US 20080273720A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2008/0273720 A1

(43) Pub. Date: Nov. 6, 2008

Johnson et al.

(54) OPTIMIZED PIEZO DESIGN FOR A MECHANICAL-TO-ACOUSTICAL TRANSDUCER

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(21) Appl. No.: **11/421,345**

(22) Filed: **May 31, 2006**

Related U.S. Application Data

(60) Provisional application No. 60/685,841, filed on May 31, 2005, provisional application No. 60/685,842, filed on May 31, 2005.

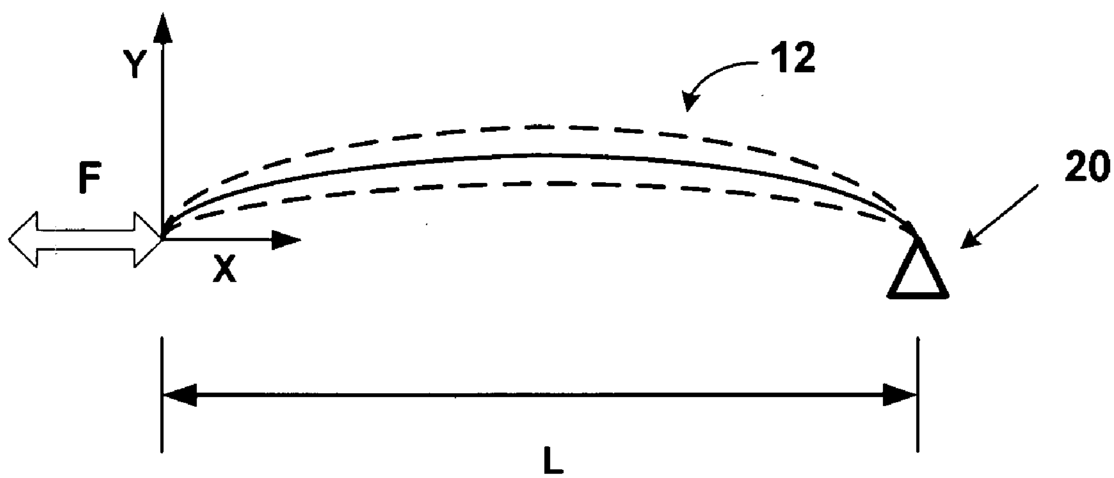
Publication Classification

(51) **Int. Cl.**
H04R 17/00 (2006.01)

(52) **U.S. Cl.** **381/190**

(57) **ABSTRACT**

The present invention relates to an acoustic transducer that coverts a mechanical motion into acoustical energy. The acoustic transducer includes a diaphragm and at least one support on at least a portion of the diaphragm. At least one actuator may then be provided that is operatively coupled to the diaphragm, wherein the diaphragm or the actuator include one or more areas of reduced stiffness relative to other areas on the diaphragm or actuator. In addition, the present invention relates to modifications in actuator design with respect to engagement of the diaphragm and engagement of the actuator with a given support.



