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[54] ELECTROACOUSTIC TRANSDUCER RESISTANT TO EXTERNAL MECHANICAL VIBRATIONS

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[52] **U.S. Cl.** **310/9.4,** 310/8.2, 310/8.4
[51] **Int. Cl.** **H01v 7/00**
[58] **Field of Search**.....310/8.2, 9.1–9.8, 310/8.4

[56] **References Cited**

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Primary Examiner—James D. Trammell
Assistant Examiner—Mark O. Budd
Attorney—R. J. Guenther et al.

[57] **ABSTRACT**

An electromechanical transducer element is supported within a transducer housing by a resilient mounting assembly which includes a mass element and a pair of conical washers. The washer stiffness and the mass element are adjusted for a natural resonant frequency below the transducer operating frequency band. Externally generated mechanical vibrations applied to the transducer housing are transmitted through the mounting assembly to the transducer largely at low frequencies, and thus do not interfere with transducer operation in the frequency band of interest.

12 Claims, 2 Drawing Figures

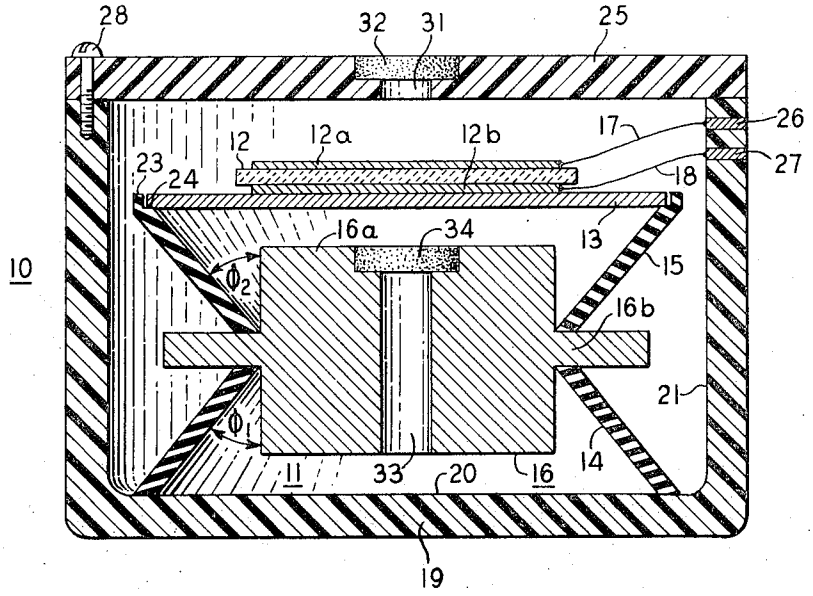

FIG. 1

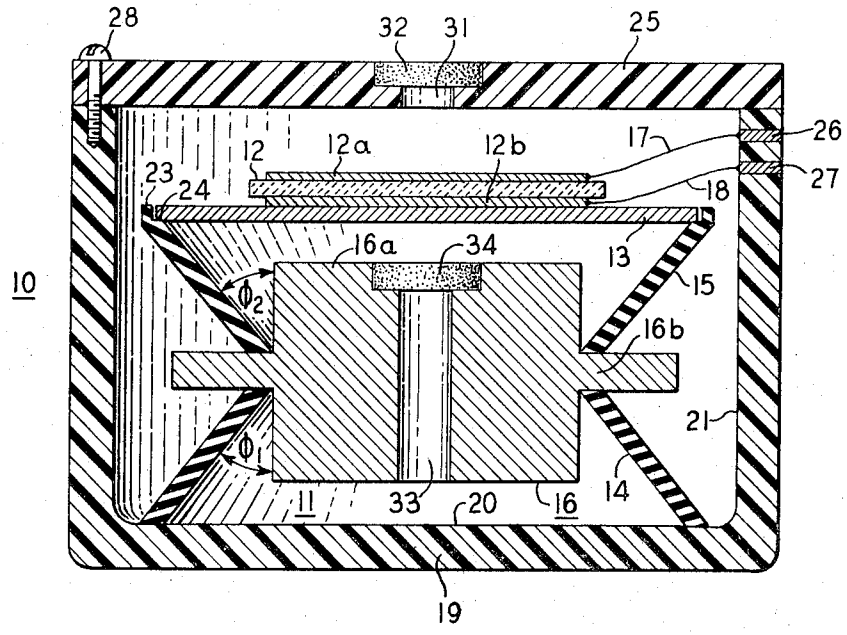
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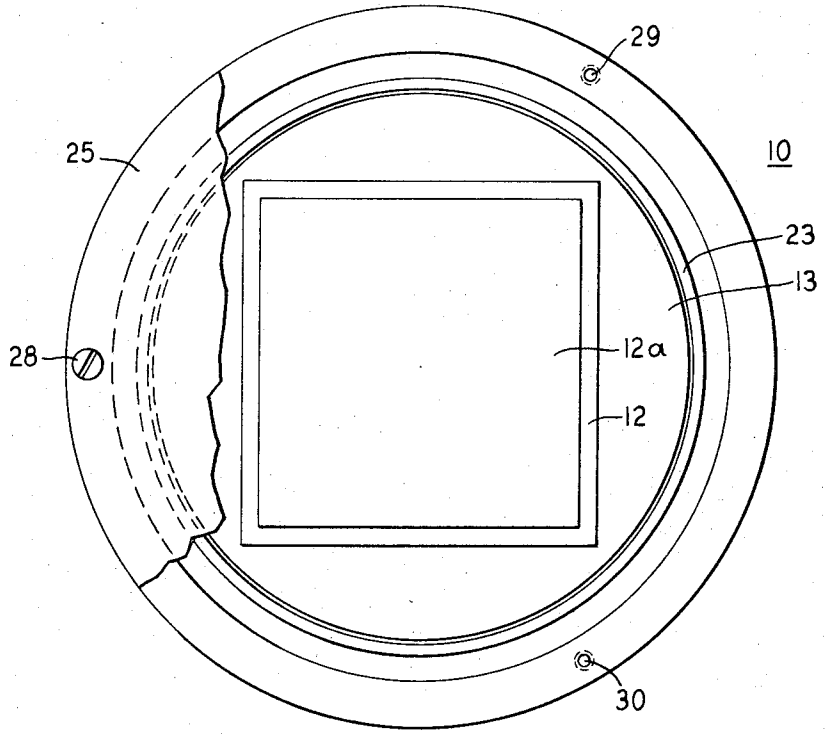
FIG. 2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ELECTROACOUSTIC TRANSDUCER RESISTANT TO EXTERNAL MECHANICAL VIBRATIONS

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 wherein a mechanical filter is provided to render the instrument resistant to interference from externally generated mechanical vibrations.

2. Description of the Prior Art

The need for an electroacoustic transducing instrument that is compact, stable and efficient has led designers, especially in the telephone industry, to seek practical alternatives for the devices now in use. One such alternative, which is quite attractive from a cost point of view, and which is capable of meeting performance objectives, is the piezoelectric ceramic transducer. This transducer, however, and others of the electromechanical type, presents problems in the design of a suitable means for appropriately supporting the transducing element with the transducer housing, so as to achieve a desired frequency response