

[54] **ELECTROACOUSTIC TRANSDUCER
HAVING TRANSDUCING ELEMENT
SUPPORTING MEANS**

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[51] Int. Cl. **H01v 7/00**

[58] Field of Search. **310/8, 8.2, 8.3,
310/8.5, 8.6, 9.1-9.4**

[56] **References Cited**

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[57] **ABSTRACT**

An electromechanical transducer element is supported within a transducer housing by a trilaminar diaphragm comprising a layer of viscoelastic material sandwiched between a pair of rigid plates. By locating the neutral bending plane of the composite diaphragm-element structure in the center layer of viscoelastic material, where shear stresses are maximal, the resultant shear deformation in the viscoelastic material advantageously dissipates vibratory energy. This provides a means of reducing undesirable peaks in the transducer's frequency response and results in a more uniform response characteristic.

10 Claims, 2 Drawing Figures

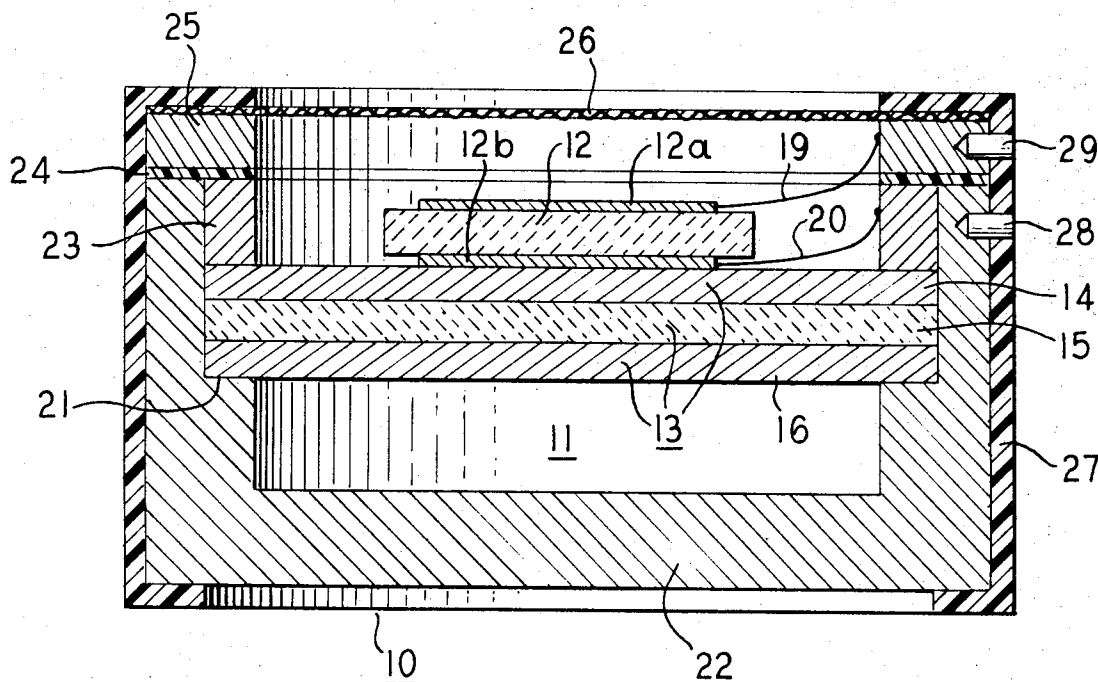


FIG. 1

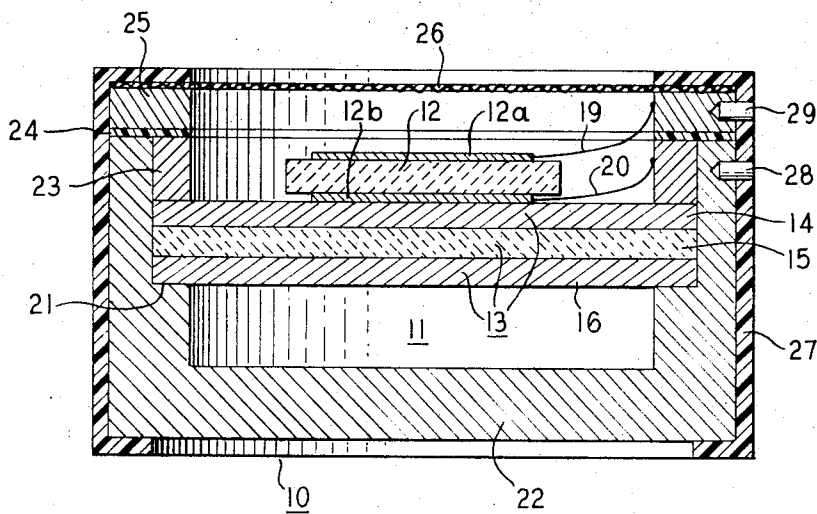
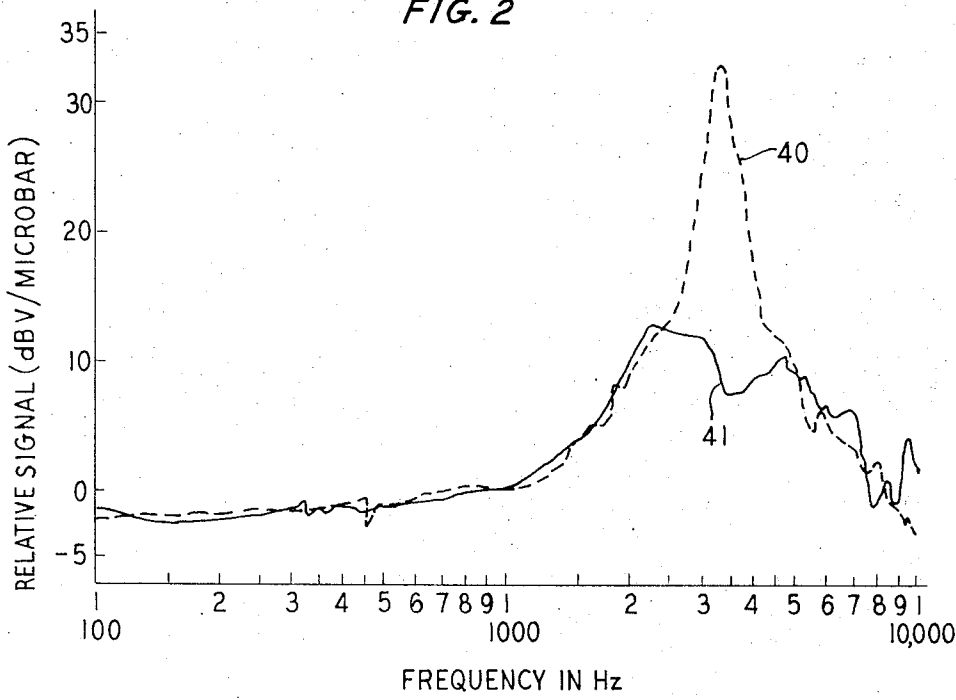


FIG. 2



ELECTROACOUSTIC TRANSDUCER HAVING TRANSDUCING ELEMENT SUPPORTING MEANS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to electroacoustic transducers utilized to convert sound energy into electrical energy, and vice-versa, and, more particularly, to such transducers having improved means for supporting an electromechanical transducing element within the transducer housing.

2. Description of the Prior Art

