June 18, 1963 T. J. KEARNEY ETAL 3,094,314

SANDWICH TYPE TRANSDUCER AND COUPLING

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FIG. 1

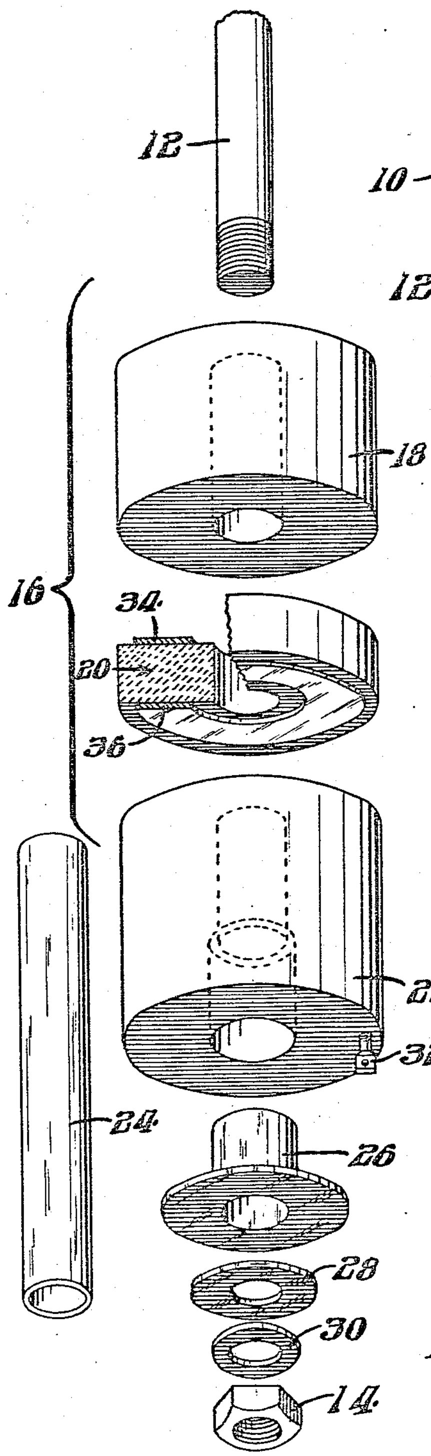


FIG. 2

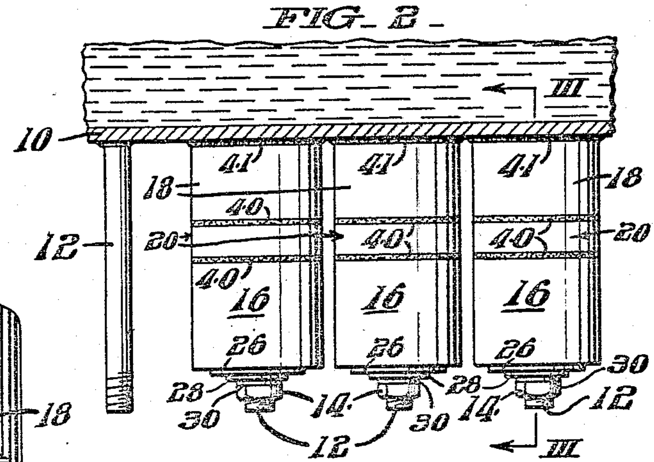
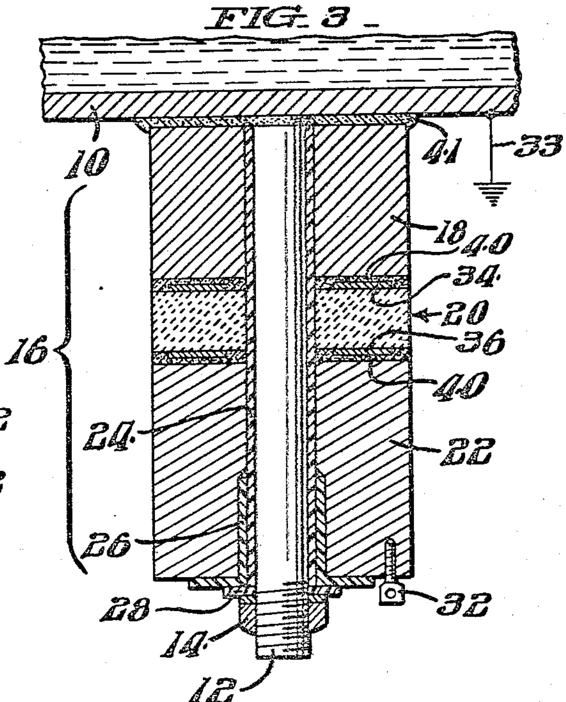


