

June 27, 1967

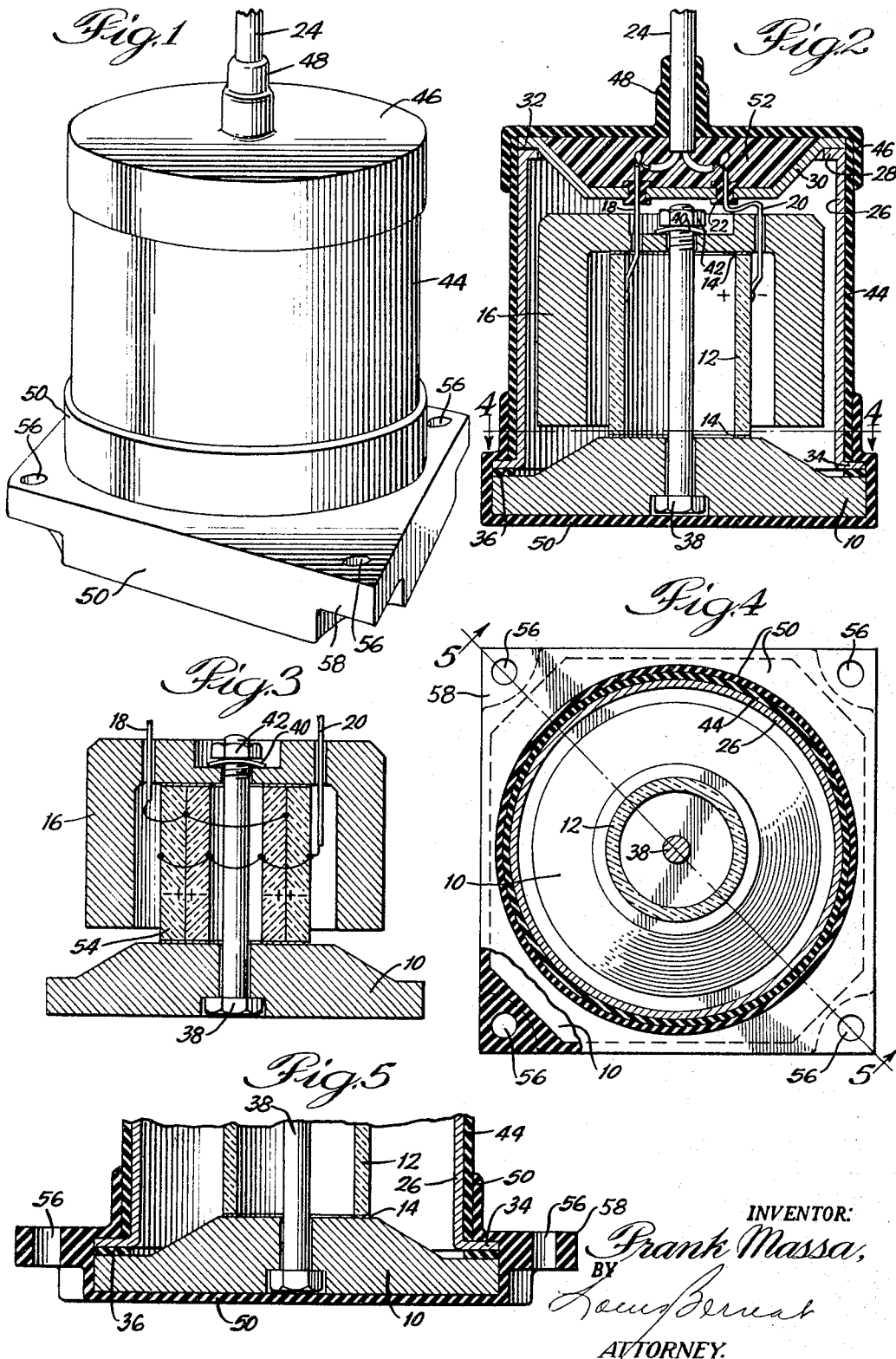
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ELECTROACOUSTIC TRANSDUCER