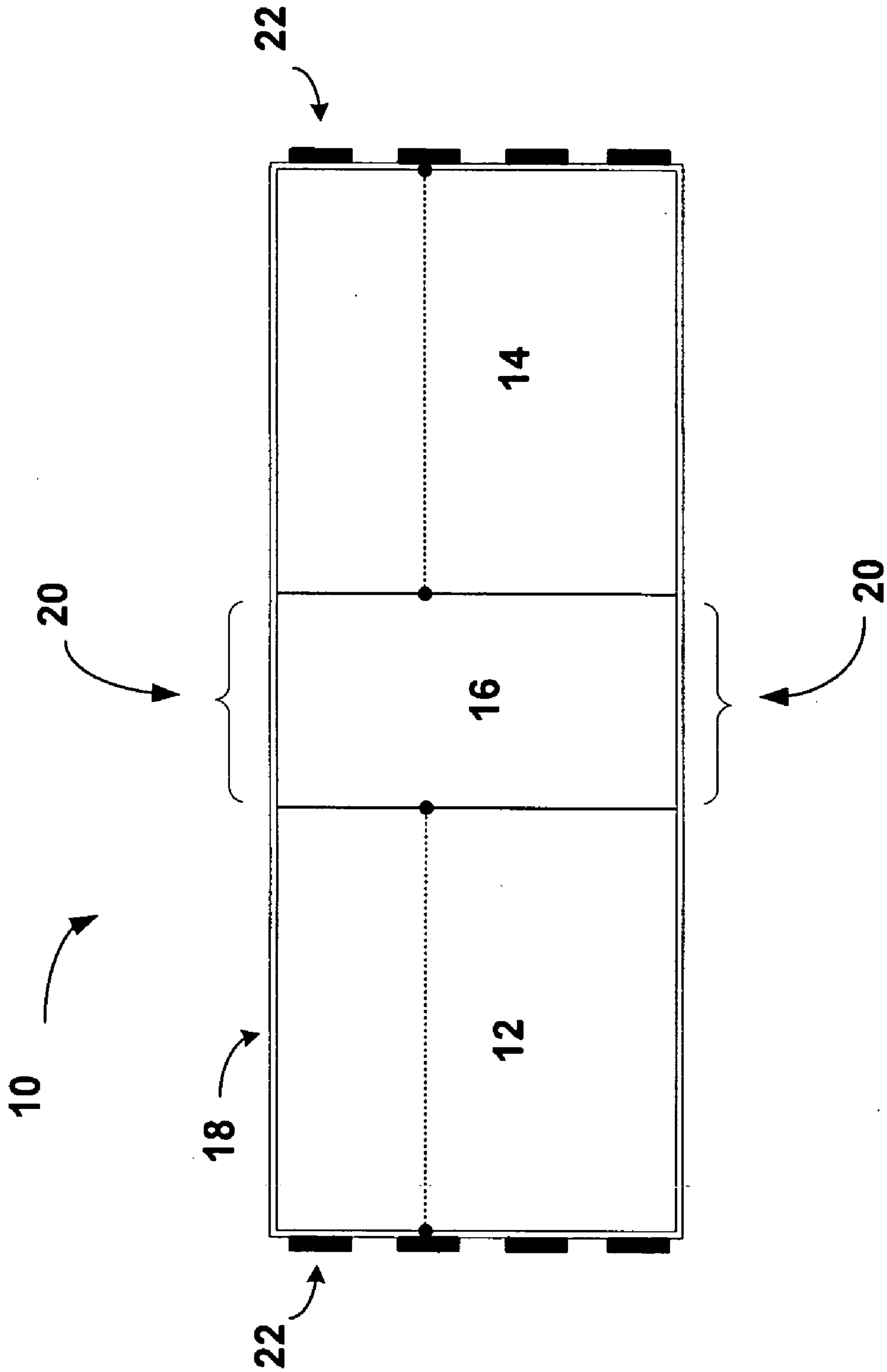


FIG. 1

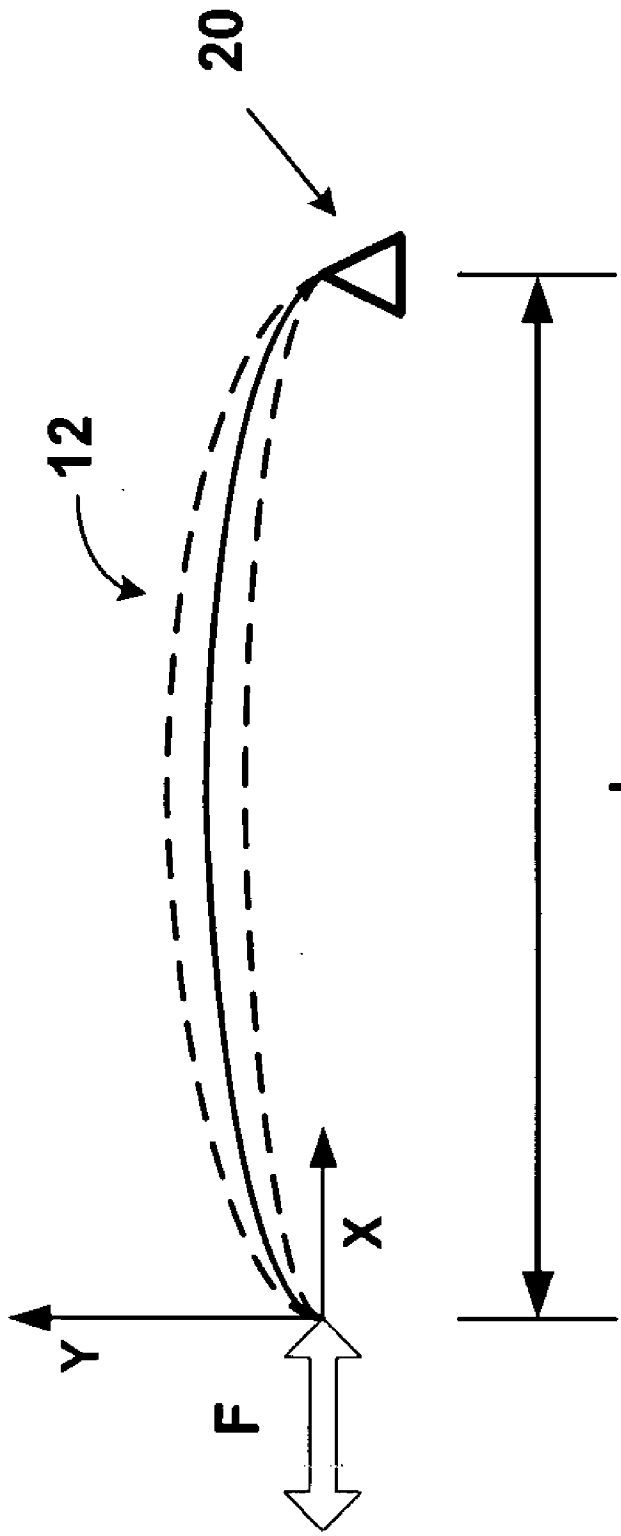


FIG. 2

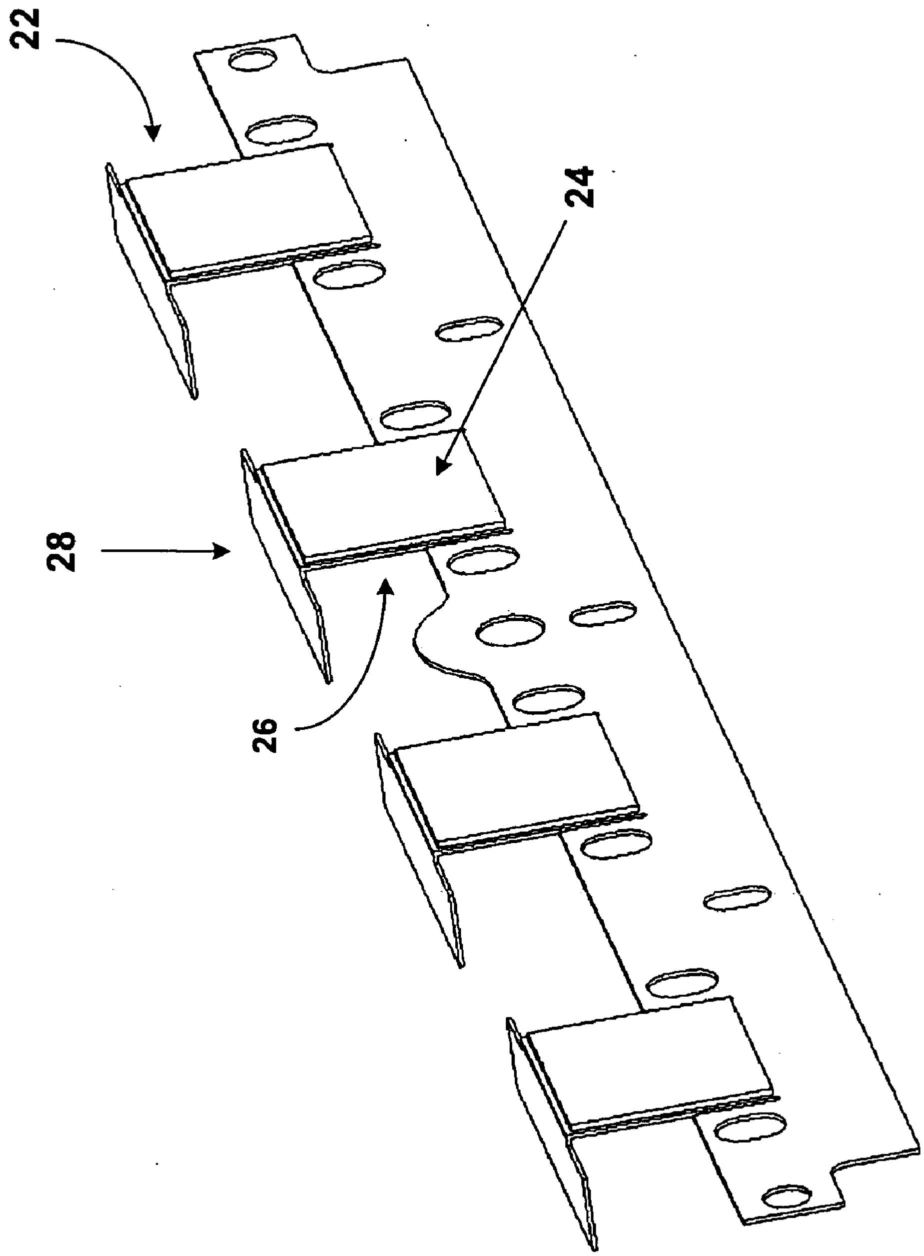


FIG. 3

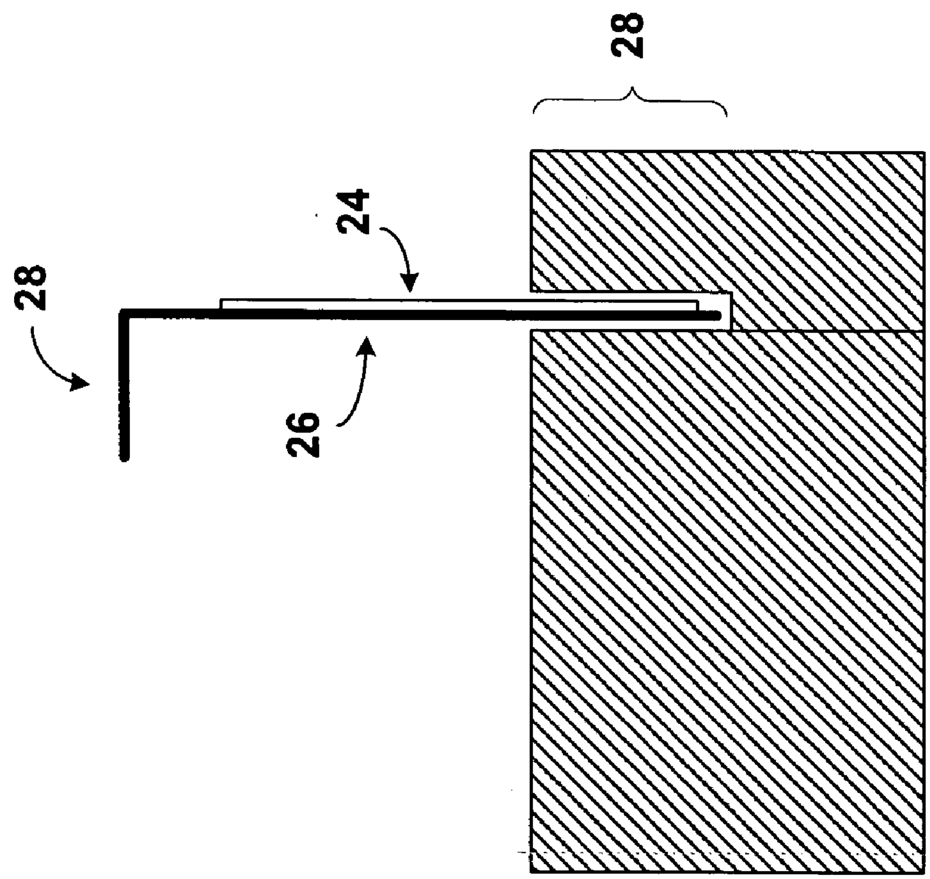


FIG. 4

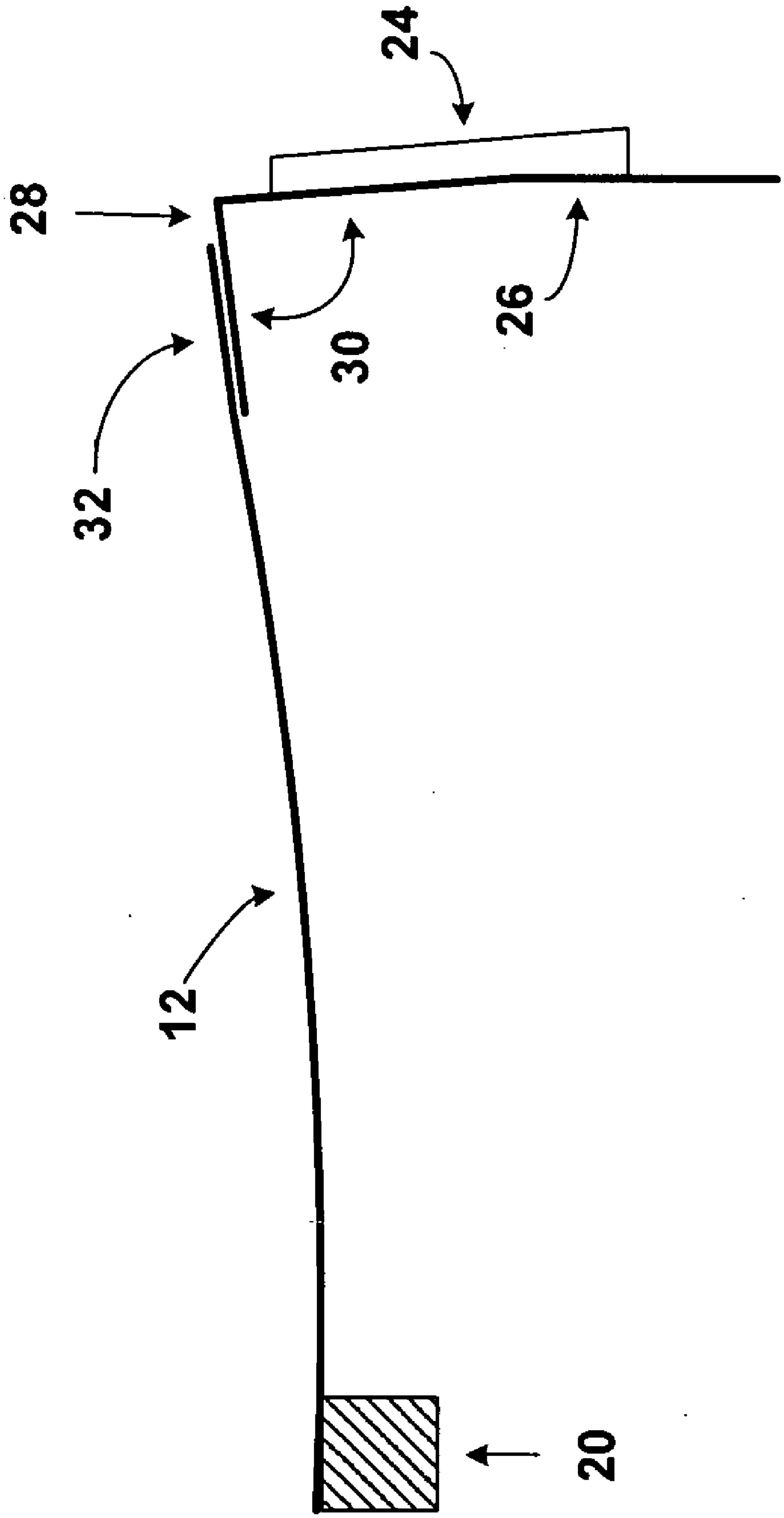


FIG. 5

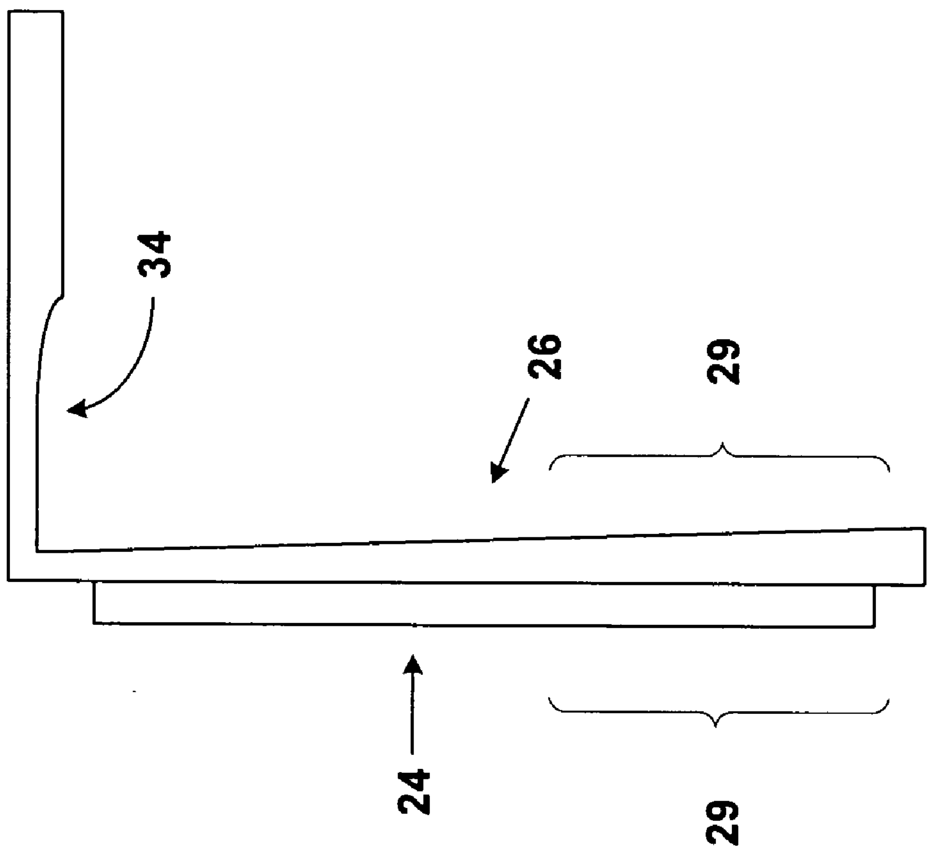


FIG. 6

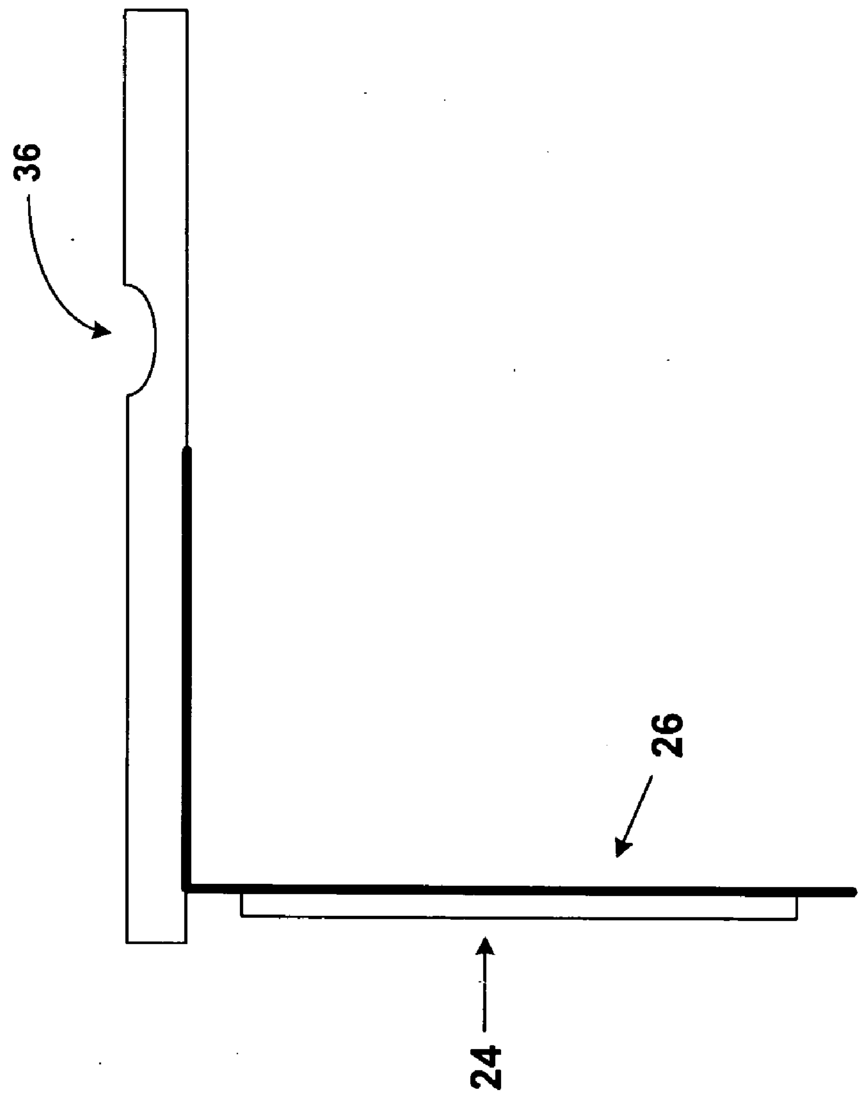


FIG. 7

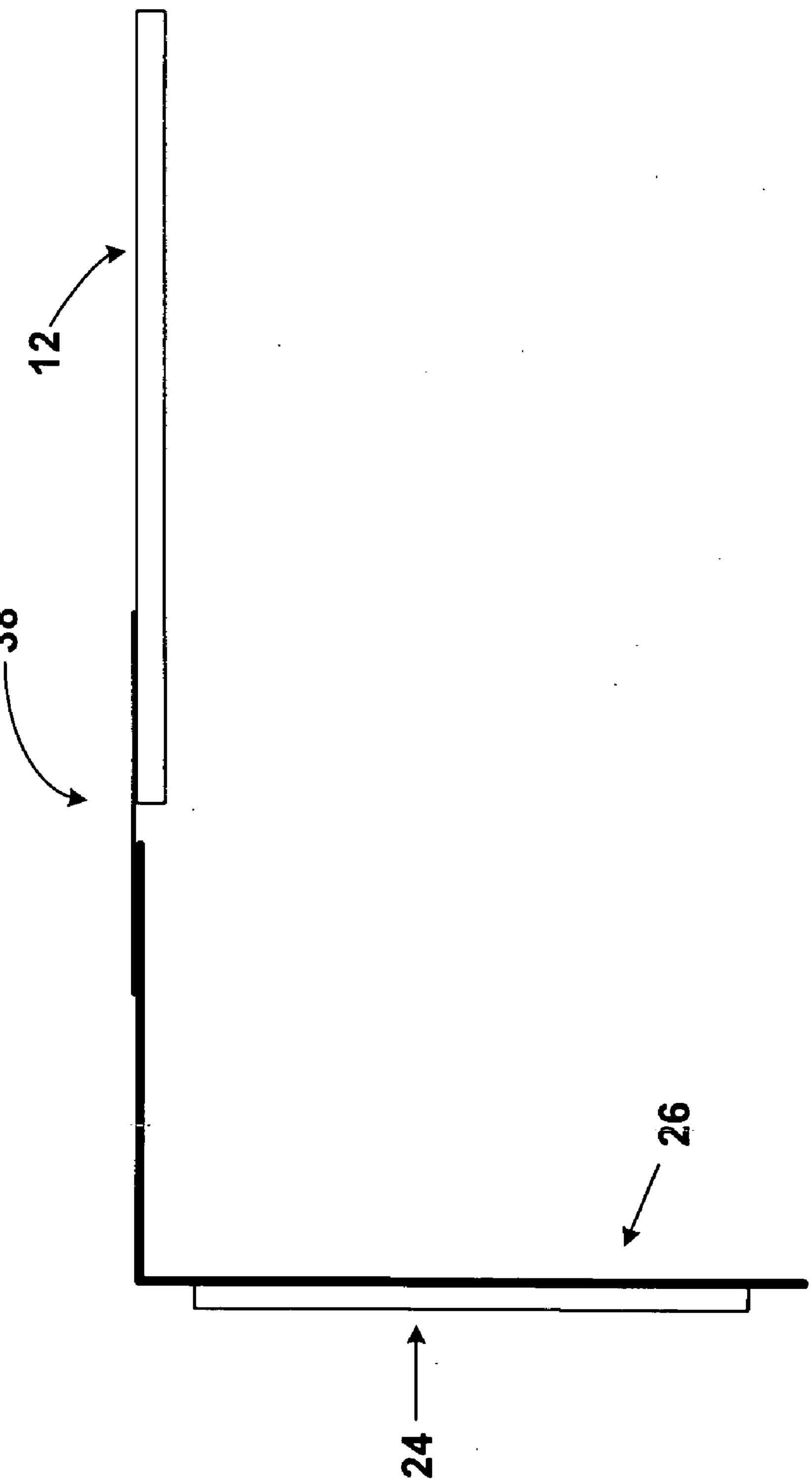


FIG. 8

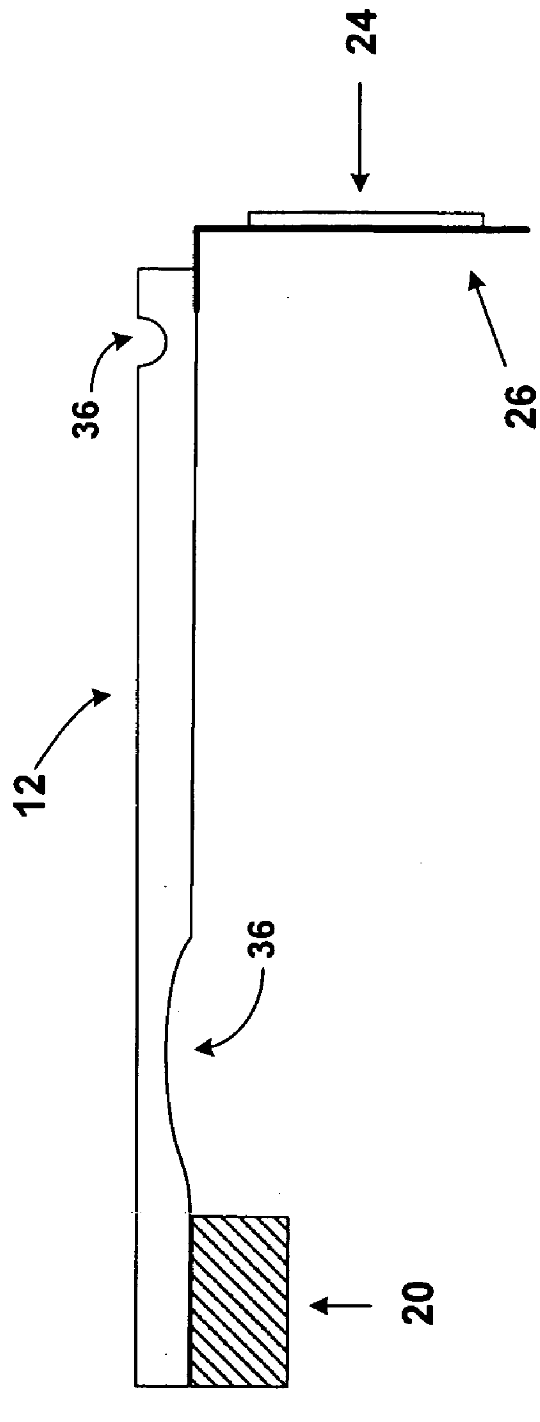


FIG. 9

OPTIMIZED PIEZO DESIGN FOR A MECHANICAL-TO-ACOUSTICAL TRANSDUCER

[0001] This application claims the benefit of U.S. Provisional Applications Ser. Nos. 60/685,841 and 60/685,842, both