FIG. 3



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SANDWICH TYPE TRANSDUCER AND COUPLING

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This invention relates to piezoelectric transducers and in particular to an improved type of sandwich transducer especially suited for use in cleaning apparatus for effecting ultrasonic agitation of aqueous or other cleaning liquids.

It is well known that the power (ultrasonic wave amplitude) required to reach the cavitation threshold in an aqueous or other liquid is less at lower than at higher frequencies. It has been observed, for example, that the power required for cavitation increases rapidly above 100 kilocycles (kc.). Accordingly, it has been the practice to design ultrasonically agitated apparatus employing transducers submerged in aqueous or other liquids in tanks or other vessels, to operate at frequencies in the range from about 20 to 40 kc. Assuming the transducer crystal is of barium titanate, as is common, to obtain a frequency of 40 kc. would require the crystal to be about 2 inches thick and to obtain a frequency of 28 kc. would require a crystal over 3 inches thick. The use of blocks of barium titanate of such large thickness has a number of disadvantages. In the first place, it is difficult to polarize blocks of barium titanate of great thickness. Secondly, the total volume of barium titanate involved to produce industrial size ultrasonic cleaning equipment would be so great as to increase the cost excessively. Third, high driving voltages are required to operate equipment utilizing such thick blocks of barium titanate. Fourth, it is more difficult to fasten thick barium titanate blocks securely. Finally, the use of barium titanate blocks of large size limits the size of the tank and the method of tank fabrication because such blocks can be applied successfully only to thin membranes, i.e. to tank bottoms in the 16–20 gauge range to obtain high efficiency of transmission.

Our present invention overcomes the above enumerated deficiencies of the prior art techniques.

Our invention will be best understood from a consideration of the following detailed description of a preferred embodiment illustrated in the drawing in which:

FIG. 1 is an exploded illustration of a sandwich transducer according to our present invention.

FIG. 2 is a side elevational view of three transducers supported from the bottom of a tank of cleaning liquid.

FIG. 3 is a view, in cross section, along the line III—III of FIG. 2.

In describing the preferred embodiment of the invention illustrated in the drawing, specific terminology has been resorted to for the sake of clarity. However, it is not our intention to be limited to the specific terms selected and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

Referring first to FIGS. 2 and 3, the numeral **10** represents the bottom (or wall) of a tank containing an aqueous or other cleaning liquid. The tank bottom (or wall) **10** may be fabricated of steel plate of a thickness of about 1/16" to 3/16".

Secured to the tank bottom (or wall) **10**, as by welding, are a plurality of similar spaced-apart studs **12** the outer end of each of which is threaded for receiving the nuts **14**. Each stud **12** and nut **14** supports a transducer assembly **16** as shown in cross section in FIG. 3 and as shown clearly in exploded form in FIG. 1.

Transducer assembly **16** includes three main components, namely, an aluminum block **18**, a disc **20** of polarized piezoelectric material such as barium titanate or barium titanate mixed with calcium titanate, lead zirconate or other suitable material, and a block **22** of mild steel. Each of the components **18**, **20** and **22** is preferably of cylindrical configuration with an axial bore through which the stud **12** is passed. An insulating sleeve **24**, preferably of extruded plastic material such as polyethylene, separates the components **18**, **20**, and **22** from the stud **12**. A molded half-spool **26**, of insulating material such as nylon, insulates the steel block **22** from a washer **28**.

The optimum length of the aluminum slug **18** is a function of the operating frequency and of the thickness of the steel tank bottom. In a typical case, for an operating frequency of 28 kc., and a steel tank bottom in the range of from 1/16" to 3/16" thick, we employ an aluminum slug **18** of the type 2024–T351 aluminum having a diameter of 2 inches, an axial bore of 25/64 inch and a length of 1.25 inches. For an operating frequency of 40 kc. the aluminum slug **18** would have a length of about 0.75 inch.

