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ULTRASONIC TRANSDUCER WITH ABSORPTIVE LOAD

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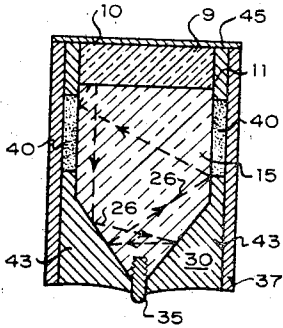


Fig. 1

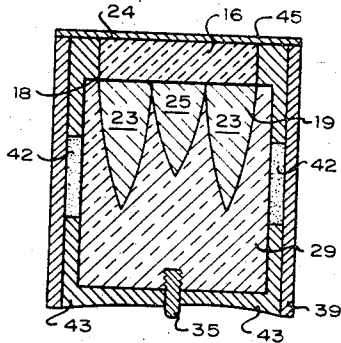


Fig. 3

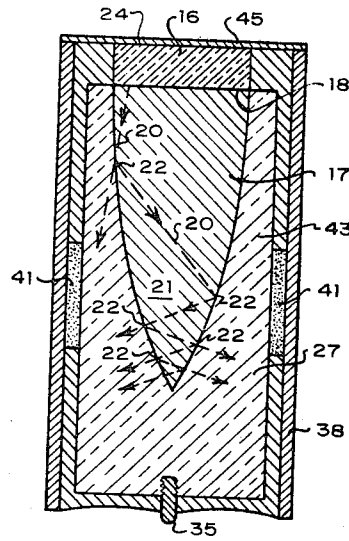


Fig. 2

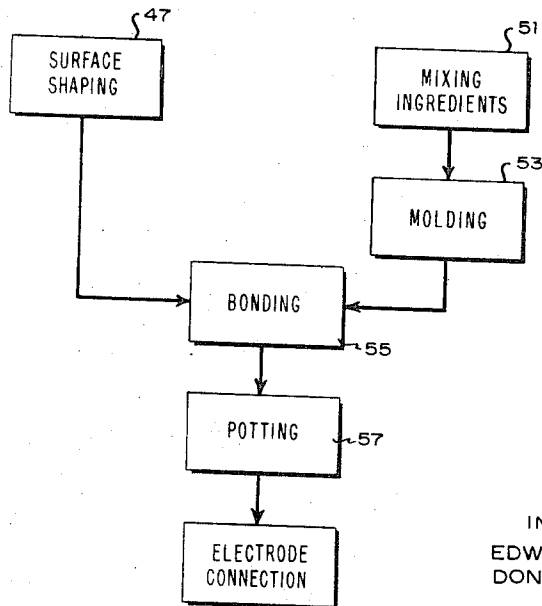


Fig. 4

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ULTRASONIC TRANSDUCER WITH ABSORPTIVE LOAD

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ABSTRACT OF THE DISCLOSURE

An improved ultrasonic transducer includes an absorptive load which is acoustically coupled to a piezoelectric crystal and which includes particles of heavy metal in a matrix of thermoplastic binder.

Certain known ultrasonic transducers include a piezoelectric element mounted with one surface oriented to provide an output of ultrasonic wave energy in response to signal excitation of the element. The back or opposite surface is coupled to an internal absorptive load to prevent the generated ultrasonic wave energy which propagates in the direction opposite to the output wave from reflecting off the back surface and appearing at the output surface. This absorptive load commonly includes a dense material such as finely divided tungsten in an epoxy binder. However, because of the viscous properties of the epoxy binder, only low ratios of tungsten to epoxy can be uniformly mixed. The resulting matrix of cured epoxy and tungsten particles provides a poor match of the acoustic impedance of the piezoelectric element, where the term "acoustic impedance" of a substance as discussed herein commonly relates to the product of the density of the substance and the velocity of sound propagation through the substance.

Accordingly, it is an object of the present invention to provide an improved ultrasonic transducer having a highly absorptive internal load acoustically coupled to the piezoelectric element at the acoustic impedance level of the element.

It is another object of the present invention to provide a method of making improved ultrasonic transducers.