Filed March 28, 1966

2 Sheets-Sheet 1



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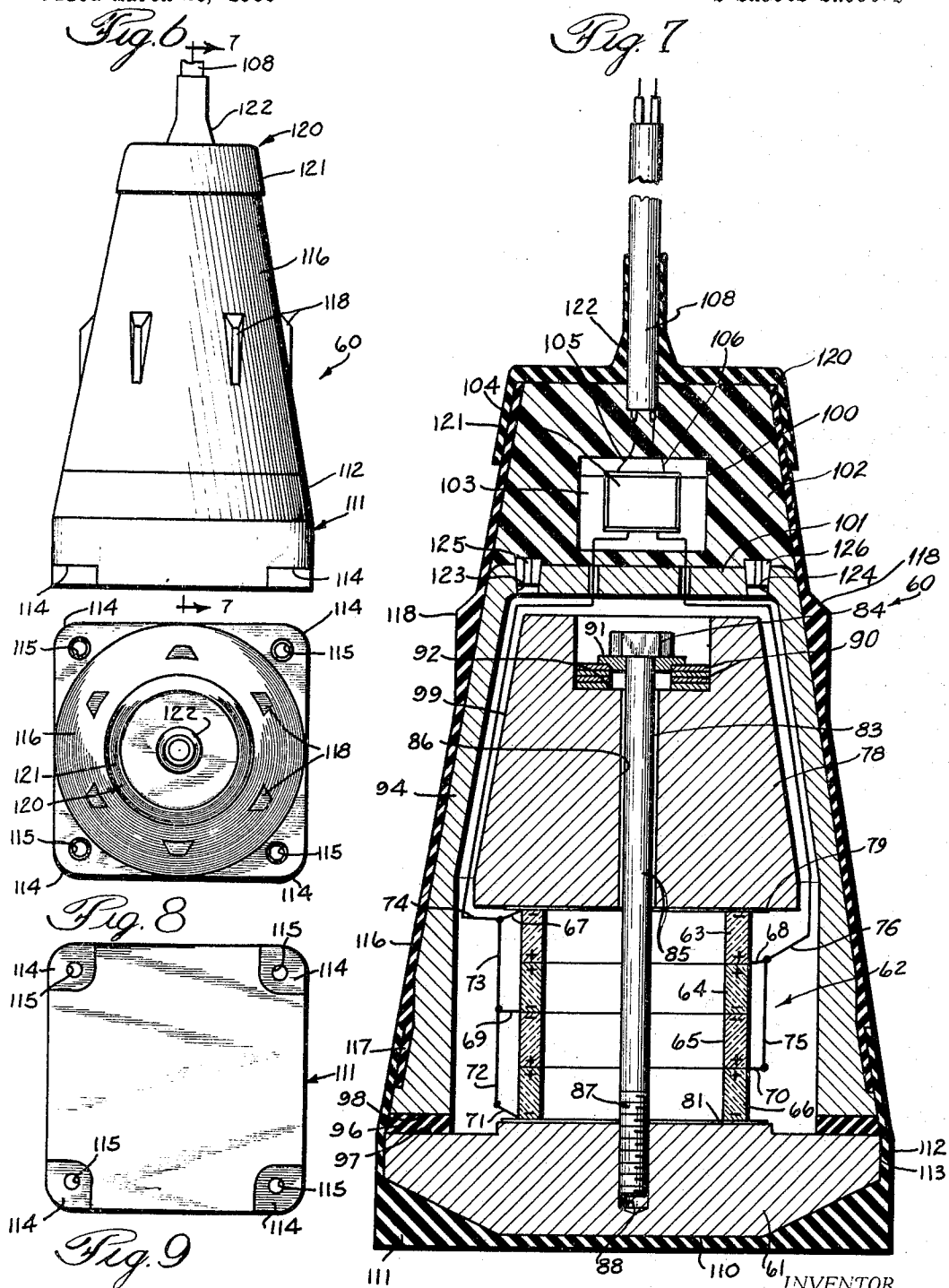
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2 Sheets-Sheet 2



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ELECTROACOUSTIC TRANSDUCER

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24 Claims. (Cl. 340—10)

This application is a continuation-in-part of my copending application entitled "Electroacoustic Transducer," filed Feb. 15, 1962, Ser. No. 173,510 now abandoned.