While electroacoustic transducers, particularly of the piezoelectric ceramic type, possess advantages of reduced size and increased stability when compared to other instruments serving the same function, various design problems have prevented their widespread use in telephone and other electronic systems. Notable among these problems has been the need for a suitable means for supporting the transducing element within the transducer housing that not only provides a desired frequency response characteristic, but also meets design requirements in terms of ruggedness, simplicity and stability with age and temperature variations. Conventional transducing element supports have typically included a pair of gaskets, at least one of which is rubber, for supporting opposite faces of the element. These gaskets, or O-rings as they are sometimes called, are compressed against the periphery of the faces, so that a pressure seal is provided, and the element held in the desired position. Unfortunately, while such supporting means are relatively simple and inexpensive to produce, several disadvantages are inherent in their use. First, and most importantly, the stiffness of the vibratory system is closely related to the amount of compression applied to the rings. As a result, small changes in manufacturing tolerances, assembly techniques, or in rubber composition produce varying amounts of compression, which in turn may often adversely affect the transducer frequency response characteristics, or, at least, cause unwanted variations in such characteristics between individual transducers of the same lot. Second, overcompression of the gaskets leads to possible element damage in either assembly or during use, if the transducer is dropped, while undercompression may result in lateral movement of the element and consequent misalignment. Additionally, exposure of the rubber rings to the atmosphere within the transducer housing often causes rubber deterioration, which leads to undesirable shifts or changes in transducer performance.