In accordance with the illustrated embodiment of the present invention, the ultrasonic-wave energy internal absorptive load is molded from a dry mixture of finely divided tungsten and finely divided thermoplastic material in very high proportions of tungsten and is acoustically coupled to the back surface of the piezoelectric element for high absorption of internal ultrasonic wave energy.

Other and incidental objects of the present invention will be apparent from a reading of this specification and an inspection of the accompanying drawing in which:

FIGURE 1 is a sectional view of one embodiment of an improved ultrasonic transducer according to the present invention;

FIGURES 2 and 3 are sectional views of other embodiments of the improved ultrasonic transducers of the present invention including acoustically transmissive bodies in the absorptive load; and

FIGURE 4 is a flow chart showing the process for producing an improved ultrasonic transducer according to the present invention.

Referring to FIGURES 1 and 4 there is shown a piezoelectric element 9 formed of such material as lead metaniobate or barium titanate having a back surface 11 and a front or output surface 10. These surfaces of the piezoelectric element are lapped to desired shape in the step 47 of FIGURE 4.

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In one embodiment of the present invention, an internal absorptive load 15 may then be bonded to the back surface of the piezoelectric element 9 with a close match of acoustic impedances in order to prevent the generated ultrasonic wave energy propagating in a direction opposite to the output wave from reflecting at the back surface 11 of the element 9 and appearing as an undesirable wave at the front surface 10 of the element 9. This absorptive load 15 is formed according to one embodiment of the present invention by mixing together in the process step 51 of FIGURE 4 about 27 parts by weight of tungsten powder having a particle size of about 10 microns and 1 part by weight of a powdered thermoplastic material such as polyethylene.

In general, in order to match the acoustic impedance of known piezoelectric materials, the ratio of particulate matter to binder should be in excess of about 15:1 where the specific gravity of the particulate matter is at least about 7. At the other limit, ratios greater than about 32:1 for tungsten particles (specific gravity=18) causes the acoustic impedance of the molded slug to drop off and the slug to become mechanically weak and crumbly. It is believed that both effects are attributable to insufficient binder between particles. Also, in order to insure that individual particles do not resonate under ultrasonic excitation the dimensions of the particles should not be greater than about .2 or .3 of a wavelength of the ultrasonic wave in the particle material. Thus, for uniform dry mixing of the particles and binder, the binder should also have a particle size which is less than or about equal to the particle size of the dense material. The binder must also have the physical property of being able to attain a liquid state during molding so that the powdered binder can melt and flow together to coat the dense particles and fill the voids therebetween. For good ultrasonic energy absorptive properties of the molded slug, the binder material should provide ultrasonic wave energy attenuation of at least about 4 db per centimeter of path length in a sample of the binder material. In molding step 53, the mixture is compressed in a mold to expel air and to bring the particles in the mixture into intimate contact. The mold is then heated to a temperature at which the thermoplastic material flows in a liquid state (about 600° F. for polyethylene) and the mixture is compressed at about 30,000 p.s.i. for a few minutes. The mixture is then cooled while maintaining the pressure, and when adequately cooled, is ejected from the mold as a slug having a dense, homogeneous, electrically conductive matrix structure of conductive particles with the binder coating the particles and filling the voids therebetween. The slug is then processed as later described to form the internal absorptive load 15 for the piezoelectric element 9. In a system of units in which the acoustic impedance of water is 1.5, the molded slug has an acoustic impedance of 16 plus or minus 1% and thus closely matches the acoustic impedance of lead metaniobate which has an acoustic impedance of 16.