This invention relates generally to improvements in transducers for transforming electrical energy to sound energy and more particularly to new and improved electroacoustical transducers of the type adapted for operating underwater within the audible frequency range.

Those skilled in the art appreciate that in the use of underwater electroacoustical transducers operating within the audio frequency range, it is necessary to drive relatively large radiating piston areas at appreciably large amplitudes of vibration if efficient high power sound energy is to be generated. For the lower audio frequencies in the range of a few hundred to a few thousand cycles per second, it is advantageous to build up the large radiating piston surface by a mosaic of several small modules arranged in a suitable array.

Accordingly, it is a primary object of this invention to provide unique transducer module constructions adapted for use in multiple arrays.

It is a further object of this invention to improve the efficiency of an electroacoustic transducer adapted for radiating underwater sound within the audible frequency range.

It is another object of this invention to reduce the overall size of an electroacoustic transducer module by a unique construction which serves to distribute the internal weight of the operating elements in a more advantageous manner.

It is a still further object of this invention to reduce the cost of a manufacture of an efficient underwater electroacoustic transducer.

It is still another object of this invention to improve the corrosion resistance of an electroacoustic transducer as well as to reduce the effects of erosion due to cavitation which generally may occur at the vibrating surface of a high power transducer operating in shallow water.

It is still another object of this invention to provide a new and improved flexible shock mounts for the transducer assemblies which are formed as integral parts of a transducer diaphragm protective structure.

A still further object of the invention is to provide transducer assemblies having improved shapes to facilitate mounting in a multiple array.

Yet another object of the invention is to provide transducer assemblies using piezoelectric elements requiring high voltages, wherein voltage breakdowns are obviated.

Still another object of the invention is to provide transducer assemblies incorporating impedance transformation means as a part thereof without substantially reversing overall size.

A still further object of the invention is to provide transducer assemblies in which the effects of contraction and expansion of parts from temperature changes are obviated.

The above and other objects of the invention will become evident in the following detailed description. The novel features which are characteristic of the invention are set forth with particularity in the appended claims.

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The invention itself, however, both as to its organization and method of operation, as well as advantages thereof, will best be understood from the following description of several embodiments thereof when read in connection with the accompanying drawings, in which:

FIGURE 1 is a perspective view of one illustrative embodiment of the invention;

FIGURE 2 is a vertical sectional view taken through the illustrative transducer embodiment of FIGURE 1;

FIGURE 3 is a partial vertical sectional view of a modification of the invention wherein the use of piezoelectric crystal plates has been substituted for the polarized ceramic cylinder used in FIGURES 1 and 2 embodiment;

FIGURE 4 is a sectional view taken substantially as shown along the line 4—4 of FIGURE 2;

FIGURE 5 is a partial sectional view taken substantially as shown along the line 5—5 of FIGURE 4;

FIGURE 6 is a side elevational view of another modified form of transducer assembly according to the principles of the invention;

FIGURE 7 is a vertical sectional view on an enlarged scale taken substantially along line 7—7 of FIGURE 6;

FIGURE 8 is a top plan view of the assembly of FIGURE 6; and

FIGURE 9 is a bottom plan view of the assembly of FIGURE 6.

Turning now to the drawings, and more specifically to FIGURES 1 and 2 thereof, there is shown a preferred illustrative transducer construction embodying some of the basic principles of the invention. A rigid, vibratile piston plate 10 is preferably made of a material having a high stiffness-to-mass ratio. For example, magnesium and aluminum alloy are some of the materials that may advantageously be used. In accordance with a feature of this invention, it is even more advantageous to employ a type of aluminum casting which has a sponge-like structure and which has a density of only a fraction of solid aluminum and yet retains a very high stiffness for the piston plate 10 which is necessary in order that it will vibrate without break-up of its surface at the frequency of operation.

A transducer element 12, which may be a ceramic cylinder of polarized barium titanate or lead zirconate titanate or any other suitable material which is well known in the art for converting electrical energy to vibrational energy, is bonded at one of its ends to the plate 10 by means of a suitable cement 14. The opposite end of the transducer element 12 is similarly bonded to the flat surface of a weight member 16. Advantageously, the transducer element 12 has (+) and (−) electrodes, as shown, to which insulated electrical conductors 18 and 20 are soldered. The conductors 18 and 20 are positioned through insulating bushings 22 in the housing cap structure 30 and the ends of the conductors are soldered to the leads from a cable 24, as shown.