To avoid the problems inherent in the use of rubber gaskets, other prior art transducers have employed a thin diaphragm, usually metal, to support the transducing element, the diaphragm being rigidly edge-clamped to the housing at its periphery. Unfortunately, such a transducer typically exhibits a frequency response characteristic which contains a peak on the order of 35 dB with respect to its low frequency value, due to the undamped natural resonance of the diaphragm. This peak is highly undesirable, particularly in telephone system applications, and must be considerably reduced for satisfactory transducer operation.

Accordingly, it is the broad object of the present invention to provide an electroacoustic transducer, preferably of the piezoelectric ceramic type, having an

improved means for supporting the transducing element within the transducer housing.

A further object of the invention is the provision of a supporting means for an electromechanical transducing element that may be rigidly mounted within a transducer housing, thereby eliminating problems associated with varying degrees of supporting means compression, and yet enabling the achievement of a desired transducer frequency response characteristic.

SUMMARY OF THE INVENTION

Each of the foregoing and additional objects are achieved in accordance with the principles of the invention by the provision in an electroacoustic transducer of an improved means for supporting the transducing element within a housing which includes a trilaminar diaphragm comprising a layer of viscoelastic material sandwiched between a pair of rigid plates. The transducing element is securely fastened to the diaphragm, and the composite diaphragm-element structure is arranged so that its neutral bending plane is located in the center layer of viscoelastic material. Rigid edge clamping may be employed to support the diaphragm within the transducer housing.

The design of the supporting means described above takes advantage of the principle that shear stress energy is dissipated in a viscoelastic material and may be maximized by constraining the material at its outer surfaces. By locating the neutral bending plane of the composite diaphragm-element structure in the center layer of the viscoelastic material, where shear stresses are maximal, the total amount of energy dissipated is sufficient to significantly reduce the resonant peak normally associated with a rigidly clamped supporting structure. Accordingly, a desired transducer frequency response characteristic may be achieved without sacrificing the benefits of rigid mounting, which include ease of transducer assembly and reduction of the likelihood of element damage or misalignment caused by over or under compression of gaskets. Additionally, since the viscoelastic material is completely encased by the outer layers of non-dissipative material and by the transducer housing, contamination or deterioration thereof due to exposure to the atmosphere within the housing is avoided.

BRIEF DESCRIPTION OF THE DRAWING

The aforementioned and other features and advantages of the instant invention will become more readily apparent to persons skilled in the art by reference to the following detailed description, when read in light of the accompanying drawing, in which:

FIG. 1 is a central cross-sectional view of an electroacoustic transducer constructed in accordance with the principles of the invention, and

FIG. 2 is a graph comparing a typical frequency response characteristic of the transducer of FIG. 1 to a similar characteristic of a transducer including a simple metallic diaphragm for supporting the transducing element.

DETAILED DESCRIPTION

Referring now to FIG. 1, there is shown in central cross-sectional view an electroacoustic transducer con-

structed in accordance with the principles of the invention. The transducer comprises a housing, designated generally at 10, defining an internal chamber 11, and a planar electromechanical transducing element 12 within the chamber. Means for supporting the element 12 within the chamber 11 includes a trilaminar planar member 13, to be described more fully hereinafter.

Transducing element 12 may be of the piezoelectric ceramic type, and comprise a disc or slab of a polarizable ferroelectric ceramic material such as barium titanate, lead titanate-lead zirconate, or sodium potassium niobate. The disc may be fabricated in various ways, one of which is fully described in application, Ser. No. 190,209, filed Oct. 18, 1971, by T. C. Austin and H. W. Bryant, entitled the same as the instant application and assigned to the same assignee. After fabrication, electrodes are affixed to both faces of the ceramic disc, such as electrodes 12a and 12b, shown greatly enlarged in FIG. 1 for the purposes of illustration only. The electrodes may be formed from thin sheets of metal foil cemented to the ceramic faces, or by plating a thin metallic layer directly onto the ceramic.

