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RESONANT LOW-FREQUENCY TRANSDUCER

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FIG. 1.

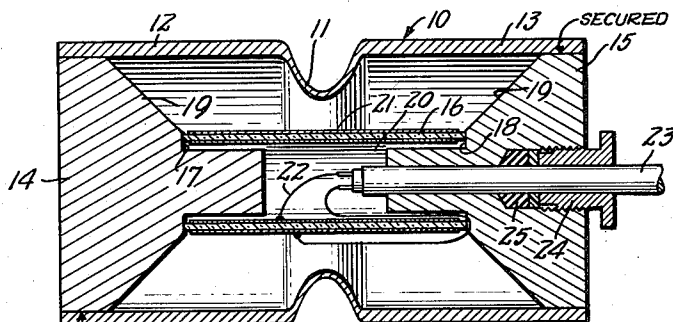


FIG. 2.

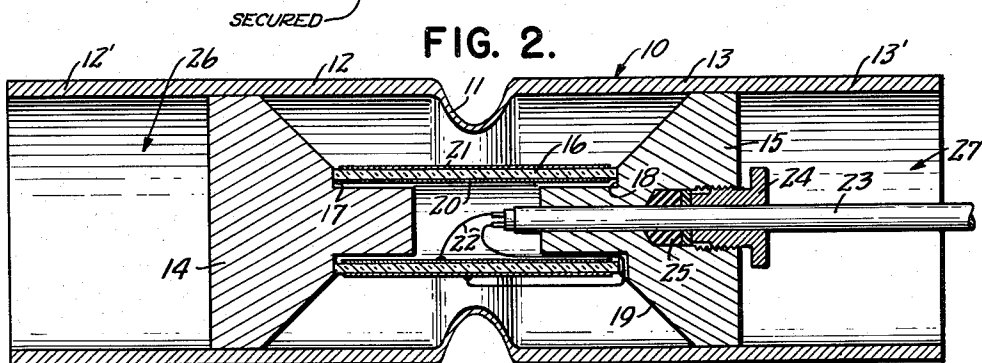


FIG. 3.

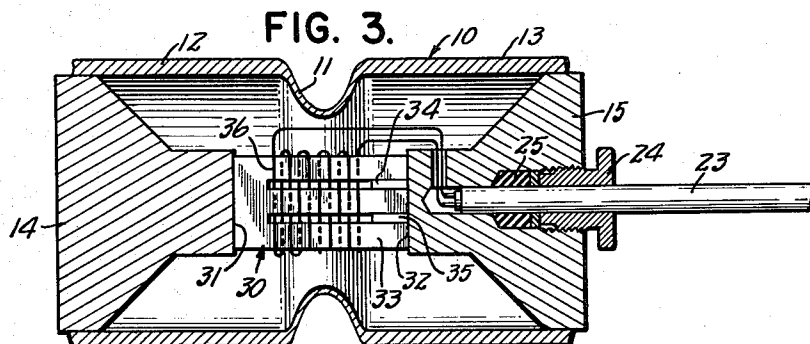
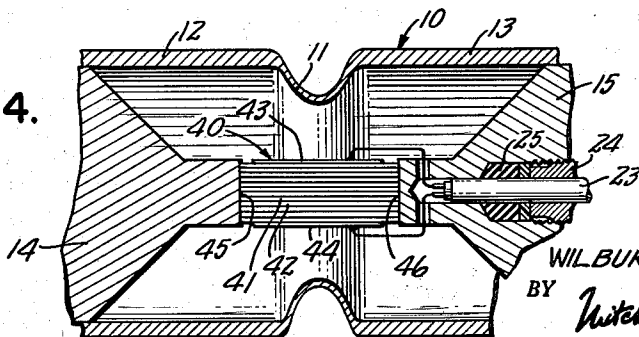


FIG. 4.



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RESONANT LOW-FREQUENCY TRANSDUCER

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20 Claims. (Cl. 340-10)

My invention relates to low-frequency mechanically resonant structures and is particularly adaptable for immersion in a liquid and in combination with an electromechanical transducer element, the arrangement being such that mechanically resonant properties dominate overall performance.

