Feb. 14, 1961 D. H. HOWRY ET AL **2,972,068**

UNI-DIRECTIONAL ULTRASONIC TRANSDUCER

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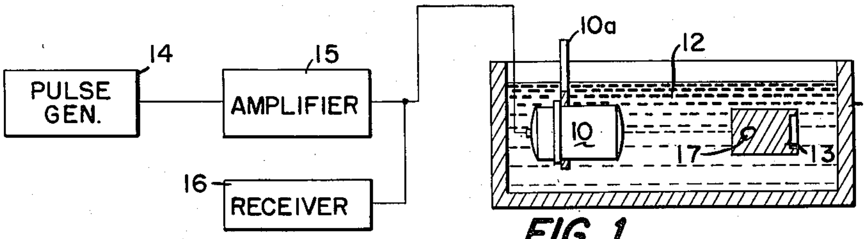

FIG. 1.

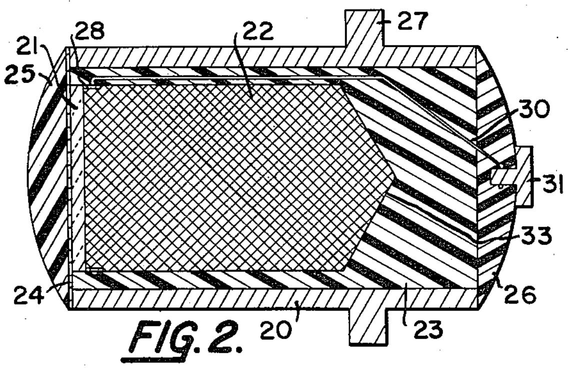

FIG. 2.

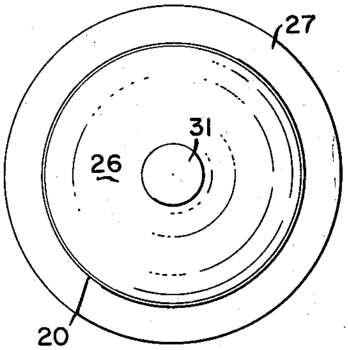

FIG. 3.

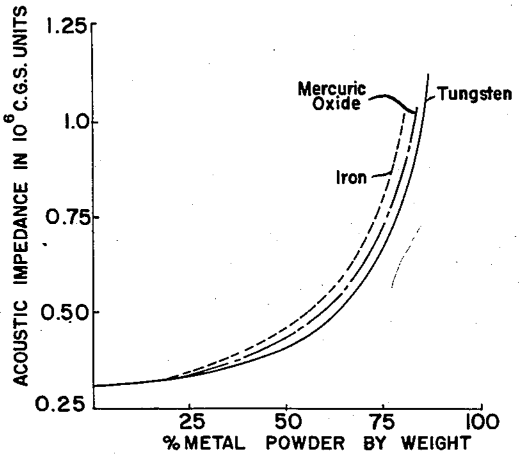

FIG. 4.

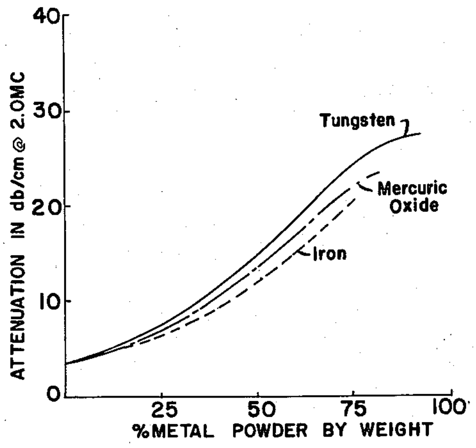

FIG. 5.

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UNI-DIRECTIONAL ULTRASONIC TRANSDUCER

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This invention relates to electroacoustic transducer apparatus for ultrasonic energy systems and particularly to devices and methods for minimizing interference and signal distortion due to reflection of ultrasonic energy in such apparatus.

Many applications employing ultrasonic wave energy require that an electroacoustic transducer be operated in a liquid. It is desirable that the electroacoustic transducers, commonly piezoelectric crystals, shall operate with high efficiency and with minimum distortion or signal interference due to reflection of compressional waves from the various surfaces of the transducer assembly. Many devices have been provided to increase the effectiveness of piezoelectric transducers of the type which radiate or receive energy on one side only; in general, these arrangements comprise a first body of material for conducting the energy away from the back face of the crystal and a second body of sound absorbing material for dissipating the energy and minimizing its return to the crystal. In this type of device the first body is usually designed to have an acoustic impedance which is intermediate that of the crystal and that of the absorber and is commonly selected as the geometric mean of these two acoustic impedances. To a first approximation the acoustic impedance of a body varies as the product of the density of the body and the velocity of propagation of sound waves in the body. Many different materials and combinations of materials, often in laminated form have been employed to secure impedance matching bodies for use with piezoelectric crystals. For example, alternate layers of plastic and metal sheet have been employed in one form of such device; and, in another form, which secures an acoustic impedance intermediate that of the crystal and the liquid in which it is used, comprises a plastic body having metal particles suspended therein. The sound absorbing bodies have usually been constructed of some form of fibrous material such as felt. The devices employed heretofore have been of complicated construction and costly to manufacture or have not been entirely satisfactory for meeting exacting requirements. Accordingly, it is an object of the present invention to provide an improved electroacoustic transducer for ultrasonic apparatus which is of simple construction and highly effective in operation.