Planar member 13, which supports transducing element 12, includes, in accordance with the invention, a top layer 14, a middle layer 15, and a bottom layer 16, bonded together to form a trilaminar structure. The shape of member 13 is preferably round or disc-like, but other shapes are intended to be within the scope of the invention. Top and bottom layers 14 and 16, respectively, are fabricated from a mechanically rigid material, such as a metal. However, other suitably rigid substances, such as hard plastic, may be used in lieu thereof. Middle layer 15 is fabricated from a viscoelastic or stress absorbing material, more particularly, a lightly cross-linked, long chained elastomer, such as a polyester-based polymer, which exhibits a relatively high shear loss factor ($\tan \delta$) over the frequency and temperature range in which transducer operation is intended. A viscoelastic tape No. 112, manufactured by the Minnesota Mining and Manufacturing Company, is one example of a suitable viscoelastic material. This material exhibits a $\tan \delta = 1.10$ at 1 kHz and 23°C. Other materials having a shear loss factor greater than 0.2 may be used in practicing the invention, but materials having a $\tan \delta$ in excess of 1.0 are preferred.

After forming each of layers 14, 15 and 16 to the desired shape, they are bonded together to form trilaminar member 13 by means of a suitable adhesive coating applied between the various interfaces. In the case of the aforesaid No. 112 tape, which is itself an adhesive, the layers are simply placed in proper alignment, and pressure applied to form a suitable bond.

Assembly of the transducer of FIG. 1 is accomplished by first attaching transducing element 12 to top layer 14 of member 13 by means of cement, epoxy, or other suitable material. In the case where top layer 14 comprises an electrically conductive metal, electrode 12b may be arranged to make electrical contact directly therewith through the cement layer. Otherwise one end of a first thin strip 20 of electrically conductive material may be attached to electrode 12b before element 12 is secured to member 13. The composite diaphragm-element structure is next seated on an annu-

lar inwardly facing lip 21 formed in a cup shaped body member 22, the outer diameter of the lip being substantially equal to the diameter of member 13. A metallic retaining washer 23 of suitable size is then positioned on member 13 and within body member 22, so that member 13 is securely held in proper position. The remaining end of strip 20 may next be attached to washer 23, thereby providing electrical continuity between electrode 12b and member 22. A pair of suitably dimensioned washers 24 and 25 are then seated atop the open end of cup shaped member 22, washer 24 being fabricated from an electrically insulating material such as hard plastic, and washer 25 being fabricated from a conductive metal. Electrical contact between the latter and electrode 12a of element 12 is provided by a second strip 19, similar to strip 20, as shown in FIG. 1. Assembly is completed by covering the top or open end of housing 10 with an acoustic cloth 26 to provide protection against dust accumulation within the transducer, and by encasing the transducer in a thin plastic shell 27 having a generally U-shaped cross-section. Electrical connection between the transducer and an external load or source is accomplished by appropriately connecting leads to the external portions of a pair of terminal rivets 28 and 29 which extend through shell 27 and engage member 22 and washer 25, respectively.

Operationally, the transducer of FIG. 1, when used as a microphone with a piezoelectric ceramic transducing element, transforms acoustic energy to electrical energy by converting the cupping or spherical bending action induced in element 12 by the incoming sound waves to a voltage generated across electrodes 12a and 12b by piezoelectric action. The frequency response characteristic associated with this conversion is largely a function of the mechanical properties of the diaphragm supporting the transducing element. For example, a transducing element supported solely by a rigidly edge-clamped disc of 0.003 inch thick aluminum exhibits a characteristic as shown in curve 40 of FIG. 2, wherein it can be seen that a peak of approximately 35 dB with respect to the 1 kHz level is experienced at about 3 kHz. This peak, due to the natural resonance of the metal disc, is highly undesirable in most transducer applications, and must be substantially reduced for satisfactory operation.

In accordance with the invention, the advantageous design of supporting member 13 provides the required degree of peak suppression when the neutral bending plane of the composite diaphragm element structure (12 and 13) is located in or near the center plane of layer 15 of viscoelastic material, where shear stresses are maximal. Such location is accomplished by analysis, in well known manner, of the thickness and density of the various layers of member 13 and of element 12, and by adjusting the aforesaid variables to accomplish the desired result. One arrangement of dimensions found suitable for use in the transducer is given as follows:

	Material	Density (gm/cm ³)	Diameter (inches)	Thickness (inches)
Transducing element 12	Lead titanate- lead zirconate	7.8	0.500	0.005
Top layer 14	Aluminum	2.7	0.720	0.0018
Middle layer 15	No. 112 Viscoelastic tape	1.0	0.720	0.004

Bottom layer 16	Aluminum	2.7	0.720	0.0025
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It is to be clearly understood that numerous other combinations of materials and sizes will perform equally well in accordance with the invention.

