United States Patent

Williams

[15] **3,689,783**

[45] **Sept. 5, 1972**

[54] **ULTRASONIC TRANSDUCER WITH HALF-WAVE SEPARATOR BETWEEN PIEZOELECTRIC CRYSTAL MEANS**

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[21] Appl. No.: **123,204**

[52] **U.S. Cl.** **310/8.3,** 310/8.7, 310/9.1, 310/26

[51] **Int. Cl.** **H04f 17/00**

[58] **Field of Search**..........310/8.2, 8.3, 8.7, 9.1, 9.4, 310/8.9, 26

[56] **References Cited**

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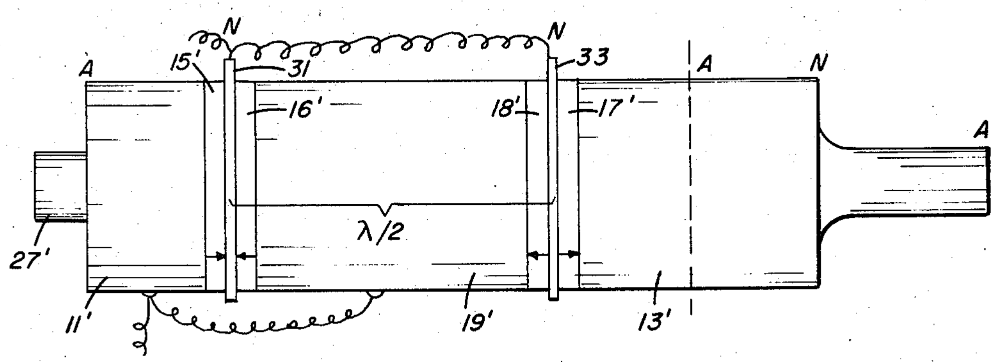
[57] **ABSTRACT**

An ultrasonic transducer comprises metal front and rear masses, two piezoelectric crystal means sandwiched therebetween, and a thick metal separator nearly one half wavelength thick between the crystal means to provide improved cooling by conduction of heat from the crystals. The transducer should have a length equal to a multiple of half wavelengths, and at least two half wavelengths, from end to end. A horn having a length equal to one half wavelength can comprise a part of the transducer, in which case the transducer length equals three half wavelengths.

