March 21, 1961 G. E. HENRY ET AL 2,976,434

TRANSDUCER ASSEMBLY

Filed June 13, 1957

Fig. 1

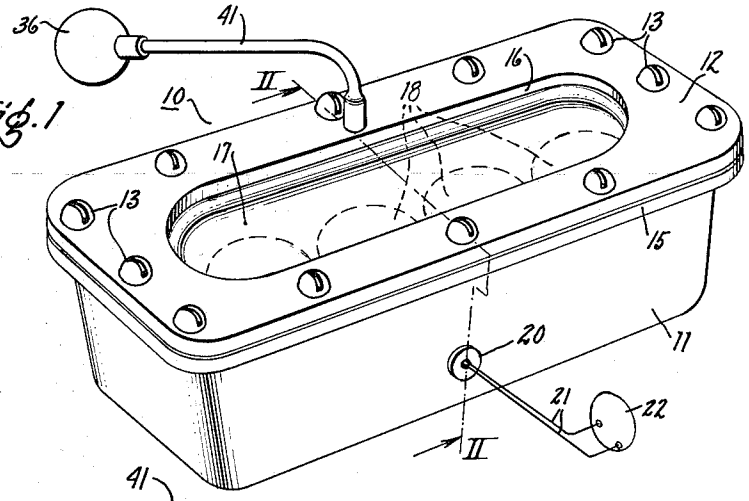


Fig. 2

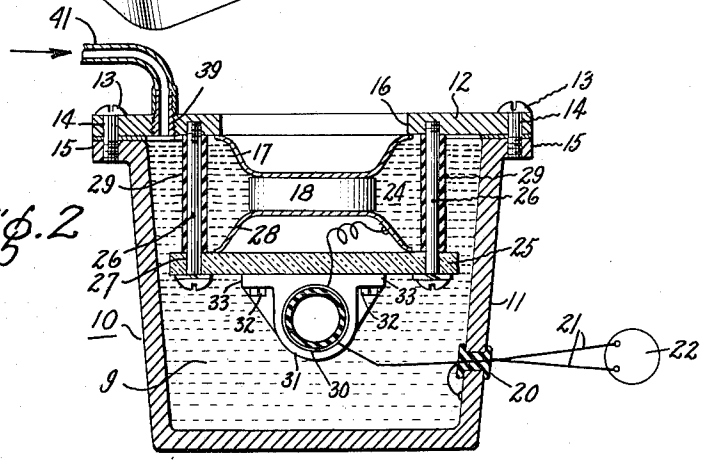


Fig. 3

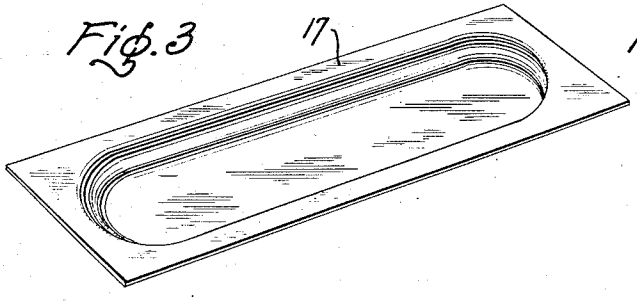


Fig. 4

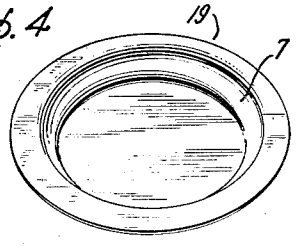
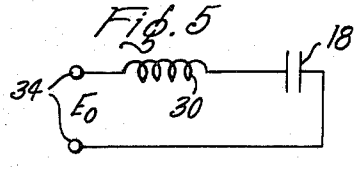


Fig. 5



Inventors:
George E. Henry
Daniel I. Evans.
by Merton D Morse
Their Attorney

United States Patent Office

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TRANSDUCER ASSEMBLY

George E. Henry, Schenectady, and Daniel I. Evans, Scholarie, N.Y., assignors to General Electric Company, a corporation of New York

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2 Claims. (Cl. 310—9.4)

This invention relates to transducer assemblies and is applicable to transducer assemblies wherein quartz crystal transducers or ceramic transducers, such as barium titanate, are used to produce ultrasonic compressional waves in a liquid. For example, the invention is particularly applicable to ultrasonic cleaning machines wherein a transducer assembly introduces ultrasonic compressional waves into an organic solvent.