The recessed portion of the housing cap structure 30, within which the electrical connections are made, is filled with a hard, insulating compound 52, such as epoxy, which serves to securely anchor the cable 24.

A tubular housing structure 26 is formed with an inwardly turned flange portion 28, which serves as a seat for the housing cap structure 30, and is preferably cemented in place thereat with a waterproof, strong cement 32, such as epoxy. At the opposite end of the housing structure 26, there is an outwardly turned flange portion 34, whose outer contour is preferably the same as the outer contour of the plate 10. Advantageously, a resilient gasket 36 is cemented between the flange portion 34 and the mating surface of the

piston plate 10. In accordance with this invention, the thickness and stiffness of the gasket 36 material is selected such that the resonant frequency of the mass of the housing structure 26 and the compliance of the gasket 36 occurs in a range well below the frequency of operation of the transducer assembly. It will be appreciated by those skilled in the art that this selection is made so that at the frequency of operation of the transducer assembly, the vibrating plate 10 will be uncoupled from the housing structure 26 and thus, the housing structure 26 effectively will remain stationary which, in turn, prevents any undesirable radiation of sound from the rear of the transducer assembly. This advantageous construction results in improved efficiency because only useful sound energy is radiated from the front face of the vibrating piston plate 10.

The plane surface of the weight member 16 to which the cylindrical transducer element 12 is attached preferably may be recessed as shown. This allows most of the weight member 16 to surround the cylindrical transducer element 12 and thereby serves to keep the overall length of the assembly at a minimum and thus reduce the size of the transducer. A further advantage gained from this unique construction resides in the fact that the assembly is much more rugged to withstand shock and vibration than would be the case if the weight member 16 were extended beyond the ceramic cylinder transducer element 12 and thereby cause a greater stress at the cement joints 14 during transverse applications of mechanical shock.

In the illustrative embodiment of FIGURE 2, the weight member 16 is shown as a hollow cup-shaped piece which surrounds the ceramic transducer element 12. As an alternative embodiment, the ceramic cylinder transducer element 12 may be formed with a large diameter and the shape of the weight member 16 correspondingly modified so that the greater part of the latter is in the form of a solid cylinder which fits within the hollow cylinder transducer element 12. In such a modification, an enlarged peripheral flange end is machined on one end of the solid cylindrical weight member to permit the attachment of the weight member to the end of the ceramic transducer element. It can be seen that in this case, most of the weight would be placed inside the ceramic cylinder transducer element instead of being placed outside the periphery of the cylinder, as shown in the embodiment of FIGURE 2.

In accordance with another feature of this invention, the reliability of the transducer under high power operation may further be increased by the use of a bolt 38 to clamp the piston plate 10 and weight member 16 to the transducer element 12. Advantageously, a spring washer 40 is selected so that its compression by the nut 42 applies a sufficient force to the assembly to prestress the cylinder transducer element 12 to a value greater than the stresses that will be developed at the joints 14 during vibration of the cylinder transducer element at the maximum power rating of the transducer assembly.

In order to prevent corrosion of the transducer assembly in salt water environments, the structure described hereinabove may be completely covered with a waterproof material, such as the rubber seal shown in FIGURES 1 and 2. This outer seal may comprise a rubber cylinder 44 bonded to the outer periphery of the housing structure 26. A molded rubber cap 46 is cemented over the end of the rubber cylinder 44, as illustrated. The cap 46 also may be provided with a molded tapered portion 48 which seals to the cable 24 and completes the waterproofing of the back end of the transducer assembly. At the front end of the assembly, a cap 50 of rubber or other waterproof material, is bonded to the front radiating face of the plate 10. Preferably, the same rubber material may be used to cover the outer sides of plate 10, continuing over the flange portion 34 and extending over part of the rubber cylindrical cover 44 thereby totally enclosing and sealing every exposed portion of metal in the assembly. As a result of

this unique and highly advantageous arrangement, it is possible to employ low-cost, ordinary steel for the housing structure, which reduces the cost of manufacture.

