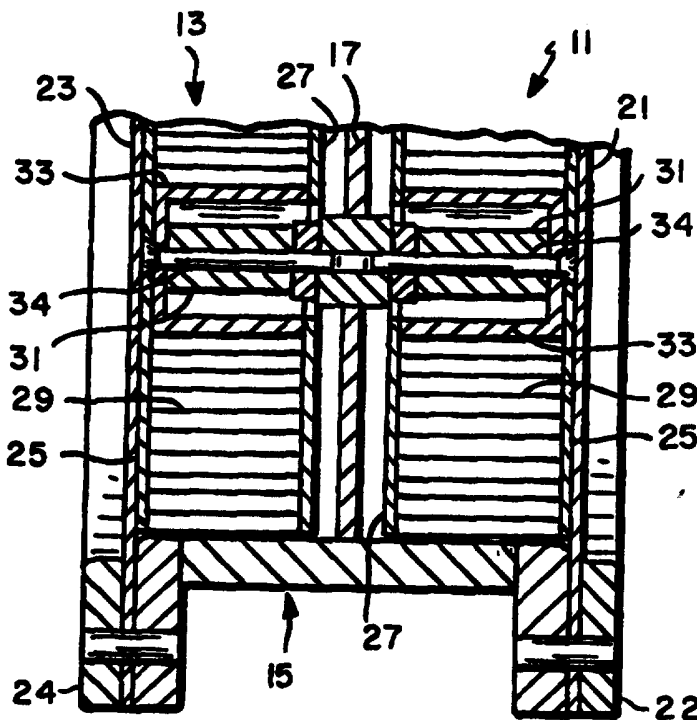
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(54) Title: UNDERWATER ACOUSTIC PROJECTOR

(57) Abstract

The underwater sound projector disclosed herein employs, as radiating surfaces or pistons, stiff, lightweight honeycomb panels (11) whose mass is substantially less than the inertial component of the radiation impedance over the operating frequency range. The panels (11) are driven in opposition by a plurality of linear actuators, e.g., piezoelectric stacks (31), distributed essentially uniformly over the panels (11) so that each stack drives an essentially equal area of the panel and flexing of the panel is avoided. Compliance reactance of the actuators is made to cancel the inertial reactance of the radiation impedance at all frequencies within a decade-wide frequency band. In this way, operation similar to resonance, with its high efficiency, is achieved continuously over a decade-wide frequency band.



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UNDERWATER ACOUSTIC PROJECTOR

BACKGROUND OF THE INVENTION

The present invention relates to an underwater sound projector and more particularly to such a projector which operates efficiently over a wide frequency range.

For towed array, active sonar systems such as are employed for anti-submarine warfare (ASW), it is highly desirable that the transducers used in the array be operable over a wide band of frequencies with high efficiency. It is also desirable that the transducers have a physical configuration that lends itself to underwater towing with low drag.

While various expedients have been proposed for broadening the response of some transducer designs, most prior art transducers, in fact, operate in a mode which involves a fixed-frequency mechanical resonance of the transducer itself, with the resonance frequency slightly modified by the radiation impedance. Examples of such transducers are the so called bending moment transducers of the type disclosed in U.S. Patents 3,150,347, 4,972,390 and 5,204,844. Various electromagnetic low frequency transducers have been devised which have fixed-frequency resonances with relatively broad responses, but these have typically entailed bulky and heavy physical configurations.

Among the several objects of the present invention may be noted the provision of an underwater sound projector which is operable efficiently over a wide range of frequency; the provision of such a transducer which is efficiently operable over a range of frequencies spanning three octaves; the provision of such a projector which provides a configuration suited for

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underwater towing; the provision of such a projector which provides desirable directivity characteristics; the provision of such a projector that can be neutrally buoyant; the provision of such a transducer which is highly reliable and which is of relatively simple and inexpensive construction. Other objects and features will be in part apparent and in part pointed out hereinafter.

SUMMARY OF THE INVENTION

The underwater sound projector of the present invention is adapted for radiating sound energy over a range of frequencies into a body of water in which the projector is immersed. A pair of stiff lightweight plates are employed as complimentary aligned and spaced apart pistons with their peripheries being flexibly sealed to exclude water from the space between them. A plurality of linear actuators, e.g., piezoelectric stacks, are provided between the pistons for driving them in opposition thereby to radiate sound energy into the body of the water, the inertial component of the radiation impedance being substantially greater than the mass of the panels over the range of frequencies of interest.