It is another object of this invention to provide a substantially rigid body constituting a combined acoustic impedance matching and energy absorbing unit for ultrasonic wave transmission systems and the like.

It is a further object of this invention to provide an acoustic impedance matching element for application to piezoelectric crystal transducers and which is an electric conductor and may be employed as an electrode at one face of the crystal.

It is a further object of this invention to provide an improved method for making acoustic impedance matching elements for ultrasonic energy transmission systems employing piezoelectric crystal transducers.

The present invention is based upon the discovery that a highly effective acoustic impedance matching element for piezoelectric crystals may be constructed from a synthetic resin having therein a high concentration of a fine powder of a heavy metal, and, that, contrary to current teaching, this composite material may be made to act as an efficient absorber of ultrasonic wave energy, the attenuation increasing with increased density of the metal in the resin.

Briefly, in carrying out the objects of this invention in one embodiment thereof, a single body or block of material is provided which is capable of acting as an acoustic impedance matching unit for a piezoelectric crystal and which at the same time is an energy dissipating unit. Thus a crystal transducer may be backed by a single block of material which performs both functions required for minimizing the presence of unwanted wave energy of the crystal, thereby simplifying the transducer assembly. This acoustic impedance matching and absorbing material comprises a synthetic resin having therein a high concentration by weight of a fine powder of a heavy metal, or of a high density metallic compound, the total weight of the metal being substantially greater and for many applications several times greater than that of the synthetic resin. The required density of the metal powder in the resin body may be secured by first mixing the resin and a catalyst and the fine metal powder and then placing the mixture in a suitable mold until the resin has set, thereby bonding the metal in its high density concentration. If higher densities are required in order to match higher acoustic impedances, the mixture may be centrifuged while still in the liquid state. In ultrasonic wave equipment this invention has made possible the required impedance matching characteristics, together with the high attenuation. A relatively short impedance matching member can produce attenuations as high as 80 decibels or a 10,000 to 1 reduction of reflected signal amplitude.

The features of novelty which characterize the invention are set forth in the appended claims. The invention itself, however, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of one type of ultrasonic testing equipment employing a transducer embodying the invention;

Fig. 2 is an enlarged longitudinal section view of the transducer of Fig. 1;

Fig. 3 is an end view of the transducer of Fig. 2;

Fig. 4 is a graph illustrating the acoustic impedance characteristics of three different materials suitable for acoustic impedance elements embodying the invention; and

Fig. 5 is a graph illustrating the attenuation characteristics of the three materials of Fig. 4.

Referring now to the drawing, the ultrasonic testing equipment illustrated in Fig. 1 comprises an electroacoustic transducer **10** supported on a hanger **10***a* in a tank **11** containing water or other liquid **12**, and positioned to direct pulses of ultrasonic wave energy toward a steel casting or other object **13** which is to be examined for flaws. The transducer is energized by pulses produced by a generator **14** and supplied through an amplifier **15** to the transducer. Pulse echoes returning from the object **13** excite the transducer as a receiver and the resulting electrical impulses are supplied to a receiver **16** where they are utilized to determine physical characteristics of the object; for example, echoes from irregularities in the object due to a cavity or other flaw **17** may be used to indicate the depth of the flaw and its position. This general type of ultrasonic testing equipment has been used for flaw detection in industry for a considerable time.

In equipment such as that illustrated, it is necessary to secure high resolution of the returning echo signals if significant results are to be secured; for example, a small flaw lying close to the surface of a casting may go undetected when resolution is poor. Reflections or transient effects within the transducer crystal may so distort or confuse the received echoes as to render indistinguishable two echoes produced a short interval apart. One step toward minimizing this difficulty is to construct the transducer so that it is unidirectional and will transmit and receive signals at one face only. The unidirectional characteristic is secured in the illustrated embodiment of this invention by employing a backing member for the piezoelectric crystal which has an acoustic impedance matching that of the crystal, and which also effects a high degree of attenuation of the wave energy received from the crystal.

