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SEARCH ROOM

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PRE-STRESSED SPHERICAL ELECTRO-ACOUSTIC TRANSDUCER

Filed May 22, 1964

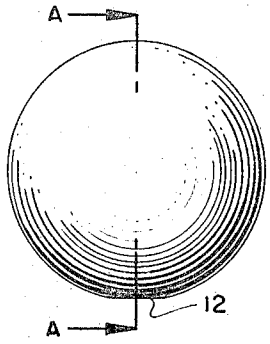


FIG. 1.

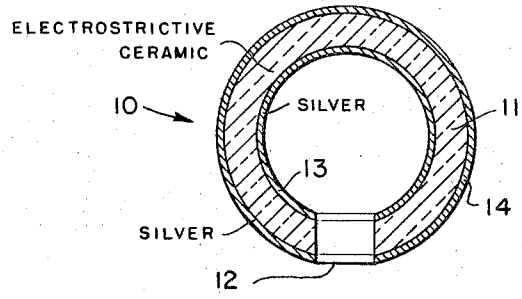


FIG. 2.
(PRIOR ART)

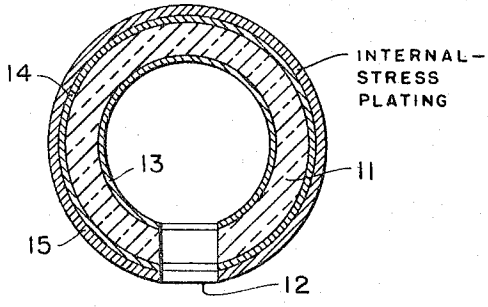


FIG. 3.

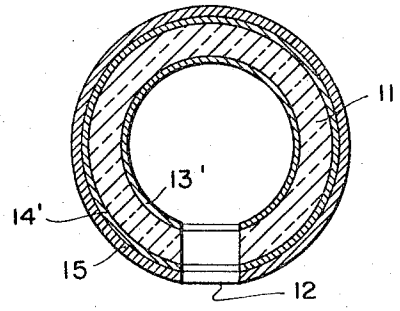


FIG. 4.

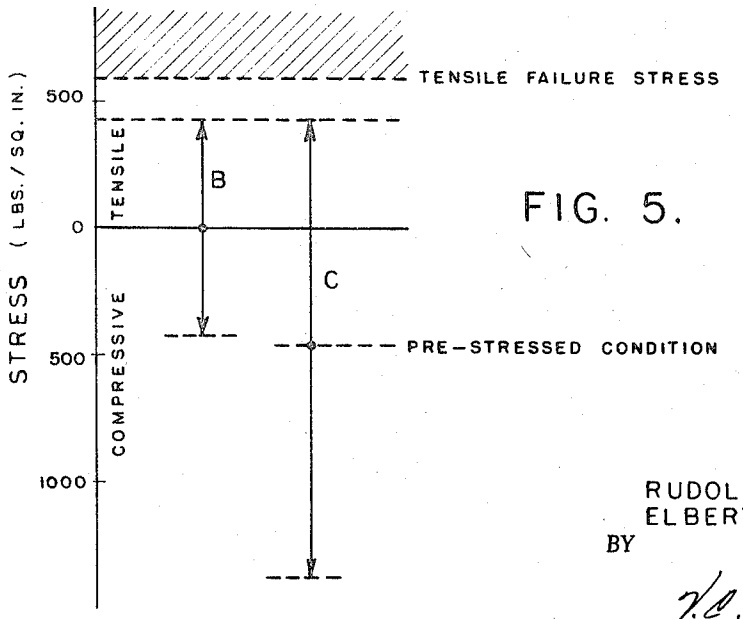


FIG. 5.

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PRE-STRESSED SPHERICAL ELECTRO-ACOUSTIC TRANSDUCER

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4 Claims. (Cl. 310—8.5)

The present invention relates to electro-acoustic transducers and in particular to such transducers made of electro-strictive ceramic material and of spherical-shell configuration, for use in underwater applications.