The length of steel slug **22** is a function of the mass required to reduce the natural frequency of the crystal **20** to the frequency desired for the sandwich transducer assembly. For a frequency of 28 kc. we employ a steel slug **22** of A1S1 type 1018 or 1020 steel having a diameter of 2 inches, a bore of 25/64 inch (7/8 inch at the end which receives half-spool **26**) and a length of 1.75 inches. A comparable mass of copper or its alloys such as brass and bronze may be used as an equivalent for the steel slug.

Stated generally, the optimum length of the aluminum slug **18** is approximately one-quarter wavelength at the operating frequency (actually somewhat less than 1/4 wavelength).

For an operating frequency of 28 kc. we use, for the piezoelectric crystal **20**, a disc of barium titanate having a diameter of 2 inches, an axial bore of 0.437 inch, and a thickness of 0.5 inch. Both the upper and lower flat surfaces of the disc **20** are silvered to provide the conductive silvered areas **34**, **36**, shown in the drawing. A conductive adhesive **40**, preferably an epoxy resin having mixed therein a considerable quantity of finely-divided conductive material such as aluminum or lead dust, is employed for bonding the crystal disc **20** to the aluminum and steel slugs **18**, **22**, respectively, as shown in the drawing. The electrical contact of the piezoelectric material is through the conductive adhesive **40** and the silvered areas **34**, **36**. A similar conductive adhesive **41** is employed for bonding the other flat-surfaced end of the aluminum slug **18** to the bottom (or wall) **10** of the tank.

The steel slug **22** is provided with a drilled and tapped hole for receiving the terminal stud **32**. Stud **32** functions as one terminal for the radio-frequency energy applied from a source not shown. The bottom (or wall) **10** of the tank is grounded, as at **33**, to provide a ground return to the grounded side of the radio-frequency source.

To assemble the transducer sandwich, the three elements **18**, **20** and **22** are first compressed in the order named in a fixture together with the adhesive **40** in order to displace all air from the interfaces and to assure uniform distribution of the adhesive and conducting powder mixture. The transducer sandwich is then heated to the recommended temperature for the curing of the particular adhesive material used.

Prior to mounting the transducer sandwich assembly on the tank, the sandwich assembly may be checked for both frequency and capacitance.

By maintaining normal production tolerances of approximately plus or minus 0.0025 inch in length on the metallic elements and plus or minus 0.002 inch in thickness of the piezoelectric ceramic, it is possible to produce a batch of forty or more of these sandwich transducers by the assembly method briefly described above with a maximum frequency variation of about 200 cycles per second. The capacitance can be kept within the range of 0.0013 to 0.0016 microfarad.

The assembled, checked and inspected transducer sandwiches can then be mounted on the tank bottom (or wall) **10**, or on any other suitable metallic surface, by applying a thin coating of conductive adhesive between the aluminum element of the transducer and the surface of the metallic element to which it is to be fastened and inserting the sandwich assembly together with the sleeve **24** over the stud **12** and securing the same by means of the half-spool **26**, washers **28** and **30**, and nut **14**, as shown in the drawing.

The entire assembly may then be placed in an oven for curing. By the means just described, an exceptionally good acoustically coupled device is produced.

One terminal of the radio-frequency supply is connected to the steel slug **22** by way of the terminal stud **32**. The tank or surface to which the assembly is mounted is the grounded element of the radio-frequency circuit. It will be seen that the radio-frequency current flows through the transducer sandwich assembly with a minimum of wiring. The radio-frequency energy applied in this manner excites the piezoelectric element and produces highly efficient conversion of radio-frequency energy into mechanical energy, particularly when the radio frequency source is a generator of the type described in co-pending patent application entitled Radio Frequency Generator for Driving Piezoelectric Transducers filed by Frank J. Opolski et al. on June 17, 1960, Serial Number 36,796.

Transducer assemblies of the type just described lend themselves to economical construction and to high production rates with close quality control. Quality control of frequency and capacitance of each transducer sandwich is important in producing an efficient group of transducers for agitating the aqueous or other cleaning liquid. The transducer sandwiches are checked in air (before mounting) in order to classify them into groups with narrow frequency ranges. These transducers will all show the same relative decrease in frequency when mounted because the additional loading caused by the tank wall which changes the frequency to a frequency lower than that of the originally measured frequency is the same for all the transducer assemblies.

Aluminum is used as the material between the steel tank bottom or wall and the piezoelectric element because the impedance of aluminum is closer to that of the piezoelectric material than is that of any other commonly available metallic material of construction. When the steel tank bottom (or wall) **10** is 1/16" to 3/16" thick, which is an appreciable fraction of a wavelength at an operating frequency of 28 kc., the tank bottom (or wall) **10** becomes an integral part of the transducer sandwich and the R-F energy is transmitted from the piezoelectric material through the aluminum slug **18** and the tank bottom or wall into the liquid being agitated very efficiently. This is indicated by the observed uniformity of temperature maintained within the transducer sandwich and the very small variation of that temperature from the temperature of the cleaning liquid in the tank. A poor impedance coupling between the piezoelectric element and the liquid being agitated will cause internal friction in the piezoelectric material and result in depolarization.

In addition to offering a desirable impedance coupling, aluminum offers the further advantage of a high rate of heat conductance. These factors are important because the transducer assembly described above is enabled to operate at maximum power within plus or minus 2° F. of the ultrasonically agitated liquid. The maintenance of this small temperature difference is an indication of satisfactory transducer operation.

It is possible to remove and replace a faulty transducer

sandwich by merely tapping the particular assembly and exerting a twisting force to break the adhesive joint **41** between the aluminum slug **18** and the surface of tank **10**. Usually only a fillet of the adhesive will remain on the tank around the former periphery of the transducer. This fillet can be readily removed by a sharp instrument and another transducer sandwich of prechecked equivalent frequency and capacitance substituted in the system. The removal of the transducer sandwich from the tank surface **10** on which it is mounted, in the manner just described, is possible because the conductive adhesive **40** between the ceramic element **20** and the metallic elements **18** and **22** on either side thereof makes stronger joints than does a similar conductive adhesive **41** between the two metallic elements **18** and **10**.

It will also be noted that with the construction shown and described, the conductive adhesive merely provides good acoustical coupling and good radio frequency conductance. It does not support the weight of the transducer. This is supported by the nut. Thus, the adhesive need not resist the mechanical stress ordinarily present in other constructions arising from the weight of the transducer assembly itself.

While the example shown in the drawing and described in detail refers mainly to the mounting of our sandwich type transducer assembly to the bottom or wall of a tank and below the level of the cleaning liquid contained therein it will be readily seen that other locations are possible. For example, in the case of liquids of sufficiently good dielectric properties the assemblies of the present invention can be located within the tank itself by being fastened to suitable plates suspended or otherwise located therein. In the case of liquids with unsuitable dielectric properties the plate to which our transducer assemblies are mounted may form one surface of a complete enclosure for the groups of transducer assemblies. The various liquids which make open plate mountings possible or which may require enclosure of the transducer assemblies are well known to those skilled in the art. This makes possible a tailoring of the transducerized tank to fit any task which may arise.

While the preferred embodiment of this invention has been described in some detail, it will be obvious to one skilled in the art that various modifications may be made without departing from the invention as hereinafter claimed.

Having thus described our invention, we claim:

1. In combination: a tank adapted to contain an ultrasonically agitated cleaning liquid; a plurality of studs secured to and projecting from the outer surface of the bottom of said tank, each stud being provided with adjustable fastening means at its outer end; a plurality of axially bored sandwich-type-transducer assemblies each supported by one of said studs through said axial bore and comprising in outward order an aluminum block, a cylindrical piezoelectric crystal having silvered opposing faces and a steel block; means insulating said stud from said assembly and conductive adhesive means securing said aluminum and steel blocks to the opposing faces of said piezoelectric crystal and connecting said aluminum block to the outer surface of the bottom of said tank.

2. The combination of claim 1 in which said steel block has a mass adapted to reduce the natural frequency of the piezoelectric crystal to the desired frequency of the sandwich transducer assembly.

3. The combination of claim 2 in which said aluminum block has a length of approximately one-quarter wave length at the operating frequency of the transducer sandwich assembly.

4. In combination: a vessel adapted to contain an ultrasonically agitated cleaning liquid; a plurality of studs secured to and projecting outwardly from the outer surface of said vessel; a plurality of axially bored sandwich-type transducer assemblies each supported by one of said studs; each assembly comprising an aluminum block, a piezoelec-

tric crystal and a steel block; conductive adhesive means securing said aluminum and steel blocks to opposing faces of said crystal and conductive adhesive means connecting said aluminum block to the said outer surface of said vessel.

