Fig. 1

A

\[ \frac{\lambda}{4} \]

\[ \frac{\lambda}{2} \]

B

VELOCITY v. LOCATION

C

MECHANICAL STRESS v. LOCATION

D

ELECTRICAL STRESS v. LOCATION

E

POWER LOSS OF PIEZOELECTRIC ELEMENT DUE TO MECHANICAL STRESS v. LOCATION

F

POWER LOSS OF PIEZOELECTRIC ELEMENT DUE TO ELECTRICAL STRESS v. LOCATION

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FIG. 2

Internal Power Dissipation of Loaded Transducer as a Function of Mechanical Output Amplitude

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It is apparent, therefore, that in order to provide a transducer which is characterized by high efficiency and high motional amplitude, and which provides for a better utilization of the piezoelectric material, the piezoelectric material advantageously should be placed away from the node of the electromechanical transducer construction. Quite specifically, it has been discovered that a transducer characterized by a high motional amplitude and improved performance is obtained when the piezoelectric material is placed between the node and the antinode at a location which, when operating at a substantially large motional amplitude, the power loss of the piezoelectric material resulting from the mechanical stress substantially equals that resulting from the electrical stress.

One of the principal objects of this invention, therefore, is the provision of a new and improved electromechanical transducer construction.

Another important object of this invention is the provision of an electromechanical half-wave resonator comprising a mass of metal and a piezoelectric transducer means coupled to the mass for providing sonic energy in response to high frequency electrical energy applied to the transducer means.

Still another important object of this invention is the provision of an electromechanical half-wave resonator using a piezoelectric material which is placed at a location which appears to be optimum for obtaining highly efficient operation of the resonator.

A further object of this invention is the provision of an electromechanical transducer of the clamped sandwich construction using a piezoelectric disk for converting electrical energy to ultrasonic vibrations, the piezoelectric disk being placed at a location at which, when operating the transducer to produce a high motional amplitude, the electrical and mechanical losses of the piezoelectric material are substantially equal.

A still further and other object of this invention is the provision of a sonic transducer which is characterized by improved utilization of the piezoelectric material.

Further and still other objects of this invention will be more clearly apparent by reference to the following description when taken in conjunction with the accompanying drawings, in which:

FIGS. 1A through 1F depict a schematic representation of a typical half-wave sonic transducer per prior art and graphs pertaining thereto;

FIG. 2 is a graph of the internal power dissipation of a half-wave transducer as a function of mechanical output amplitude and as a function of the placement of the piezoelectric element which converts the electrical energy applied to mechanical motion;

FIG. 3 is a view of the improved transducer design in accordance with the teachings of this invention; and

FIG. 4 is a view similar to FIG. 3, but showing a modification.

Referring now to the figures and FIG. 1 in particular, FIG. 1A illustrates a composite piezoelectric transducer comprising a piezoelectric element 12 which is disposed between two one-quarter wave masses 14 and 16, thereby providing the well known sandwich construction. Coupling between the masses 14 and 16 and the element 12 may be effected through an epoxy bond. Also, the use of a central bolt for maintaining the assembly under compression is well known. The rear mass 14 and the front mass 16, as shown, are of the same dimension and material, such as steel, aluminum or titanium, and together with the piezoelectric disk form a half-wave resonator. For the purpose of the graphs per FIGS. 1B through 1F, the piezoelectric disk 12 is centered about the node of the resonator. This fairly standard representation of a composite piezoelectric transducer operating as a half-wave resonator, aside from
The numerical values of the two piezoelectric loss components depend, of course, on the mechanical transducer amplitude and the degree of loading (power output) selected, as well as on the dimension of the piezoelectric element. However, for a given transducer per FIG. 1A, operated at its predetermined maximum allowable amplitude, the ratio will typically be as shown in FIGS. 1E and 1F, indicating that the piezoelectric element when located at the node is subjected to a much greater mechanical stress than to an electrical stress. A far more efficient operation at high motional amplitude can be achieved if the piezoelectric element 12 is moved away from the node and, conversely, a still higher motional amplitude can be achieved for the same allowable total power dissipation. This will be clearly apparent by reference to FIG. 2 which shows the internal power dissipation of the piezoelectric element (combined electrical and mechanical heat loss) of the loaded electroacoustic transducer as a function of mechanical output amplitude. The abscissa and ordinate are labeled in arbitrary units, but provide an indication of relative magnitude.

Curve 15 depicts the internal power dissipation of the piezoelectric element as a function of mechanical output amplitude when the piezoelectric element is located at the node as shown in FIG. 1A. As is evident, the internal power dissipation decreases to a minimum at a motional amplitude value of "I" and then rapidly rises as the mechanical amplitude of the transducer increases to a higher value. As stated heretofore, the rapid increase in power dissipation in the piezoelectric element limits the motional amplitude which can be obtained from the transducer. Curve 16 shows an improved arrangement wherein the piezoelectric element has been moved to a location between the node and the antinode, see FIG. 1A, specifically at a point where the power dissipation responsive to mechanical stress substantially equals the dissipation due to electrical stress, such location being in the vicinity of thirty degrees, considering the antinode to be located at 0 degrees and the node at 90 degrees. As seen from FIGS. 1E and 1F at this location the mechanical and electrical power loss curves are substantially of the same amplitude. The minimum value of internal power dissipation occurs at an amplitude value of "2," showing that the output amplitude of the transducer has been improved by a factor of two for the same internal dissipation. Curve 17 shows a still further improvement wherein the output end of the transducer has been reduced in diameter, such as is shown in FIG. 3, obtaining mechanical amplification of the motion while maintaining the piezoelectric element in the vicinity of 30°. As is apparent the power dissipation is a minimum at the mechanical amplitude value of "3." If the original transducer design per FIG. 1 were operated at this motional amplitude, it will be seen by reference to curve 15, the power dissipation of the ceramic material would increase approximately by a factor of eight. Hence, the improved arrangement provides a transducer which is capable of being operated at high motional amplitude while having a comparatively low power dissipation and, therefore, operating under conditions of very high efficiency.