filed May 31, 2005, which are incorporated herein by reference. Reference is also made to U.S. application Ser. No. [TBD] entitled "Diaphragm Membrane And Supporting Structure Responsive To Environmental Conditions", filed simultaneously herewith, whose teachings are also incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Mechanical-to-acoustical transducers may have one actuator that may be coupled to a speaker membrane or diaphragm that may then be anchored spaced from the actuator. Such a system may provide a diaphragm-type speaker where a display may be viewed through the speaker. The actuators may be electro-mechanical, such as electromagnetic, piezoelectric or electrostatic. Piezo actuators do not create a magnetic field that may then interfere with a display image and may also be well suited to transform the high efficiency short linear travel of the piezo motor into a high excusion, piston-equivalent diaphragm movement.

SUMMARY OF THE INVENTION

[0003] In one exemplary embodiment, the present invention relates to an acoustic transducer that coverts a mechanical motion into acoustical energy. The acoustic transducer includes a diaphragm and at least one support on at least a portion of the diaphragm. At least one actuator may then be provided that is operatively coupled to the diaphragm, wherein the diaphragm or the actuator include one or more areas of reduced stiffness relative to other areas on the diaphragm or actuator.

[0004] In another exemplary embodiment the present invention relate to an acoustic transducer that coverts a mechanical motion into acoustical energy. The acoustic transducer includes a diaphragm and at least one support on at least a portion of the diaphragm. At least one actuator may then be provided that is operatively coupled to the diaphragm, wherein the actuator and the diaphragm have a stiffness, and wherein the diaphragm and the actuator are joined by a material of reduced stiffness relative to the actuator stiffness or the diaphragm stiffness.

[0005] In another exemplary embodiment, the present invention relates to an acoustic transducer that coverts a mechanical motion into acoustical energy, The acoustic transducer includes a diaphragm and at least one support on at least a portion of the diaphragm. At least one actuator may then be provided that is operatively coupled to the diaphragm, wherein the activator comprises a piezo actuator wherein all or a portion of the actuator, not coupled to said diaphragm, may be restricted in its movement.