13 Claims, 5 Drawing Figures



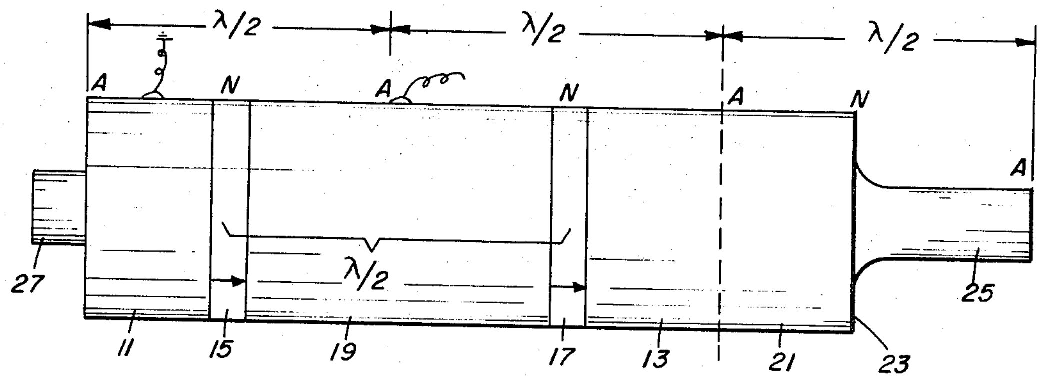


FIG. 1

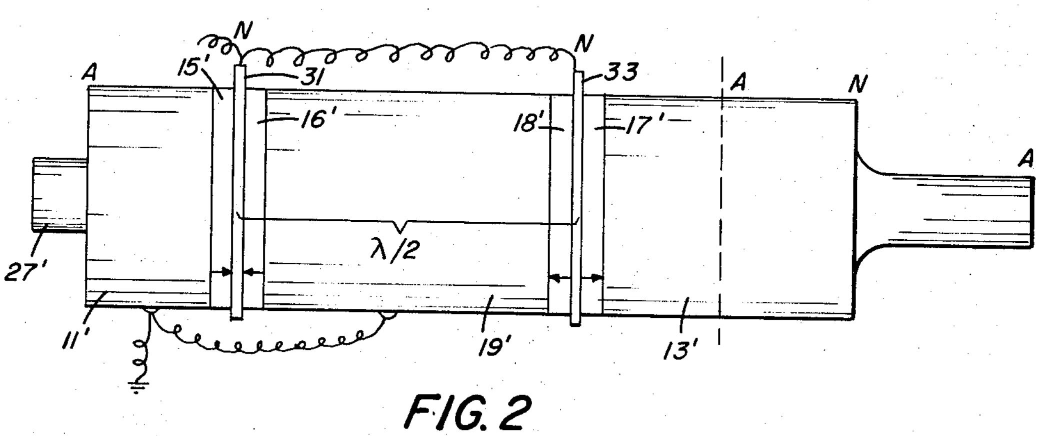


FIG. 2

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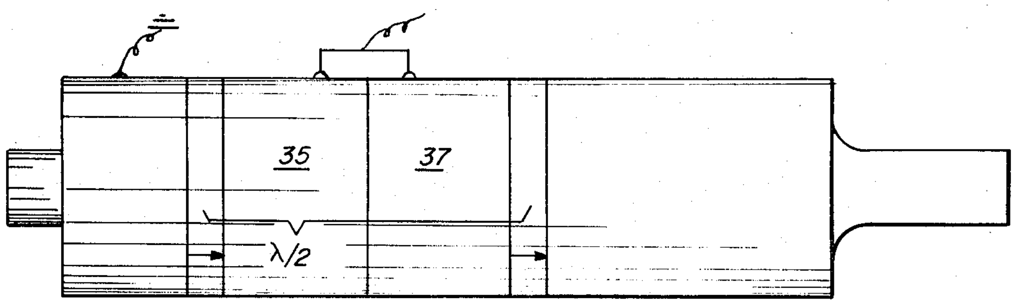