In accordance with one aspect of the present invention, the compliance of the linear actuator is such that

$$C_m \alpha = 1$$

where C_m is the combined mechanical compliance of the actuators and α is the product circular frequency times inertial component of the radiation impedance, over the frequency range where α is substantially constant. A preferred method of fabricating the pistons is to fabricate them as honeycomb cored panels.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a face view of a circular underwater sound projector constructed in accordance with the present invention, parts being broken away;

Figure 2 is a sectional view taken substantially on the line 2-2 of Figure 1;

Figure 3 is a face view of a rectangular underwater sound projector constructed in accordance with the present invention, again with parts being broken away; and

Figure 4 is a graph illustrating calculated normalized radiation impedance for a projector of the type illustrated in the Figure 3.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Figures 1 and 2, the projector illustrated there employs a pair of pistons 11 and 13 which are set into corresponding recesses in a circular frame 15. While frame 15 is shown as including a central web 17, this web may be omitted in some arrangements since the pistons are driven in opposition as described hereinafter. The pistons may be described as complimentary, aligned and spaced apart. Flexible diaphragm seals 21 and 23 retained by clamp rings 22 and 24 are provided for flexibly sealing the piston panels so as to exclude water from the space between them. As will be understood, sliding or O-ring seals might also be employed.

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In accordance with one aspect of the present invention, the pistons 11 and 13 are constructed as relatively stiff, lightweight plates, preferable by being made up of honeycomb cored panels. As may be seen in Figure 2, the panels comprise outer and inner skins of stainless steel, designated by reference characters 25 and 27 respectively, separated by an aluminum honeycomb 29. As is understood by those skilled in the art, such a construction is highly resistant to bending since the skin panels take up the tension and compression forces of bending while the honeycomb maintains the desired spacing between the skins.

The pistons 11 and 13 are driven in opposition by a plurality of piezoelectric stacks 31 which are distributed essentially uniformly over the panels so that each stack drives an essentially equal area of the panel. Magnetostrictive or other types of linear actuators might also be used. Combined with the inherent stiffness of the panels, this distributed arrangement essentially eliminates flexing of the panels. In the illustrated embodiment, the stacks 31 work against the central web 17 but, as will be understood, in other arrangements where the web is omitted, a longer stack might be employed where each piston is, in effect, driven with respect to the opposite piston.

As illustrated, the stacks 31 are set into recesses in the piston panels formed by flanged cylindrical sockets 33 and are clamped by through bolts 34. These sockets facilitate the coupling of driving forces from each stack to the corresponding local area of the honeycomb panel while maintaining the panel's structural integrity. These sockets also allow the two pistons 11 and 13 to be closely spaced, thereby making the overall projector thinner. As described in greater detail hereinafter, the piezoelectric stacks 31 are configured to provide a compliance or spring constant which is matched to the change in

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the inertial component of the radiation impedance with frequency over the operating frequency range.

Figure 3 illustrates a rectangular projector configuration which is particularly well adapted for inclusion as a transducer in a towed underwater array. For such an application, the rectangular pistons 51, set in a frame 53, may, for example, have a height of 5 meters and a width of 1 meter. Such a configuration gives significant directivity in the vertical dimension, which is useful in avoiding ocean bottom reflections, while being essentially omni-directional in azimuth over the working frequency range of 400 Hz to 3000 kHz. Again, piezoelectric stacks 55 are distributed essentially uniformly over the pistons so that each stack drives an essentially equal area of the honeycomb panel. Arrangement of the stacks within recessed flanged cups is essentially the same as in the construction of Figures 1 and 2.

As will be understood, the piston construction employed in the preferred practice of the invention inherently provides a relatively thin panel, so that the transducer as a whole is relatively thin, e.g., 0.17 meters. Thus, the transducer itself provides a good approximation of a fin, which can be relatively easily towed, rather than having to be fit into a flooded tow body as is the case with most prior art projectors intended for the same applications.

Figure 4 is a graph illustrating calculated and normalized radiation impedance for a 1 meter by 5 meter radiating piston such as is employed in the projector illustrated in Figure 3. The resistive component of the radiation impedance is represented by the curve 41 while the reactive or inertial component is represented by the curve 43. The abscissa values are the products of acoustical wave number and piston width. As may be

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seen, the inertial component drops off significantly after a maximum at about 1.5, corresponding to 360 hertz. While there are various discontinuities in the behavior of the reactive component, the general behavior can be characterized as a slope (reference character 44) indicating that the radiation reactance decreases inversely with increasing frequency. The asymptotic frequency dependence of the reactive component can be expressed as follows:

$$I_m (Z_{rad}) \rightarrow \frac{8 \rho c^2 a b}{\pi \omega (a \& b)} = \frac{\alpha}{\omega}$$

where a and b represent the projector width and height.