In order that the transducer performance be enhanced, it is desirable that the weight member 16 be made greater than the weight of the sound generating piston plate 10. As a result of this construction, the vibration of the cylinder transducer element 12 will move the lighter piston plate 10 to a larger degree than would be the case if the weight member 16 were small compared to the weight of the piston plate 10. The front rubber cap 50 may be separately molded and then cemented in place, as shown in FIGURE 2, or it may be molded in place. It has been found advantageous to mold the rubber cap 50 in place and, at the same time, to incorporate molded shock mounts in the corners of the front face for isolating the transducer assembly from its mounting, as will be more fully described hereinbelow with respect to the embodiments of FIGURES 1, 4 and 5.

FIGURE 3 illustrates an alternative embodiment which utilizes piezoelectric crystal plates 54 as the transducer material in place of the ceramic cylinder 12 shown in FIGURE 2. The crystal plates 54 may be 45° Z-cut ammonium dihydrogen phosphate or any other piezoelectric crystal well known in the art and capable of converting electrical signals to mechanical vibrations. In accordance with a feature of this invention, the crystal plates have (+) and (−) electrode bearing faces which are connected with like polarities together, as shown schematically in FIGURE 3, and the like polarities are connected to the electrical conductors 18 and 20 which serve the same function as the leads shown in FIGURE 2 and identified by the same reference numerals.

FIGURE 4 is a sectional view taken along the line 4—4 of FIGURE 2, and illustrates one preferred embodiment of shock mounts 58 which are formed as part of the rubber molding associated with the transducer face. FIGURE 5 is a partial sectional view taken along the line 5—5 of FIGURE 4. It can be seen that the dotted line in FIGURE 4 defines the contour of the vibratile piston plate 10 in which the corners are chamfered to allow the space for molding a rubber shock mount 58 in each corner of the transducer assembly. The view in FIGURE 5 shows the general shape of the molded rubber cap 50, which provides a complete watertight covering for the radiating face and the side edges of the piston plate 10. This arrangement results in the provision of four rubber mounts 58 having the clearance holes 56. Those skilled in the art will appreciate that this permits the transducer assembly to be resiliently mounted at its four corners when it is installed into its mounting support for operation.

Referring now to FIGURES 6–9, reference numeral 60 generally designates a transducer assembly having a modified construction. The assembly 60 comprises a rigid vibratile piston plate 61 which is similar to the piston plate 10 and is preferably made of a material having a high stiffness-to-mass ratio. For example, magnesium and aluminum alloys are some of the materials that may advantageously be used. In accordance with a feature of this invention, it is even more advantageous to employ a type of aluminum casting which has a sponge-like structure and which has a density of only a fraction of solid aluminum and it retains a very high stiffness for the piston plate 61 which is necessary in order that it will vibrate without break-up of its surface at the frequency of operation.

A transducer unit generally designated by reference numeral 62 is provided which comprises four cylindrical elements 63–66 in end-to-end relation and having electrode means on the end faces thereof. Preferably, the elements 63–66 may be ceramic cylinders of polarized barium titanate or lead zirconate or any other suitable material which is well known in the art for converting electrical energy to vibrational energy. Advantageously,

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the elements 63-66 are polarized as indicated by the (+) and (-) indications on the drawing, with faces of like polarity in abutting relation. To supply electrical energy to the transducer elements, the electrode on one face of the element 63 is extended to provide a lead 67; one of the electrodes on the abutting faces of the elements 63 and 64 is extended to provide a lead 68; one of the electrodes on the abutting faces of elements 64 and 65 is extended to provide a lead 69; one of the electrodes on the abutting faces of elements 65 and 66 is extended to provide a lead 70; and the electrode on the other face of element 66 is extended to provide a lead 71. Lead 71 is connected through a conductor 72 to the lead 69 which is connected through a conductor 73 to the lead 67, lead 67 being connected to a conductor 74. Lead 70 is connected through a conductor 75 to the lead 68 which is connected to a lead 76. By application of a high voltage to the conductors 74 and 76, the transducer unit 62 may be operated at a high power output level.

