Nov. 27, 1962 N. G. BRANSON 3,066,232

ULTRASONIC TRANSDUCER

Filed June 12, 1959

FIG 1

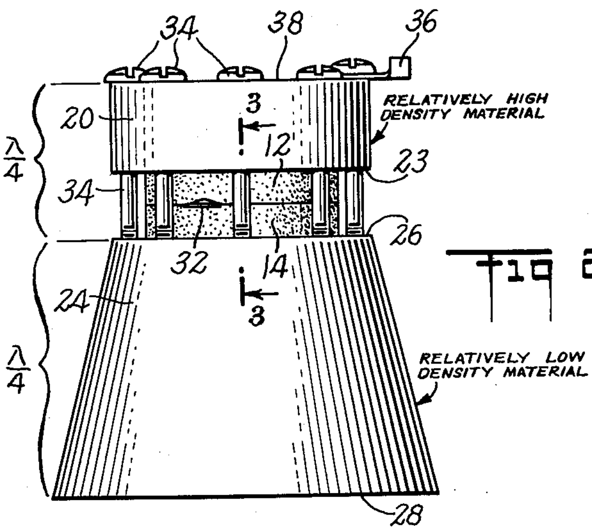


FIG 2

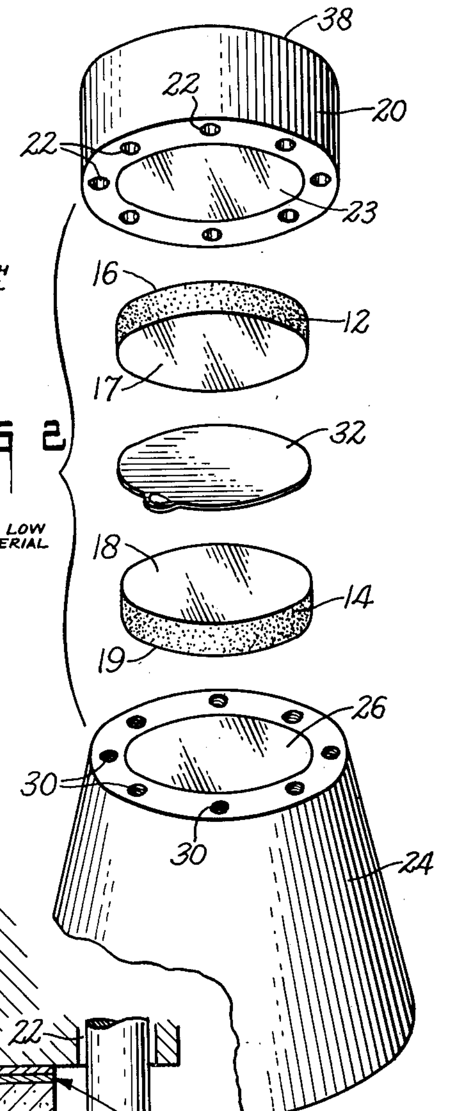
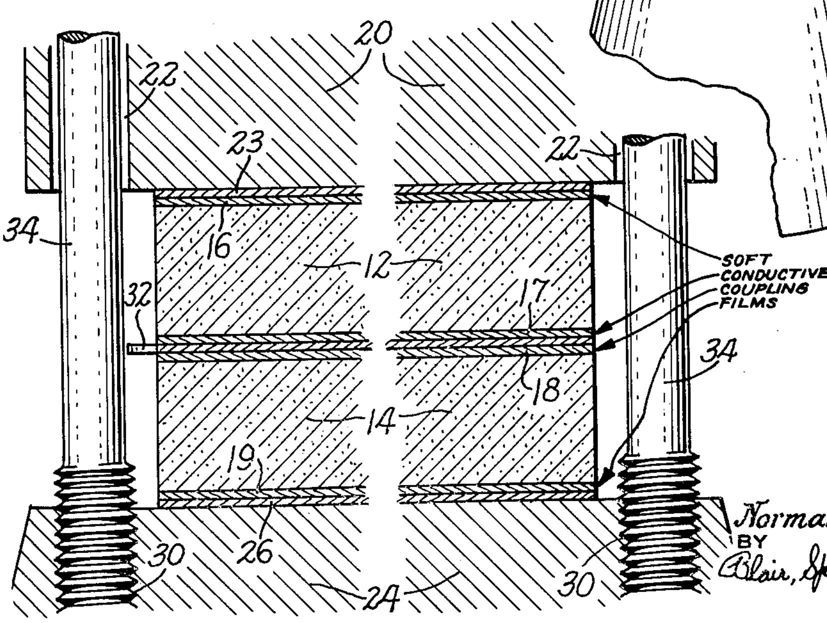