In accordance with an important aspect of the present invention, the compliance reactance of the piezoelectric stacks is selected to cancel the mass reactance of the radiation reactance such that

$$C_m \alpha = 1$$

Where C_m is the combined mechanical compliance of the actuators and α is as defined above.

With this matching of compliance or spring constant with the inertial component of radiation impedance, a behavior essentially equivalent to resonance in terms of transduction efficiency is obtained over a wide range of frequencies. This can be explained in the following manner.

In general, resonant behavior occurs when the reactive impedance in the system is equal to zero.

$$I_m (Z_{rad}) + I_m (Z_{mech}) = 0$$

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Z_{mech} is the mechanical impedance of the pistons and the actuators. The piston mass is M_p .

$$I_m (Z_{\text{rad}}) + \omega M_p - \frac{1}{\omega C_m} = 0$$

and further if the radiation reactance is in the range described above:

$$\frac{\lambda}{\omega} + \omega M_p - \frac{1}{\omega C_m} = 0$$

However, if the mass of the piston (M_p) is made substantially less than the inertial component of the radiation reactance in the frequency range of interest, the corresponding term in the above equation drops out, and there remains.

$$\lambda C_m = 1$$

so that resonant type behavior becomes pervasive over the frequency range. The limit on this behavior is when, at higher frequencies, the mass reactance of the projector exceeds the radiation mass, i.e., the inertial component of the radiation reactance.

However, as will be understood from the foregoing explanation and the graph of Figure 4, this condition of pervasive resonance can exist over a quite substantial frequency range, e. g. over three octaves. Over this range the projector will exhibit relatively high efficiency in the conversion of electrical energy to acoustic energy. Not only is this useful range considered to be substantially greater than that available with prior art arrangements, the physical configuration of the

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projector is well-suited for underwater towing as described previously.

In view of the foregoing it may be seen that several objects of the present invention are achieved and other advantageous results have been attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it should be understood that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

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Claims

What is claimed is: .

1. An underwater sound projector for radiating sound energy over a range of frequencies F1 to F2 into a body of water into which the projector is immersed, said projector comprising:

a pair of complementary, aligned and spaced apart panels constructed as stiff, lightweight plates;

means for flexibly sealing the peripheries of said panels to exclude water from the space between them;

a plurality of actuators between said panels for driving said panels in opposition, thereby to radiate sound energy into said body of water, the inertial component of the radiation impedance being substantially greater than the mass of the panels over the frequency range F1-F2.

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2. A projector as set forth in claim 1 wherein the compliance of the actuators is such that

$$C_m \alpha = 1$$

where α is the product of circular frequency and the radiation reactance within the range F1-F2 and C_m is the compliance of the stacks to the linear actuators.

3. An underwater sound projector as set forth in claim 1 wherein said linear actuators are distributed essentially uniformly over said panels so that each actuator drives an essentially equal area of the panel thereby to minimize flexibility of the panel.

4. An underwater sound projector as set forth in claim 1 wherein said linear actuators are piezoelectric stacks.

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5. An underwater sound projector for radiating a substantially constant amount of sound energy over a range of frequency F1 to F2 into a body of water into which the projector is immersed, said projector comprising:

a pair of complementary, aligned and spaced apart panels constructed as stiff, lightweight cored plates;

means for flexibly sealing the peripheries of said panels to exclude water from the space between them;

a plurality of linear actuators between said panels for driving said panels in opposition, thereby to radiate sound energy into said body of water, the compliance of the actuators being such that

$$C_m \alpha = 1$$

where α is the product of circular frequency and the radiation reactance within the range F1-F2 and C_m is the compliance of the stacks.

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6. A projector as set forth in claim 5 where said actuators are distributed essentially uniformly over the panels so that each stack drives an essentially equal area of the panel and there is essentially no flexing of the panel.

7. A projector as set forth in claim 5 wherein the inertial component of the radiation impedance is substantially greater than the mass of the panels over the frequency range F1-F2.