A weight member 78 is secured against the end face of the element 63 which carries the electrode 67, preferably with a thin insulating washer 79 being provided. At the opposite end of the transducer unit 62, the end face of the element 66 is disposed against a central portion of the vibratile element 61, preferably with a thin insulating washer 81 being provided.

To hold the weight member 78, transducer unit 62 and vibratile plate 61 in assembly, securing means are provided which comprise a bolt 83 having a head portion 84 and a shank portion 85 extending through an opening 86 in the weight member 78 with an end portion 87 of the shank portion 85 being threaded into an opening 88 in the vibratile plate 61. In accordance with a specific feature of the invention, a plurality of "Belleville" springs 90 are disposed between a collar 91 engaged by the head 84 and a weight surface of a recess 92 in the base member 78. The springs 90 are cup-shaped washers which behave as springs of relatively high stiffness and when the bolt 83 is tightened, the basic vibrating elements of the assembly are held together with substantially uniform pressures between the end faces of the transducer unit 62 and the weight member 78 and vibratile plate 61. Without the compression springs, the tension in the bolt 83 would be a function of temperature because of differences in thermal expansion of the various materials which make up the complete vibrating structure. With the spring elements 90 compressed by a fractional part of an inch, variations in dimensions of the assembled parts of a few thousands of an inch will be negligible in determining the applied compressive force to the assembled elements.

A hollow rigid housing structure 94 is provided in surrounding relation to the transducer unit 62 and the weight member 78 with resilient means in the form of an annular gasket 96 being disposed between an open end of the housing structure 94 and a peripheral portion of the vibratile plate 61. As shown, the gasket 96 is disposed between facing surfaces 97 and 98 of the plate 61 and the housing 94, respectively, the surfaces 97 and 98 being planar surfaces transverse to the axis of vibratile movement of the plate 61. Preferably, the gasket 96 is cemented to the surfaces 97 and 98 with strong waterproof cement such as an epoxy. It will be noted that the gasket 96 compresses and expands with vibratile movement of the plate 61 and when the assembly is placed under water, the water pressure compresses the gasket 96 to a certain degree, to insure an effective seal.

In accordance with the invention, the thickness and stiffness of the gasket 96 is selected such that the resonant frequency, determined by the mass of the housing structure 94 and the compliance of the gasket 96 occurs in a range well below the frequency of operation of the transducer assembly. With this arrangement, the vibrating plate 61 will be uncoupled from the housing structure 94 and thus the housing structure 94 can effectively remain stationary to prevent any undesirable radi-

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ation of sound from the rear of the transducer assembly. This advantageous construction results in improved efficiency because only useful sound energy is radiated from the front face of the vibrating piston plate 61.

According to a specific feature of the invention, the hollow rigid housing structure 94 is tapered, the diameter or transverse dimension thereof at the open end which is adjacent the plate 61 being substantially greater than the diameter or transverse dimension at the opposite end thereof. This arrangement permits the assembly of a number of transducer assemblies within a minimum circle diameter so that a maximum power density can be achieved with an overall structure which is quite compact.

Preferably, the weight member 78 has an outer surface 99 which has a taper corresponding to that of the wall of the housing structure 94, so as to permit the weight member 78 to have a maximum size relative to the overall size of the assembly.

A further feature of the invention is in the provision of a coupling transformer 100 which is supported on the outside of an end wall 101 of the housing structure 94 preferably by means of a molded potting compound 102 which encloses the transformer 100. The transformer 100 is of conventional construction, including a three-legged core structure 103 formed of stacked laminations with primary and secondary windings 104 on a center leg of the core 103, the secondary winding being connected to the conductors 74 and 76 and the primary winding being connected through conductors 105 and 106 to conductors of a waterproof cable 108, the end of the cable 108 being enclosed in the potting compound 102.

To prevent corrosion of the assembly in salt water environments, a cover of waterproof material is bonded to a radiating face 110 of the vibratile plate 61 and completely encloses the housing structure 94 to provide a water-tight seal around the transducer assembly. In particular, a molded rubber cap 111 is provided having an internal contour of the same shape as the contour of the radiating face 110, the internal surface of the cap 111 being bonded to the face 110 by means of a suitable cement, such as an epoxy. Preferably the cap 111 may be molded directly to the surface of the piston 110 by curing the rubber compound in a mold using the piston 110 as an insert. The cap 111 has an integral annular flange portion 112 which embraces a peripheral edge 113 of the plate 61 and which embraces an end portion of the housing structure 94.

