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SPHERICAL TRANSDUCER

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Fig. 1.

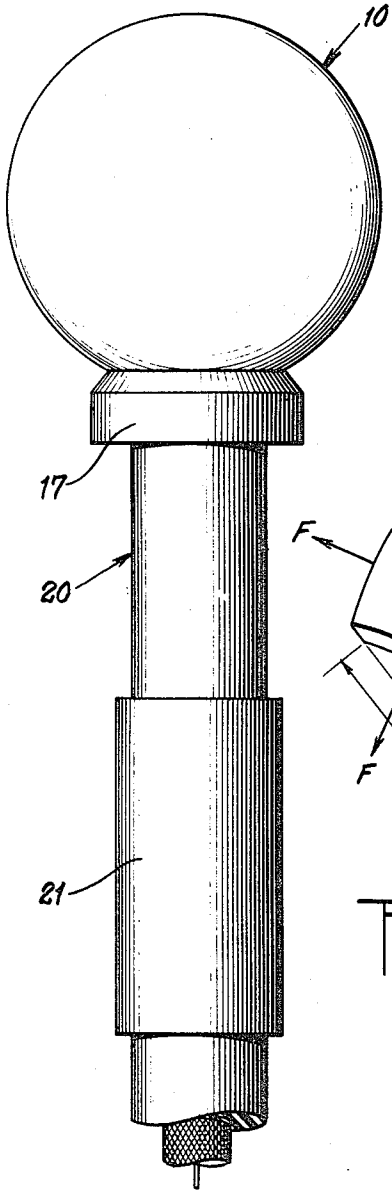


Fig. 2.

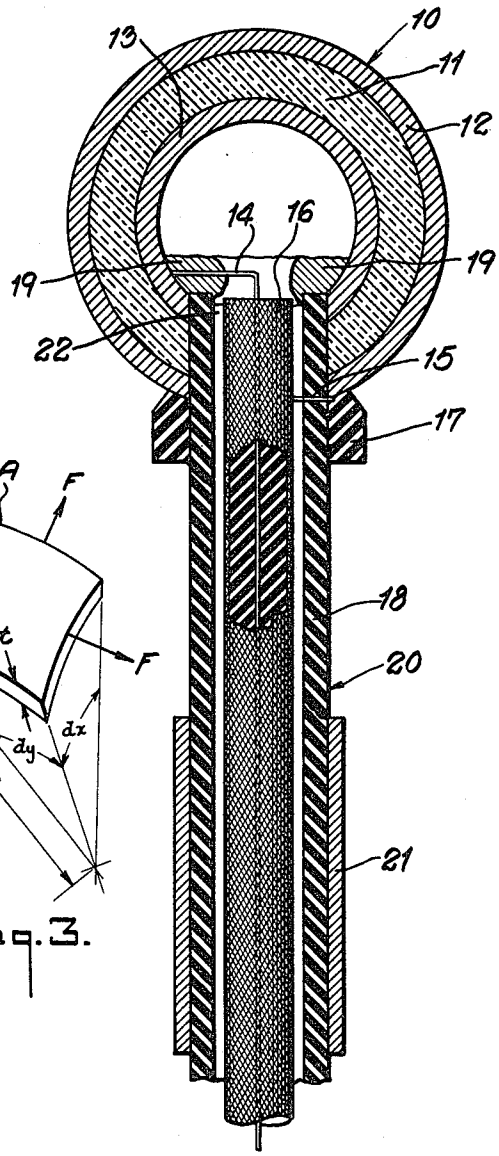


Fig. 3.

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SPHERICAL TRANSDUCER

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Our invention relates to spherical transducers and in particular to those which are reversible and may be employed in high intensity fields.

An important object of our invention is to provide a reversible spherical transducer of small size and dimensions.

A further object of our invention is to provide a transducer whose response characteristics are essentially omnidirectional.

A still further object of our invention is to provide a transducer which may be employed in conjunction with a directional reflector or other directive device.

Other objects and advantages of our invention will be apparent during the course of the following description.

In the accompanying drawings, forming a part of this application, and in which like numerals are employed to designate like parts throughout the same.

Figure 1 is a vertical view of an embodiment of our invention,

Figure 2 is a vertical section of the embodiment of Figure 1, and

Figure 3 is employed to illustrate the theory underlying our invention.