characteristic and yet provide a sufficient degree of mechanical isolation between the housing and the element. One approach utilized in prior art piezoelectric ceramic transducers is to mount the transducing element between a pair of compliant rubber gaskets, as shown in U.S. Pat. No. 3,137,836 issued to C. P. Glover on June 16, 1964. Unfortunately, such an arrangement leads to the possibility of ceramic element damage if too much compression is applied to the rings during assembly. Additionally, overcompression generally increases the mechanical coupling between the element and its housing, leading to the undesirable interference from the mechanical vibrations mentioned above. On the other hand, if an exceedingly soft supporting arrangement is used to reduce mechanical coupling as, for example, in the case of a small amount of gasket compression, the transducer frequency response characteristic may often be unsatisfactory. Furthermore, a minimum amount of compression must be applied, for otherwise the transducing element may become dislocated from its desired position within the housing.

Another approach has been to mount the entire transducer in an encasement of compliant material, such as rubber. The rubber stiffness and transducer mass are adjusted to obtain a resonance at a frequency below the transducer operating frequency band, so that externally generated mechanical vibrations within the operating band are attenuated. This approach suffers the disadvantage of requiring a good deal of space, and additionally meets with difficulty in achieving a resonant frequency that is consistent among transducers in a production lot.

A third approach available to avoid interference with the transducer response from mechanical vibrations is to attach mass elements directly to the vibrating element, thereby lowering its resonant frequency and decreasing its sensitivity to high-frequency disturbances. Unfortunately, since the mass element is attached directly to the transducing element, the instrument sensitivity at high frequencies is reduced for both mechanically induced vibrations and for acoustically induced vibrations in the same frequency band, the latter of which may be important in attaining a transducer frequency response characteristic of a desired shape.