8. An underwater sound projector as set forth in claim 5 wherein said actuators are piezoelectric stacks.

9. An underwater sound projector as set forth in claim 5 wherein said panels are constructed as honeycomb cored plates.

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10. An underwater sound projector for radiating sound energy over a range of frequencies F1 to F2 into a body of water into which the projector is immersed, said projector comprising:

a pair of complementary, aligned and spaced apart panels constructed as stiff, lightweight honeycomb cored plates;

means for flexibly sealing the peripheries of said panels to exclude water from the space between them;

a plurality of actuators between said panels for driving said panels in opposition, thereby to radiate sound energy into said body of water, the inertial component of the radiation impedance being substantially greater than the mass of the panels over the frequency range F1-F2, the compliance of the piezoelectric stacks being such that

$$C_m \alpha = 1$$

where α is the product of circular frequency and radiation reactance within the range F1-F2 and C_m is the combined compliance of the stacks.

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11. An underwater sound projector as set forth in claim 10 wherein the stacks extends into flanged cups embedded into the honeycomb coring of said plates.

12. An underwater sound projector as set forth in claim 10 wherein said panels are about one meter wide and about five meters high.

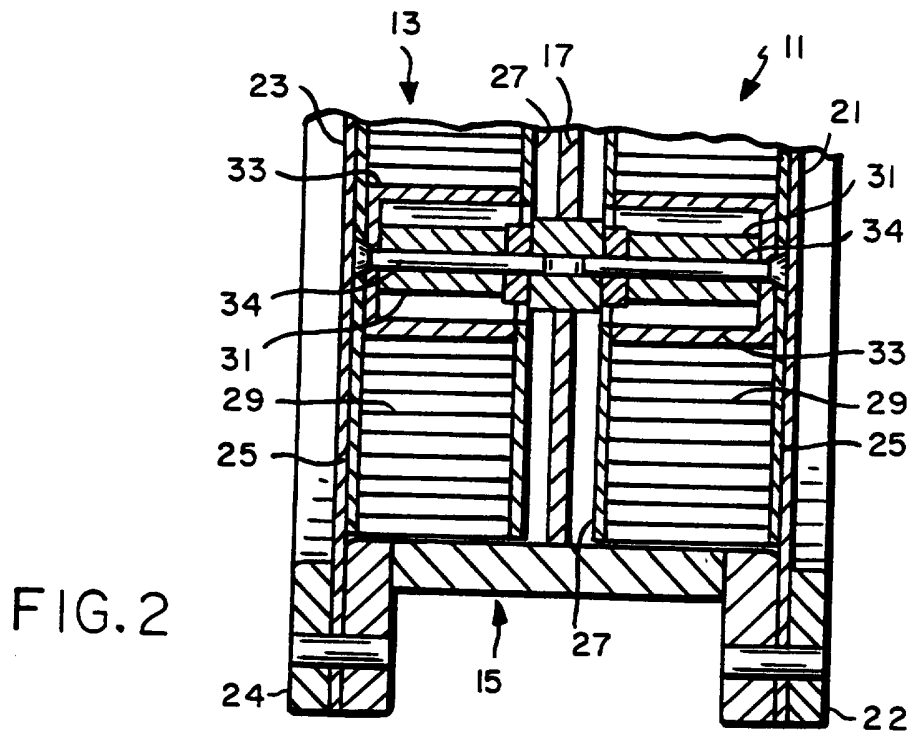
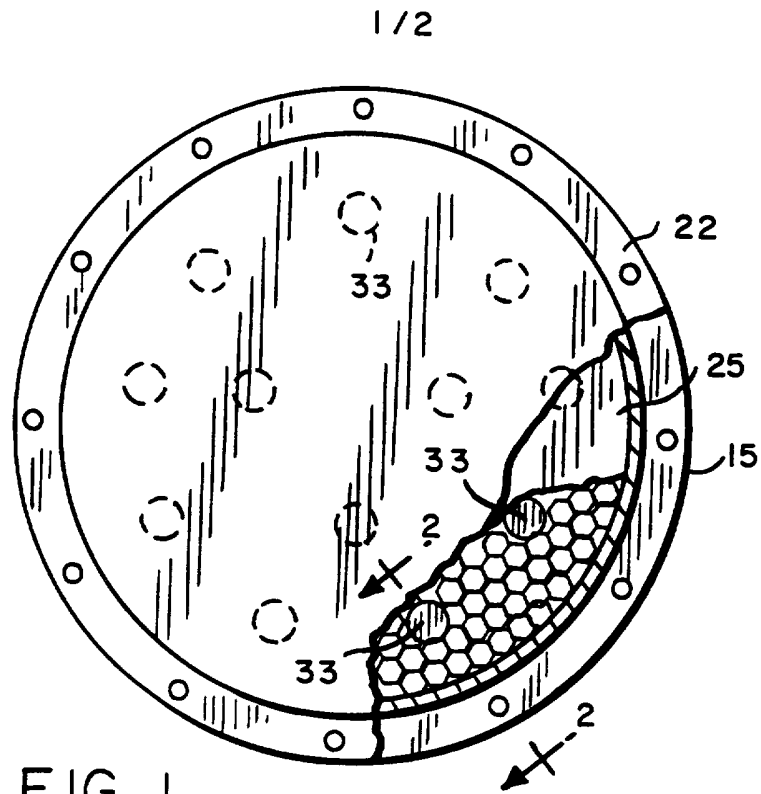


