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ACOUSTIC CONVERSION APPARATUS

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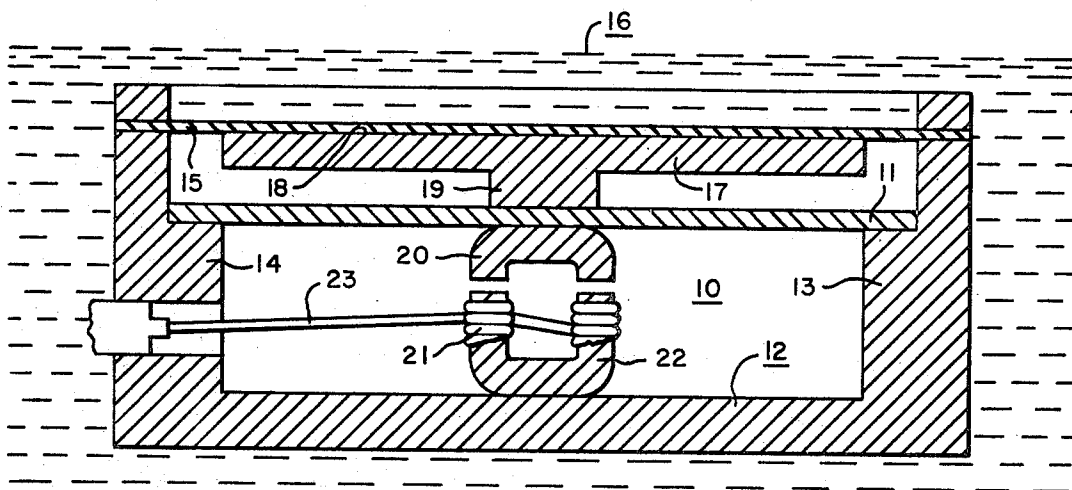