FIG 3



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ULTRASONIC TRANSDUCER

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This invention relates to an improved ultrasonic transducer. More particularly, it relates to an ultrasonic transducer assembly which includes mass loaded ceramic elements and an integral acoustic horn. The transducer assembly is a resonant unit, and one feature of the invention is that no cements or fluid couplants are required at the interfaces of the various elements of the assembled transducer.

There exists a need for ultrasonic transducers which have very high ratios of radiated power to radiating area. Such transducers find use in ultrasonic cleaning apparatus, homogenizing equipment, and other applications where the desire is to apply large quantities of ultrasonic energy to a material. Piezoelectric crystal transducers may be used in such transducers, but they are rather expensive and brittle and produce relatively low power to area ratios unless they are excited by very high driving voltages which are hard to control for proper safety in conventional industrial applications.

Ceramic materials such as barium titanate are characterized as being ferroelectric since the crystal domains of the material may be polarized through the application of a large electric field and a residual polarization will remain in the material when the field is removed. These materials, when polarized, exhibit piezoelectric properties. However materials such as barium titanate have relatively low Curie temperatures, at which they become depolarized and lose their piezoelectric properties. The Curie temperature of barium titanate varies from between 120 degrees to 130 degrees centigrade. Because these materials are heated when an alternating field is applied, which produces the ultrasonic energy when they are used as a transducer, the maximum power output of ceramic transducers is limited by the Curie temperature. It is therefore desirable to use ceramic materials having high Curie temperatures in ultrasonic transducers.

New ceramic materials have been and are being developed, an example of which is Lead Titanate Zirconate, commonly referred to as PZT. This material has a Curie temperature of 300 degrees centigrade. It therefore can handle much higher power than previous ceramic transducer materials and it is consequently desirable that PZT be used in ultrasonic transducers, particularly where such use requires operation at higher ambient temperatures as, for example, in ultrasonic treatment of materials immersed in heated chemical solvents. Lead Titanate Zirconate is, however, substantially more expensive than prior materials, such as barium titanate, and this expense has in the past limited its use in u'trasonic transducers. One reason for prohibitive cost of employing PZT in ultrasonic transducers for ultrasonic cleaning apparatus is that in such apparatus it is desirable, in order to produce optimum cavitation in the cleaning fluids, that the transducer be operated at a relatively low ultrasonic frequency, of about 20 kilocycles, at which frequency a resonant plate of PZT would be approximately three inches thick.

Also, if PZT is excited to produce the maximum power of which it is capable in transducer configurations of the prior art, this power is so great that cavitation takes place at the interface between the transducer and the medium to which the energy is being applied, decoupling the transducer from the medium. Therefore most of the increased power is lost before it can be usefully introduced into the interior of the ultrasonic cleaning medium. Various couplants such as cements, or fluid couplants, now used in the ultrasonic art are unable to withstand the stresses produced at non-compliant interfaces by the very high sonic pressures which may be generated when using PZT. For example, a backing plate cannot be cemented to a piece of PZT by the couplants now used because these couplants do not stand up under the very high pressures, of from 1,000 to 2,000 pounds per square inch, generated at the interface between the mass of the backing plate and the mass of the rest of the transducer when the PZT material is operated at maximum power.