It is an object of the invention to provide improved structures of the character indicated.

It is another object to provide an improved underwater resonator particularly for operation at relatively low frequencies.

It is another object to provide a high efficiency underwater-sound projector particularly applicable in the lower audio-frequency range.

It is a general object to achieve the above objects while avoiding large massive constructions, that is, by maximizing power output per pound of transducer.

Other objects and various further features of novelty and invention will be pointed out or will occur to those skilled in the art from a reading of the following specification in conjunction with the accompanying drawings. In said drawings, which show, for illustrative purposes only, preferred forms of the invention:

Fig. 1 is a longitudinal sectional view of a resonant structure incorporating features of the invention and shown in combination with a transducer element so as to dominate the performance thereof; and

Figs. 2, 3, and 4 represent modifications of the structure of Fig. 1.

Briefly stated, my invention contemplates a tubular resonant structure involving longitudinally spaced counterweights or masses, longitudinally connected to each other by longitudinally compliant means, and having a response primarily on the longitudinal axis. Such structures resonate parasitically when the surrounding medium is excited in phase and near the longitudinal resonance frequency of the device; and by connecting longitudinally acting transducer elements in direct thrusting relation with the respective counterweights, electromechanical transducers having similar resonant properties are provided. In one general form to be described, counterweight action is achieved primarily by reason of masses forming physical parts of the transducer itself, whereas in another general form, the substance of one or both of the end masses or counterweights is defined by the liquid in which the device is immersed for operation, said liquid being trapped or localized by free-flooded chambers or cup structures at the longitudinal ends of the device.

Referring to Fig. 1 of the drawings, my invention is shown in application to a longitudinally resonant structure comprising an elongated cylinder 10 of sufficient radial thickness to be relatively stiff and, therefore, not radially resonant at the low frequency for which the device is to respond. The primary action desired of the member 10 (in addition to providing a watertight housing) is one of longitudinal compliance; this action is

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provided by a circumferentially continuous radial deformation 11 formed centrally of the cylinder 10, thus defining a compliance connecting two relatively stiff end portions 12-13. For symmetry of the device, I prefer that the compliant deformation 11 be longitudinally centrally located. End masses or counterweights 14-15 provide means for closing off the inner (pressure-releasing) volume of my resonator and are thus preferably circumferentially continuously secured to the stiff cylinder portions 12-13. In the form shown, the masses or counterweights 14-15 and the affixed stiff end of the housing 10 provide essentially the only counterweight action of the device and are therefore shown connected to the longitudinal ends of the cylinder 10. The structure thus far described will resonate longitudinally and can be made to do so parasitically, when immersed in a liquid, with performance in the lower audio-frequency range.

In accordance with a feature of the invention, a longitudinally acting electromechanical transducer element may be arranged within the resonator and in direct thrust-transmitting and thrust-receiving abutment with both counterweights 14-15. In the form shown, such transducer element comprises an elongated piezoelectric cylinder 16, as of barium titanate. The cylinder 16 may be strongly bonded at its longitudinal ends to shoulders 17-18 on the counterweights 14-15, and the counterweights 14-15 are preferably tapered outwardly (as at 19), from the shoulder 17-18 to the cylinder 10, for better thrust-transmitting relation between the transducer element 16 and the longitudinally compliant cylinder 10. The transducer element 16 is completed by inner and outer foil electrodes 20-21 applied thereto, and lead connections 22 are served by a cable 23 passing through one of the counterweights 15 and suitably sealed, as by bushing 24 and gland means 25.

The arrangement of Fig. 2 closely resembles that of Fig. 1 and therefore corresponding parts have been given the same reference numerals. The essential difference between the two structures is that, in Fig. 2, low-frequency performance is achieved with minimum structural weight, by relying on locally trapped volumes of liquid to provide part of the opposed counterweight action. This may be achieved by attaching relatively stiff free-flooded chambers or open cups to the counterweights or closure members 14-15, but in the form shown, cups 26-27 are defined by merely extending the end skirts 12'-13' of the cylinder 10. Again, the thickness of the skirts 12'-13' is preferably such that these portions shall be relatively stiff, so that radial resonance within the cups 26-27 shall occur substantially above the predominant low-frequency resonance characteristic of the longitudinal mode of operation of the device. The cup depths are generally less than $\frac{1}{4}$ of a wavelength of sound in the medium at the operating frequency.