FIG. 1

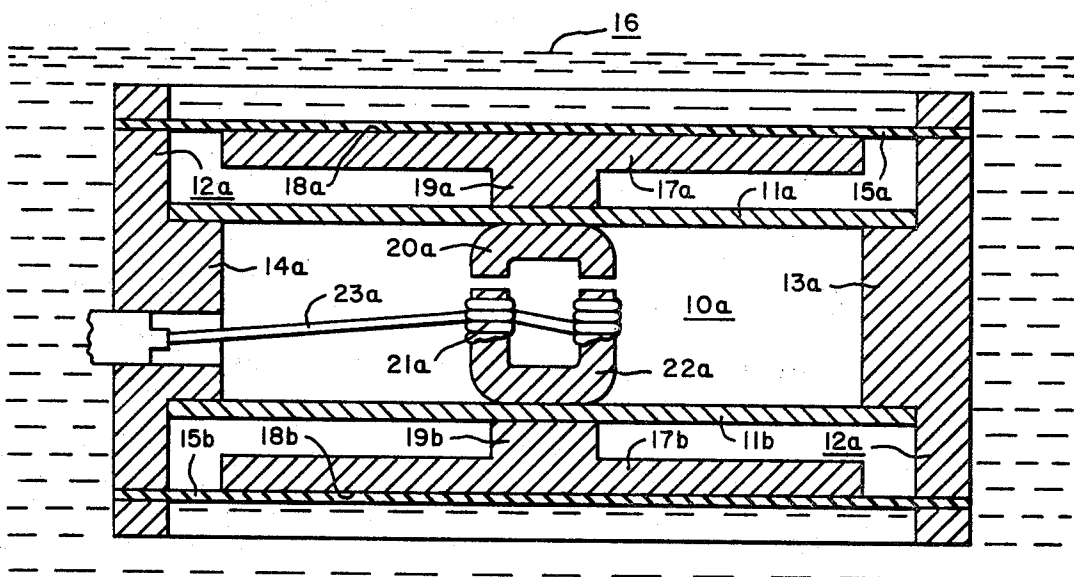


FIG. 2

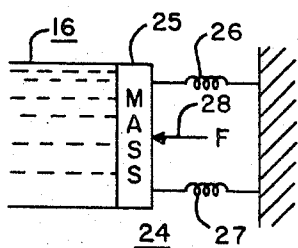


FIG. 3

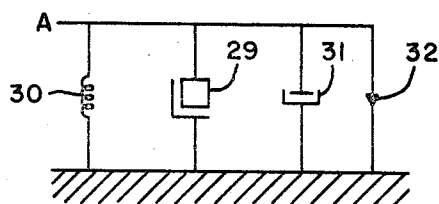


FIG. 4

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ACOUSTIC CONVERSION APPARATUS

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14 Claims

ABSTRACT OF THE DISCLOSURE

Disclosed are compact, light-weight transducers usable for converting acoustic power. One such transducer supplies acoustic power at low frequencies to water that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the water. The transducer includes a vibratile bar and a piston mounted within a waterproof housing and adjusted to form, together with the effective mass (M_L) of the water, an oscillatory system of prescribed resonant frequency. Magnetic drive circuitry vibrates the bar at the resonant frequency and acoustic power is supplied to the water at that frequency by the radiating face of a piston which is coupled to the water via a compliant rubber section of the housing. Other embodiments are also covered.

The invention described herein may be manufactured and used by the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

SUMMARY OF THE INVENTION

This invention relates to energy and power conversion apparatus such as transducers and more particularly to those which are usable for converting acoustic energy or power.

In various systems it is necessary to convert non-acoustic energy or power into that of the acoustic type by the use of transducers, acoustic generators, and the like. However, the environment or medium to which the acoustic power is to be supplied or from which it is to be received, often has an effect on the size, weight or complexity of the conversion apparatus. For example, if acoustic power is to be supplied by a transducer to a liquid medium such as water, the water itself has an effective mass which provides an acoustic load for the transducer. It is, therefore, an object of the present invention to provide new and improved acoustic energy conversion apparatus such as transducers, and a further object to provide compact, lightweight acoustic transducers which reduce or otherwise compensate for the effects of acoustic loading on the transducer operation.

Thus, in accordance with the present invention there is provided a compact, lightweight, low frequency transducer usable for supplying acoustic power to a liquid medium that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the medium. The transducer includes a vibratile element and means for supporting the vibratile element for permitting the element to vibrate. Also included is a movable mass member operably connected to the vibratile element for coupling acoustic power from the vibratile element to the liquid medium. The vibratile element and mass member are adjusted to form, together with the effective mass (M_L) of the liquid medium, an oscillatory system having a resonant frequency which is substantially equal to a desired transducer operating frequency. Further included is means affixed to said support means for vibrating the vibratile element at substantially the resonant frequency for supplying acoustic power at the resonant frequency to the liquid medium so that the

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effects of the reactive component (X_L) of the acoustic load on the power supplied to the liquid medium are minimized.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring to the drawings:

FIG. 1 is a diagram of one form of transducer in accordance with the invention;

FIG. 2 is a diagram of another form of transducer in accordance with the invention;

FIG. 3 is a schematic representation of a basic resonator for use in describing the transducer systems of FIGS. 1 and 2; and

FIG. 4 is a mechanical equivalent of the basic resonator of FIG. 3.

DESCRIPTION OF THE INVENTION

Description of the embodiment of FIG. 1

FIG. 1 depicts one form of energy conversion apparatus, transducer 10 shown operating as a low frequency acoustic generator, for supplying acoustic power to a liquid medium. However, it will be recognized that transducer 10, appropriately modified, is also usable in accordance with the invention as an acoustic receiver. As shown, power is supplied to a liquid medium that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the medium. Transducer 10 includes a vibratile element, shown for example as vibratile bar 11, which exhibits a spring constant K. Transducer 10 further includes means for supporting vibratile bar 11 for permitting the bar 11 to vibrate, this means being depicted as a waterproof housing 12 having a first sidewall 13 and a second sidewall 14. One end of vibratile bar 11 is connected to first sidewall 13 and the other end is connected to second sidewall 14 for permitting the bar, or at least a portion thereof, to vibrate. Housing 12 further includes a compliant section 15, composed of rubber or other suitable material, through which acoustic power is coupled to the liquid medium, in this case water 16, in which the transducer 10 may be used. The water 16 provides the acoustic load having the substantial reactive component (X_L) which results from the effective mass (M_L) of the water 16.