For ultrasonic cleaning applications of the type contemplated herein, the compressional sound waves are generated in the cleaning liquid by the rapid up-and-down motion (at an ultrasonic frequency) of one face of a transducer. The up-and-down motion of the face results from the fact that the slab becomes alternately thicker and thinner as the polarity of electric charges on the two faces is reversed.

To excite uniform vibration of the transducer slab in its thickness mode, it is necessary to spread the opposing electric charges evenly over the two faces of the slab. This can be done by placing two separate bodies of conducting material (electrodes) in contact with the two faces or in very near proximity to the two faces. Since it is necessary for the active, working face to move up and down at an ultrasonic rate in order to produce the desired compressional waves in the fluid, the conductive material must move up and down with the face without interfering with this motion. Such a conductive material is subjected to extremely high mechanical stresses as the face moves up and down. It is also subjected to cavitation erosion. Consequently, it is very difficult to produce for such a crystal an electrode which will be permanent.

In an effort to increase electrode life many different forms of electrodes have been tried but one of the best and most popular constitutes a thin film (.001" or thereabouts) of silver-gold-nickel alloy bonded directly to the face of the crystal. Such an electrode is serviceable only for a limited time such as a few days or weeks or sometimes only a few hours when the crystal is driven at high power. Another expedient has been to leave the upper face of the slab free of any metal deposit and utilize a body of water simultaneously as the electrode and as the power accepting medium (acoustic load). Such an arrangement is satisfactory when the situation calls for sound waves in an aqueous medium. However, where the ultrasonic transducer assembly is required to work directly into an organic solvent liquid, such as trichlorethylene, this arrangement is not feasible because such an organic solvent cannot serve as an electrode.

As previously indicated, the transducing slab must be held with its upper face in proximity to the acoustic load. It is generally undesirable to have the liquid power acceptor enter the container which encloses the slab. Therefore, there is the additional problem of providing a suitable gasket between the slab and its sealed container. The problem is complicated by the fact that the seal must be provided between the face of the slab which moves up and down at a rapid rate and the container which does not follow this motion. It is not a practical solution to provide a clamp around the outer portion of the slab since this prevents radiation from around the edges of the upper face of the slab and permits free radiation only from the central portion.

As was previously indicated, the compressional waves are generated in the power acceptor due to the fact that the transducing slab becomes alternately thicker and thinner as the polarity of electric charges on the two faces is reversed. The power transferred to the acceptor is a maximum when the velocity-amplitude of the surface of the transducing slab is a maximum. Under general conditions, the velocity-amplitude of the transducing surface in question is a maximum when the polarity of the electric charges on the two transducer faces is reversed at a frequency which corresponds to the resonant frequency of the transducing slab. If quartz crystals are used as transducer elements, they must be driven at high voltage (say 5,000 volts) in order to achieve the high power transfer needed for ultrasonic cleaning purposes. However, it is generally not desirable to apply such a high voltage to the transducer supply lines. A convenient means of obtaining the desired high voltage across the faces of the transducing slab without using such a high voltage on the supply lines is to connect the transducing slab, which acts as a capacitor, in a series circuit with an inductance which is of such a value as to provide series resonance with the transducing slab. The power transfer between the transducing slab and the power acceptor is sharply dependent upon the condition of resonance (the tuning) of this series circuit. Hence, a further problem encountered in providing ultrasonic cleaning equipment of the type contemplated herein is the accurate tuning of the transducer circuit after it has been sealed in a container.

Accordingly, it is an object of this invention to provide a transducer assembly including electrodes which are substantially permanent.

Another object of this invention is to provide such an assembly wherein acoustic radiation is available from the entire face of the transducer.