FIG. 3

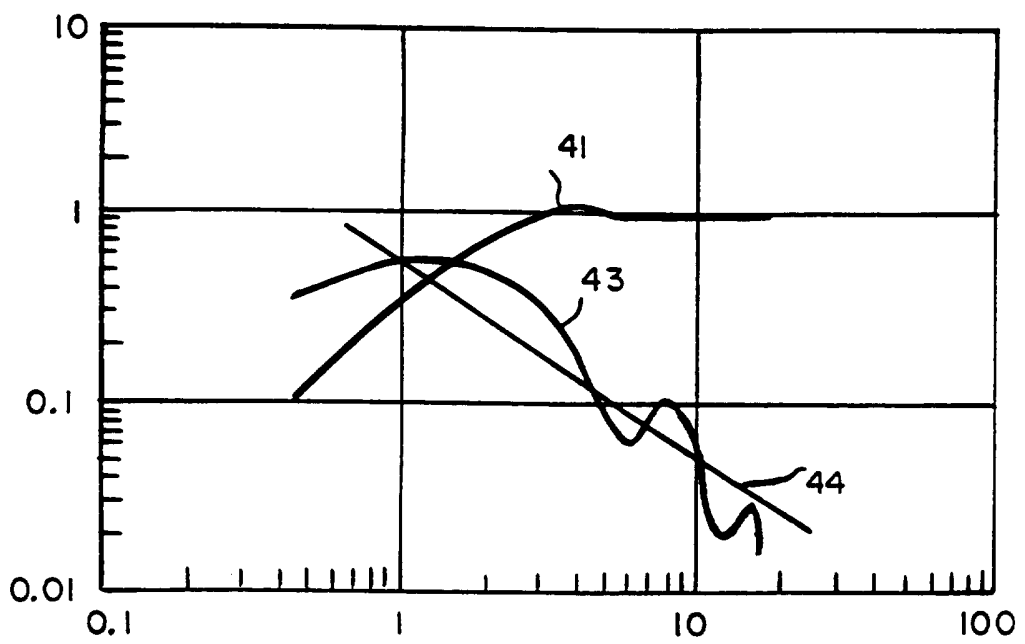
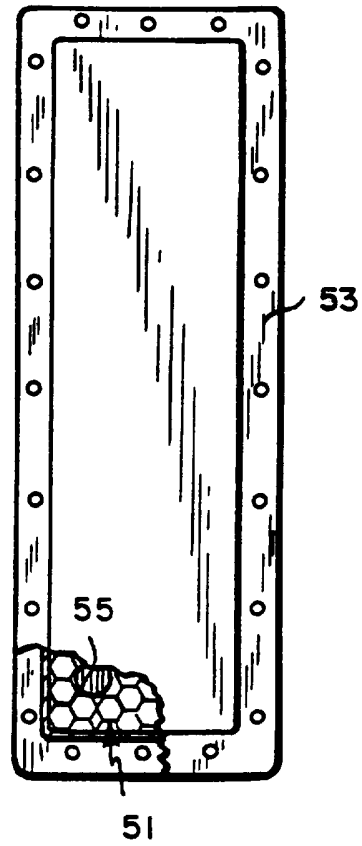


FIG. 4
SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/02530

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04R 17/00
US CL :367/153; 310/337

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)

U.S. : 367/153, 155, 157, 158, 163, 174; 310/337

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,204,844 (ERICKSON) 20 APRIL 1993	1-8
--	See entire disclosure	-----
Y		9-12
Y	US, A, 4,735,096 (DORR) 05 APRIL 1988 See Figures 1, 2, and 4.	9-12
A	US, A, 2,906,991 (CAMP) 29 SEPTEMBER 1959	1-12
A	US, A, 3,538,494 (ERICKSON) 03 NOVEMBER 1970	1, 3 & 4
A	US, A, 4,845,688 (BUTLER) 04 JULY 1989	
A	US, A, 2,405,472 (TUTTLE) 06 AUGUST 1946	

Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search

15 MAY 1996

Date of mailing of the international search report

13 JUN 1996

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