FIG. 3

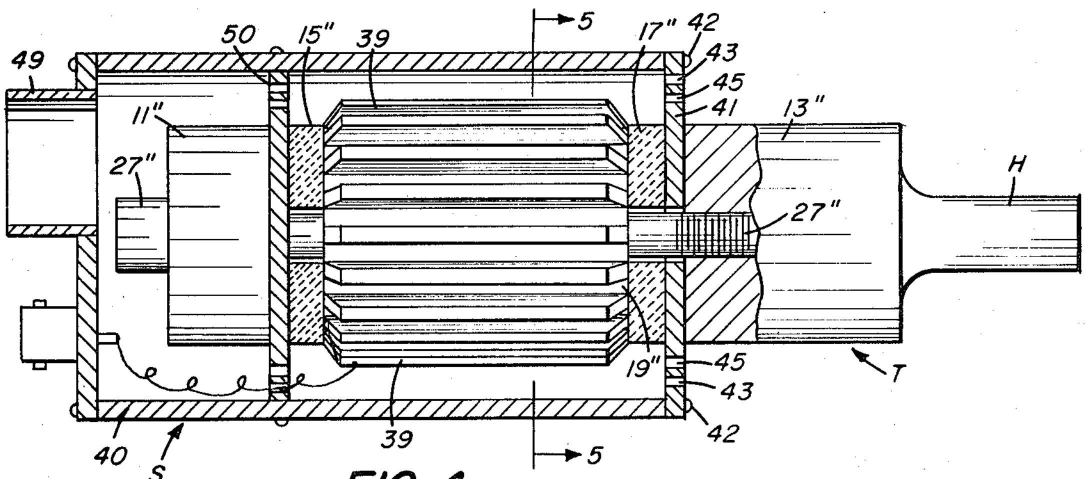

FIG. 4

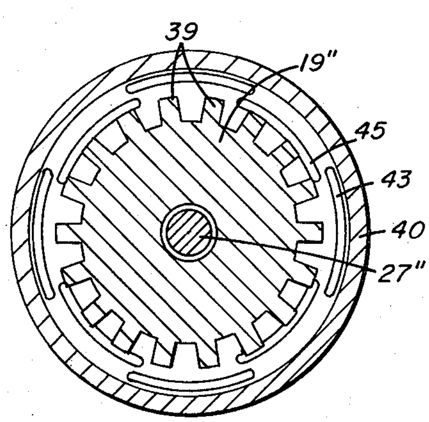

FIG. 5

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ULTRASONIC TRANSDUCER WITH HALF-WAVE SEPARATOR BETWEEN PIEZOELECTRIC CRYSTAL MEANS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a novel ultrasonic transducer design, and particularly to such an ultrasonic transducer so constructed as to promote the cooling of the ceramic piezoelectric crystalline elements during operation of the transducer.

2. Description of the Prior Art

Ultrasonic transducers are well known which comprise a metal front mass, a metal rear mass, and piezoelectric crystal means comprising one or more piezoelectric crystal elements sandwiched between the masses. When two piezoelectric crystal elements are employed, it is customary to provide a thin metal separator between the elements and to connect one side of the electrical circuit to such separator. Such separators in the past have been so thin as to impart only limited cooling effect during operation of the transducer. Examples of prior art transducers are shown in U.S. Pat. Nos. 3,328,610, 3,368,085, and 3,495,104.

SUMMARY OF THE INVENTION

In accordance with my present invention I provide an improved ultrasonic transducer design wherein the metal separator between two piezoelectric crystal means is of great thickness compared to the prior art so as to provide for the absorption and conduction of heat away from the crystal elements during operation of the transducer. Such an improved ultrasonic transducer comprises a metal front mass, a metal rear mass, two piezoelectric crystal means sandwiched between the two masses and located at nodal points, and a metal separator having a thickness nearly equal to a half wavelength between the two crystal means. A horn can extend from the front mass, either integral therewith or attached thereto.

The parts advantageously are cylindrical and can be clamped together by a single central bolt, by a number of peripheral bolts, or by a surrounding tension shell.

My improvements lie in constructing the transducer to have a length equal to a multiple of half wavelengths, and at least two half wavelengths, from end to end; locating the two crystal means at two different nodal points; constructing the metal separator between the two crystal means to be nearly one-half wavelength thick or long; and positioning the positively polarized surfaces of individual crystal elements so that the two crystal means do not buck each other when energized by high frequency alternating current such as 20–40 KHz or even higher.

Heat can be dissipated from the crystal elements and the metal parts of the transducer by passing a flowing stream of cooling air externally around them and/or through them internally; or by immersing them in a cooling liquid. Heat transmission away from the transducer can be improved by providing a plurality of heat conductive fins on the metal separator.

Suitable crystal discs are commercially available from the Clevite Corporation, of Cleveland, Ohio, and have been polarized at the manufacturer's and marked with a dot on the positively polarized surface.

THE DRAWINGS

In the drawings:

FIG. 1 is a side elevational view of an ultrasonic transducer embodying the principles of the invention;

FIG. 2 is a side elevational view of a different embodiment of a transducer embodying the invention;

FIG. 3 is a side elevational view of still another embodiment of the novel transducer;

FIG. 4 is a side elevational view, parts being broken away and shown in vertical section, of still another embodiment of transducer mounted in a support housing; and

FIG. 5 is a cross sectional view taken along the line 5—5 in FIG. 4.

The Preferred Embodiments

Referring to FIG. 1, there is shown an ultrasonic transducer comprising a driver section composed of a cylindrical rear mass **11**, a cylindrical front mass **13**, two like-polarized (note arrows) piezoelectric crystal discs **15** and **17** arranged in contact with flat faces of the rear and front masses respectively, and an intermediate metal separator **19** between the two crystal elements and having flat faces in contact therewith. The front mass **13** is integral with a metal velocity transformer or horn **21** which extends forwardly and is provided with an annular shoulder **23** terminating in an operating end **25** of greatly reduced diameter. The whole assembly is held together by a longitudinal metal bolt **27** which extends through central bores in the assembled parts and is threaded at its forward end to front mass **13**, care being taken to insulate the bolt internally from parts **15**, **17** and **19** by suitable electrical insulation or by suitable spacing.