A movable mass member, shown as piston 17 having a reactive component (X_R) resulting from the piston mass (M_R) is operably connected to the vibratile bar 11 and arranged to be coupled to the water 16 via compliant section 15, for supplying acoustic power to the water 16. The piston has a radiating portion or face 18 which contacts compliant section 15. The piston 17 is shown to also include a spacer portion 19 which is connected to the vibratile bar 11. If desired, however, a separate spacer element, appropriately connected, may be employed between piston 17 and the vibratile bar 11. Also, if desired, the separate compliant section 15 may be eliminated so that radiating face 18 directly contacts the water provided, for example, that piston 17 is itself compliantly mounted to housing 12.

The piston 17 mass (M_R) and the vibratile bar 11 of spring constant K are adjusted to form, together with the effective mass (M_L) of the water 16, an oscillatory system having a resonant frequency

$$\omega_0 \doteq \left(\frac{K}{M_L + M_R} \right)^{1/2}$$

which is substantially equal to a desired operating frequency for transducer 10. This is substantially the frequency at which power is to be supplied to the water 16.

Transducer 10 further includes means for vibrating vibratile bar 11 at substantially the resonant frequency for supplying acoustic power at the resonant frequency to the

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water 16 so that the effects of the reactive component (X_L) of the acoustic load on the power supplied to the water 16 by the piston 17 are minimized. In fact, at the resonant frequency, the vibratile bar 11 generates a spring force (F) which substantially cancels out both the reactive component (X_L) resulting from the piston 17 mass (M_R) and the reactive component of the acoustic load resulting from the effective mass (M_L) of the water 16.

The means for vibrating the bar 11 is shown as a magnetic drive circuit which includes an iron armature 20 affixed to the vibratile bar 11, and a coil 21 wound about a laminated steel core 22 which, in turn, is mounted to the bottom of housing 12. An input signal, generated, for convenience, at an external location (not shown) is supplied to coil 21 from a watertight connection via cable 23. If desired, other arrangements may instead be employed for vibrating the vibratile bar 11.

OPERATION OF THE TRANSDUCER SYSTEM OF FIG. 1

In the embodiment of FIG. 1, transducer 10 is shown to be light weight and compact for supplying acoustic power at low frequencies to the water 16. Such transducers are particularly suitable for use in conjunction with small underwater devices such as torpedoes and the like, but of course are also usable in various other applications. The compactness of transducer 10 tends to restrict the available area, and thus the size, of radiating face 18 of piston 17. In addition, since transducer 10 is operable at low frequencies, such as but of course not limited to, the range of 50 Hz. to 500 Hz., the wavelengths of these operating frequencies will be much larger than the size of the radiating face 18 of piston 17.

Under the aforementioned operating conditions for transducer 10, the water 16 provides an acoustic load which may be further explained by reference to the fact that the water 16 may be referred to as providing, with respect to the operation of transducer 10, a complex impedance (Z_L). This impedance is separable into its real and imaginary components ($Z_L = R_L + jX_L$), where the acoustic resistance (R_L) of the water 16 is defined as the real component and is the component associated with the dissipation of energy, and the acoustic reactance (X_L) of the water 16 is the imaginary component of the acoustic impedance that results from the effective mass (M_L) of the water 16. Under the aforementioned operating conditions for transducer 10, the reactive component (X_L) is of much greater magnitude than the resistive component (R_L). Because of the relatively low magnitude of the real component (R_L), a transducer 10 which provides a large displacement capability is desired. In addition, a large force (F) is similarly desired in order to overcome the relatively large or substantial reactive component (X_L).