The electroacoustic transducer **10** shown in detail in Figs. 2 and 3 comprises a cylindrical case or housing **20** of brass or other suitable metal near one end of which is mounted a flat disc-shaped piezoelectric crystal **21** with its rear face cemented or bonded to a backing member **22.** The backing member and the crystal are embedded in a body of synthetic resin **23** which fills the space between these elements and the inner wall of the housing **20.** A thin metal deposit or coating **24** connected to housing **20,** provides the front electrode of the crystal, and a cover window or lens **25** of a synthetic resin such as polystyrene is sealed to the crystal and housing to provide a durable and moisture-proof structure. The opposite end of the transducer is closed and sealed by an end piece **26** of suitable synthetic resin which thus provides a completely sealed and rugged unit. A flange **27** on the case **20** is provided for mounting the transducer in its support. A film or layer **28** of metal or other material of high electrical conductivity is secured about the circumference of the member **22** at the end adjacent the crystal; the member **22** is conducting and thus provides the back electrode of the crystal. Connection to this back electrode is made through a wire **30** extending from the film **28** to a contact button **31** at the rear end of the transducer.

The backing member **22** is formed from a composite material comprising a synthetic resin having therein a mass of extremely fine powder of a heavy metal, the weight of the metal constituting the major part of the weight of the member. This material has an acoustic impedance of the same order as that of the piezoelectric crystals commonly employed in ultrasonic equipment, and, by selecting the proper density of the metal in the plastic, very close matching acoustic impedances may be secured. In addition, the loss or energy absorbing characteristics of the material provide increased attenuation of the signal energy with increased density of the metal powder. These combined characteristics make it possible to employ a single block of material for performing both the impedance matching and energy dissipating functions required of the backing members for unidirectional piezoelectric transducers designed to operate at frequencies in the range of 200 kilocycles to say 20 megacycles. The acoustic absorption increases as the frequency increases, and for higher frequencies relatively short backing members may be employed. By using a powder of a heavy conducting metal such as tungsten and a sufficiently high density, the resulting material is made to be electrically conducting.

By directing the wave energy reflected from the surfaces of the backing member to strike the crystal at a predetermined average angle the effectiveness of the backing member may be increased further. The member **22** as illustrated is cylindrical in form with a flat front face and a conical rear face, indicated at **33.** The sides of the cone **33** are at an angle of thirty degrees to the plane of the front face; this has been found to be the optimum angle for assuring the return of reflected energy to the crystal at a maximum oblique angle so that it has a minimum driving effect and also increases the average length of the paths of reflected wave energy thereby securing greater dissipation of the energy.

Various synthetic resins may be employed, for example, polyester resins and polystyrene, and it has been found that epoxy resins are particularly well suited for this purpose. The metal powder is selected in accordance with the characteristics to be secured; the heavier metals such as tungsten being required to secure the higher acoustic impedance values necessary for some piezoelectric crystals. Brass, iron, mercuric oxide, gold, platinum, molybdenum and other metals are suitable depending upon the acoustic impedance characteristics to be secured. Of these, iron and mercuric oxide result in a composite material of poor electrical conductivity not suitable for applications where electrical conductivity is desired as in the member **22** of Figs. 2 and 3, tungsten and the noble metals are suitable for providing conducting elements. The heavier metals are required when high acoustic impedance is to be secured; for example, to match the impedance of lithium sulphate monohydride crystals tungsten powder is employed.

Several different methods may be employed for making the backing block material; the preferred method, particularly when high acoustic impedance and high attenuation are to be secured, involves the use of a centrifuge. In the practice of this method the liquid resin and catalyst are first mixed and then the fine metal powder is added and is mixed with the liquid resin and catalyst. The mixing must be thorough and it has been found desirable to whip or agitate the mixture for about ten minutes. The mixture is then placed in suitable mold, preferably having a flat end and which fits the tubes of the centrifuge. The composite mixture is centrifuged until the resin has set up or cured and thereby retains the metal powder in its centrifuged location, the greater mass of the powder being concentrated toward the closed end of the mold. The mold is then removed and the body of composite material is cut to the required length, the bottom face is ground smooth and flat and the opposite end machined to provide the thirty degree cone form. Various metallic powders have been tried and found suitable for the purposes of this invention. In general, the particle size of the powder should be materially less than one-quarter wave length in the block material used. Powders ranging in particle size from about 200 mesh, i.e., 70 microns, to a few microns diameter have been employed for use at frequencies in the range of 200 kilocycles to 15 megacycles and have proved satisfactory in operation. For the purpose of securing the highest attenuation, the larger particle sizes should be employed at the lower frequencies in the above range, and, in general, particle sizes of the order of one-tenth wave length or less are highly effective.