The front and rear masses **11** and **13** and the separator **19** can be constructed of the same or different metals, such as aluminum, titanium, steel and the like. The crystal elements **15** and **17** can be any of the well known types such as barium titanate or lead-zirconate-titanate (PZT), which have been purchased in the polarized condition and are mounted with their positively polarized surfaces facing in the same direction as shown by the arrows so that they do not buck one another when energized. When using the thin separator plates of the prior art, the crystals are positioned with their positively polarized surfaces both facing toward the separator plate.

My novel transducer as shown is 1½ wavelengths long from end to end, and embodies a separator plate **19** which is nearly one-half wavelength thick, this being many times thicker than the conventional thin separator plate.

Referring to FIG. 1 the crystal discs **15** and **17** are located at (and preferably centered on) nodal points N (for maximum effectiveness in driving the transducer). Shoulder **23** also is located at a nodal point N. Thus there are provided three nodal locations at which the transducer can be mounted in a support without dissipating energy by damping the desired longitudinal vibrations (between crystal **15** and rear mass **11**; between crystal **17** and front mass **13**; and at shoulder **23**). On the other hand the greatest longitudinal vibration or excursion of the transducer occurs at the antinodes A, one of which is at the front end of the horn **21** which is adapted to engage with work to be spliced or otherwise treated. Vibration at the end of the horn, of course, is amplified by reducing the diameter of the horn as shown at **25**.

With this construction cooling is promoted by separating the crystal elements from one another by the substantial thickness of separator **19**. Moreover, heat which is generated in the crystals **15** and **17** when they are energized is dissipated by conduction through the three adjoining metal members **11**, **13** and **19** having much greater mass and thermal conductivity than the ceramic crystal elements, thus preventing excessive heat from building up in the apparatus.

A typical transducer in accordance with FIG. 1 had a combined horn **21** and front mass **17** of titanium 3.212 inches long, an aluminum separator **19** 2.125 inches long, and a steel back mass **11** 0.917 inch long, and was successfully operated at 40 KHz. Crystals are 0.25 inch thick. Horn **25** has a 0.5 inch diameter, and the rest of the transducer is 1.5 inches in diameter.

Referring to FIG. 2 there is shown another embodiment comprising similar front and rear masses **11′**, **13′**, and a similar thick metal separator **19′** between two composite crystal means. Each composite crystal means comprises a pair of thin piezoelectric crystal discs **15′**, **16′** and **17′**, **18′**, with individual thin metal separator plates **31** and **33** between discs of the respective pairs, and each pair is located at a nodal point. The two separator plates **31** and **33** are electrically connected in parallel to one side of the energizing electrical circuit, and the rear mass **11′** and thick separator **19′** are connected in parallel to the other side of the energizing circuit. The advantages of this construction are that it provides higher conductance to better match a low source impedance generator, and requires lower driving voltage.

The crystals as purchased from the manufacturer are all polarized the same, and are so positioned in the transducer that the crystals of one pair do not buck the crystals of the other pair. Thus the marked positive surfaces of crystals **15′**, **16′** are positioned facing toward one another and separator **31**, while the marked positive surfaces of crystals **17′**, **18′** are positioned facing away from one another and separator **33**. Consequently, both crystals of one pair will expand axially when a positive voltage side of an alternating current is applied, while both crystals of the other pair will contract axially; and vice versa when the negative voltage side of an alternating current is applied. Converse positioning can be used as effectively, i.e., the marked positively polarized surfaces of crystals **15′**, **16′** facing away from one another, and the marked positively polarized surfaces of crystals **17′**, **18′** facing toward one another.