In accordance with a specific feature of the invention, the cap 111 is generally rectangular, preferably substantially square as shown in FIGURES 8 and 9, and the four corner portions thereof are so formed as to be thinner than the plate 61 and as to define integral mounting tab portions 114, the portions 114 being preferably provided with openings 115 therethrough, for mounting on a rigid support structure.

The rubber cover further comprises a tapered or frusto-conical rubber sleeve 116 which surrounds the housing structure 94 and preferably also surrounds the molded potting compound 102 which surrounds the transformer 110. An end portion 117 is preferably disposed within the flange portion 112 of the cap 111, and the outer surface of the housing structure 94 is recessed for this purpose.

In accordance with a further specific feature, the rubber sleeve member 116 is provided with a plurality of peripherally spaced tapered integral wedge portions which serve as additional shock mounts when the transducer is assembled into a frame-like mounting structure. Thus, the mounting structure may include a portion having an internal cylindrical surface for engagement by the tapered wedge portions 118.

The rubber cover for the assembly further includes a cap 120 having an annular flange portion 121 surrounding an end portion of the sleeve 116. The cap 120 addi-

tionally has a strain relief extension 122 which embraces the cable 108.

Still another feature of the invention relates to the prevention of voltage breakdowns within the transducer assembly while permitting application of high voltages to the transducer elements 63-66, to obtain high power operation thereof. In accordance with this feature, openings 123 and 124 are provided in the end wall 101 of the housing structure 94, to permit the space within the housing structure 94 and around the transducer unit 62 to be filled with an inert dry gas, after the plate 61 is secured to the open end of the housing structure 94 through the washer 96. After filling the space with an inert dry gas, rubber plugs 125 and 126 are inserted in the openings 123 and 124, after which the transformer 110 and potting compounds 102 are installed. Thereafter, the cap 111, sleeve 116 and cap 120 are installed to provide the waterproof cover.

It will be understood that modifications and variations may be effected without departing from the spirit and scope of the novel concepts of this invention.

I claim as my invention:

1. In an electroacoustic transducer assembly, transducer means having opposite end surfaces, a weight member secured against one of said end surfaces of said transducer means, a vibratile plate having a radiating face on one side thereof and having a central portion on the opposite side thereof secured against the other of said end surfaces of said transducer means, a hollow rigid housing structure surrounding said transducer means and said weight member and having an open end adjacent a peripheral portion of said vibratile plate, and resilient means interposed between said open end of said housing structure and said peripheral portion of said vibratile plate arranged to flexibly seal said housing structure to said vibratile plate.

2. In an electroacoustic transducer assembly as defined in claim 1, said resilient means being arranged to compress and expand with vibratile movement of said plate relative to said housing structure.

3. In an electroacoustic transducer assembly as defined in claim 2, said housing structure and said vibratile plate having facing surfaces in parallel planes generally transverse to the direction of vibratile movement of said plate relative to said housing structure, and said resilient means being of washer-shaped configuration interposed between said facing surfaces.

4. In an electroacoustic transducer assembly as defined in claim 1, the compliance of said resilient means and the mass of said rigid housing being such as to resonate at a frequency lower than the frequency of operation of said transducer assembly.

5. In an electroacoustic transducer assembly as defined in claim 1, a cover of waterproof material bonded to said radiating face of said vibratile plate and completely enclosing said housing structure to provide a water-tight seal around said transducer assembly.

6. In an electroacoustic transducer assembly as defined in claim 1, a molded cup-shaped member of resilient waterproof material receiving said vibratile plate there-within and extending around said resilient means and around said open end of said housing structure.

7. In an electroacoustic transducer assembly as defined in claim 1, a cover member of resilient material bonded to said radiating face of said vibratile plate and having integral mounting tab portions projecting from the periphery thereof.

8. In an electroacoustic transducer assembly as defined in claim 1, said transducer means being shaped as a hollow cylinder having parallel planar end faces transverse to the axis thereof to define said opposite end surfaces.

