July 23, 1946. L. G. BOSTWICK 2,404,360

TUNABLE UNDERWATER SIGNAL SOURCE

Filed June 5, 1942 2 Sheets-Sheet 1

FIG. 1

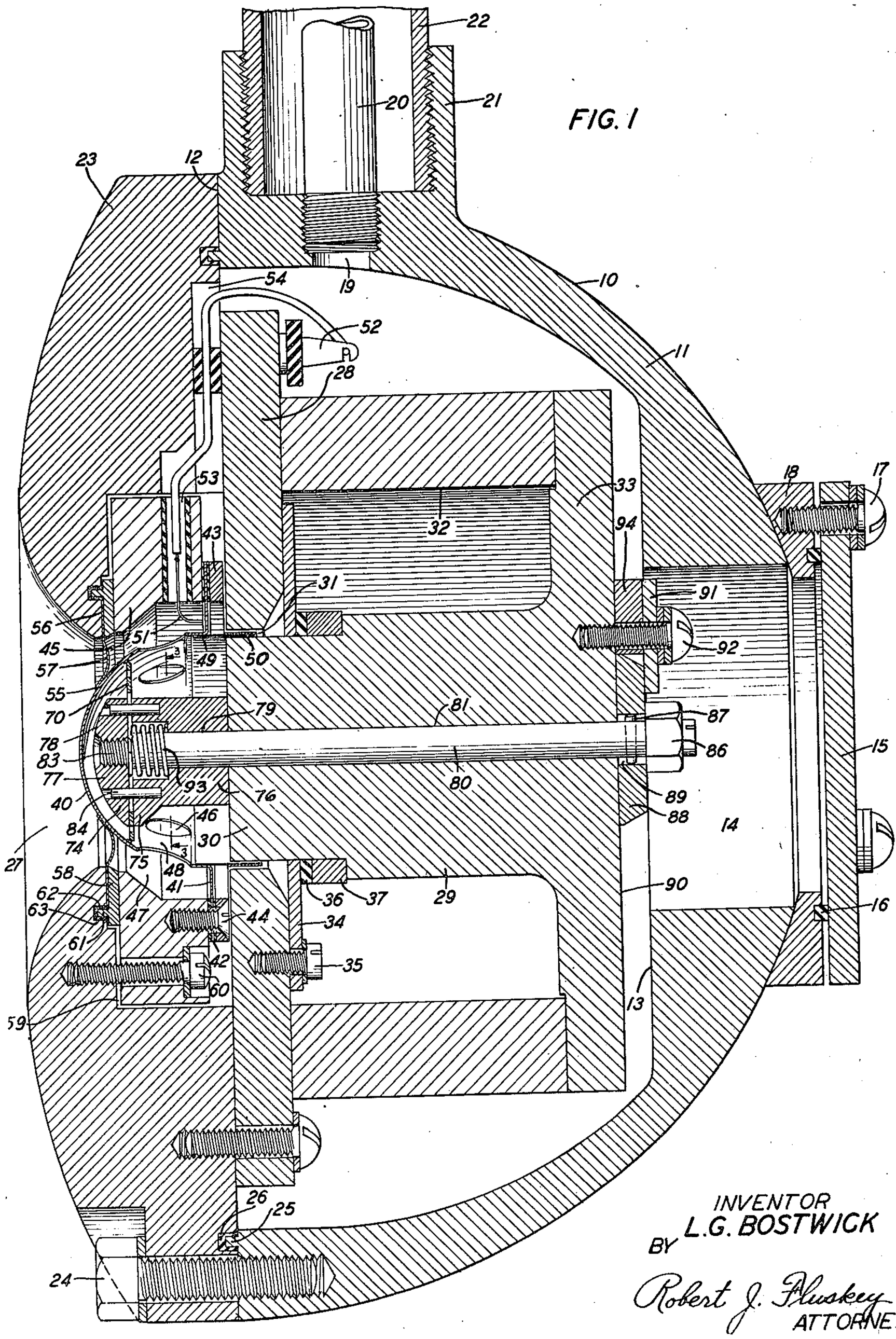

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FIG. 2

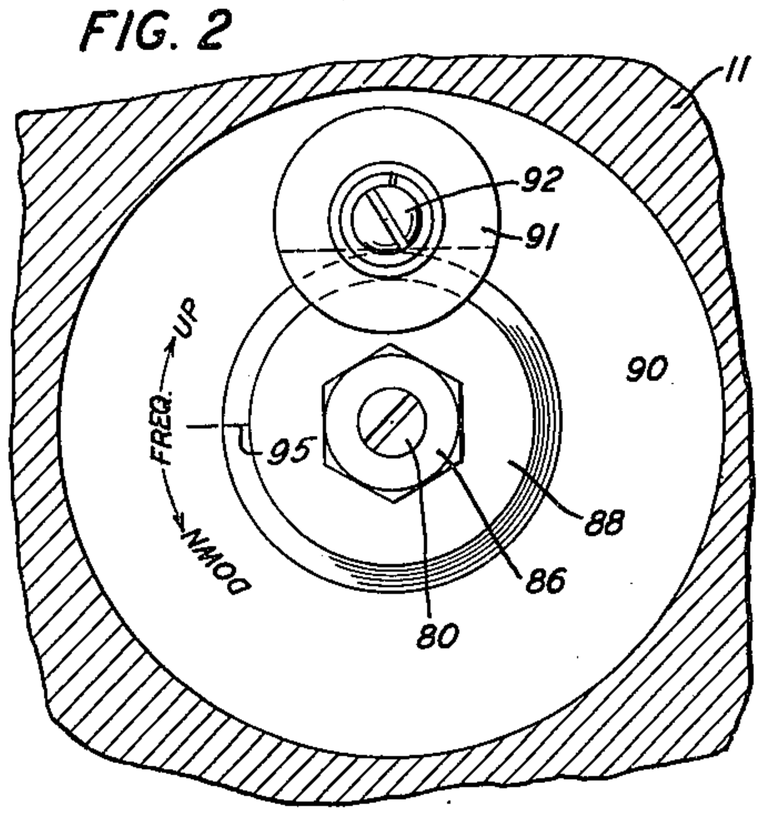


FIG. 4