Referring to FIG. 3, the construction is similar to that of FIG. 1 except that the intermediate half wave separator between crystals comprises two elements **35** and **37** of equal dimensions but of different metals having different densities, which are arranged face-to-face between the crystals. For example, light weight titanium or aluminum can be used for the rear half section **35** (constituting the front part of the rear one-half wave section of the entire transducer), and a relatively heavy element **37** of steel can be used for the front half section **37** (constituting the rear part of the front one-half wave section of the entire transducer), to produce velocity increase through conservation of momentum. In this design the electrical connection is to both of the elements **35** and **37** across the interface.

Now referring to FIGS. **4** and **5** there is shown ultrasonic apparatus comprising an ultrasonic transducer T mounted in a suitable support S to permit air cooling of the transducer. In this modification the thick half wave metal separator **19″** between crystal elements **15″** and **17″** carries a series of longitudinally extending radial fins **39** on its exterior for dissipating the heat generated in the crystals. Alternatively, circumferential fins or flanges can be used.

In this apparatus the transducer T is positioned within a cylindrical housing **40** and is mounted thereon by a mounting plate or flange **41** which is clamped firmly between the front crystal **17″** and the rear end of the front mass **13″** by means of the central bolt **27″**. Thus the mounting plate **41** can be considered as part of the front mass **13″**.

Mounting plate **41** is connected to housing **40** in any desired way, as by a series of small screws or bolts **42**. In order to damp the transmission of vibrations from transducer T to support S, the support plate **41** is provided with two series of circumferentially extending overlapping slots **43** and **45** arranged on different circumferences.

Cooling is improved by flowing cool air into the housing **40** through an inlet **49** to pass over the fins **19″** and out through the slots **43** and **45**. Internal air cooling can also be employed as in U.S. Pat. No. 3,555,297 of C.W. Pierson; or as in application Ser. No. 118,797 filed on Feb. 25, 1971 by Thomas E. Loveday, titled "-Cooled Ultrasonic Transducer."

Where greater rigidity and stability of mounting are required than with the single support plate **41**, a second similar perforate support plate **50** can be clamped at a nodal point between the rear mass **11″** and the adjoining crystal element **15″**, and mounted on the housing **40** in any desired way, as by radial screws.

Support S not only provides for cooling the transducer, but also can be clamped in a suitable apparatus for holding the transducer in operating position. Such apparatus can be either stationary or can be designed to move the transducer along, as when performing a splicing operation on plastic sheets (as in U.S. Pat. No. 3,556,912 of Burgo and Pierson).

The ultrasonic transducers described above are simple in construction and easily manufactured because all elements are cylinders of equal diameter which are easily machined and can be clamped together by a single bolt. Cooling is greatly improved, especially for continuous duty high power applications such as the splicing of plastic webs. The principles of the invention also apply to ultrasonic transducers which terminate at the front end of the front mass **13**, for example as employed for the agitation of cleaning solutions for the for mixing of liquids by fastening the transducer to a tank wall.

With the foregoing principles in mind, a person skilled in this art can calculate the theoretical physical dimensions for an ultrasonic transducer constructed of specific metals and for a specific resonant frequency, from the relationship and formula:

$$\lambda = c/f$$

where λ is one wavelength in inches, c is the longitudinal bar velocity of sound through the metal (inches/second), and f is the desired resonant frequency in Hz. For example, if separator **19** is to be aluminum and the operating frequency is to be 40 KHz,

$$\lambda = c/f = \frac{203,000 \text{ in./second}}{40,000} = 5.1 \text{ inches}$$

Dividing by 2, the length of separator **19** for one-half wavelength should be 2.6 inches. The same type calculations determine the theoretical length of the other metal parts **11**, **13**, and **21**. The longitudinal bar velocities for many materials are listed in Appendix B on page 363 of the book Ultrasonic Engineering by Julian R. Frederick, published by John Wiley & Sons, Inc. (1965). The bar velocity in titanium is not listed, but is 1.96×10in/s.

To establish the nodes within each of the separated driving elements **15** and **17**, the physical length of the separator **19** should be shortened to less than λ/2 to account for the portions of the transducer length occupied by the driving elements.