Various polycrystalline ceramic materials, when suitably prepared, fabricated and employed in accordance with known techniques (for example as described by R. Goldman in "Ultrasonic Technology," published in 1962 by Reinhold Publishing Corp.), have been found to be eminently satisfactory as electro-acoustic transducers both for transmission (conversion of A.C. excitation to acoustic output energy) and for reception (conversion of incident acoustic energy to an output electrical signal). In the transmission mode of operation in particular, such transducers are subjected to considerable internal stresses, alternately tensile and compressive, because of the vibrational forces resulting from the A.C. excitation. Characteristic of ceramics in general, the tensile strength of these transducers is far lower than their compressive strength, posing limitations upon the excitation voltage, the internal power density and the acoustic intensity at the radiating surface which can be handled without rupture of the transducer operating in the transmission mode. The problem of increasing acoustic power beyond the normal limitation posed by low tensile strength of the ceramic material has in some non-spherical transducer instances been overcome through the use of composite transducers, sandwich-type construction and mass-loaded units, where it is possible to pre-stress the ceramic elements in compression. Such techniques, however, are not applicable to omni-directional electro-acoustic transducers of spherical-shell configuration with which the present invention is concerned.

It is therefore an object of the invention to provide a novel structure enabling increase in the power handling capabilities of spherical-shell ceramic transducers.

Another object of the invention is to provide a spherical-shell ceramic transducer which is pre-stressed in novel manner to increase the power-handling capability of the transducer without deteriorating its omni-directional field pattern.

A further object of the invention is to provide a ceramic transducer of spherical-shell configuration with an outer electrode under tensile stress to place the ceramic material under initial compression.

These and other objects and advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following description when considered in connection with the accompanying drawing wherein:

FIG. 1 illustrates the external appearance of a spherical-shell ceramic transducer unit;

FIG. 2 is a cross-sectional view taken along line A—A in FIG. 1 and illustrating the structure of a prior art ceramic transducer unit of spherical-shell configuration;

FIG. 3 is a similar cross-sectional view illustrating the structure of a spherical-shell transducer unit in accordance with the present invention;

FIG. 4 is a similar view illustrating another transducer unit embodying the present invention; and

FIG. 5 presents a diagrammatic comparison of the safe peak stress excursions in a prior art spherical-shell transducer and that made possible in a transducer according to the present invention.

Referring generally to FIGS. 1, 2, 3 and 4 of the drawing which illustrate spherical-shell ceramic transducer units, cable connections thereto are omitted, as well as mounting and sealing structures, since they may take any form in accordance with known and conventional techniques and are not of particular concern to the present invention. FIG. 2 concerning a prior art transducer unit, and FIGS. 3 and 4 concerning transducer units exemplifying the present invention, are cross-sectional views each taken along the line A—A of FIG. 1 which illustrates the external appearance of sperical-shell ceramic transducer units.

Referring now in particular to FIG. 2, the transducer unit there shown is typical of the prior art and consists of a suitable electro-strictive ceramic material which is cast or otherwise formed as a spherical shell **11** (dimensioned to be resonant in the spherical mode at a predetermined frequency) with an opening **12** no larger than necessary to enable application of the inner electrode **13** and electrical connection thereto. The inner and outer electrodes **13** and **14**, respectively, are applied in any conventional manner, generally most conveniently by coating the ceramic surfaces with any so-called silver paste or silver paint formulated for such purpose, then subjecting the so-treated ceramic shell to a firing process which results in the formation of a thin layer of silver upon the inner and outer surfaces of the ceramic shell.

By way of specific example of power handling capabilities, a prior art transducer as thus far described but further to be understood as employing cobalt-additive barium 5% calcium titanate as the electro-strictive ceramic material, in a comparatively thin-walled spherical-shell configuration having a diameter of about 0.5 inch and a wall thickness of about 0.05 inch, has been found to have a maximum safe acoustic power-handling capability of approximately 185 watts, when submerged in seawater at comparatively shallow depth and pulsed for say several hours at a low duty rate (say 0.1% duty at 1 to 2 pulses per second), but to shatter upon first application of a pulse resulting in an acoustic power of approximately 370 watts. The unstressed initial condition of the ceramic and the safe peak stress excursions for such a transducer are illustrated diagrammatically at B in FIG. 5.

In accordance with the present invention, however, wherein the spherical transducer is further provided with an outer electrode specifically having internal tensile stress which places the ceramic material under a predetermined degree of initial compression, the peak stress excursions which can be safely used are increased as illustrated at C in FIG. 5, correspondingly enabling application of much greater excitation and development of much greater acoustic intensity without rupture of the transducer.