[0006] In another exemplary embodiment, the present invention relates to an acoustic transducer that coverts a mechanical motion into acoustical energy. The acoustic transducer includes a diaphragm and at least one support on at least a portion of the diaphragm. At least one actuator may then be provided that is operatively coupled to the diaphragm, wherein the actuator includes a substrate that extends outward from the actuator and which supplies an attachment area for coupling to the diaphragm.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a planar view of a mechanical-to-acoustical transducer, coupled to a diaphragm,

[0008] FIG. **2** is an exemplary cross-sectional view illustrating diaphragm flexing.

[0009] FIG. **3** is an exemplary view of an actuator array.

[0010] FIG. **4** is an exemplary view of an actuator in a clamped position.

[0011] FIG. **5** is an exemplary cross-sectional view of an acoustic transducer and diaphragm configuration.

[0012] FIG. **6** is an exemplary cross-sectional view of a piezo actuator.

[0013] FIG. **7** is an exemplary cross-sectional view of a piezo actuator and a portion of an attached diaphragm.

[0014] FIG. **8** is an exemplary cross-sectional view of a piezo actuator and a portion of an attached diaphragm,

[0015] FIG. **9**. is an exemplary cross-sectional view of a piezo actuator and a diaphragm attached to a support.

DETAILED DESCRIPTION

[0016] A mechanical-to-acoustical transducer, coupled to a diaphragm, for the purpose of producing audio sound, is disclosed in U.S. Pat. No. 7,038,356, whose teachings are incorporated herein by reference. In one configuration, the transducer amounts to a piezo motor coupled to a diaphragm so that the excursion of the actuator is translated into a corresponding, mechanically amplified excursions of the diaphragm. The diaphragm may be curved and when optically clear, can be mounted on a frame over a visual display to provide an audio speaker. The diaphragm may therefore be characterized by a relatively large, pistonic-equivalent excursion. A typical amplification or mechanical leveraging of the excursion may be five to fifteen fold.

[0017] FIG. **1** illustrates in planar top view an exemplary mechanical-to-acoustical transducer **10** of the present invention. As illustrated, two diaphragm channels **12** and **14** may be separated by a relatively inactive zone **16** wherein the membrane may be rigidly engaged to the frame **18** along the horizontal cross-bars of the frame shown generally at **20**. With reference to FIG. **2**, the piezo actuators **22** under electrical conditions may produce both a positive and negative motion along the X-axis that produces a corresponding positive and negative pistonic displacement along the Y-axis, by flexing and unflexing the diaphragms **12** and **14**. Since the piezo may be fixed at one end, the motion along the X axis as it is driven produces a mechanical levering. FIG. **2**, for simplicity, illustrates a mono speaker.

[0018] As illustrated, along one edge of the two diaphragms may be a number of piezo actuators **22** which may be discrete or separate actuators or an array of actuators. An exemplary array of such piezo actuators is shown in FIG. **3**. The array of piezo actuators may therefore extend along all or portion of an entire edge of the diaphragm which may in turn allow for the piezo drivers themselves to be conveniently stored on a roll and cut to length depending upon the size of given application (i.e., edge length of a given diaphragm that is being configured for mechanical-to-acoustical engagement). As shown in FIG. **3** the piezo actuators **22** may include ceramic material **24** and metallic substrate material **26**. In addition, the metallic substrate material may include a section that extends outward, as shown generally at **28** and which, as more fully described below, provides relatively more efficient attachment to the diaphragm material.

[0019] In addition, it may be noted that one method of optimizing the relative stiffness and response of the driving end of the piezo, is to clamp a relatively large section of the piezo, which may then restrict the piezo movement when electrically activated. Such clamping may also be facilitated by use of an adhesive as between the frame and the actuator. As shown in FIG. **4**, by clamping any portion of the surface of the active ceramic, higher output of the piezo can be obtained. As illustrated, about 30-40% of the ceramic has been clamped at region **28**. That is, the piezo is no longer capable of bending about the relatively weaker metallic substrate portion in the clamed region as shown. Accordingly, the force that is applied by the piezo is optimized and increased as delivered to the diaphragm. It has been found that by clamping between 10-75% of the surface of the ceramic, including all values and increments therein, a relatively higher force may occur at the piezo tip (proximate the diaphragm).

[0020] In addition, it may be appreciated that the piezos herein which include a ceramic layer and at least one conductive (metallic) layer on an opposing side may resemble a capacitor in performance. Accordingly, the larger the surface area of the conductive metallic layer may provide a piezo that may retain more charge and provide greater relative output. In addition, the performance of the piezo may be altered in the event that the conductive electrode layers are selectively applied to the ceramic. For example, if the conductive layer may be applied to the ceramic in a graduated pattern, such would then provide the greatest relative change at the desired location at the piezo tip. It may therefore be appreciated that by way of such design, apart from improving the output at the piezo tip, the ability to clamp on the active area of the piezo is improved with a reduced possibility of piezo failure, and in addition, by use of a graduated or discontinuous electrode layer, one may tune and optimize the performance of the piezo for a given diaphragm requirement.

[0021] With attention next directed to FIG. **5**, it can be seen that by extending a portion of the piezo array substrate beyond the ceramic portion and forming and bending it at an angle (see arrow **30**), a relatively large area may be provided for attachment of the piezo to the diaphragm at region **32**. By extending the substrate **26** outward from the ceramic one may provide two advantages. First, a relatively large area may be provided for diaphragm attachment which may more efficiently couple the piezo to the diaphragm. Secondly, by adjusting the angle of the outwardly projecting substrate from the ceramic one may better maintain a desired curvature in the diaphragm by providing a generally tangent attachment location (see again region **32**) as between a portion of the diaphragm and the outwardly extending piezo substrate material. By tangent attachment it may be understood that a portion of the surface of the diaphragm may engage with a portion of the surface of the actuator. Accordingly, in the context of the present invention when the diaphragm may be convex or concave, the angle **30** may be in the range of 45-145 degrees, including all increments and values therein.

[0022] Attention is next directed to FIG. **6** which illustrates another form of the piezo that may be employed in the mechanical-to-acoustical transducer of the present invention. As can be seen, the piezo substrate may be tapered over its length to again provide for the ability to increase force at the piezo tip. As illustrated, the substrate may be tapered and become thinner as one moves away from the clamped zone, shown generally at **29**. Accordingly, the ceramic may then be able to more efficiently bend the relatively thinner substrate than a relatively thicker portion of the substrate resulting in more force at the tip of the piezo that may then be mechanically engaged with the diaphragm. It may therefore be appreciated that one may adjust the thickness of the metal substrate at any location along its length in order to optimize the force vs. deflection characteristic of the piezo actuator. In addition, as shown in FIG. **6** the metal substrate that extends outwardly towards the diaphragm may itself include an area of reduced thickness **34** which in turn may provide a region of relatively reduced thickness and lower stiffness compared to other sections of such substrate. Such region of reduced thickness may then provide a pivot location as more fully described below. In addition, such area of reduced thickness on the piezo may assume a variety of geometrical shapes, beyond what is illustrated in FIG. **6**.

[0023] FIG. **7** illustrates the configuration wherein the pivot (e.g. region of reduced thickness) **36** may be similarly incorporated directly into the diaphragm. Accordingly, a portion of the diaphragm may be of reduced thickness and provide relatively lower stiffness and a flexure point that allows the diaphragm to pivot about such location when activated by the piezo. Stiffness of the diaphragm or metal substrate of the piezo may be determined by a combination of its material modulus (tensile or flexural) and its cross-section (area moment of inertia). In addition, although the area of reduced thickness **36** is shown as a circular type cut-out, it may again be appreciated that any geometry may be considered to provide reduced thickness or to allow the pivoting as noted herein.

[0024] FIG. **8** illustrates the configuration wherein the pivot may amount to a separate piece of material that connects the piezo and the membrane. The material, as illustrated, may be of reduced thickness relative to either the metallic piezo substrate material and/or diaphragm material. FIG. **9** illustrates that a diaphragm **12** may again be contoured, as shown in cross-section, at those locations wherein it may engage the support **20** or piezo actuator. As can again be appreciated, those sections of the diaphragm that may be of reduced thickness would again flex more readily than those sections that are not of such reduced thickness. It may therefore be appreciated that by this technique, one or a plurality of locations on the diaphragm may be thickened or thinned in order to provide increased flexibility at any desired location. The advantages that also may be realized are that one may develop a more efficient audio speaker for any given piezo array.

[0025] In addition, it can be appreciated that the diaphragm material, being composed of a polymeric type resin, may be prepared such that desired regions of the diaphragm may have different elastic modulus properties (e.g., flexural modulus or "E_{flex}" as compared to other regions of the diaphragm. For example, upon exposure to irradiation (e.g., UV light), the exposed polymeric material may undergo crosslinking type reactions, thereby increasing the value of E_{flex} in those areas of exposure, relative to those areas that may remain unexposed. In such manner, as opposed to development of a pivot location in the diaphragm be employing areas of reduced thickness, one may develop areas in the diaphragm that may have reduced stiffness relative to other areas of the diaphragm. It is therefore contemplated herein the diaphragm may also be prepared such that it relies upon different materials at different locations, with varying stiffness characteristics.

[0026] The foregoing description is provided to illustrate and explain the present invention. However, the description hereinabove should not be considered to limit the scope of the invention set forth in the claims appended here to.

What is claimed is:

1. An acoustic transducer that coverts a mechanical motion into acoustical energy, said acoustic transducer comprising:

a diaphragm;

at least one support on at least a portion of said diaphragm;

at least one actuator operatively coupled to said diaphragm, wherein said diaphragm or said actuator include one or more areas of reduced stiffness relative to other areas on said diaphragm or actuator.

2. The acoustic transducer of claim **1** wherein said diaphragm has a thickness and said area of reduced stiffness includes an area in said diaphragm of reduced thickness.

3. The acoustic transducer of claim **1** wherein said actuator has a thickness and said area of reduced stiffness includes an area in said actuator of reduced thickness.

4. The acoustic transducer of claim **1** wherein both said diaphragm and said actuator include an area of reduced stiffness relative to other areas on said diaphragm and actuator.

5. The acoustic transducer of claim **1** wherein said support overlies a video screen and said diaphragm is spaced from said video screen.

6. An acoustic transducer that coverts a mechanical motion into acoustical energy, said acoustic transducer comprising:

a diaphragm;

at least one support on at least a portion of said diaphragm;

at least one actuator operatively coupled to said diaphragm, wherein said actuator and said diaphragm have a stiffness, and wherein said diaphragm and said actuator are joined by a material of reduced stiffness relative to said actuator stiffness or said diaphragm stiffness.

7. The acoustic transducer of claim **6** wherein said support overlies a video screen and said diaphragm is spaced from said video screen.

8. An acoustic transducer that coverts a mechanical motion into acoustical energy, said acoustic transducer comprising:

a diaphragm;

at least one support on at least a portion of said diaphragm;

at least one actuator operatively coupled to said diaphragm, wherein said activator comprises a piezo actuator wherein all or a portion of said actuator, not coupled to said diaphragm, is restricted in its movement.

9. The acoustic transducer of claim **8** wherein said actuator is restricted in its movement by clamping all or a portion of said actuator.

10. The acoustic transducer of claim **8** wherein said support overlies a video screen and said diaphragm is spaced from said video screen.

11. An acoustic transducer that coverts a mechanical motion into acoustical energy, said acoustic transducer comprising:

a diaphragm;

at least one support on at least a portion of said diaphragm;

at least one actuator operatively coupled to said diaphragm, wherein said actuator includes a substrate that extends outward from the actuator and which supplies an attachment area for coupling to said diaphragm.

12. The acoustic transducer of claim **11** wherein said substrate attachment area for said diaphragm comprises an area for which the diaphragm may tangentially attach to said actuator.

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