Calculations as described above enable a skilled person to design only close approximations of the lengths of transducer elements for several reasons, among which are the facts that the formula is based on a long extremely thin bar of uniform diameter, that velocities in commercial alloys vary slightly from the velocities in pure metals, that the mechanical design of practically useful transducers requires the presence of one or more connecting bolts and that the horn **21** is of different diameters. Consequently, the several metal parts are fabricated to a length slightly greater than theoretical, assembled, operated, and then pared down to the correct length so that the nodes and antinodes will be properly located and the desired operating frequency maintained. Many techniques for locating the nodes and antinodes are well known, such as observing the effect of vibrations on powder, or probing the transducer with a piezoelectric phonograph needle pick up.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

I claim:

1. In an ultrasonic transducer comprising a metal front mass, a metal rear mass, two piezoelectric crystal means sandwiched between said masses, and a heat dissipating metal separator between and in contact with said two crystal means, the improvement wherein the length of said transducer is a multiple of half wavelengths, and at least two half wavelengths, from end to end thereof; wherein said crystal means are located at different nodal points one half wavelength apart; and wherein said metal separator is nearly one half wavelength thick thereby presenting substantial surface area for heat disposal so as to provide for cooler and consequently higher power operation.

2. In an ultrasonic transducer in accordance with claim **1**, a metal horn projecting from said front mass, said horn including a terminal portion of reduced diameter, said horn having a length equal to one half wavelength, said horn having a free end located at an anti nodal point.

3. In an ultrasonic transducer in accordance with claim **2**, said metal separator being a unitary metal body.

4. In an ultrasonic transducer in accordance with claim **2**, said metal separator comprising two aligned members formed of metals having different densities.

5. In an ultrasonic transducer in accordance with claim **2**, said two crystal means each comprising a single crystal element, each crystal element having a positively polarized surface facing in the same direction as the positively polarized surface of the other crystal element.

6. In an ultrasonic transducer in accordance with claim **2**, said two crystal means comprising first and second pairs of crystal elements, and first and second metal electrical conductors therebetween, respectively, the crystal elements of said first pair having positively polarized surfaces facing toward said first conductor, the crystal elements of said second pair having positively polarized surfaces facing away from said second conductor.

7. In an ultrasonic transducer in accordance with claim **6**, said conductors being electrically connected together in parallel into one side of an electrical circuit, and said rear mass and said separator being electrically connected in parallel into the other side of said electrical circuit.

8. In an ultrasonic transducer in accordance with claim **2**, said metal separator having a plurality of heat conductive fins projecting therefrom.

9. In an ultrasonic apparatus, a transducer in accordance with claim **2**, a support housing enclosing said transducer, and means for blowing cooling gas into said housing and over the exterior of said transducer.

10. In an ultrasonic apparatus, a transducer in accordance with claim **8**, and means for blowing cooling gas over said fins.

11. In an ultrasonic apparatus, a transducer in accordance with claim **2**, a support housing enclosing said transducer, at least one perforate mounting plate means clamped between elements of said transducer at at least one nodal point, said mounting plate means being also fastened to said support housing.

12. In an ultrasonic transducer comprising a metal front mass, a metal rear mass, two piezoelectric crystal means sandwiched between said masses, and a heat dissipating metal separator between and in contact with said two crystal means, the improvement wherein the length of said transducer is a multiple of half wavelengths, and at least two half wavelengths, from end to end thereof; wherein said crystal means are located at different nodal points one half wavelength apart and are polarized and arranged to expand and contract in opposite phase relationship; and wherein said metal separator is nearly one half wavelength thick thereby presenting substantial surface area for heat disposal so as to provide for cooler and consequently higher power operation.

13. In an ultrasonic transducer in accordance with claim 1 said crystal means being so polarized and so arranged relative to one another that when energized with high frequency alternating current, expansion of one crystal means occurs at the same time contraction of the other crystal means occurs, and vice versa.

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PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,689,783 Dated September 5, 1972

Inventor(s) David A. Williams

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading on the first page of the patent, "Fairport" should read --Rochester--.
Also in the heading, the assignee should be listed as --Eastman Kodak Company, Rochester, N. Y.--.
In column 5, line 19, change "1.96 x 10 in/s" to read --1.96×10^5 in/s--.

Signed and sealed this 22nd day of May 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents