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Massa

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[54] **ELECTROACOUSTIC TRANSDUCER WITH IMPROVED SHOCK RESISTANCE**

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[52] **U.S. Cl.** ....**340/10,** 310/8.2, 310/8.3, 310/8.7, 340/8 R

[51] **Int. Cl.** **H04r 17/00**

[58] **Field of Search** 340/10, 8; 310/8.2, 8.3, 8.4, 310/8.7, 9.6

[56] **References Cited**

UNITED STATES PATENTS

3,396,285	8/1968	Minchenko	310/8.2
3,474,403	10/1969	Massa et al.	340/10
3,043,967	7/1962	Clearwaters	340/10 UX
3,328,751	6/1967	Massa	340/10
3,360,665	12/1967	Boswell	310/8.3 X

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[57] **ABSTRACT**

An electromechanical transducer assembly comprises a stacked group of axially aligned piezoelectric ceramic rings. Plates, which have a larger diameter than the ceramic rings, are positioned between each of the adjoining faces of the ceramic rings. Therefore, the edges of the plates extend outwardly beyond the periphery of the ceramic rings. A tape or filament is tightly wound about the rim of each ceramic ring to maintain a radial stress upon the ceramic elements.

7 Claims, 5 Drawing Figures

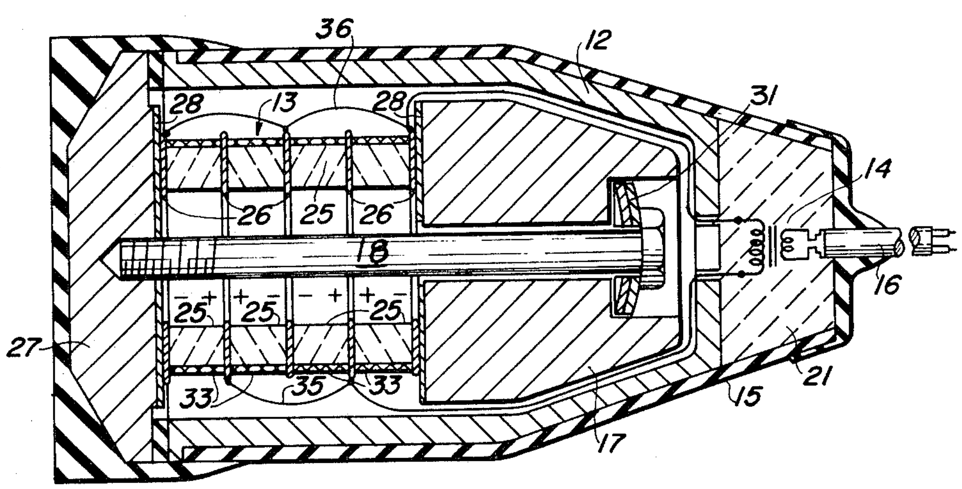


FIG-1

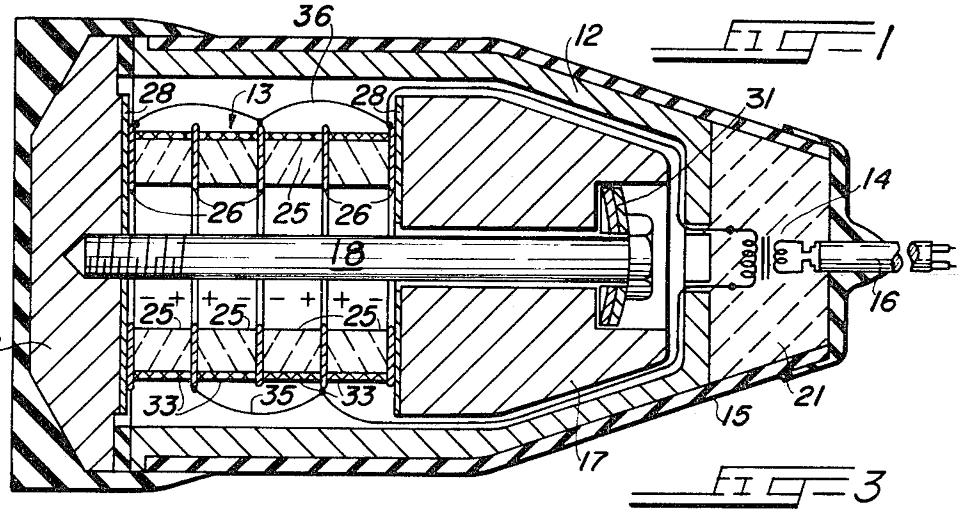


FIG-3

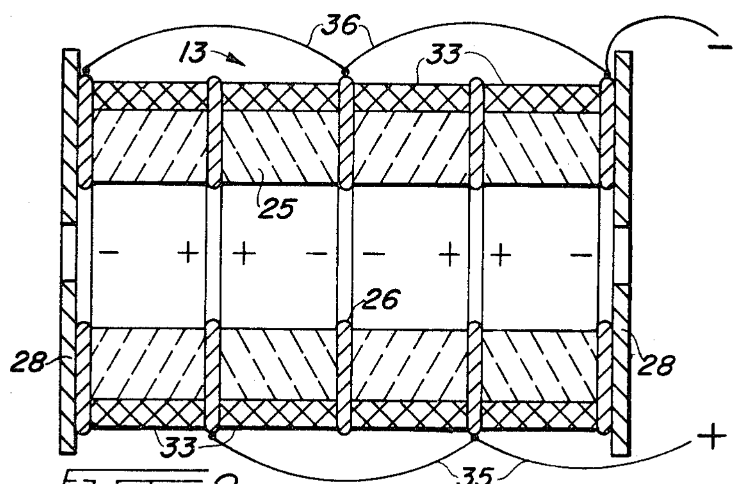


FIG-2