Referring now to the exemplary embodiment of the novel and improved spherical-shell transducer unit illustrated in FIG. 3, the structure and manufacture thereof may be the same as has been described for the prior art transducer unit shown in FIG. 2 except for additional application of an outer coating **15** of conductive material deposited with inherent internal stress and thus serving to place the ceramic shell **11** under initial compression. Outer coating **15** is preferably of nickel and applied by the process of electro-deposition, since nickel can be readily applied in virtually any thickness, bath control is simple, and throwing power is good; the nickel coating can be readily deposited with pre-determined tensile stress and in pre-determined thickness to pre-stress the ceramic shell to a desired degree, the resultant coating is hard, corrosion resistant, directly solderable, and has a high tensile strength. Bath compositions for stress plating may be of

the Watts type, but baths having chloride ion provide greater stress development; sulfamate baths containing chloride ion will develop about 10,000 lbs./sq. in. which is sufficient in most cases. All-chloride baths can be employed to develop considerably greater stress where this may be desired in some cases.

While the exemplary embodiment of the novel and improved spherical transducer illustrated in FIG. 3 has been described as involving application of a pre-stressed coating of nickel by electro-deposition over a basis coating of silver in particular, since most of the proprietary fired-on silver paints or silver pastes normally used for electrostrictive ceramic electrodes withstand the mildly acidic nickel electroplating solution quite well, it will be understood that other basis coatings may be employed. As an example, in another embodiment illustrated in FIG. 4, the inner electrode **13'** may again be silver or of any other readily applied and strongly adherent metal coating, and the otuer electrode basis coating **14'** in this instance may be an electroless nickel coating which makes an excellent base for stress nickel electroplate and is in fact particularly applicable to spherical transducers of small size, as in the particular example given herein, which may make silver coating difficult.

Having described the novel manner in which the power-handling capabilities of spherical-shell ceramic transducers can be increased, it will now be understood that the particular thickness to which the high tensile stress coating should be deposited is a function of its specific internal stress figure and the desired value of compressive bias, and that the necessary external coating thickness can in fact be pre-computed. For example, first computing the tensile failure stress, taking the above-mentioned case wherein the diameter and wall thickness of the spherical-shell ceramic unit are 0.5 inch and 0.05 inch, respectively, and wherein the unit shatters when the acoustic power reaches 370 watts, and making use of the equation

$$P=\sqrt{2\cdot 10^7\cdot \rho CI} \qquad (1)$$

wherein P is the peak value of the dynamic pressure at radiating surface, dynes/sq. cm.,

ρ is the seawater density, gms./cc.,

C is the velocity of sound in seawater, cm./sec.,

I is the acoustic power density a the radiating surface, in watts/sq. cm., and

ρC is 150,000

the failing figure for P is found to be 16.4×10^6 dynes/sq. cm. Making use of the equation

$$S=\frac{P}{4}\cdot\frac{D}{t} \qquad (2)$$

which holds for comparatively thin-walled spherical shells, wherein D/t is the ratio of spherical-shell diameter to wall thickness, and wherein S is the internal peak stress in the same units as that of pressure P, the failure stress is found to be 41×10^6 dynes/sq. cm., equivalent to about 600 lbs./sq. in., as indicated in FIG. 5. At the safe acoustic

power-handling capability of approximately 185 watts, the internal peak stress is about 425 lbs./sq. in., as indicated at B in FIG. 5. Assuming now that it is desired to pre-stress the ceramic material in compression to about 475 lbs./sq. in., as indicated at C in FIG. 5, and that the tensile stress figure of the outer metal coating is 10,000 lbs./sq. in., the necessary thickness x of the coating can be computed from the equation

$$\frac{x}{t}=\frac{475}{10000} \qquad (3)$$

the thickness in this instance therefore being found to be 0.0043 inch. Again making use of Equations 1 and 2, the safe power-handling capacity of this pre-stressed spherical-shell transducer is found to be about 935 watts, very significantly increased over that of the unstressed transducer.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An electro-acoustic transducer comprising:

(a) an electro-strictive ceramic shell of spherical configuration and having an access aperture therein,

(b) said ceramic shell having a first electrode extending continuously over its inner surface and a second electrode extending continuously over its outer surface,

(c) said ceramic shell being normally subject to tensile rupture upon application of excitation voltage exceeding a predetermined magnitude, and

(d) said second electrode comprising a metal coating applied by electro-deposition and characterized by comparatively high tensile stress therein and of suitable thickness to initially bias said ceramic shell in compression, whereby to enable safe application of excitation voltage exceeding said predetermined magnitude and resulting in acoustic power intensity increased beyond that normally possible.

2. A transducer in accordance with claim **1** wherein said tensile stress is of the order of at least 10,000 lbs./sq. in.

3. A transducer in accordance with claim **1** wherein said metal coating is nickel.

4. A transducer in accordance with claim **3** wherein said tensile stress is of the order of 10,000 lbs./sq. in.

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