In the drawings, wherein for the purpose of illustration, is shown a preferred embodiment of our invention, the numeral **10** designates the microphone assembly, the numeral **11** designates the electromechanical transducer; the numeral **12** designates the outer electrode and the numeral **13** designates the inner electrode. The numeral **14** designates the center conductor which is electrically connected to the inner electrode **13** and the numeral **15** designates the electrical connection from the cable shield **16** to the outer electrode **12**.

The numeral **17** designates the compliant insulator and the numeral **18** designates the insulating outer jacket of the cable **20**. The numeral **19** designates the sealing compound and the numeral **21** designates the cable clamping surface and the numeral **22** designates the hole in the sphere through which the connections are made.

Microphone assembly **10** is spherical so that its surface looks the same to sound which is impinged on it from any direction. In the embodiment of our invention shown in the figures, the active transducer element **11** is a hollow spherical ceramic to whose surfaces have been applied electrodes **12** and **13**. A small hole **22** is cut in the sphere so that cable **20** may be inserted and the necessary electrical connections made from center conductor **14** to inner electrode **13** and from the shield **16** to outer electrode **12**. The insulating outer jacket of cable **20** is cut back where cable **20** enters hole **22** and a plastic casting compound **19** is inserted in the hole **22** alongside cable **20** and allowed to flow inside **10** and to harden and set. This insures good mechanical bonding of the cable **20** to the microphone assembly **10**. Compliant insulator **17** is bonded to **10** so as to completely surround hole **22** and is compliant so that the

transducer takes all the acoustic force which is applied to the microphone.

Other embodiments and methods for mounting and assembling transducers, produced in accordance with our invention, may be employed. One such method contemplates inserting a rubber or plastic-covered flexible shielded cable in hole **22** in the transducer **11** and sealing hole **22** with hard glass or a like material.

The electrodes may be on both surfaces as shown in the figures or may be applied to either surface depending on the particular application. Or, a strain gauge wire on a metallic sphere may be employed as the active element in the device.

When microphone assembly **10** is placed in an acoustic field, the sound impinges on **10** radially and compresses and expands transducer **11** in radial mode. The resonant frequency of 11 in the radial mode is very high which fact, coupled with the low mechanical Q of the sphere, permits the microphone to possess a broad frequency response beyond that attainable with diaphragm type microphones. We have found that the microphones and hydrophones produced in accordance with our invention have omnidirectional response in both the vertical and horizontal directions. For the purpose of this discussion the vertical plane is that which contains the axis of cable **20** and the horizontal plane is the plane which is perpendicular to the axis of cable **20**.

Units produced according to our invention are particularly useful in high intensity fields and may be used as microphones, hydrophones, projectors or loudspeakers. This is due to the fact that these spherical sensitive elements are electro-acoustically reversible.

In the field of subaqueous sound transmisison and reception, hydrophones have been most generally produced in the shape of hollow cylinders. The resonant frequency of a sphere in radial mode is approximately 1.7 times higher than that of a cylinder of the same radius and in addition, there is no length mode of vibration to consider when spheres are used instead of cylinders. The higher resonant frequency of the sphere as compared to the cylinder improves the frequency response of the sphere over that of the cylinder. The plot of output voltage against frequency is essentially flat for frequencies below the first resonant frequency of the transducer.

To determine the radial resonant frequency of a sphere, consider the portion of the spherical surface A of Figure 3. We have the fundamental equation: $F_1=ma$ where

F_1=force of inertia
m=mass
a=acceleration

In addition, we have: $m=R_0dy\times R_0dx\times t\times p$; and

$$a=\frac{d^2R}{d\theta^2}$$

where

p=density
t=thickness
θ=time
R_0=radius

From which:

$$F_1=ma=R_0^2dxdytp\frac{d^2R}{d\theta^2}$$

Likewise, the fundamental equation for the elastic force is given by:

$$\frac{S}{E'}=\frac{\Delta R}{R_0}$$

where

S=stress

$$E'=\frac{E}{1-\phi}$$

E=Young's modulus

ϕ=Poisson's ratio

The force in the radial direction is given by:

$F_r=F \sin dy+F \sin dx$ and for small values of dy *and* dx, assuming $dy=dx$, we obtain: $Fr=2Fdy$.