Since transducer 10 is physically small with respect to the wavelength in the water 16 which provides the acoustic load, transducer 10 for purposes of analysis may be approximated as a point source or radiating pulsating sphere. In such an acoustic system the radial velocity (u) for the surface of a sphere is approximately given by the equation:

$$u = U_0 \cos \omega t = Re U_0 e^{j\omega t} \quad (1)$$

the radiated power (W) is approximately given by the equation:

$$W = (r_0 c k^2 S^2 U_0^2) / 8\pi \quad (2)$$

where S =area of the radiating face 18 of piston 17 (assumed for purposes of analysis to be circular and un-baffled); r_0 =density of the water 16; $k^* = (2\pi)/\lambda$; and c =speed of sound in the water 16.

Based upon these results, the power delivered to the water is independent of the particular shape of the radiating face 18 of piston 17 but is proportional to the volume velocity of the "source," transducer 10. Conse-

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quently, the displacement (X) is approximately given by the equation:

$$X = \frac{U_0}{2\pi F} = \frac{U_0}{\omega} \quad (3)$$

where F =the frequency of operation; X =maximum displacement.

The reactive component (X_R) of piston 17 varies only slightly for various conditions of baffling and is approximately given by the equation:

$$X_R = \frac{8}{3} r_0 c S (k^* a = \frac{2r_0 a}{k^* 2} \quad (4)$$

where a =radius of piston.

FIG. 3 is a schematic representation of a basic single degree of freedom system or resonator 24, for use in describing the transducer 10 system of FIG. 1. In FIG. 3, mass 25 is representative of the mass (M_R) of piston 17 while first spring element 26 and second spring element 27, each of magnitude $K/2$, are representative of the effective spring constant K of the suspension of the mass 25. Horizontal arrow 28 is representative of the force F supplied to the system.

FIG. 4 depicts a mechanical equivalent circuit of the FIG. 3 system. Here mass unit 29 of magnitude M is representative of the sum of the magnitudes of the mass 26 (M_R) of piston 17 and the effective mass (M_L) provided by the water 16. Unit 30 represents the effective system spring constant K exhibited by vibratile bar 11, dashpot 31 of magnitude B represents the real component (R_L) of the water 16 plus resistive system losses, assumed here to be nonexistent, and downward arrow 32 represents supplied force F .

The resulting complex displacement (X) can be obtained by the following equation:

$$X = \frac{F e^{j\omega t}}{\omega Z_L} \quad (5)$$

Complex mechanical impedance at point A in FIG. 4 is given by the equation:

$$Z_L = R_L + j \left(\omega [M] - \frac{K}{\omega^2} \right) \quad (6)$$

where $R_L = B$ (no system losses; $\omega = 2\pi F$ solving for the maximum real displacement component:

$$X_{\max} = \frac{F}{\omega \sqrt{R_L^2 + \left(\omega [M] - \frac{K}{\omega^2} \right)^2}} = \frac{F}{\omega \sqrt{R_L^2 + I_L^2}} \quad (7)$$

where

$$I_L = \left(\omega M - \frac{K}{\omega} \right)$$

Choosing a value of ω such that $I_L = 0$, we have for $X_{\max}$:

$$X_{\max} = \frac{F}{\omega_0 R_L}$$

where:

$$\omega_0 = \sqrt{\frac{K}{M}} = \sqrt{\frac{K}{M_L + M_R}} \quad (8)$$

The total power (W) delivered to the system may be obtained by use of the following equation:

$$W = \frac{F^2}{2Z_M} \cos \theta \quad (9)$$

where:

$$\cos \theta = \frac{R_L}{I_L}$$

In terms of R_L and I_L defined above

$$W = \frac{F^2 R_L}{2 I_L^2} \quad (10)$$

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at the resonant frequency (ω_0) the power delivered to the system is given by:

$$W = \frac{F^2}{2R_L} \quad (11)$$

The value of R_L can be obtained from Equation 2 which results from the simple source approximation of the un baffled circular piston.