The novel ultrasonic transducer configuration of the present invention solves the above problems and makes full use of the high power capabilities of PZT by placing two thin discs of PZT material between a massive back plate and a conical acoustic horn which acts as a front plate. The horn and back plate have a plurality of screws passing between them under great tension which hold the active material and massive plates together as a unit. By using two discs of PZT, rather than one, the driving potential is applied to a conducting plate between the two discs and the front plate and back plate are kept at ground potential, thus eliminating many insulation problems. Solid soft precious metal films are placed between the elements of the transducer to eliminate the need for fluid couplants.

It is therefore a primary object of the invention to produce a much improved ultrasonic electro-acoustical transducer. Another object of the invention is to make full use of the high power characteristics available in PZT or other ceramic materials when used in such an electro-acoustical transducer. A further object of the invention is to produce such a transducer for operation at a relatively low frequency, as for example 20 kilocycles, using small quantities of expensive ceramic materials.

Another object of the invention is to provide an improved ultrasonic transducer having the above characteristics for use in ultransonic cleaning apparatus, and in other applications of ultrasonic energy to materials. Still another object of the invention is to provide such a transducer for coupling maximum power into a l'quid mass or volume. A further object of the invent'on is to reduce the power to area ratio at the face of transducers using high power materials such as PZT to be'ow that which causes cavitations at the transducer-sonic medium interface while still utilizing the maximum power characteristics of the transducer material.

A further object of the invention is to provide an acoustically and electrically resonant ultrasonic transducer of the above character.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts which will be exemplified in the construct'on hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which:

FIGURE 1 is a side view of the ultrasonic electro-acoustical transducer of the present invention;

FIGURE 2 is an exploded view of the transducer of FIGURE 1; and,

FIGURE 3 is a sectional view partially cut away of the transducer of FIGURE 1, selected parts of the transducer being shown to an enlarged scale, taken along line 3—3 of FIGURE 1.

Similar reference characters refer to similar elements throughout the several views of the drawing.

In general, the ultrasonic transducer of the present invention comprises two flat discs of piezoelectric material, preferably a ceramic having high power capabilities such as PZT, mounted between an aluminum acoustic horn one-quarter of a wave-length long, in terms of the resonant mode of the transducer, and a steel back plate which together with the piezoelectric disc forms a unit one-quarter wavelength in thickness. A plurality of screws between the back plate and the horn are uniformly tightened to great tension and hold the unit together under substantial pressure. Precious metal films are used between the various elements of the transducer to acoustically couple them together, and to provide low resistance electrical contact with opposite faces of the active piezoelectric elements.

More particularly, referring to FIGURES 1, 2 and 3, in the ultrasonic transducer of the present invention, designed for use as a resonant transducer at 20 kilocycles, there are two ceramic discs, **12** and **14** respectively, of PZT, each of which is a quarter of an inch thick and approximately one and one-half inches in diameter. The ceramic discs **12** and **14** have their flat surfaces, **16—17** and **18—19** respectively, plated with a soft precious metal such as gold, platinum or silver, which will not readily oxidize and is a good conductor of electricity. When the transducer is clamped together under pressure the soft metal films flow, filling up small imperfections and voids in the surfaces **16—17** and **18—19**, as well as the metallic surfaces with which they are in contact, and thus afford a continuous coupling between the discs **12** and **14** and the other elements of the transducer.