5. The combination of claim 4 in which said steel block has a mass adapted to reduce the natural frequency of the piezoelectric crystal to the desired frequency of the sandwich transducer assembly.

6. The combination of claim 5 in which said aluminum block has a length of approximately one-quarter wave length at the operating frequency of the transducer sandwich assembly.

7. A sandwich type piezoelectric transducer assembly comprising a stud fastened at one end to the outer surface of a vessel adapted to contain an ultrasonically agitated cleaning liquid; an insulating sleeve over said stud; a three-element cylindrical axially-bored sandwich assembly through which said stud and sleeve pass, said three elements comprising a piezoelectric crystal with its opposed flat surfaces at least partially silvered, an aluminum slug having one of its flat surfaces secured to one of said flat surfaces of said crystal by a conductive adhesive and a steel slug having one of its flat surfaces secured to the other of said flat surfaces of said crystal by a conductive adhesive; a conductive adhesive connecting the other flat surface of said aluminum slug to said outer surface of said vessel; and a fastening means on said stud for supporting said sandwich assembly.

8. A sandwich type transducer assembly comprising: a stud fastened at one end to the outer surface of a vessel adapted to contain an ultrasonically agitated cleaning liquid; a three-element axially bored cylindrical sandwich assembly through which said stud passes, said three elements comprising a piezoelectric crystal, an aluminum slug secured to one of the opposing surfaces of said crystal by a conductive adhesive and a steel slug secured to the other of said opposing surfaces of said crystal by a conductive adhesive; a conductive adhesive connecting an opposing surface of said aluminum slug to said outer surface of said vessel; and means for holding said sandwich assembly on said stud.

9. A sandwich type transducer assembly comprising: a stud fastened at one end to the outer surface of a vessel adapted to contain an ultrasonically agitated cleaning liquid; an axially bored cylindrical three element sandwich assembly through which said stud passes, said three elements comprising a piezoelectric crystal having its opposed flat surfaces at least partially silvered, an aluminum slug having one of its flat surfaces secured to one of said flat surfaces of said crystal by a conductive adhesive and a steel slug having one of its flat surfaces secured to the other of said flat surfaces of said crystal by a conductive adhesive; a conductive adhesive connecting the other flat surface of said aluminum slug to the said outer surface of said vessel; and means for holding said sandwich assembly on said stud.

10. A sandwich type transducer assembly comprising: a stud fastened at one end to a metallic plate located within a vessel adapted to contain an ultrasonically agitated cleaning liquid; a three-element axially bored cylindrical sandwich assembly through which said stud passes, said three elements comprising a piezoelectric crystal, an aluminum slug secured to one of the opposing surfaces of said crystal by a conductive adhesive and a steel slug secured to the other of said opposing surfaces of said crystal by a conductive adhesive; a conductive adhesive connecting an opposing surface of said aluminum slug to said plate; and means for holding said sandwich assembly on said stud.

11. A sandwich type piezoelectric transducer assembly comprising: a stud fastened at one end to a metal plate at least one surface of which at said point of fastening is adapted to be in contact with an ultrasonically agitated cleaning liquid; a three-element cylindrical axially-bored sandwich assembly through which said stud passes, said three elements comprising a piezoelectric crystal having its opposed flat surfaces at least partially silvered, an aluminum slug having one of its flat surfaces secured to one of said flat surfaces of said crystal by a conductive adhesive, and a metal slug having one of its flat surfaces secured to the other of said flat surfaces of said crystal by a conductive adhesive; a conductive adhesive connecting the other flat surface of said aluminum slug to said metal plate; and fastening means on said stud for supporting said sandwich assembly.

12. An assembly as claimed in claim 11 characterized in that said metal slug is steel.

13. An assembly as claimed in claim 11 characterized in that said metal slug is a copper alloy.

References Cited in the file of this patent

UNITED STATES PATENTS

2,714,672	Wright et al.	Aug. 2, 1955
2,873,392	Rich	Feb. 10, 1959
2,891,176	Branson	June 16, 1959
2,947,889	Rich	Aug. 2, 1960

FOREIGN PATENTS

879,929	Germany	June 18, 1953