Since the power delivered to the acoustic medium is given by:

$$W = \frac{U_o^2 R_L}{2} \quad (12)$$

The value of R_L may be obtained by equating the value of power given by Equation 2 and the Equation 12 and solving for R_L . The resulting value for R_L is:

$$R_L = \frac{r^2 c k^2 a^2 S^2}{4} \quad (13)$$

and the force (F) necessary to deliver a given amount of power to the system is:

$$F = \sqrt{2R_L W} \quad (14)$$

Under operating conditions, the supplied input signal which may be of a prescribed frequency, supplies an alternating current to coil 21 which causes armature 20 to be attracted to the pole piece of core 22. This phenomenon occurs twice every cycle and thus produces a motion at twice the rate of the input signal frequency. The vibratile bar 11 of spring constant K, and the piston 17 of mass M_R or the combination thereof are preselected or adjusted so that, together with the mass M_L of the acoustic load, an oscillatory system is formed having a resonant frequency

$$\omega_{O1} = (K_1 / [M_{R1} + M_L])^{1/2}$$

which is substantially equal to the desired transducer 10 operating frequency. The appropriate frequency input signal is supplied to vibrate bar 11 at substantially the resonant frequency, thereby causing transducer 10 to operate at substantially that frequency so the effects of both the reactive component (X_L) of the acoustic load resulting from the effective mass (M_L) of the water 16 and the reactive component (X_R) resulting from the piston 17 mass (M_R) are substantially eliminated from the power supplied to the water 16.

DESCRIPTION AND OPERATION OF THE EMBODIMENT OF FIG 2

FIG. 2 depicts another form of energy conversion apparatus, transducer 10a for supplying acoustic power to a liquid medium, water 16, that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the water 16. Transducer 10a is constructed and operates in a manner analogous to that described with reference to transducer 10 of FIG. 1 and includes elements 11a-15a and 17a-23a, which correspond to like elements 11-15 and 17-23 of transducer 10 shown in FIG. 1. However, in the transducer 10a of FIG. 2, unit 11a is referred to as a first vibratile bar of spring constant K_1 , since transducer 10a also additionally includes a second vibratile bar 11b of spring constant G_2 oppositely spaced from the first bar 11a. Both vibratile bars 11a and 11b have respective ends thereof connected to sidewalls 13a and 14a of housing 12a. Similarly, unit 17a is referred to as a first piston 17a having a reactive component (X_{R1}) resulting from the piston mass (M_{R1}). Piston 17a is operably connected to the first vibratile bar 11a and arranged to be coupled to the water 16 via first compliant section 15a. The vibratile bar 11a of spring constant K_1 and the first piston having a reactive component (X_{R1}) resulting from the piston mass (M_{R1}) are preselected or adjusted to form,

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together with the effective mass (M_L) of the water 16, a first oscillatory system having a first resonant frequency

$$\omega_{O1} = (K_1 / [M_{R1} + M_L])^{1/2}$$

which is substantially equal to the desired transducer operating frequency.

Further included in transducer 10a is a second piston 17b, having a reactive component (X_{R2}) resulting from the piston mass (M_{R2}). Piston 17b is operably connected to the second vibratile bar 11b and arranged to be coupled to the water 16 via a second compliant section 15b which is substantially oppositely spaced from said first compliant section 15a, for supplying acoustic power to the water 16. The vibratile bar 11b of spring constant K_2 and the second piston mass 17b of mass (M_{R2}) are adjusted to form, together with the effective mass (M_L) of the water 16, a second oscillatory system having a second resonant frequency

$$\omega_{O2} = (K_2 / [M_{R2} + M_L])^{1/2}$$

Units 17b and 18b are adjusted or selected so that this second resonant frequency is substantially equal to the first resonant frequency and thus also to the desired transducer operating frequency. This is done simply because it is desired to operate both oscillatory systems at one frequency. However, the use of two different resonant frequencies is not precluded. Similarly, transducer 10b can include even more vibratile bars 11 and pistons 17 providing additional oscillatory systems. Thus, acoustic power can be provided at various different frequencies or the power supplied at one frequency can be increased. Additional compliant sections 15 would also be included as needed.