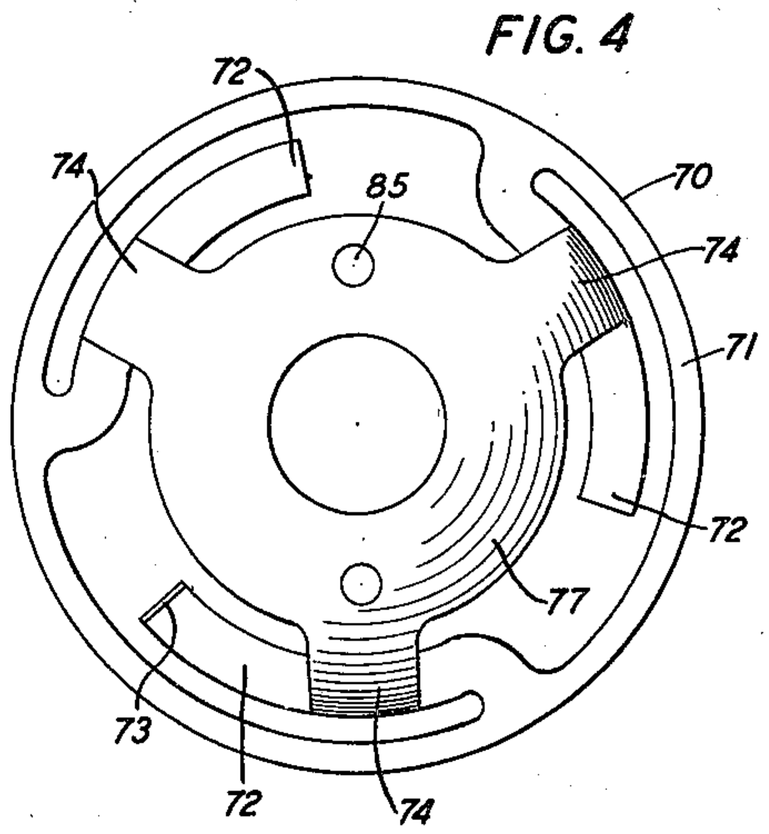


FIG. 3

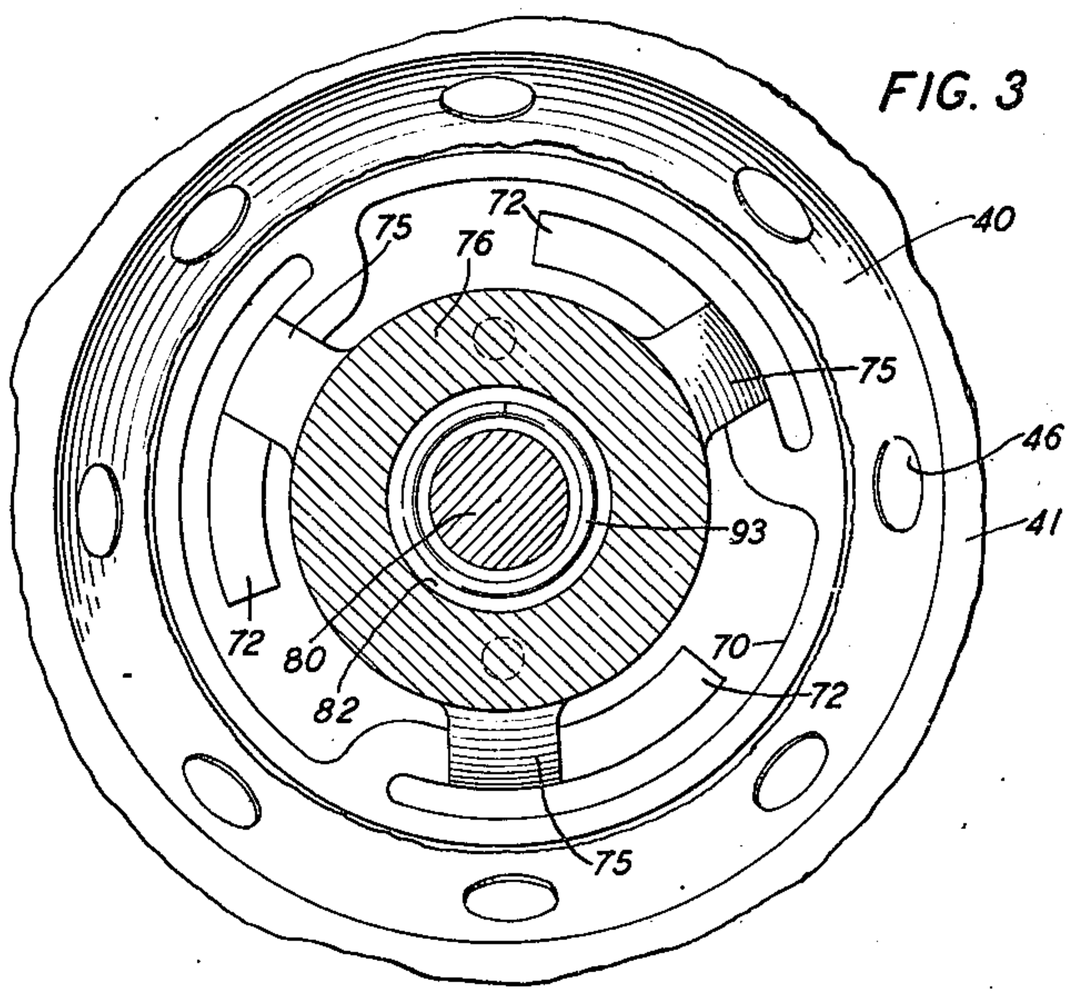
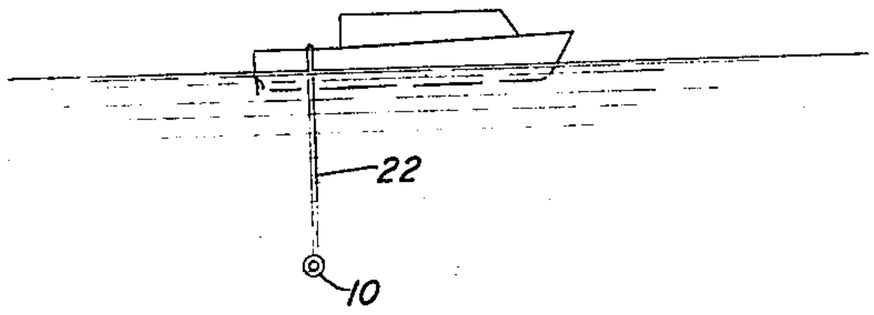


FIG. 5



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UNITED STATES PATENT OFFICE

2,404,360

TUNABLE UNDERWATER SIGNAL SOURCE

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Application June 5, 1942, Serial No. 445,973

7 Claims. (Cl. 177—386)

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This invention relates to electromechanical devices, and, more particularly, to a tunable signal source for underwater signaling and calibration purposes.