9. In an electroacoustic transducer assembly as defined in claim 8, said transducer means comprising a plurality of cylindrical elements one disposed concentrically within another with the outer cylindrical surface of one

element against the inner cylindrical surface of another element, and electrode means on the cylindrical surfaces of said elements.

10. In an electroacoustic transducer assembly as defined in claim 8, said transducer means comprising a plurality of cylindrical elements in end-to-end relation and having planar end faces in abutting relation, and electrode means on the end faces of said elements.

11. In an electroacoustic transducer assembly as defined in claim 8, securing means extending from said weight member through said transducer means to said vibratile plate to hold said weight member and said vibratile plate tightly against said end faces of said transducer means.

12. In an electroacoustic transducer assembly as defined in claim 11, said securing means comprising compressible spring means, a bolt member extending through said compressible spring means, and means on said bolt member for compressing said spring means to develop a spring force holding said vibratile plate and said weight member against said end faces of said transducer means with a substantially uniform pressure.

13. In an electroacoustic transducer assembly as defined in claim 12, said compressible spring means comprising at least one cup-shaped washer operative as a spring having relatively high stiffness.

14. In an electroacoustic transducer assembly as defined in claim 1, said transducer means including a piezoelectric crystal plate formed of 45 degree Z-cut ammonium diphydrogen phosphate.

15. In an electroacoustic transducer assembly as defined in claim 1, said hollow rigid housing structure being tapered from a large transverse dimension at said open end to a small transverse dimension at an opposite end position beyond said weight member.

16. In an electroacoustic transducer assembly as defined in claim 15, a cover of resilient material against the outer surface of said hollow rigid housing structure, and a plurality of peripherally spaced integral tapered wedges on said cover for defining shock mounts for mounting of said transducer assembly in a frame-like mounting structure.

17. In an electroacoustic transducer assembly as defined in claim 1, a transformer having a primary and secondary winding, potting material enclosing said transformer and supporting said transformer on said housing structure beyond said weight member, conductor means connecting one of said windings to said transducer means, and cable means connected to the other of said windings.

18. In an electroacoustic transducer assembly as defined in claim 17, said housing structure having an end wall beyond said weight member with said potting material and said transformer being positioned on the outer side of said end wall, and a cover of waterproof material bonded to the radiating face of said vibratile plate and completely enclosing said housing structure and said potting material to provide a water-tight seal around said transducer assembly.

19. In an electroacoustic transducer assembly as defined in claim 18, said cable being waterproof, and said cover including an integral strain-relief extension sealingly fitted over said cable.

20. In an electroacoustic transducer assembly as defined in claim 1, said weight member having a portion projecting toward said vibratile plate in spaced relation to said transducer means such that a substantial portion of the mass of said weight member lies within a region defined by spaced apart parallel planes intersecting said opposite end surfaces of said transducer means.

21. In an electroacoustic transducer assembly as defined in claim 20, said projecting portion of said weight member being in the form of an annular flange portion surrounding said transducer means.

22. In an electroacoustic transducer assembly as defined in claim 1, said transducer means including piezo-

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electric elements having electrodes thereon, conductor means for applying high voltages to said electrodes for high power operation of said transducer means, and an inert dry gas filling the space within said housing structure surrounding said transducer means.

23. In an electroacoustic transducer assembly as defined in claim 1, said weight member shaped as a truncated cone with the large diameter of said weight member placed in contact with said transducer means.

24. In an electroacoustic transducer assembly as defined in claim 23, said hollow rigid housing structure being tapered from a large transverse dimension at said open end to a small transverse dimension at on opposite end position beyond said truncated cone shaped weight member wherein the large diameter of said weight member is placed in contact with said transducer means.

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Disclaimer

3,328,751.—*Frank Massa*, Cohasset, Mass. ELECTROACOUSTIC TRANSDUCER. Patent dated June 27, 1967. Disclaimer filed Apr. 10, 1980, by the *Stoneleigh Trust of Cohasset, Mass.*, represented by Donald P. Massa and Fred M. Dellorfano, Jr. (Co-Trustees).

Hereby enters this disclaimer to claims 10, 15, 16, 17, 18, 19, 22, 23 and 24 of said patent.

[*Official Gazette, June 17, 1980.*]