A back plate **20**, which may be formed of cold rolled steel, is 0.675 inch thick and 2 inches in diameter. A plurality of cylindrical holes **22** are drilled through the back plate **20** near its peripheral cylindrical wall. The front face **23** of the back plate **20** may be plated with precious metal, as are the ceramic surfaces **16—17** and **18—19**. A front plate **24** is made of aluminum shaped into a frustum of a cone. The front plate **24**, which serves as an acoustic horn for the transducer, is 2 inches thick along its axis. The small end **26** of the horn **24** is 2 inches in diameter and the large end **28** is 3 inches in diameter. A plurality of tapped holes **30** are located near the periphery of the small end **26** of the horn **24** and correspond in position to the holes **22** in the back plate **20**. The small end of the horn **24** may be plated with precious metal as are the ceramic surfaces **16—17** and **18—19**. An inert metallic sheet **32** which may be of nickel, is clamped between the two discs **12** and **14** and serves as one of the electrical conductors of the transducer.

Referring particularly to FIGURE 1, a plurality of screws **34** pass through the holes **22** in the back plate **20** and thread into the tapped holes **30** in the horn **24**. In the embodiment shown, the screws are preferably 10/32 screws made of stainless steel and are uniformly tightened to approximately 30 inch-pounds torque. An electrical connector **36** is attached to the transducer by one of the screws **34**. As previously stated, when the screws **34** are tightened, the soft metal films at the faces **16—17** and **18—19** of the ceramic discs **12** and **14**, and the corresponding films at the faces **23** and **26** of the back plate **20** and horn **24**, flow and serve as the couplants between the interfaces of the back plate **20** and the disc **12**, the disc **12** and the nickel sheet **32**, the nickel sheet **32** and the disc **14**, the disc **14** and the front plate horn **24**, combining the various elements of the transducer into a unified acoustical unit. When the discs **12** and **14** are of ceramic material, as in the present embodiment, they may be plated by the manufacturer in order to facilitate their polarization, and this plating of gold, silver or platinum may serve as the coupling film. However, if unplated discs are used precious metal foils may be inserted between the elements, or the surfaces **23** and **26** and the sheet **32** may be thickly plated.

The completed unit, shown in FIGURE 1, is attached to the side walls of an ultrasonic cleaning tank by bolting it to the tank, or by an adhesive bond between the front face **28** of the horn **24** and the cleaning tank wall, or in any other convenient manner.

The whole transducer is one-half wavelength thick from the back face **38** of the back plate **20** to the front face **28** of the horn **24** and is therefore resonant, when the transducer is operated at 20 kilocycles. The horn **24** is one-quarter wavelength thick between the small end **26** and the large end **28**, at resonance. The ceramic discs **12** and **14** would freely resonate individually at 300 kilocycles in their thickness mode. The back plate **20**, ceramic disc **12**, nickel sheet **32** and ceramic disc **14** form a unit which is one-quarter wavelength thick in terms of the resonant mode of the transducer. Thus the whole transducer is one-half wavelength in total thickness.

Since there is approximately 500 pounds linear force on each of the screws **34**, there is approximately 4,000 pounds total force clamping the transducer together. This force is distributed over the area of the interfaces between the ceramic discs **12** and **14** and the other elements. This area is 1.76 square inches. The unit is thus held together by a pressure of 2,270 pounds per square inch, but this pressure may vary over a range of 2,000 to 5,000 pounds per square inch. Since, when operated at maximum power, the pressures developed by the ultrasound at the interfaces of the transducer are from 1,000 to 2,000 pounds per square inch, the interface sound pressure never exceeds the clamping pressure and the various elements of the transducer are never allowed to separate or knock together. The screws **34** stretch approximately one thousandth of an inch when they are tightened and vary in length over a few ten thousandths of an inch when the transducer is operated. Thus the screws **34** act as springs between the masses of the back plate **20** and the horn **24**, and they are preferably of proper dimension and elasticity to allow the back plate **20** and the horn **24** to mechanically resonate at the resonant frequency of the transducer.