The force F is equal to the stress times the area or

$$F=S\times t\times R_0dx;\ F=\frac{E'\Delta R}{R_0}tR_0dx$$

from which, the radial force, F_r, is given by:

$$F_r=2E'\Delta Rtdxdy$$

For equilibrium, the force of inertia is equal to minus the elastic force, so that:

$$R_0^2dydxtp\frac{d^2R}{d\theta^2}=-2E'\Delta Rtdxdy$$

$$R_0^2p\frac{d^2R}{d\theta^2}=-2E'\Delta R$$

$$\frac{d^2R}{d\theta^2}+\frac{2E'\Delta R}{pR_0^2}=0$$

also,

$$\Delta R=R-R_0=A \text{ (amplitude of motion)}$$

$$R=A-R_0$$

where

R=mean radius

R_0=a constant

so that:

$$\frac{d^2A}{d\theta^2}+\frac{2E'A}{pR_0^2}=0$$

and

$$A=c' \sin\left(\sqrt{\frac{2E'}{pR_0^2}}\theta+k\right)$$

so that

$$w=\sqrt{\frac{2E'}{pR_0^2}}$$

and since

$$f_s \text{ (frequency of resonance)}=\frac{w}{2\pi}$$

$$f_s=\frac{1}{2\pi R_0}\sqrt{\frac{2E'}{p}}$$

For barium titanate:

$$\phi=.32 \text{ and } \sqrt{\frac{E}{p}}=4.2\times10^5 \text{ cm./sec.}$$

and we obtain:

$$f_s=\frac{1}{\pi R}\sqrt{\frac{+E}{2p(1-\phi)}}=\frac{1.15\times10^5}{R \text{ (in cm.)}} \text{ cycles/sec.}$$

The mechanical figure of merit, Q, for a subaqueous sound receiver (hydrophone) is given by:

$$Q=\frac{wL}{R}$$

where

$L=tp_m$

$R=p_wc_w$

$$w=\frac{1}{a}\sqrt{\frac{2E}{p(1-\phi)}}$$

$$\sqrt{\frac{E}{p}}=c_m$$

c_m=velocity of sound in the ceramic
p_m=density of the ceramic
t=thickness of the ceramic wall
α=mean radius
c_w=velocity of sound in water
p_w=density of the water
ϕ=Poisson's ratio (.32 for barium titanate)

from which:

$$Q=\frac{1}{a}\sqrt{\frac{2E}{p(1-\phi)}}\times tp_m\times\frac{1}{p_wc_w}$$

$$=\frac{1}{a}\sqrt{\frac{2}{(1-\phi)}}\sqrt{\frac{E}{p}}\frac{tp_m}{p_wc_w}=\sqrt{\frac{2}{(1-\phi)}}\frac{p_mc_m}{p_wc_w}\times\frac{t}{a}$$

For barium titanate and sea water, we obtain:

$$Q=1.72\times\frac{5.5\times4.2\times10^8}{1\times1.4\times10^5}\times\frac{t}{a}$$

$$=28.4\frac{t}{a}$$

and if t is small with respect to a, Q is low.

When devices made in accordance with our invention are employed for subaqueous sound reception or transmission, they are suitably treated so that the liquid in which they are immersed cannot enter into contact with the active element or the electrodes.

Our invention contemplates the use of the units, produced in accordance therewith, in directional microphones, hydrophones, projectors and loudspeakers. The location of the unit at the focus of a parabolic reflector, for instance, results in a very good directional electroacoustical device. This is due to the fact that the inherently uniform response of the unit in free space permits sound pickup from any direction and all sound reflected from the parabolic reflector onto the sensitive element is unattenuated due to the direction of incidence to the sensitive element. The unit is equally well adapted to use in conjunction with any other type of directional device.

While we have described our invention by means of specific examples and in a specific embodiment, we do not wish to be limited thereto for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of the invention.

Having thus described our invention, we claim:

1. An electroacoustical transducer for insertion in an acoustic transmission medium comprising a hollow spherical, piezoelectric ceramic element in said medium, said ceramic element having an opening therein, electrodes affixed to the inner and outer surfaces of said ceramic element, a cable comprising two electrical conductors and an outer compliant sheath, said cable being affixed to said ceramic element at said opening, means for connecting one of said electrical conductors to the inner of said electrodes and the other of said electrical conductors to the outer of said electrodes, a compliant member surrounding said cable in contact with said ceramic element, and means within said opening for sealing said opening whereby the interior of said ceramic element is isolated from said medium.

2. The invention as described in claim 1 wherein the

ratio of the thickness of said ceramic element to the radius of said ceramic element is small.

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