The vibrating means in this embodiment vibrates the first and second vibratile bars 11a and 11b, and includes magnetic drive circuitry, which, as described with regard to FIG. 1, additionally includes an iron armature 20a affixed to the vibratile bar 11a. However, coils 21a, wound about laminated steel core 22a, are mounted to the second vibratile bar 11b instead of being mounted to the housing 12a. Thus, the supplied signal causes vibratile bars 11a and 11b to vibrate for generating respective spring forces F_1 and F_2 . Here again transducer 10a supplies acoustic power at the resonant frequency to the water so that the effects of the reactive component (X_L) of the acoustic load on the power supplied to the water 16, in this case by pistons 17a and 17b, are minimized. In fact, at the resonant frequency, force F_1 substantially cancels out the effects of both the reactive component (M_L) of the acoustic load and the reactive component (M_{R1}) of the first piston 17a on the power supplied to the water 16 via the first piston 17a. Similarly, force F_2 substantially cancels out the effects of both the reactive component (M_L) of the acoustic load and the reactive component (M_{R2}) of the second piston 17b on the power supplied by the second piston 17b to the water 16. It will be recognized that it might be appropriate in some instances to have separate means for vibrating each of vibratile bars 11a and 11b. Such might be the case, for example, if the oscillatory systems have different resonant frequencies, as aforementioned, and the vibrating means causes each vibratile bar to resonate at the resonant frequency of the oscillatory system in which that particular vibratile bar 11 is included.

Also in the embodiment shown in FIG. 2, the first and second pistons 17a and 17b are oppositely spaced from each other and positioned within the housing so that each of the pistons 17a and 17b supply acoustic power to the water 16, in a substantially opposite direction from the other piston. In addition, the magnetic drive circuitry of the vibrating means causes the first and second oscillatory systems to operate approximately 180° out of phase with each other. Thus, there is substantially no resultant force on the housing 12a for causing any movement of transducer 10a when transducer 10a is in operation.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed to cover all such changes and modifications as may fall within the true spirit and scope of the invention.

What is claimed is:

1. A compact, light weight, low frequency transducer usable for supplying acoustic power to a liquid medium that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the medium, said transducer comprising:

a vibratile element;

means for supporting said vibratile element for permitting said element to vibrate;

a movable mass member operably connected to said vibratile element for coupling acoustic power, from said vibratile element to the liquid medium, said vibratile element and mass member adjusted to form, together with the effective mass (M_L) of the liquid medium, an oscillatory system having a resonant frequency which is substantially equal to a desired transducer operating frequency;

and means, affixed to said support means, for vibrating said vibratile element at substantially the resonant frequency for supplying acoustic power at said resonant frequency to the liquid medium so that the effects of the reactive component (X_L) of the acoustic load on the power supplied to the liquid medium are minimized.

2. A transducer as described in claim 1, wherein said support means includes first and second side-walls, and said vibratile element, exhibiting a spring constant K, is connected between said first and second side-walls for permitting said element to vibrate.

3. A transducer as described in claim 1, wherein said support means includes a compliant section and said mass member includes a radiating portion which supplies acoustic power to the liquid medium via said compliant section.

4. A transducer as described in claim 1, wherein said support means includes a compliant section and first and second sidewalls, said vibratile element, exhibiting a spring constant K, is connected between said first and second sidewalls for permitting said element to vibrate, and said mass member includes a piston of mass M_R operably connected to the vibratile element and arranged to be coupled to the liquid medium via said compliant section, for supplying acoustic power to said liquid medium, the spring constant K and the piston mass M_R adjusted to form, together with the mass (M_L) of the liquid medium, an oscillatory system having a resonant frequency

$$\omega_0 = (K/[M_R + M_L])^{1/2}$$

5. A transducer as described in claim 4, wherein said vibratile element includes a vibratile bar of spring constant K, having one end connected to said first side-wall and the other end connected to said second sidewall, and said support means permits at least a portion of said bar to vibrate.