A further object of this invention is to provide a transducer assembly which includes a fluid tight seal around the transducer.

Another object of this invention is to provide a highly accurate means of tuning an enclosed transducer.

In accordance with the preferred embodiment of this invention, the transducer assembly is provided by spring mounting the transducer between two diaphragms, one of which serves as an acoustic window to permit the vibratory energy from the transducer to pass virtually unimpeded therethrough. Tuning of the transducer energizing circuit by adjusting the assembly operating pressure is also provided.

The novel features which are believed to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which:

Figure 1 is a perspective view illustrating a sealed container designed to enclose a transducer assembly which may be used in untrasonic cleaning applications;

Figure 2 is a section of the apparatus of Figure 1 taken on section lines II—II illustrating the transducer assembly and associated electrical circuitry;

Figures 3 and 4 illustrate two types of diaphragms

which may be utilized as electrodes and seals for transducer assemblies within the contemplation of the invention; and

Figure 5 is a schematic diagram of an electrical circuit for energizing the transducer.

Figure 1 illustrates a sealed container 10 which is generally of a rectangular configuration which container encloses the ultrasonic transducing equipment. The container is provided with a tub-like bottom portion 11 and a flat top plate 12 which fits over the bottom portion 11. The top plate 12 is secured at its outer edges to the bottom portion 11 by any convenient means such as by a series of bolts 13 which protrude through apertures 14 around the outer periphery of the top plate and through a flange or lip portion 15 around the top of the bottom portion 11 of the container. The top plate 12 has a centrally located aperture or window 16 which, as illustrated, is somewhat elliptical in shape. The aperture or window 16 is provided to allow ultrasonic waves to pass from the interior of container 10 upwardly through the wnidow. Some means is preferably provided to produce a liquid tight seal between the top plate and the bottom portion 11 of container 10 for two reasons: The first reason is that in the particular embodiment illustrated the entire container 10 is intended to be immersed in an organic solvent such as trichlorethylene and the second reason is that it is generally desired to surround ultrasonic generating transducers with a dielectric material such as oil. Thus, the container is sealed to prevent liquids from entering or leaving the container 10. This seal is accomplished by providing a window closing diaphragm 17 which is large enough to cover the entire aperture 16 and which is generally dish-shaped. The diaphragm 17 is preferably of a metal such as type 347 stainless steel which is permanently soldered or brazed to the underside of the top plate 12 in order to provide both a liquid tight seal and an electrical connection. The cross-sectional view of Figure 2 illustrates this point most clearly.

The diaphragm 17 is illustrated in perspective in Figure 3. The configuration of the outer periphery of the diaphragm 17 is only important to provide the proper liquid seal between the top plate and the window portion. However, as will be explained in detail subsequently, the dish shape of the diaphragm itself is an important part to the present invention.

In the embodiment of the invention illustrated, the window is elongated to accommodate a plurality of crystal transducing elements as the elements 18 are placed side by side. This arrangement gives a relatively long and narrow area of intense ultrasonic energy having the general configuration of the window 16. However, window 16 may be given any desired shape. For example, if only one circular transducer is used, the window 16 is made circular and the dish-shaped diaphragm 7 may have a circular periphery. Such a diaphragm is illustrated in Figure 4 and given the reference numeral 19.

The sealing properties of the diaphragm 17 have been explained in connection with the above description. However, reference should be had to the cross-sectional view of the container 10 taken along the section lines II—II as illustrated in Figure 2 in order to fully appreciate the roll played by the diaphragm 17 in the present invention.

Since the container 10 encloses electrical equipment for generating ultrasonic compressional waves it is necessary to provide a liquid-tight feed-through bushing 20 through which electrical leads 21 may be brought from a source of alternating voltage 22. For purposes described in detail subsequently, container 10 is also provided with a pressure outlet which includes a nipple 39, threaded into the upper plate 12 and providing a passage therethrough. An ordinary hand bulb or pump 36 and hose 41 combination is attached to the nipple 39 to provide a means of adjusting the pressure inside the container 10.