An object of the invention is to improve sources or devices adapted to radiate or project signal wave energy of known or preassigned magnitude into a liquid medium, and from which the signal wave pressure and velocity or amplitude at some specified position in the signal wave field may be evaluated for hydrophone calibrations and other underwater signal measurements.

A feature of the invention comprises providing means in an electromechanical transducer for use under water, to tune the vibrating system or diaphragm of the transducer to different frequencies.

A further feature comprises associating an adjustable stiffness means or member with the moving system of a transducer of the moving coil type to tune the system to particular different frequencies.

In accordance with the invention, an electromechanical transducer of the type incorporating a coil-driven diaphragm operating substantially like a piston, is utilized as a source of signal wave energy in a liquid medium, such as water. The diaphragm may be of thin sheet metallic material, having a semispherical or dome-shaped central portion. On the inner surface, that is, the surface not exposed to the water, the dome-shaped portion may have an adjustable stiffness member secured thereto, the stiffness member comprising a metallic spider. The latter may be provided with a plurality of elongated portions or fingers to be adjustably engaged by relatively rotatable members associated with and supported by the magnetic structure of the transducer.

A more complete understanding of the invention will be obtained from the detailed description that follows taken in conjunction with the appended drawings, wherein:

Fig. 1 is a cross-sectional view of a submarine signal source embodying the invention;

Fig. 2 shows a fragment of the device of Fig. 1, looking into the opening in the rear portion of the enclosure for the device;

Fig. 3 shows a fragment of the device of Fig. 1, the sectional view being taken along line 3—3 thereof;

Fig. 4 shows a front view of the adjustable stiffness member associated with the diaphragm, together with one of the relatively rotatable members adjustably engaging the stiffness member; and

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Fig. 5 illustrates how the device of Fig. 1 may be immersed in a liquid medium, being suspended therein, for example, from a boat.

With reference to the drawings, the submarine signal device 10 comprises a relatively rigid, nonresonant metallic enclosure including a bowl-shaped casing 11 having an upper, substantially planar rim portion 12 and a centrally apertured base portion 13. The base aperture 14 may be closed in water tight manner by a cover plate 15, gasket 16 of resilient material, for example, rubber, and fastening members 17 that engage with an annulus 18 that may be welded or otherwise secured to the casing around the aperture 14. The casing also may have a threaded opening 19 for engagement by a rigid tube or pipe 20 through which a gas, such as air under pressure, may be introduced into the interior of the enclosure, and an interiorly threaded flange 21 for engagement by a second rigid tube or pipe 22 concentric with and enclosing the tube 20. The tube 22 constitutes a rigid support or suspension for the device 10. The enclosure also includes a centrally apertured front plate 23 clamped at its peripheral portion to the rim portion of the casing by a plurality of spaced fastening members 24. The rim portion 12 is provided with an annular ridge 25 that projects into an annular recess in the plate, the gasket 26 of soft rubber constituting an air and water-tight seal. The central opening 27 of the plate 23 is closed by a portion of the vibrating or moving system of the transducer, of which more anon.

The electromechanical transducer comprises a magnetic structure including an outer plate pole 28, annular in shape and, for example, of magnetic iron; a center pole 29, for example, of a low carbon magnetic steel, having a cylindrical pole portion 30 projecting into the plate pole opening and defining a restricted annular air gap 31 with the plate pole; and an annular permanent magnet 32, for example, of an aluminum-nickel-cobalt steel, mounted between the annular flange portion 33 of the center pole and the undersurface of the plate pole. The inner end of the air gap is closed by a metallic plate member 34, which has a central opening making a sliding fit with the pole portion 30, and which is secured to the plate pole by a plurality of spaced fastening members 35. A gasket 36 of resilient material is clamped between the inner edge of the plate 34 and the spacer 37.