The device of Fig. 3 resembles that of Fig. 2 except that the driving element 30 is magnetostrictive and is bonded at its longitudinal ends to suitable pedestals 31-32 on the counterweights or closure members 14-15. As shown, the transducer element 30 happens to be of the variety described in greater detail in my co-pending application Serial No. 475,462, filed December 15, 1954, now abandoned. It therefore suffices here to say that the element 30 comprises a stack of like E-laminations 33 of magnetostrictive material, the openings between ends of the legs of which are closed by permanently magnetized material, as by magnetized ferrite inserts 34-35. The winding 36 linking the various flux paths in the element 30 is preferably of the basket-weave construction described in said application, and leads may be brought out through one of the counterweights 15 in the manner previously described.

The arrangement of Fig. 4 illustrates still another transducer element for use with my basic resonator structure. In Fig. 4, the transducer element 40 comprises a stacked plurality of like piezoelectric crystal slabs 41—42, with outer foil electrodes 43—44 spanning the same. The ends of the elongation axes of the crystals 41—42 are shown bonded to suitably formed pedestals 45—46 on the end masses or closure members 14—15. Electrical leads to the electrodes 43—44 may be supplied by way of cable means 23, as previously described.

It will be appreciated that I have described basically simple resonant structures particularly applicable to lower audio-frequency performance when immersed in liquid, as for underwater use. My structures are particularly efficient when excited by electromechanical transducer elements, and all of these structures lend themselves to the maximizing of power output per pound of transducer. The latter result is aided by the liquid-trap means 26—27, which may also be viewed as a mechanism for additionally loading the counterweights of a basic or standard configuration (Fig. 1) in order to construct the same for still lower frequency performance.

While I have described the invention in detail for the preferred forms illustrated, it will be understood that modifications may be made within the scope of the invention as defined in the claims which follow.

I claim:

1. An electromechanical transducer, comprising an elongated relatively stiff tubular member having an axially compliant portion intermediate the ends thereof, first and second massive counterweights within said member and peripherally continuously secured to said member at locations on opposite sides of said compliant portion, and a transducer element between said counterweights and in direct longitudinal thrust-transmitting relation with said counterweights, said element having an electrical response reflecting longitudinal stress fluctuations therein.

2. A mechanically resonant structure, comprising an elongated relatively stiff tubular member having a peripherally continuous radially extending axially compliant deformed portion intermediate the ends thereof, and first and second massive counterweights within said member and peripherally continuously secured to said member at locations on opposite sides of said compliant portion.

3. An electromechanical transducer, comprising an elongated tubular member having a relatively stiff axially compliant portion intermediate the ends thereof, first and second counterweights within said member and peripherally continuously secured to said member at locations on opposite sides of said compliant portion, a transducer element between said counterweights and in direct longitudinal thrust-transmitting relation with said counterweights, said element having an electrical response reflecting longitudinal stress fluctuations therein, and first and second cups carried by said counterweights and facing longitudinally outwardly of each other; whereby, when immersed in a liquid, the liquid contained within said cups may provide additional loading mass determining resonant properties of said transducer, without proportionally adding to the weight of the transducer structure alone.

4. A transducer according to claim 3, in which said cups are defined as end extensions of said tubular member by securing said counterweights to said tube inwardly of the longitudinal ends of said tubular member.

5. An electromechanical transducer, comprising an elongated relatively stiff axially compliant tubular member, two counterweights contained within said member and secured to each other by way of a compliant portion of said member, and a transducer element between said counterweights and in direct longitudinal thrust relation with said counterweights, said element having an electrical response reflecting longitudinal stress fluctuations therein.

6. An electromechanical transducer, comprising a

transducer element having an electromechanical response for one axis of longitudinal stress fluctuation, counterweights in direct thrusting relation with said element on said axis and on opposite sides of said element, and longitudinal compliant means longitudinally interconnecting said counterweights independently of their connection by way of said element.