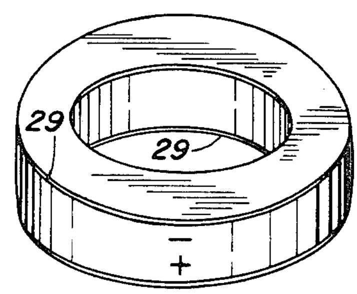


FIG-5

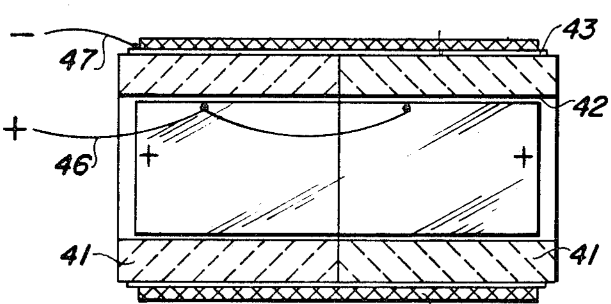
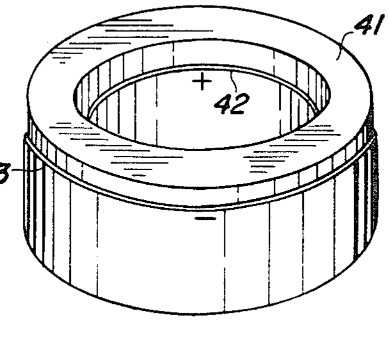


FIG-4



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ELECTROACOUSTIC TRANSDUCER WITH IMPROVED SHOCK RESISTANCE

This invention relates to improved electroacoustic transducers and more particularly to transducers which can withstand severe mechanical shock, such as might be encountered during underwater explosions.

Reference is made to the earlier transducer designs disclosed in U.S. Pat. Nos. 3,474,403; 3,328,751; and 3,266,011. This invention is an improvement, which has a greatly improved shock resistance, as compared with these and other similar transducers.

These transducers generally incorporate a number of electromechanical transducers elements interposed between a vibratile plate member of diaphragm or piston plate and an inertial support. The transducer elements are piezoelectric rings positioned in end-to-end relationship. When an electrical oscillating signal is applied to these elements, they compress and expand to cause a corresponding vibratile movement of the piston member.

An alternative construction places the transducer elements between two vibratile piston plates which engage opposite end faces of the composite transducer unit. Both of these piston plates simultaneously radiate sonic energy.