The vibrating or moving system of the transducer comprises a substantially semispherical or dome-shaped diaphragm 40, formed from sheet

metal, for example, .010 inch in thickness and composed of a beryllium-copper alloy, and having a peripheral planar flexible portion 41 and a rim portion 42, the latter being positioned between insulating washers, and secured by clamping member 43 and a plurality of fastening members 44 to the annular member 45. The diaphragm contains a plurality of equally spaced openings 46 interconnecting the spaces or chambers 47, 48. An annular coil form 49 is suitably fastened to the diaphragm at the junction of its planar and dome-shaped portions. In turn, a coil 50 of edge wound, insulated aluminum ribbon is supported on the form so as to be positioned in the air gap 31. The coil leads 51 (only one of which is shown) are brought out to terminals 52 on the plate pole through insulation-lined passages 53 in the member 45 and the recess 54 in the front plate 23. Connection with a suitable source of electric wave or signal current for the device may be made through suitable conductors (not shown) connected to the terminals 52 and brought into the casing through the pipe 20. Only the central area of the diaphragm is exposed to the water, the area exposed being determined by the annular flexible flange or closure member 55. The latter may be of sheet metal, for example, .002 inch in thickness and of a beryllium-copper alloy, comprise a planar outer portion 56 and an inner grooved or convexly curved portion 57. The portion 56 is secured, as by soldering, to a mounting ring 58; the latter is clamped by the member 45 against the front plate 23, the member 45 being secured to the plate 23, in the recess 59, by a plurality of spaced fastening members 60. The interfitting ridge 61, recess 62 and resilient gasket 63 constitute an air and water-tight junction. The gaseous pressure within the enclosure of the device 10 is maintained at a value less than the hydrostatic pressure acting on the exposed surface of the diaphragm and flange portion 57; hence, there will be a differential pressure tending to thrust the transducer moving system inwardly toward the magnetic structure. The gaseous contents of the device's enclosure have access to the inner surfaces of the flange member and the non-exposed surfaces of the diaphragm through the space 54, the passages 53, the passages 46 and the restricted passage between the plate pole and member 43.

An adjustable stiffness member 70 is secured, for example, by solder, to the inner surface of and concentric with the diaphragm. It may be of sheet metallic material, for example, of phosphor bronze and approximately .03 inch in thickness, and comprise an annular rim portion 71 and a plurality of equally spaced, inwardly and circumferentially extending spring arms or flexible projections 72. The free end of one of the arms 72 is bent to provide a stop 73. The arms 72 are adapted to be positioned between the aligned, equally spaced, radial projections or jaws 74, 75 of the separable and rotatable members 76, 77 of a non-magnetic material, such as brass. Member 76 is provided with a pair of parallel machined surfaces, one of which is in engagement with the pole portion 30 and the other of which is in juxtaposition to the planar machined surface of the member 77 whose other surface 78 is contoured similarly to that of the central area of the diaphragm from which it is spaced. The member 76 contains a passage 79 for an elongated member or rod 80 that projects through a passage 81 in the center pole. The passage 79 expands into the recess 82 which contains a helical

spring 93, preferably normally under compression. The rod 80 is provided with a threaded end portion 83 for engagement with a central tapped opening in member 77. Diametrally disposed pins 84 projecting from the member 76 make sliding fit with the passages 85 in member 77. The end of the rod 80 remote from the diaphragm is slotted to receive a suitable tool, for example, a screw-driver. Near such slotted end, the rod is threaded for engagement by a clamping member or screw nut 86, and contains an opening with which a pin 87 makes a tight fit. A circular plate 88, with beveled outer edge and a central passage 89 for the rod and recesses for the ends of the pin 87, is positioned between the bottom surface 90 of the magnet structure and the member 86. Normally the plate 88 is held in fixed position by a clamping plate 91 and clamping screw 92, the latter projecting through the plate 91 and a spacer member 94 into the center pole.