Accordingly, it is a broad object of the present invention to provide an electroacoustic transducer, preferably of the piezoelectric type, that is resistant to externally generated mechanical vibrations, and yet capable of achieving a desired frequency response characteristic.

Additional objects of the invention include the provision in such a transducer of means for supporting the transducing element that achieve a desired degree of mechanical isolation between the element nd the instrument housing that is easily assembled without danger of element damage, and that is relatively efficient in converting sound energy into electrical energy, and vice versa, over the operating band of interest.

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 a novel resilient mounting assembly for supporting the transducing element within the transducer housing. Briefly, the assembly includes a mass element, a first resilient conical washer for supporting the mass element and spacing it from the housing bottom, and a second resilient conical washer supported by the mass element and in turn adapted to support the transducing element. The stiffness of the first washer and the mass element are arranged for a natural resonant frequency f_o below the low frequency limit f_1 of the transducer operating frequency band. Externally generated low-frequency mechanical vibrations applied to the transducer housing are thereby easily transmitted through the washer-mass element combination, whereas vibrations in the transducer operating band are attenuated, and thus do not interfere with transducer operation. The advantageous shape of the second washer adds an additional degree of mechanical decoupling between the transducer housing and the transducing element, further improving overall performance.

By the advantageous arrangement of a mounting assembly in accordance with the invention wherein the mass element is indirectly connected to the transducing element, unlike the above-mentioned prior art instruments, the efficiency of the transducer in converting sound energy to electrical energy, and vice versa, is not reduced, and a desired frequency response characteristic is easily obtained. Additionally, since gaskets and other rigid supporting means are not required, transducer assembly can be expeditiously accomplished without danger of element damage or transducer malfunction due to over or undercompression.

BRIEF DESCRIPTION OF THE DRAWING

The aforementioned and other features and advantages of the instant invention will become more readily apparent to those 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 top view of the transducer of FIG. 1 with a portion of the coverplate removed.

DETAILED DESCRIPTION

Referring now to FIGS. 1 and 2, there is shown in central cross-sectional and top views, respectively, an electroacoustic transducer constructed in accordance with the principles of the invention. The transducer comprises a housing, designated generally at **10**, and a planar electromechanical transducing element **12** attached to a diaphragm **13** within the housing. A resilient mounting assembly, to be described more fully hereinafter, is provided for supporting the diaphragm-element structure within an internal chamber **11** defined by the housing.

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 myself, entitled "Electroacoustic Transducer Having Improved Transducing Element Supporting Means" and assigned to the same assignee. After fabrication, electrodes are affixed to both faces of the ceramic disc, such as electrodes **12*a*** and **12*b***, shown greatly enlarged in FIG. 1 for the purpose of illustration. 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. Thin metal foil leads **17** and **18** are attached to electrodes **12*a*** and **12*b***, respectively, for enabling connection to transducing element **12**.

Transducing element **12** is next affixed to a thin plate or diaphragm, such as diaphragm **13**, which serves to support element **12**. Diaphragm **13** may be fabricated from a metal such as nickel-steel, brass, or the like, and has a surface area at least coextensive with the area of element **12**. While in certain cases the outer peripheries of element **12** and diaphragm **13** may be congruent, it may be advantageous in other instances, to be explained hereinafter, to employ different shapes for the aforesaid components, and/or non-symmetrically locate element **12** with respect to diaphragm **13**. Fastening of element **12** to diaphragm **13** may be accomplished by applying a layer of cement, epoxy, or other suitable adhesive therebetween, and by applying pressure thereto. If desired, lead **18** may be attached to diaphragm **13** instead of electrode **12*b***; in this event, the cement used must be electrically conductive, or alternatively, a very thin layer of nonconducting cement may be employed, provided metal-to-metal contact between electrode 12b and diaphragm **13** is assured when these components are pressed together. To prevent rupture or damage to the element-diaphragm bond due to temperature changes, the coefficient of thermal expansion of the diaphragm material is preferably selected to be comparable to the thermal coefficient of element **12**.