This invention provides an additional degree of shock protection to the improved transducer construction described in U.S. Pat. No. 3,474,403.

Accordingly, an object of the invention is to provide new and improved piezoelectric transducers with greatly improved shock resistant construction. Here an object is to provide such a transducer which is much more economical to build than those which were constructed heretofore.

Another object of the invention is to provide a transducer using a plurality of piezoelectric ceramic elements. In particular, an object is to provide multi-element transducers having circumferentially compressive stressed ceramic elements.

In keeping with an aspect of the invention, these and other objects are accomplished by a transducer enclosed in a rigid housing terminating a waterproof cable. Inside the housing is a transducer assembly having a plurality of axially aligned piezoelectric ceramic rings or disc-shaped elements separated by metallic plates. The plates extend radially beyond the rim surface of the ceramic, thereby forming flanges to make a bobbin-like structure. A tape or filament of material, such as fiberglass, is tightly wound upon the rims of the ceramic elements and between flanges formed by the plates. This way, the ceramic rings may be compressively stressed in a more uniform manner.

An inventive structure embodying these objects, features, and advantages will become more fully apparent from the following description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a cross-sectional view of one embodiment of the invention which incorporates an underwater transducer incorporating a stack of ring-shaped piezoelectric elements;

FIG. 2 is a cross-sectional view of a bobbin-like structure comprising the stack of ring-shaped piezoelectric elements with a filament tape tightly wound between flange plates which project outwardly from the rims of the ceramic elements;

FIG. 3 is a perspective view of a single piezoelectric element taken from the stack of FIG. 2;

FIG. 4 is a cross-sectional view showing a second embodiment of the invention incorporating another type of polarized ceramic element; and

FIG. 5 is a perspective view of a single piezoelectric element taken from the stack of FIG. 4.

A fully assembled underwater transducer is shown in FIG. 1. The major elements of this transducer are a rigid housing **12**, a stack of piezoelectric elements **13**, a transformer **14**, a waterproof covering **15** and a waterproof cable **16**. The housing **12** encloses the non-radiating portions of the transducer assembly comprising the transducer assembly **13**, an inertial element **17**, and a stress bolt **18**. Behind the housing **12** and inside the waterproof covering **15** is a chamber **21** housing the coupling transformer **14**, which is suspended in a suitably rigid potting compound.

The completed transducer assembly comprises a plurality of axially aligned, piezoelectric ceramic rings **25** separated by metal flange plates **26**. A vibratile plate piston or diaphragm **27** is positioned against one end of the piezoelectric ceramic stack **13** and the inertial element **17** is positioned against the other end of the stack. A mechanical attachment is accomplished by passing the stress bolt **18** through one or more Belleville springs **31**, the inertial element **17**, the ceramic stack **13**, and piston **27**. The bolt **18** is tightened to a point where a predetermined axial compressive stress is applied to the entire assembly.

For more information about this construction, reference may be made to U.S. Pat. Nos. 3,474,403 and 3,328,751.

The inventive transducer element **13** may become more apparent from a study of FIGS. **2** and **3**, which include part of FIG. **1** enlarged to show greater detail.

In greater detail, the assembly is here shown as including four ring-shaped piezoelectric ceramic elements **25**. Any suitable, well known, ceramic material may be used, such as lead-zirconate-titanate, for example. These ring-shaped elements are polarized with the electrical field applied along their axial or thickness dimension. This polarization is indicated in the drawing by "+" and "—" signs. An electrode **29** is formed on each side of each ceramic ring **25**, as shown in FIG. **3**.

The four ceramic rings **25** are aligned and stacked in a side-by-side relationship. The orientation is such that similar polarities are positioned next to each other. Thus, two positive electrodes come together when the first two and last two elements are placed next to each other. Two negative electrodes come together at the center of the stack. The two electrodes at the outside ends of the stack are negative.

According to the invention, ring or disc-shaped plates **26** are placed between each pair of common electrodes and against the outside two electrodes. Further, an insulating disc **28** is placed on each of the opposite ends of the stack. The plates **26** have a diameter which is larger than the diameter of the ceramic rings. Therefore, each pair of plates **26**, and the intermediate ceramic ring forms a bobbin-like structure. Or stated another way, the plates form circular ridges projecting outwardly beyond the ceramic surface.