In other embodiments of the present invention as illustrated in FIGURES 2 and 3, the internal absorptive load element may not be able to match the high acoustic impedance of the piezoelectric element using the highest ratios of tungsten particles to binder. Thus, the absorptive load may be formed to include a body 17, 19 of acoustically conductive material such as brass having an acoustic impedance of 36-37.5. This closely matches the acoustic impedance of certain piezoelectric materials, say lead titanate zirconate having an acoustic impedance of about 38. The body 17, 19 decreases monotonically in cross-sectional area with distance from the piezoelectric element 16 as one cone 21 or as a plurality of inverted concentric cones 23, 25. Alternatively, the cones may be eccentric.

ly or generally asymmetrically arranged to eliminate in-phase reflections from different tapering cone surfaces. The inverted cones in the embodiment of FIGURE 3 provide the advantage of large tapering surface area within a housing of shorter axial length. These cone-shaped bodies 17, 19 are molded into the absorptive load 27, 29 while it is being formed in a manner as previously described in connection with internal load 15 so that the tapering surfaces of the body 17, 19 are in intimate acoustical contact with the absorptive load 27, 29. A composition of 32:1 of particulate material to binder yields an absorptive load 27, 29 which has an acoustic impedance of about 19. Thus, ultrasonic wave energy propagating from the back surface 18 of the element 16 is transmitted 20 within the body 17, 19 and is greatly dissipated in the absorptive load 23 at each reflection 22 from an interface of the body 17, 19 and absorptive load 27, 29. About 5% of the incident wave energy is absorbed by the load material at each reflection 22 as a result of the relationship of acoustic impedances. Wave energy traveling in the body 17, 19 thus undergoes multiple reflections at the tapered surfaces of the body 17, 19 and thus travels along an extended path 20 involving considerable time delay and energy dissipation before possibly returning to the back surface 18 of element 16. Any wave reflections within the absorptive load 27, 29 which may return to the tapered surfaces of body 17, 19 are greatly attenuated and are out of time phase and thus generally have negligible effect on the output from the front surface 24 of the element 16. In the embodiment of FIGURE 1, the end 30 of the absorptive load 15 which is remote from the element 9 is tapered either by machining or by molding for reasons as discussed above in order to increase the mean path length 26 back to the element 9 for reflections of ultrasonic wave energy in the absorptive load 15.

In each of the illustrated embodiments of the present invention, the upper end of the internal load, which may be either the brass body 17, 19 or the molded acoustically absorptive material 15, is lapped on a surface having a shape which is the complement of the shape of the back surface 13, 18 of the piezoelectric element 9, 16. This insures that the internal load mates intimately with the back surface 13, 18 of the element 9, 16.

A thin layer of a suitable adhesive is then applied to one of the mating surfaces of the element 9, 16 and internal load and the element 9, 16 and internal load are then bonded together in the process step 55 of FIGURE 4. This bonding together of the piezoelectric element and internal load insures good acoustic coupling of ultrasonic wave energy into the absorptive load and thus greatly eliminates interface reflections.

The bonded element-load unit is accurately positioned

in housing 37-39 using spacers 40-42 with the front surface 10, 24 of element 9, 16 and the edge of housing 37-39 substantially positioned in the plane of the front surface of the piezoelectric element. The entire unit is potted together in the process step 57 of FIGURE 4 using a suitable binder 43 such as epoxy which is then cured to its final state to complete the front surface of the ultrasonic transducer. This front surface may then be lightly lapped or polished to remove any excess potting compound and to provide a smooth, continuous front surface for the transducer unit. Electrical connections to the piezoelectric element 9, 16 may then be made through the front plate 45 and through the electrically conductive internal load and terminal connector 35 at the rear end of the transducer unit. The ground connection is formed through housing 37-39 to the conductive front plate 45 which is attached to the output surface 10, 24 of the element 9, 16 using a suitable binder to serve as an electrode and also to protect and seal the transducer against environmental conditions.

We claim:

1. Acoustic energy apparatus comprising:
 - an element having a selected acoustic impedance and having an output surface and another surface which vibrate in response to a signal applied thereto;
 - an acoustically transmissive coupling member having an acoustic impedance substantially equal to the selected acoustic impedance of said element and being acoustically coupled to said other surface of the element which vibrates; and
 - a matrix structure acoustically coupled to said coupling member and including particulate matter in a binder in a ratio by weight of particulate matter to binder in said matrix structure greater than about 15 to 1 for particulate matter having a specific gravity greater than about 7.
2. Acoustic energy apparatus as in claim 1 wherein: the cross sectional area of said coupling member decreases monotonically with distance from said element over a portion of the length thereof.

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