As may best be seen by reference to Figure 2, the container 10 encloses the entire transducer assembly 24. The assembly 24 includes a piezoelectric or electrostrictive element 18 mounted with its upper surface in alignment with the ultrasonic window or aperture 16 in the top plate 12 in such a manner that its upper surface is in intimate contact with the upper window sealing diaphragm 17. In order to support the piezoelectric element 18 in this position, a supporting platform 25, which is preferably an insulating material such as glass or any one of the mica compositions commercially available, is suspended from the top plate 12 by means of bolts 26 which pass through apertures 27 in the supporting platform and into the bottom of the top plate 12. Spacers 29 are positioned around the bolts 26 and between the supporting platform 25 and top plate 12. Immediately on top of the supporting platform 25 is a metal pillow for the piezoelectric element 18 which consists of an inverted diaphragm 28. For convenience and economy the pillow diaphragm 28 is identical to the sealing diaphragm 17. The piezoelectric element 18 is then sandwiched between the two diaphragms 17 and 28 so that the metal diaphragms and the upper and lower surfaces of the piezoelectric element 18 are in intimate contact. Thus, the diaphragms 17 and 28 may be used as electrodes for the piezoelectric element 18. Since it is desirable to apply a high voltage between the electrodes 17 and 28 on opposite sides of the piezoelectric element 18, the container 10 is filled with a dielectric material 9 such as oil to prevent a voltage breakdown between the electrodes. In order to make the lower diaphragm 28 a more effective cushion or pillow, it is preferred that it contain a "bubble" of trapped air in its dished-out portion. Since the diaphragm 28 is inserted in container 10 with its dished-out portion down (toward the bottom of container 10) any air initially under the diaphragm is trapped; therefore, it is not necessary to provide a seal around its lower edge for applications where the container 10 is not tilted. If the transducer assembly container 10 is to be used in any position other than the upright position illustrated, the air must be sealed under the pillow 28.

For reasons explained in more detail subsequently, the circuit of the piezoelectric element 18 includes an inductance coil 30 which is selected in accordance with characteristics of the particular piezoelectric element. Since these two circuit elements are matched it is convenient to mount them both in the container 10. The inductance coil 30 is mounted on the lower side of the support member 25 by means of a yoke 31. Yoke 31 may be secured to the support member 25 by any convenient means such as by screws 32 threaded through feet 33 of the yoke 31 and into the support member 25.

The electrical circuit connections for the transducer may best be seen by reference to the circuit diagram of Figure 5. This circuit consists of the piezoelectric element 18 which acts as a capacitor and the inductance coil 30 connected in series between a pair of input terminals 34. The input terminals 34 are connected to receive a high frequency alternating voltage E_0 from the voltage source 22 which is not illustrated. In order to provide an optimum velocity-amplitude of the upper surface of the piezoelectric element 18 and hence a maximum energy transfer from the transducer 24 through the window 16, the frequency of the supply voltage E_0 is adjusted to the frequency of resonance of the piezoelectric element 18 and the value of inductance 30 is chosen to provide series resonance in the circuit. For these conditions the velocity-amplitude of the upper surface of piezoelectric element 18 is a maximum.

In order to see how the circuit elements are electrically connected, reference should be made to Figure 2. One of the input leads 21 is connected to the conducting

container 10, through the feed-through bushing 20 and the opposite input lead 21 is connected to the coil member 30. Coil member 30 is connected to the pillow diaphragm 28 which is in intimate contact with the lower face of the piezoelectric element 18. The opposite diaphragm 17 is connected to the top plate 12 of container 10 which is at ground potential. The piezoelectric element 18 constitutes the dielectric material between the diaphragms 17 and 28 which act as capacitor plates. The pillow diaphragm 28 is electrically insulated from the container and from the window diaphragm 17 since it is supported on the insulating support member 25.