The plates **26** may be made of any suitable electrically conductive material such as a metal or a metallized glass. Alternatively, the plates may be a metallized fired ceramic, such as alumina. Preferably, the inner and outer surfaces of the plates are rounded to avoid edges. Primarily, this rounding serves the electrical function of reducing corona which might otherwise form at sharp edges during high power operation. The rounding provides the mechanical function of making a smoother device which is less likely to cut other materials during fabrication or operation.

The stack is completed by the insulating discs **28** attached to the outer ends of the assembly. Alternatively, these insulating discs may be formed on the inside surface of the vibratile plate member or piston **27** and mass element **17**.

To assemble the structure, an electrically conductive cement, such as an epoxy with silver dust, is first applied to the electrodes **29**, and the mating surfaces of the plates **26**. Then, the ceramic and plate elements are placed in axial alignment within a fixture or jig. A suitable mechanical clamp holds the structure together until the cement becomes rigid.

Means are provided for applying a compressive radial stress, uniformly to each of the ceramic elements. In greater detail, after the cement has become rigid the assembly **13** is placed on a lathe, bobbin winding machine, or the like. Then the outer periphery of each ceramic ring is tightly wrapped with a non-conductive material **33**. This wrapping material may be any suitable tape or filament, such as a glass fiber. A bonding agent (such as epoxy) coats this wrapping material to consolidate it into a solid mass.

The plates **26** form projections or barriers which act as a bobbin or coil form to contain the wrapping material. Known techniques may be used to distribute the wrapping material uniformly over the entire exposed ceramic surface. Finally, the positive plates are electrically joined by the wire **35** and the negative plates are joined by the wire **36**. These wires may be soldered in place, and led through holes in the rigid housing **12** to a primary winding on the transformer **14**.

The advantages of this invention should now be clear to those who are skilled in the art. After the wrapping material is consolidated, the tight wrapping applies a radial compressive stress which is uniformly maintained within the ceramic material. A result is that the ceramic rings are protected against a premature fracture. It has been found that transducers constructed in this manner are able to withstand the high shock pressure of nearby underwater explosions.

A second embodiment of the invention is shown in FIGS. **4** and **5**. This embodiment may be used interchangeably with the structure **13** of FIGS. **2** and **3**.

More particularly, two tubular ceramic piezoelectric elements **41** are placed end-to-end, axially aligned relationship, and bonded together, as by epoxy, for example. An electrode **42** is formed about the inside circumference of the ceramic tube and an electrode **43** is formed about the outside circumference of the ceramic tube. While any of many known methods may be used to form these electrodes, I prefer to use a fired silver. During the polarization of the piezoelectric material, positive and negative potentials are applied to the electrodes **42**, **43**. Therefore, the material is polarized at right angles with respect to the axis of the cylinder.

After the bonded, polarized ceramic tube is completed, electrical conductors **46**, **47** are soldered to the electrodes **42**, **43**, respectively. Then a wrapping material **48** is tightly and uniformly wound about the outside periphery of the tube. Again, a suitable bonding agent may be used to consolidate the wrapping.

The structure of FIG. **4** uses two separate cylindrical elements **41**, instead of a single cylinder. The advantage of this arrangement is that the overall transducer characteristics are more uniform. In greater detail, it is well known that the piezoelectric constants of polarized ceramic materials vary over relative wide ranges. By selecting and matching the two individual cylinders, it is possible to provide assembled pairs having average characteristics. Thus, the transducers have a much more uniform characteristic than would be possible if a single element were used. As a result, it is possible to mix high and low tolerance elements, and thereby use substantially an entire production run.

The foregoing specification speaks of the use of a glass fiber for the wrapping material. This material is desirable in the embodiment of FIG. **2** since the nonconductivity does not interfere with the potential distribution along the surface which varies between the positive and the negative polarities. However, in the embodiment of FIG. **4**, the electrode **43** has substantially the same potential over its entire surface. Therefore, the wrapping material may be conductive. Thus, a high tensile steel wire may be used to wrap the surface.