Adjustment of the jaws or projections along the length of the spring arms 72 is accomplished in the following manner. The clamping member 86 is unscrewed, whereby the compressed spring 93 forces the member 77 outwardly toward the diaphragm a distance determined by the extent to which the nut 86 is loosened which should be sufficient to relieve the arms 72 of the clamping action of the jaws 74, 75. The screw 92 is loosened to relieve the clamping action of the plate 91 on the plate 88. A suitable tool is inserted in the slotted end of rod 80 and the rod is turned clockwise or counter-clockwise to the desired extent. Since the rod is fastened to the member 77 and the latter to the member 76, the members 76, 77 turn through the same angle as the rod 80 and their aligned jaws 74, 75 are nearer or more remote from, say, the free end of the arms 72 than before the adjustment. The stop 73 limits adjustment beyond the free end of the arms. The plate 88 is caused to turn simultaneously through the action of the ends of the pin 87 in their recesses. The desired adjustment having been made, the screw 92 is tightened, whereby plate 91 clamps the plate 88 in its adjusted position. The nut 86 is then tightened to draw the members 76, 77 together against the resistance of the spring 82, and to cause the jaws 74, 75 again to clamp the spring arms 72 between them. An adjustment so made alters the length of the spring arms 72 associated with the diaphragm 40 and, thereby, the effective stiffness of the moving system of the transducer, and changes the resonant frequency thereof. If desired, the plate 88 may be provided with a mark or line 95 on its beveled edge as a point of reference for use with a frequency scale that could be placed on the surface 90 adjacent the plate 88. This scale might be in terms of specific frequency values, or indicate the direction of adjustment to give a higher or a lower frequency than that for which the device might initially be adjusted. Obviously, the cover plate 15 would be removed before any adjustment could be made, and the adjustments would be made with the device out of the liquid medium.

The device described hereinabove may be used to radiate signal wave energy over a desired frequency range, for example, up to about 1500 cycles per second, into a liquid medium, such as water, the energy so radiated to be used for calibration or other submarine signal purposes, the output of the device being determinable from relatively direct and simple electrical measurements, as a result of the inclusion in the device of the

described arrangement for tuning the device's moving system or diaphragm to different frequencies.

The acoustic power P_A radiated by the described source is equal to the square of the current i_c through the moving coil multiplied by the electrical motional resistance r_e times a factor to allow for energy dissipated in mechanical losses in the vibrating system. This factor is the ratio of the radiation resistance R_R of the diaphragm to the total mechanical resistance R of the vibrating system which, in any practical case, consists of the radiation resistance plus a mechanical dissipative resistance R_L. Thus

$$P_A = i_c^2 r_e \left(\frac{R_R}{R_R + R_L}\right) \tag{1}$$

r_e can be readily measured on an impedance bridge with the source normally placed under water, but to evaluate

$$\frac{R_R}{R_R + R_L}$$

requires a procedure as described below.

The electrical motional impedance $r_e + jx_e$ is related to the mechanical impedance $R + jX$ of the vibratory system of a moving coil type source in the following manner:

$$r_e + jx_e = \frac{(Bl)^2(R + jX)}{(R^2 + X^2) \times 10^9} \tag{2}$$

Where:

B=magnetic flux density of gap in which the coil moves

l=total length of conductor in moving coil (electrical values are expressed in practical units and mechanical values in c. g. s. magnetic units)

If the stiffness of the vibrating system can be adjusted to tune the system at any frequency, then at this frequency the reactive components drop out and Equation 2 simplifies to

$$r_e = \frac{(Bl)^2 \times 10^{-9}}{R} \tag{3}$$

and since $R = R_R + R_L$

$$R_R + R_L = \frac{(Bl)^2 \times 10^{-9}}{r_e} \tag{4}$$

Thus, by measuring r_e with the source normally in water, and knowing the gap flux density and length of conductor in the moving coil, $R_R + R_L$ can be evaluated. To determine the other unknown, R_R, in Equation 1, the source is removed from the water, and the vibrating system tuned to the same frequency in air. Since the radiation resistance of a diaphragm in water is several hundred times that of the same diaphragm in air, Equation 4 for this condition becomes:

$$R_L = \frac{(Bl)^2 \times 10^{-9}}{r_{e(air)}} \text{ (approx.)} \tag{5}$$

Where $r_{e(air)}$=electrical motional resistance with source in air.

Subtracting (5) from (4) gives

$$R_R = (Bl)^2 \times 10^{-9} \left[\frac{1}{r_e} - \frac{1}{r_{e(air)}}\right] \tag{6}$$

Dividing (6) by (4) gives:

$$\frac{R_R}{R_R + R_L} = 1 - \frac{r_e}{r_{e(air)}} \tag{7}$$

Substituting (7) in (1) gives:

$$P_A = i_c^2 r_e - \frac{i_c^2 r_e^2}{r_{e(air)}} \tag{8}$$

From this equation (8), it is apparent that the acoustic power output from the source in water may be evaluated by tuning the vibrating system and making two measurements of the electrical motional resistance at a resonance frequency in water and in air. From the value so obtained, the sound pressure and the velocity at any specified point in the water can be evaluated in accordance with well-established sound field distribution theory. Tuning the vibrating system in the above-described manner results in large electrical motional resistance values which are easily separated from the damped resistance values of the moving coil.