Experience has demonstrated that the arrangement discussed above provides a perfect seal for the assembly without utilizing the high compressive stresses around the rim, that the new type electrodes are relatively permanent, and that radiation may be obtained from the entire upper face of the piezoelectric element 18 and not just from the central portion as is the case in most conventional assemblies. An additional advantage occurs from the arrangement illustrated and described which relates to the electric tuning of the apparatus. As is previously indicated, the power transfer from the transducer 24 to the power acceptor is dependent upon the precise tuning of the electric circuit of the transducer to resonance. Many transducers which are utilized in conjunction with ultrasonic cleaning equipment have been found to radiate to substandard power levels because their associated electrical circuitry is slightly mistuned. This is particularly true of multiple crystal transducers. Since the transducer assemblies are ultrasonic cleaning equipment are generally sealed in a dielectric bath, tuning the circuit normally requires the troublesome process of disassembling the apparatus utilizing trial and error circuit adjustments and a subsequent reassembly and test. It is believed that stray capacitance which results when the transducer assembly is placed in its container is the major factor which causes the circuit tuning to change when the transducer is inserted in its container.

It has been found that the tuning of the circuit can be adjusted within limits by adjusting the pressure within the container 10. Reduction of the pressure inside the transducer housing increases the electrical capacitance of the system and thereby lowers the resonant frequency. Conversely, increasing the pressure inside the container 10 decreases the electrical capacitance and thereby increases the resonant frequency. This action is explained by the fact that any change in pressure within the container 10 causes a slight change in the geometrical spacing of the diaphragms 17 and 28 which support the piezoelectric element 18 and act as the electrodes of the capacitor.

The simple hand pump 36 (previously described) is provided to adjust the internal pressure in the container and thereby adjust the frequency of resonance of the electrical circuit. This simple means of adjusting the internal pressure in the container 10 from a position outside has been found to be entirely satisfactory. However, it is obvious that more complex methods of accomplishing this purpose may be used without departing from the spirit of the present invention. For example, an automatic pressure controlling means may be obtained by providing a motor driven pump to adjust the pressure in the container 10 and providing a means to control the action of the pump in response to the current in the series inductance and capacitance combination.

While a particular embodiment of this invention has been shown and described, it is not limited thereto since many modifications both in the circuit arrangement and in the instrumentalities employed may be made. It is contemplated that the appended claims will cover any such modifications as fall within the true spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. Apparatus for setting up ultrasonic compressional waves in a fluid medium including a container having an aperture therethrough and an ultrasonic transducer assembly positioned in said container to produce the compressional waves, said transducer assembly including a pair of resilient dish-shaped electrode means supported at their periphery in spaced relationship relative to each other with their dished-out portions facing outwardly away from each other and with the central areas thereof free to vibrate, one of said electrode means being positioned to seal the aperture in said container, pressure adjusting fluid disposed within said container and sealed therein by said electrode means said transducer element being positioned between said electrodes with the dished out portions of each one of said electrodes being in intimate contact with the entire surface of the respective side of the transducer element, and pressure adjusting means to adjust the spacing between said electrodes by adjusting the pressure of said fluid inside said container.

2. Apparatus for setting up ultrasonic compressional waves in a fluid medium including a fluid-filled container having an aperture therethrough and an ultrasonic transducer assembly positioned in said container to produce the compressional waves, said transducer assembly including a pair of resilient dish-shaped electrode means supported at their periphery in spaced relationship relative to each other with their dished-out portions facing outwardly away from each other and with the central areas thereof free to vibrate, one of said electrode means being positioned to seal the aperture in said container, pressure adjusting fluid disposed within said container and sealed therein by said electrode means said transducer element being positioned between said electrodes with the dished out portions of each one of said electrodes being in intimate contact with the entire surface of the respective side of the transducer element, and pressure adjusting means to adjust the spacing between said electrodes by adjusting the pressure of said fluid inside said container, an inductance connected in series circuit relationship with said electrodes to form a series resonant circuit tuned to the natural frequency of vibration of the transducer element, and fluid-tight terminal means for applying energizing electrical signals to said series tuned circuit having the same frequency as the transducer element resonant frequency.

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