Transducing element **12** and diaphragm **13** are contained in housing **10**, which comprises a cup-shaped body member **19**, preferably fabricated from a hard plastic material, having an inner bottom wall **20** and a side wall **21**, and a frontal plate **25**, also plastic. While plate **25** and body member **19** are preferably round, as shown in FIG. 2, other shapes may sometimes be advantageously employed. Means for supporting element **12** and diaphragm **13** within chamber **11** of housing **10** include first and second resilient conical washers **14** and **15**, respectively, and a mass element **16**. The latter, together with washer **14**, which supports it and spaces it from the housing bottom wall **20**, essentially forms a spring platform typically used to isolate machine vibrations from a supporting floor, as described in *Mechanical Vibrations*, J. P. Den Hartog, Fourth Edition, Chapter **2.12**. The natural resonant frequency f of the platform is determined by the stiffness s of washer **14**, and the mass m of mass element **16**, (assuming that the masses of element **12** and diaphragm **13** are small in relation to m) according to the formula:

$$f_o = 1/2\pi \sqrt{(s/m)}\ \text{Hz} \qquad (1)$$

For a low resonant frequency, the stiffness of washer **14** should be minimized, since the value of m can be increased only within the limits dictated by the size of chamber **11**. This minimization is accomplished, in part, by fabricating washer **14** from a soft silicone rubber, such as Dow Corning "Silastic" S55U, or any other similarly resilient material. Additionally, by forming the washer in the shape of a hollow frustum of a cone, with a cone angle θ_1 of approximately 25° with the vertical, the stiffness of the washer is considerably reduced, as compared to an ordinary O-ring or simple annular gasket. For a stiffness of 10×10^6 dynes/cm and a mass of 15 grams, the natural resonant frequency f_o of the platform, according to equation (1) is approximately 130 Hz. At frequencies above f_o, the combination of mass element **16** and washer **14** act as a mechanical filter, or, stated differently, high frequency mechanical vibrations originating in housing **10** are inefficiently transmitted to element **16**. Accordingly, vibrations generated by dropping, tapping and rubbing the transducer housing, and from other similar sources, will be greatly attenuated by the transducing element support platform.

A still further degree of mechanical isolation is provided between transducing element **12** and housing **10** by the provision of second resilient conical washer **15**, which like washer **14**, may be fabricated from a soft silicone rubber. Washer **15** similarly comprises a hollow frustum of a cone with a cone angle θ_2 of approximately 25° with the vertical. The base portion of washer **15** is provided with an upwardly extending annular flange **23** which defines an inwardly facing annular groove **24** for supporting diaphragm **13** and element **12** and for spacing the composite structure from mass element **16**.

In order to more fully appreciate the additional isolation provided by washer **15**, the operation of the transducer of FIG. 1 should be understood. When used as a microphone with a piezoelectric ceramic transducing element, the transducer transforms acoustic energy to electrical energy by converting the cupping or spherical bending induced in element **12** by the incoming sound waves to a voltage generated across electrodes 12a and 12b by piezoelectric action. Since this voltage is generated only by bending and not by up and down or piston-like motion of element **12** and diaphragm **13**, the outer periphery of the diaphragm should be restrained, while its central portion is allowed to move.

This restraint is provided by cementing or otherwise attaching the outer edges of diaphragm **13** to groove **24** of washer **15**. The same type of bending motion induced in element **12** by sound waves may also be generated by vibration of the transducer housing. This motion results from the transmission of a mechanical wave from the housing to the edges of diaphragm **13** through washer **14**, mass element **16** and washer **15**, while the central portion of the diaphragm and transducing element tends to remain stationary due to inertia. The design of washer **15**, in accordance with the invention, aids in isolating the transducing element from such disturbances in two ways. First, the conical shape of washer **15** changes the direction of the mechanical wave applied to element **12**, so that the undesirable component thereof in the direction perpendicular to the face of element **12** is reduced by a factor equal to the cosine of the cone angle θ_2. Secondly, the length of the path that the mechanical wave must traverse is increased, in comparison to a simple annular washer, so that additional energy is advantageously absorbed in the washer itself. Laboratory tests of a transducer wherein diaphragm **13** and element **12** are supported by a single conical rubber washer with a cone angle of 25° show an improvement of 4 dB in signal-to-noise ratio as compared to a similar transducer employing rigid clamping, thereby verifying the theoretical results stated above.

Assembly of the transducer of FIGS. **1** and **2** is accomplished by first securing the base or larger face of washer **14** to bottom wall **20** of member **19** by cement or other suitable means. Mass element **16** is next secured to the narrowed or apex and face of washer **14** in a similar fashion. In order to achieve sufficient mass and aid in properly locating the former with respect to the latter, mass element **16** may advantageously include a central body portion **16*a*** and an outwardly extending annular flange **16*b***, the lower end of portion **16*a*** being adapted to fit within the annulus of washer **14**. The apex end face of washer **15**, which is suitably dimensioned to fit over the central body portion **16*a*** of element **16** is next fastened to flange **16*b*** by cement or other suitable means. The composite diaphragm-element assembly **12, 13** is then seated on annular groove **24** of washer **15**, and similarly fastened thereto. Electrical connection to the transducer is enabled by connecting leads **17** and **18** to terminal rivets **26** and **27**, respectively, which are arranged to extend through the side wall **21** of body member **19**. Assembly of the transducer is completed by positioning frontal plate **25** atop the open end of body member **19**, and by securing it via retaining screws such as screws **28, 29** and **30** positioned around its periphery.