The aluminum front plate horn **24** has an acoustic impedance which is approximately intermediate between that of the disc **14** and water or any of the other common ultrasonic cleaning fluids so that, when the transducer is coupled to a cleaning tank, maximum power is transmitted into the ultrasonic medium within the tank. Other materials than aluminum having the proper acoustic impedance may of course be used for the horn **24**. The enlarged area of the front face **28** of the front plate horn **24** allows the acoustic energy which is imparted to the small end **26** of the horn **24** to be distributed over the large end **28** before it is coupled into the ultrasonic medium, thus facilitating the introduction of acoustical energy to a large volume of fluid. The large end **28** is large enough so that when the transducer is used at maximum permissible power, the sound intensity at that end is less than that which will produce cavitation at the coupled surface of the ultrasonic medium to which the energy is imparted. In this way maximum utilization of the PZT is achieved without producing cavitation at the transducer-sonic medium interface. As to the shape of the horn **24**, because of the shortness of the horn (one-quarter wavelength) and because a single frequency is to be utilized in the transducer, it is unnecessary that the horn **24** be in any other acoustical shape than conical. The angle of the cone is not critical, it merely must be large enough to allow the proper increase in area between the small end **26** and the large end **28** of the horn **24** when the horn is one-quarter wavelength long.

The back plate **20**, in the case of the transducer illustrated, is made of cold rolled steel, so that as previously stated, a large mass of material may be added to the transducer in a relatively small volume. However, any other convenient very dense material could be used as the back plate **20**. This large mass, which reduces the resonant frequency of the transducer, facilitates the use of relatively inexpensive thin discs of piezoelectrical material.

The transducer is excited by applying an oscillating electrical potential between the terminal **36** and the nickel plate **32**. This produces a field between the back plate **20** and the nickel plate **32** which excites the disc **12**, and a field of opposite polarity between the horn **24** and the nickel plate **32**. The screws **34** serve as conductors between the back plate **20** and the horn **24**. When the transducer is operated in air at resonance, its impedance is primarily resistive and approximately 100 ohms. When submerged, the impedance may be as much as ten times this. The transducer consumes 1 watt of power at approximately 10 volts excitation when operated in air and has a quality factor or Q of between 200 and 400 when so operated. When operated coupled to a tank, the Q will be lowered to between 10 and 30.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described my invention, what I claim as new and desire to secure by Letters Patent is:

1. An ultrasonic transducer comprising, in combination, means for transforming electrical oscillations into elastic vibrations, a front plate, a back plate, conductive elastic means under tension between said plates and forming a conductive connection between said plates, said transforming means having a first face in contact with said front plate and having a second opposed face in contact with said back plate, soft solid substantially non-oxidizing metal films at the interfaces of said transforming means and said plates, a first signal terminal connected to said back plate and a second signal terminal connected to a point between said faces whereby said metal films provide optimum acoustical and electrical coupling between said plates and said transforming means.

2. An ultrasonic transducer, comprising in combination, piezoelectric means for transforming electrical oscillation into mechanical vibration, said piezoelectric means including at least one lead titanate zirconate transducer element a conductive front plate and a conductive back plate sandwiching said piezoelectric means, said front plate being in the shape of an acoustical horn, conductive means for electrically connecting said front plate and said back plate, and for holding said front plate, said piezoelectric means and said back plate together under tension to form a unified acoustical unit whereby the compression forces of said holding means provide optimum acoustical coupling between said piezoelectric means and said plates a first signal terminal connetced to said back plate and a second signal terminal connected to a point on said piezoelectric means intermediate said front and back plate.

3. The ultrasonic transducer defined in claim 2 in which said front plate horn has an over-all length equal to one-quarter the wave length of the acoustical resonant mode of said entire unified acoustical unit.

4. The ultrasonic transducer defined in claim 2 in which said piezoelectric means includes a plurality of piezoelectric element said second terminal comprising an electrically conductive member positioned between two of said piezoelectric elements.

5. The ultrasonic transducer defined in claim 2 for use in imparting ultrasonic energy into a medium; in which said front plate horn extends to one-half the acoustical length of said unified acoustical unit and is fabricated of a material having an acoustical impedance intermediate between that of said piezoelectric means and the acoustical impedance of the medium to which the ultrasonic energy is to be imparted.