An alternative wrapping for the embodiment of FIG. **4** involves a heating process. More particularly, a cylindrical stress tube is constructed to have a predetermined interference fit over the outside of the ceramic cylinder. The outside of the ceramic cylinder is preferably ground to close tolerances, and the inside of the cylindrical stress tube is held to similar close tolerances. By heating or otherwise temporarily expanding the stress tube, it may be fitted over the outside of the ceramic cylinder. The stress tube then shrinks and applies the desired compressive stress to the outer periphery of the ceramic material.

It should be understood that modifications and variations may be made without departing from the spirit and scope of the novel concepts of this invention. Therefore, the attached claims are intended to cover all reasonable equivalents.

I claim:

1. An electromechanical transducer assembly comprising at least two transducer elements for converting electrical oscillations to mechanical vibrations, each of said transducer elements having an external peripheral surface, said transducer elements being assembled together with said external peripheral surfaces held in a substantial alignment, a plurality of plate members each having an outer periphery, the periphery of said plate members being larger in radial dimension than the external peripheral surface of said transducer elements, said transducer elements being assembled between a pair of said plate members whereby the peripheries of said plate members project beyond the peripheries of said transducer elements to provide a bobbin-like form, and a continuous filament tightly wrapped on said bobbin from in direct physical contact with the external peripheral surfaces of said transducer elements for circumferentially applying a substantially

uniform compressive stress directly to said external peripheral surfaces of said transducer elements throughout the entire ambient temperature range.

2. The invention of claim 1 further characterized in that said wrapping includes a filament which is electrically non-conductive.

3. The invention of claim 2 further characterized in that said filament is a glass fiber and still further characterized in that said filament is kept under tension while it is being wrapped over the periphery of said transducer element.

4. An electromechanical transducer assembly comprising a plurality of ring-shaped piezoelectric elements, means for bonding said elements together in substantial axial alignment, and a continuous filament of material having a modulus of elasticity generally corresponding to the modulus of elasticity of glass fiber and stainless steel, said filament being tightly wrapped in direct physical contact with the outside perimeter of said piezoelectric elements for applying a substantially uniform compressive stress around the peripheries of said bonded elements, said means for applying said uniform compressive stress being characterized in that said compressive stress is uniformly maintained with the ceramic material.

5. The assembly of claim 4 and means for applying compressive forces along substantially the aligned axis of said bonded elements.

6. The assembly of claim 5 and a plurality of metal flange plates separating said ring-shaped elements, said bonding means being epoxy cement loaded with silver dust interposed between said elements and flange plates, said axial stress applying means comprising a stress bolt and a plurality of Belleville-type springs, said peripheral compressive stress applying means comprising a fiberglass filament tightly wound around the periphery of said piezoelectric rings and between said flange plates and bonded into a consolidated solid mass by an impregnating epoxy bonding agent, said piezoelectric rings being polarized in their axial dimensions and assembled into a stack of rings with said rings oriented so that the same electrical polarities are abutting each other when adjacent rings are placed in said axial alignment, and two electrical conductors attached to alternate ones of said flange plates, respectively, according to the electrical polarities of the abutting ceramic rings, thereby providing positive and negative terminals for connecting external equipment to said assembly.

7. An electromechanical transducer assembly comprising at least two transducer elements for converting electrical oscillations to mechanical vibrations, each of said transducer elements having an external peripheral surface, said transducer elements being assembled together with said external peripheral surfaces held in a substantial alignment, a plurality of plate members each having an outer periphery, the periphery of said plate members being larger in radial dimension than the external peripheral surface of said transducer elements, said transducer elements being assembled between a pair of said plate members whereby the peripheries of said plate members project beyond the peripheries of said transducer elements to provide a bobbin-like form, and means on said bobbin form in direct physical contact with the external peripheral surfaces of said transducer elements for circumferentially applying a substantially uniform compressive stress directly to said external peripheral surfaces of said transducer elements throughout the entire ambient temperature range, said stress applying means comprising a filament taken from the class of materials having a modulus of elasticity substantially as found in glass fiber and steel wire and said filament being in direct physical contact with the external peripheral surfaces of said transducer elements.

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