While various arrangements of apertures may be provided in plate **25** to permit communication between the atmosphere and internal chamber **11**, a single centrally located and suitably dimensioned aperture **31**, as shown in FIG. **1**, will suffice. The aperture, in combination with a slab **32** of acoustic resistance material, such as porous sintered steel, forms an acoustic low pass filter, according to well-known transducer design theory, and thus serves to remove undesirable high-frequency peaks from the transducer frequency response characteristic. In a similar manner, an aperture **33** and acoustic resistance slab **34** may be provided in mass element **16**, in order to add acoustic damping to the vibratory system and thereby reduce the magnitude of any resonant peaks.

While FIG. **2** depicts a square transducing element **12** centrally mounted on a round diaphragm **13**, other combinations of different or similar shapes may sometimes be desirable, as may nonsymmetrical location of the element with respect to the diaghragm. These variations are generally intended to upset the natural resonance of the vibratory system formed by the plate and diaphragm, thereby reducing the resonant peak exhibited in the transducer frequency response characteristic. Alternatively, it may sometimes be desirable to replace diaphragm **13** and element **12** by a bilaminar piezoelectric ceramic transducing element, the construction of which is well known to those skilled in the art.

Many other 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, either or both washers **14** and **15** may be inverted, so that the larger face, or base, of each washer abuts with flange **16*b*** of mass element **16**, without affecting the ability of the resilient mounting assembly to render the transducing element resistant to externally generated mechanical vibrations. Additionally, while the peripheral shape of housing **10**, washers **13** and **14** and mass element **16** have heretofore been described as round, it should be clearly understood that appropriate modifications thereto may sometimes be required.

What is claimed is:

1. An electroacoustic transducer comprising an electromechanical transducing element,

a housing defining an internal chamber having an inner bottom wall for containing said element, and

means resistant to externally generated mechanical vibrations for supporting said element within said chamber,

said supporting means including

a mass element,

a first resilient conical washer for supporting said mass element on said bottom wall, and

a second resilient conical washer for supporting said transducing element on said mass element.

2. The invention defined in claim **1** wherein said transducing element comprises a ferroelectric ceramic material bonded to a metallic diaphragm.

3. The invention defined in claim **2** wherein said transducer has an operating frequency band having a lower limit f_1, said first washer has a stiffness s, said mass element has a mass m, and wherein $1/2\pi\sqrt{s/m}$ is less than f_1.

4. The invention defined in claim **1** wherein said first washer comprises a hollow frustum of a cone making a cone angle of approximately 25° with the vertical and said second washer comprises a hollow frustum of a cone making a cone angle of approximately 25° with the vertical.

5. The invention defined in claim **4** wherein said transducing element includes a ferroelectric ceramic selected from the group consisting of barium titanate, lead titanate-lead zirconate, and sodium potassium niobate.

6. An electroacoustic transducer comprising

an electromechanical transducing element,

a housing having an internal chamber and an inner bottom wall for containing said element,

a mass member,

first means for supporting said mass member on said bottom wall; and

second means for supporting said element on said mass member,

wherein said first means and said second means include a first resilient conical washer, and a second resilient conical washer, respectively.

7. The invention defined in claim 6 wherein said transducer has an operating frequency band, and said mass member and said first means are arranged for a natural resonance at a frequency below said band.

8. The invention defined in claim 7 wherein said first and said second conical washers each comprise a hollow frustum of a cone with a cone angle of approximately 25° to the vertical.

9. The invention defined in claim 8 wherein said mass element includes a central body portion and an outwardly extending annular flange,

said first washer includes a first apex end face,

said second washer includes a second apex end face, and

said first and second apex end faces are fastened to said flange.

10. The invention defined in claim 9 wherein said second washer further includes a base face and an upwardly extending annular flange integral with said base, said upwardly extending annular flange defines an inwardly facing annular groove,

said transducing element includes a piezoelectric ceramic material affixed to a diaphragm, and

said diaphragm is fastened to said annular groove.

11. The invention defined in claim 10 wherein said ceramic material is selected from the group consisting of barium titanate, lead-titanate-lead zirconate, and sodium potassium niobate.

12. The invention defined in claim 11 wherein said transducing element is square and said diaphragm is round.

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