6. A transducer as described in claim 1, wherein said support means includes a compliant section and first and second sidewalls; said vibratile element, exhibiting a spring constant K, is connected between said first and second sidewalls for permitting said element to vibrate; said movable mass member includes a piston having a reactive component (X_R) resulting from the piston mass (M_R), operably connected to the vibratile element and arranged to be coupled to the liquid medium via said compliant section, for supplying acoustic power to said liquid medium, the spring constant K and the piston mass M_R adjusted to form, together with the effective mass (M_L) of the liquid

medium, said oscillatory system having a resonant frequency

$$\omega_0 = (K/[M_R + M_L])^{1/2}$$

and said vibrating means causes the vibratile element to generate a spring force F which substantially cancels the effects of both the reactive component (X_R) resulting from the piston mass and the reactive component (X_L) of the acoustic load on the power supplied to the liquid medium.

7. A transducer as described in claim 6, wherein said vibrating means includes a magnetic drive circuit having a movable armature affixed to said vibratile bar and a magnetic drive coil affixed to said housing and responsive to a supplied signal for causing said vibratile element to vibrate at substantially the resonant frequency.

8. A compact, light weight, low frequency transducer usable for supplying acoustic power to water that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the water, said transducer comprising:

a water-proof housing having a compliant top section, a base, and first and second sidewalls;

a vibratile bar, of spring constant K, having one end connected to said first sidewall and the other end connected to said second sidewall for permitting at least a portion of said bar to vibrate;

a piston having a reactive component (X_R) resulting from the piston mass (M_R), operably connected to the vibratile bar for coupling acoustic power from said vibratile bar to the water via said compliant top section, the spring constant K and the mass (M_R) adjusted to form, together with the effective mass (M_L) of the acoustic load, an oscillatory system having a resonant frequency

$$\phi_0 = (K/[M_R + M_L])^{1/2}$$

which is substantially equal to a desired transducer operating frequency;

and means for vibrating said vibratile element at the resonant frequency for supplying acoustic power at said resonant frequency to the water, said vibrating means including a magnetic drive circuit having a movable armature affixed to said vibratile bar and a drive coil affixed to said base and responsive to a supplied signal for causing said vibratile bar to vibrate for generating a spring force F which substantially cancels the effects on the power supplied to the water of both the reactive component (X_L) of the acoustic load and the reactive component (X_R) resulting from the piston mass.

9. A compact, light weight, low frequency transducer usable for supplying acoustic power to a liquid medium that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the medium, said transducer comprising:

first and second vibratile elements;

means for supporting said first and second vibratile elements for permitting said elements to vibrate;

a first movable mass member operably connected to said first vibratile element and arranged to be coupled to the liquid medium for supplying acoustic power to said liquid medium, said first vibratile element and first mass member adjusted to form, together with the acoustic load provided by the liquid medium, a first oscillatory system having a first resonant frequency which is substantially equal to a first desired transducer operating frequency;

a second movable mass member operably connected to said second vibratile element and arranged to be coupled to the liquid medium for supplying acoustic power to said liquid medium, said second vibratile element and second mass member adjusted to form, together with the acoustic load provided by the liquid medium, a second oscillatory system having a sec-

and resonant frequency which is substantially equal to a second desired transducer operating frequency; and means for vibrating said first and second vibratile elements at substantially their respective resonant frequencies for supplying acoustic power at said first and second frequencies to the liquid medium so that the effects of the reactive component (X_L) of the acoustic load on the power supplied to the liquid medium are minimized.

10. A transducer as described in claim 9, wherein said first and second mass members and vibratile elements are adjusted to provide first and second oscillatory systems having substantially equal resonant frequencies for supplying power to the liquid medium at substantially one resonant frequency.