By locating the neutral bending plane of the composite diaphragm-element structure in the viscoelastic middle layer 15, the maximal shear stresses of the assembly occur in the viscoelastic layer, thereby significantly dissipating the associated energy. Since the viscoelastic material is constrained between layers of rigid material, the amount of energy dissipated is enhanced, as described by E. M. Kerwin, Jr. in "Damping of Flexural Waves by a Constrained Viscoelastic Layer," Journal of the Acoustical Society of America, Vol. 31, No. 7, July 1959. Maximum dissipation can be realized, in the general case, even where the thickness of layers 14, 15 and 16 are unequal, as long as proper account is taken in locating the neutral bending plane, so that, in certain cases, a quite thin top layer 14 may be successfully employed. The frequency response characteristic of a transducer constructed according to the specifications of the foregoing table, normalized to curve 40 at 1 kHz, is depicted by curve 41 of FIG. 2, wherein it can be seen that the undesirably high peak at about 3 kHz has been reduced by approximately 20 dB.

Returning again to FIG. 1, it can be seen that middle layer 15 of viscoelastic material is protected against exposure to the atmosphere within chamber 11 by top and bottom layers 14 and 16, respectively, and by the sidewalls of cup shaped member 22. Accordingly, the possibility of deterioration or contamination of that material is substantially reduced. It is also apparent that supporting member 13 is rigidly seated within housing 10, and the use of rubber in gaskets, or otherwise, is avoided. Thus, the problems associated with varying degrees of supporting means compression and stiffness are obviated: The degree of compactness of a transducer of the type depicted in FIG. 1 can be more fully appreciated by reference to the following typical external dimensions, given by way of illustration only, the instant invention not being limited to the sizes stated:

Outside diameter: 0.822 inch

Height: 0.302 inch

Many modifications and adaptations of this invention will readily become apparent to persons skilled in the art. For this reason, it is intended that the invention be limited only by the appended claims. For example, it should be apparent that the heretofore described electroacoustic transducer may function equally well as a receiver for converting electrical energy into sound energy, or as a microphone. Additionally, the means employed for supporting transducing element 12 may, on occasion, be useful in an instrument wherein said element is of an electromechanical type other than a piezoelectric ceramic. Still further, while the shape of the transducing element has heretofore been described as round, or disc like, it should be clearly understood that appropriate modifications to the peripheral shape of the transducer and/or its internal components may sometimes be required.

What is claimed is:

1. An electroacoustic transducer comprising, an electromechanical transducing element, a housing defining an internal chamber for containing said element, means for supporting said element within said chamber, said supporting means including a trilaminar planar member having a top layer, a middle layer and a bottom layer, said top and bottom layers comprising a rigid material and said middle layer comprising a viscoelastic material, and means for attaching said element to said planar member to form a composite structure, wherein the neutral bending plane of said composite structure is located in said middle layer.

2. The invention defined in claim 1 wherein said transducing element includes a polarizable ferroelectric ceramic material.

3. The invention defined in claim 2 wherein said ceramic material is selected from the group consisting of barium titanate, lead titanate-lead zirconate, and sodium potassium niobate.

4. The invention defined in claim 3 wherein said viscoelastic material includes a lightly cross-linked, long chained elastomer having a shear loss factor in excess of 0.2.

5. The invention defined in claim 4 wherein said rigid material includes a metal.

6. The invention defined in claim 5 wherein said metal includes aluminum.

7. An electroacoustic transducer comprising an electromechanical transducing element, a housing defining an internal chamber for containing said element, and means for supporting said element within said chamber, characterized in that said supporting means includes a trilaminar planar member having a top layer, a middle layer, and a bottom layer, said top and bottom layers consisting essentially of a rigid material and said middle layer consisting essentially of a viscoelastic material, and further characterized in that said transducing element and said supporting means form a composite structure having a neutral bending plane located in said middle layer.

8. The invention defined in claim 7 wherein said rigid material includes a metal and said viscoelastic material includes a lightly cross-linked, long chained elastomer.

9. The invention defined in claim 8 wherein said elastomer includes a polyester-based polymer having a shear loss factor greater than 0.2.

10. An electroacoustic transducer comprising, a piezoelectric ceramic transducing element, a housing defining an internal chamber for containing said element, means for supporting said element within said chamber, means for attaching said supporting means to said housing within said chamber, and means for attaching said element to said supporting means to form a composite structure having a neutral bending plane, characterized in that said supporting means includes a trilaminar planar member having a top layer, a middle layer, and a bottom layer, said top and bottom layers comprising a metal and said middle layer comprising a viscoelastic material, and further characterized in that said plane is located within said middle layer.

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