7. An electromechanical transducer, comprising a transducer element having an electromechanical response for one axis of longitudinal stress fluctuation, two cups open at one end and closed at the other and facing away from each other on said axis and in direct thrusting relation with said element on said axis and on opposite sides of said element, and compliant means longitudinally interconnecting said cups independently of their connection by way of said element.

8. An electromechanical transducer, comprising a cylindrical relatively stiff tube centrally deformed by a circumferentially continuous radially extending deformation, whereby said deformation provides an axially compliant connection between otherwise stiff end portions of said cylinder, two counterweights secured peripherally continuously to the respective ends of said cylinder, and a transducer element between said counterweights and in direct longitudinally thrusting relation with said counterweights, said element having an electrical response reflecting longitudinal stress fluctuations therein.

9. A transducer according to claim 8, in which said transducer element comprises a piezoelectric cylinder bonded at its longitudinal ends to said counterweights and coaxially supported within said first-mentioned cylinder.

10. A transducer according to claim 8, in which said transducer element is a magnetostrictive element.

11. A transducer according to claim 8, in which said transducer element includes a piezoelectric crystal.

12. A transducer according to claim 8, in which said transducer element comprises a stack of piezoelectric-crystal slabs having opposed edges in direct thrusting abutment with said counterweights.

13. A mechanical resonator for liquid immersion, comprising a stiff elongated cylinder centrally deformed with a circumferentially continuous radial deformation defining a compliant connection between two relatively stiff end portions, first and second relatively stiff closure members circumferentially continuously secured within said respective stiff end portions and symmetrically located inwardly of the longitudinal ends of said cylinder, whereby longitudinally outwardly open cups are defined at the longitudinal ends of said cylinder; the stiffness of said closure members and of said stiff end portions being such that, when immersed in a liquid, the longitudinal resonance afforded by compliant connection at said deformation between end masses, constituting essentially liquid contained in said cups, is at a frequency substantially lower than any radial or other resonance attributable to said relatively stiff portions.

14. An electromechanical transducer, comprising a stiff elongated cylinder centrally deformed with a circumferentially continuous radial deformation defining a compliant connection between two relatively stiff end portions, first and second relatively stiff closure members circumferentially continuously secured within said respective stiff end portions and symmetrically located inwardly of the longitudinal ends of said cylinder, whereby longitudinally outwardly open cups are defined at the longitudinal ends of said cylinder; the stiffness of said closure members and of said stiff end portions being such that, when immersed in a liquid, the longitudinal resonance afforded by compliant connection at said deformation between end masses constituting essentially liquid contained in said cups is at a frequency substantially lower than any radial or other resonance attributable to said relatively stiff portions; and a transducer element between said closure members in direct longitudinally

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thrusting relation with said closure members, said element having an electrical response reflecting longitudinal stress fluctuations therein.

15. A transducer according to claim 14, in which said transducer element comprises a piezoelectric cylinder 5 bonded at its longitudinal ends to said closure members and coaxially supported within said first-mentioned cylinder.

16. A transducer according to claim 14, in which said transducer element is a magnetostrictive element.

17. A transducer according to claim 14, in which said transducer element includes a piezoelectric crystal. 10

18. An electromechanical transducer, comprising a transducer element having an electromechanical response for one axis of longitudinal stress fluctuation, two 15 opposed fluid traps connected in direct thrusting relation with the opposite longitudinal ends of said element, and relatively stiff longitudinally compliant means longitudinally interconnecting said traps independently of their connection by way of said element.

19. A transducer according to claim 18, in which said traps are chambers each having at least one opening for free-flooding when immersed in a liquid. 20

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20. An electromechanical transducer, comprising a transducer element having an electromechanical response for one axis of longitudinal stress fluctuation, externally accessible electrical connections to said transducer element, two opposed counterweights connected in direct thrusting relation with the opposite longitudinal ends of said element, one of said counterweights comprising a chamber having at least one opening for free-flooding when immersed in a liquid, and relatively stiff longitudinally compliant means longitudinally interconnecting said counterweights independently of their connection by way of said element.

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