11. A transducer as described in claim 9, wherein said first and second mass members and vibratile elements are adjusted to provide first and second oscillatory systems having substantially equal resonant frequencies for supplying power to the liquid medium at substantially one resonant frequency, and wherein said first and second movable mass members are positioned within said support means and arranged for supplying acoustic power to the liquid medium in substantially opposite directions from one another.

12. A transducer as described in claim 9, wherein said first and second mass members are positioned within said support means for supplying acoustic power to the liquid medium in substantially opposite directions from one another, and wherein said first and second mass members and vibratile elements are adjusted to provide first and second oscillatory systems having substantially equal resonant frequencies for supplying acoustic power to the liquid medium at substantially one resonant frequency, and wherein said vibrating means causes said first and second oscillatory systems to operate approximately 180° out of phase with each other.

13. A compact, light weight, low frequency transducer usable for supplying acoustic power to water that provides an acoustic load having a substantial reactive component (X_L) resulting from the effective mass (M_L) of the water, the transducer comprising:

- a water-proof housing having first and second sidewalls and first and second compliant sections;
- a first vibratile bar of spring constant K_1 having one end connected to said first sidewall and the other end connected to said second sidewall for permitting at least a portion of said first bar to vibrate;
- a second vibratile bar of spring constant K_2 , having one end connected to said first sidewall and the other end connected to said second sidewall for permitting at least a portion of said second bar to vibrate;
- a first piston having a reactive component (X_{R1}) resulting from the first piston mass (M_{R1}), operably connected to the first vibratile bar and arranged to be coupled to the water via said first compliant section, for supplying acoustic power to the water, the spring constant K_1 and the first piston mass M_{R1} adjusted to form, together with the effective mass (M_L) of the water, a first oscillatory system having a first resonant frequency

$$\omega_{O1} = (K_1 / [M_{R1} + M_L])^{1/2}$$

which is substantially equal to a desired transducer operating frequency;

- a second piston having a reactive component (X_{R2}) resulting from the second piston mass (M_{R2}), operably connected to the second vibratile bar and arranged to be coupled to the water via said second compliant section, for supplying acoustic power to the water, the spring constant K_2 and the second piston mass M_{R2} adjusted to form, together with the effective mass (M_L) of the water, a second oscillatory system having a second resonant frequency

$$\omega_{O2} = (K_2 / [M_{R2} + M_L])^{1/2}$$

which is also substantially equal to said desired transducer operating frequency;

- and means for vibrating said first and second vibratile bars at substantially the resonant frequency for supplying acoustic power at said resonant frequency to the water, said vibrating means including a magnetic drive circuit having a movable armature affixed to said first vibratile bar and a drive coil affixed to said second vibratile bar and responsive to a supplied signal for causing said first and second vibratile bars to vibrate for generating respective spring forces F_1 and F_2 , force F_1 substantially cancelling the effects of both the reactive component (X_L) of the acoustic load and the reactive component (X_{R1}) resulting from the first piston mass on the power supplied to the water by said first piston, and force F_2 substantially cancelling corresponding effects of both the reactive component (X_L) of the acoustic load and the reactive component (X_{R2}) resulting from the second piston mass on the power supplied to the water by said second piston.

14. A transducer as described in claim 13 wherein said first and second piston members are substantially oppositely spaced within said housing for supplying acoustic power to the water in substantially opposite directions from one another, said first and second vibratile bars and piston members are adjusted to provide first and second oscillatory systems having substantially equal first and second resonant frequencies for supplying acoustic power to the water at substantially one resonant frequency, and wherein said vibrating means causes said first and second oscillatory systems to operate approximately 180° out of phase with each other.

References Cited

UNITED STATES PATENTS

1,968,305	9/1923	Kunze	340—12
1,590,369	6/1926	Hahnemann et al	340—8
1,640,538	8/1927	DuBois-Reymond	340—17 X
1,667,418	4/1928	Hahnemann et al.	340—8

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U.S. Cl. X.R.

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