Although the invention has been disclosed with reference to a specific embodiment, it is not limited thereto, but is of a scope evidenced by the appended claims.

What is claimed is:

1. An electromechanical transducer comprising a moving system including a diaphragm and a coil attached to the periphery of the diaphragm for movement therewith, means attached to said diaphragm inside of the area limited by the peripheral attachment of said coil for tuning the moving system to different resonant frequencies, said means comprising a sheet metal member including a plurality of spring metal arms supported at one end only, and means to vary the extent to which each of said arms is effectively coupled to the diaphragm.

2. An electromechanical transducer comprising a diaphragm having a central stiffened portion, a coil movable with said diaphragm and attached to it at the periphery of said stiffened portion, a sheet metal member attached to the stiffened portion of said diaphragm and including a plurality of projections extending radially inwardly and concentric with the diaphragm, and means adjustable along said projections for varying the extent to which each projection is effectively coupled to said diaphragm.

3. An electromechanical transducer comprising a diaphragm having a central stiffened portion, a coil movable with said diaphragm and attached to it at the periphery of said stiffened portion, a magnetic structure containing an air-gap in which said coil is positioned, said air-gap being formed by spaced outer and inner pole members, a sheet metal member attached to the stiffened portion of the diaphragm and including a plurality of projections extending radially inwardly and concentric with the diaphragm, and means supported on the inner pole member and adjustable along said projections for varying the extent to which each projection is effectively coupled to said diaphragm.

4. An electromechanical transducer comprising a diaphragm having a dome-shaped central portion, a coil movable with the diaphragm and attached to it at the periphery of said central portion, a magnetic structure containing an air-gap for said coil, said air-gap being formed by spaced inner and outer pole members, a stiffness member within the central portion of the diaphragm and comprising a rim portion secured to the diaphragm and a plurality of equally spaced spring arms extending inwardly from the rim portion, a pair of separable and rotatable members supported on the inner pole member and including a plurality of equally spaced aligned projections adapted to clamp said spring arms therebetween, and means extending through the inner pole member and operable from outside the magnetic structure for adjusting the clamping projections

to different positions along the length of said spring arms.

5. A submarine signaling device comprising a diaphragm of sheet material outwardly bowed to present a convex surface to the water, and means on the concave side of said diaphragm for varying the resonant frequency thereof, said means comprising a spider member secured to the concave side of the diaphragm and members relatively movable with respect to the spider member for adjustable engagement therewith.

6. An electromechanical transducer comprising a diaphragm having a central stiffened portion, a coil movable with said diaphragm and attached to it at the periphery of said stiffened portion, a magnetic structure containing an air-gap in which said coil is positioned, said air-gap being formed by spaced outer and inner pole members, a sheet metal member attached to the stiffened portion of the diaphragm and including a plurality of projections extending radially inwardly and concentric with the diaphragm, and means comprising a pair of separable and rotatable members supported on the inner pole member, adjustable along said projections and adapted to clamp said projections therebetween, for varying the extent to which each projection is effectively coupled to the diaphragm.

7. An electromechanical transducer comprising

a diaphragm having a dome-shaped central portion, a coil movable with the diaphragm and attached to it at the periphery of said central portion, a magnetic structure containing an air-gap for said coil, said air-gap being formed by spaced inner and outer pole members, a stiffness member within the central portion of the diaphragm and comprising a rim portion secured to the diaphragm and a plurality of equally spaced spring arms extending inwardly from the rim portion, a pair of separable and rotatable members supported on the inner pole member and including a plurality of equally spaced aligned projections adapted to clamp said spring arms therebetween, one of said rotatable members being located between the stiffness member and the diaphragm and the other rotatable member being located between the stiffness member and the inner pole member, and means extending through the inner pole member and into said rotatable members and operable from outside the magnetic structure for adjusting the clamping projections to different positions along the length of said spring arms, said means including a rod connected at its inner end to said one rotatable member and a compressed spring member surrounding a portion of the rod between said rotatable members.

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