For purposes of illustration, and not by way of limitation, a backing member for a lithium sulphate monohydride crystal having a diameter of three-quarters of an inch for operation at a frequency of 2.25 megacycles was made in the form shown in Fig. 2 and was three-quarters of an inch in diameter and had a length of one and one-quarter inches. This backing member was made by the centrifuging process described above employing an epoxy resin and an exceedingly fine tungsten metal powder having a total weight of seven and one-half times the weight of the resin and was found very satisfactory. The acoustic impedances of the crystal and this backing member are substantially identical and high attenuation of the order of 80 decibels was achieved. The epoxy resin which was used and found very satisfactory for this purpose is that sold under the name "Potting Compound #420" by the Carl H. Biggs Company of Los Angeles, California. The tungsten powder which was employed for this purpose and is of the desired exceedingly fine particle size to provide the required characteristics is that sold as "Tungsten Metal Powder M-40" by Sylvania Electric Products, Inc. Tungsten Chemical Division of Towanda, Pennsylvania.

When piezoelectric crystals are to be used which have acoustic impedances lower than that of lithium sulphate monohydride, the metal powder density will be lower for the heavier metals such as tungsten or less heavy metal powders may be employed.

Other methods which may be employed to make impedance matching and attenuation units embodying the present invention include a vacuum-pressure process, vibration and gravity settling of the powder in the liquid resin, and a sintering process wherein powdered resin and metal powder are mixed thoroughly, evacuated to remove entrapped air, and then pressed into a cake and heated to consolidate the composite mass.

In the vacuum-pressure process a closed cylindrical chamber or mold of the diameter of the body to be formed is charged with the metal powder and the pressure is lowered to remove air from the chamber. Liquid resin and catalyst are then admitted and the pressure increased to force the liquid into the entire powder mass; after setting of the plastic, the body of composite material is machined to the desired shape.

When the higher densities of metal powder in the finished product are required, the centrifuging process will often be found to be the most satisfactory of the foregoing methods. Fig. 4 shows the acoustic impedance characteristics of materials made in accordance with the present invention and formed with epoxy resin (the aforesaid potting compound) and three different metallic powders—iron, mercuric oxide and tungsten. Each of the curves shows a steadily increasing impedance up to about fifty percent of powder by weight and a rapidly increasing impedance as the percentage of powder is increased beyond the value. It will thus be apparent that materials within a wide range of impedance may be made by selecting the required percentage of powder by weight. For example, lithium sulphate monohydride crystals have an acoustic impedance of 1.12×10^6 c.g.s. units, and it will be observed that a material employing tungsten may be made to have approximately this impedance with about 87% by weight of powder.

Fig. 5 illustrates the attenuation characteristics at a frequency of two megacycles of the materials of Fig. 4. The three metals provide materials having acoustic impedances within the usable range and sufficient attenuation to secure the required absorption of energy for frequencies above 200 kilocycles without requiring an excessive length of backing member. Tungsten provides the most satisfactory material of the group illustrated and one which is electrically conducting. The materials made with iron and mercuric oxide are suitable for many applications but are not electrically conducting.

It will be understood that the selection of the synthetic resin and the metal powder will depend upon the particular application to be made and that the material

of this invention may be employed in a wide range of acoustic impedance requirements.

While the invention has been disclosed in connection with a specific form of electroacoustic transducer, other forms and applications will occur to those skilled in the art. Therefore, it is not desired that the invention be limited to the specific construction illustrated and described and it is intended, by the applied claims, to cover all modifications which fall within the spirit and scope of the invention.

We claim:

1. An electroacoustic transducer for ultrasonic energy systems and the like which comprises a piezoelectric element having front and back faces, and a substantially rigid body of a composite material in intimate contact with the back face of the crystal having an acoustic impedance substantially the same as that of said element and having high ultrasonic energy attenuation characteristics, said material consisting of a synthetic resin having distributed therein a fine powder of heavy metal constituting a major portion of said body by weight, the powder having a particle size in the range of several microns to substantially 70 microns.

2. A transducer suitable for generating highly damped ultrasonic energy pulses comprising a flat piezoelectric crystal having parallel front and back surfaces, electrode means in contact with the front and back surfaces, and a large block of damping material in intimate association with the back surface of the crystal, the damping material having a high ultrasonic energy absorption characteristic and an acoustic impedance substantially matching the acoustic impedance of the crystal, the material consisting of a mass of fine powder of heavy metal suspended in a resin, the metal powder comprising the major portion of the block by weight and having a maximum particle size of the order of one-tenth wavelength at the operating frequency of the ultrasonic energy for which the transducer is designed.

3. An article of manufacture as set forth in claim 2 wherein said metal is tungsten powder and said synthetic resin is an epoxy resin.

4. An electroacoustic transducer as set forth in claim 1 including a metal cylinder surrounding said crystal and said body and spaced therefrom, a synthetic resin filling the space between said cylinder and said body, end caps for enclosing both ends of said cylinder and for sealing said transducer, and electric conducting means providing front and back electrodes for said piezoelectric element.

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