6. The ultrasonic transducer of claim 2 in which said means for holding said front plate, back plate, and piezoelectric means together comprises a plurality of adjustable members in tension between said front plate and said back plate.

7. The ultrasonic transducer defined in claim 2 and soft solid substantially non-oxidizing metal films at the interfaces of said piezoelectric means, said front plate, and said back plate.

8. A transducer as defined in claim 7 wherein said metal films are of silver.

9. A resonant ultrasonic transducer comprising, in combination, two piezoelectric discs separated by a thin disc conductor of substantially the same diameter as said discs, a dense shallow cylinder of larger diameter than said discs forming a back plate therefor, said back plate and said disc forming a unit one-quarter wavelength thick in terms of the resonant mode of the transducer, a frustoconical acoustical horn one-quarter wavelength thick in terms of said resonant mode forming the front plate of the transducer, the small diameter end of said horn being adjacent to said piezoelectric discs, a plurality of screws between said back plate and said front plate in tension holding the transducer together as a unified acoustical unit, and soft solid slowly oxidizing metal films at the interfaces of said discs and plates.

10. A transducer as defined in claim 9 wherein said metal films are of silver.

11. A transducer as defined in claim 9 wherein said front plate is made of a material having an acoustical impedance intermediate between the acoustical impedance of said piezoelectric discs and the acoustical impedance of the medium to which ultrasonic energy is transmitted.

12. The ultrasonic transducer of claim 9, in which said piezoelectric discs comprise lead titanate zirconate.

13. The ultransonic transducer of claim 9 in which the mechanical resonant mode of said back plate, front plate, and screws occurs at the same frequency as the acoustical resonant mode of said transducer.

14. The ultrasonic transducer of claim 13 in which the tensional force developed in said screws holding the transducer together is greater than the acoustical force developed in said transducer when said piezoelectric discs are excited with the maximum permissible excitation voltage.

15. An ultrasonic transducer comprising, in combination, a pair of piezoelectric elements separated by a conductive member, an electrically conductive front plate, an electrically conductive back plate, a plurality of electrically conducting elastic members joining and electrically connecting said front plate and said back plate, said piezoelectric elements being sandwiched therebetween under a compression greater than the maximum internal pressures generated by said piezoelectric elements to form a unified acoustical unit, relatively thin films of soft substantially non-oxidizing metal between the piezoelectric elements and each of said plates and between each of said piezoelectric elements and said conductive member, whereby compression forces exerted by said elastic members provide acoustical coupling of said plates to said piezoelectric elements through said metal, while permitting mechanical resonance of said plates and means for applying an electrical signal between said conductive member and said back plate.

16. A transducer as defined in claim 15 wherein the acoustical impedance of said front plate is intermediate between the acoustical impedance of said piezoelectric

element and the acoustical impedance of the medium to which ultrasonic energy is to be imparted.

17. A transducer as defined in claim 15 wherein the density of the material of said back plate is greater than the density of the material of said front plate.

18. A transducer as defined in claim 15 wherein said front plate extends from said piezoelectric element to one half the acoustical length of the unified acoustical unit.

19. A transducer as defined in claim 18 wherein the total acoustical length of the transducer is one half wavelength of the resonant mode of the transducer.

References Cited in the file of this patent

UNITED STATES PATENTS

2,430,013	Hansell	Nov. 4, 1947
2,497,666	Gravley	Feb. 14, 1950
2,514,080	Mason	July 4, 1950
2,616,223	Jonker	Nov. 4, 1952
2,714,672	Wright et al.	Aug. 2, 1955
2,828,231	Henry	Mar. 25, 1958
2,834,158	Petermann	May 13, 1958
2,877,363	Tibbetts	Mar. 10, 1959
2,947,889	Rich	Aug. 2, 1960