The novel transducer design as calculated per curve 17 in FIG. 2 is illustrated in FIG. 3. The piezoelectric element 12 has been placed at the location where, when operating the transducer at a load or near its rated load capacity and large motional amplitude, the power loss caused by the mechanical stress applied to the piezoelectric element is substantially equal to the power losses resulting from the electrical stress, the location being in the proximity to 30 degrees. The front or outer portion 26 of the resonator has been reduced in cross-sectional area so as to decrease the force at the node for a given output amplitude. Removing the piezoelectric element assembly from the node permits the reduction of the cross-sectional area to be made pre-
closely at the node 21 where the effect upon the output amplitude apparent at the frontal surface 23 is most effective. Additionally, this construction allows shaping of the front section directly from the node into a variety of cross-sectional shapes, as required by the desired application.

The rear section 22 of the transducer has been increased in diameter over the diameter of the piezoelectric element to cause a mechanical impedance match between the metal and the piezoelectric element, typically lead zirconate titanate. The piezoelectric element, in most instances, has a higher density than the metal portions 22 and 20, the latter being most commonly steel, aluminum or titanium.

The piezoelectric element 12 is backed by a thin metallic annular electrode disk 24 and an insulator block 26, for instance beryllium oxide. The assembly is held under compression by a central bolt 28 threaded into the transducer portion 22. Conductor leads 30 and 32 apply the electrical excitation across the planar surfaces of the piezoelectric disk 12.

FIG. 4 shows a slight variation of the construction per FIG. 3. In order to avoid the need for an electrical insulator, two piezoelectric disks 12A and 12B are used with a central metallic electrode disk 24 disposed therebetween. The back piece 27 can be electrically conductive material (metal) and is on the same electrical potential as the front transducer portion.

In typical examples, a transducer design per FIG. 4, dimensioned for a frequency of 0 kHz, exhibited an internal heat loss of about 6 watts and could be loaded to power levels in excess of 200 watts providing a motion amplitude of 0.0006 inch, thereby indicating an electro-acoustic efficiency of 97 percent. The metal material used was aluminum, the rear portion 22 being two inch diameter by 1/4 inches long, the front portion 20 being 1/4 inches in diameter by 1/2 inches long. A similar transducer made of titanium delivered an output amplitude up to 0.0025 inch, operated with an internal dissipation of about 30 watts and was capable of being loaded in excess of 700 watts, the efficiency being over 95 percent.

It is apparent, therefore, that the above described transducer construction is characterized by high efficiency and constitutes a significant advance in the art. When using the construction disclosed heretofore the losses in the piezoelectric element no longer constitute the limiting factor in obtaining high motional amplitude, but the limiting factor has been moved to the metal which has higher stress limits. In practice, it has been found that, using the construction shown in FIGS. 3 and 4, metal rupture caused by excess stress and fatigue becomes the limiting factor rather than the stress in the ceramic material as experienced previously.

While there has been described and illustrated a preferred embodiment of the novel electro-acoustic transducer construction, it will be apparent to those skilled in the art that various changes and modifications can be made without deviating from the broad principle disclosed herefore.

What is claimed is:
1. An electromechanical transducer assembly comprising:
   a metallic bar;
   a piezoelectric disk driving means including means for energizing said driving means with electrical energy;
   means for mechanically coupling said driving means to said bar and causing a radial surface of said driving means to be in forced contact with a radial surface of said bar;
   said bar, piezoelectric driving means and means for coupling being dimensioned to operate substantially as a half-wave resonator along the longitudinal axis of said bar when said piezoelectric driving means is energized with electrical energy of suitable frequency, and
   said piezoelectric driving means being located outside the zone of maximum stress and at a location where the power loss of said piezoelectric means resulting from mechanical stress substantially equals the power loss resulting from electrical stress when said assembly is resonant as a half-wave resonator along its longitudinal axis and operating at a predetermined motional amplitude and power loading.

2. An electromechanical transducer assembly as set forth in claim 1, said metallic bar including a one-quarter wave resonating output portion which is of reduced cross-sectional area.

3. An electromechanical transducer assembly as set forth in claim 1, said piezoelectric driving means being of a smaller diameter than the bar surface to which said disk is coupled by said means for coupling.

4. An electromechanical transducer assembly as set forth in claim 1, said means for coupling comprising a threaded bolt.

5. An electromechanical transducer assembly as set forth in claim 1, said piezoelectric driving means being located substantially in the vicinity of 30 degrees assuming the node to be located at 90 degrees and the anti-node at zero degrees.

6. An electromechanical transducer assembly as set forth in claim 5, said piezoelectric driving means comprising two stacked disks having a metallic electrode disposed therebetween for providing electrical connection to one side of each disk.

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