Feb. 6, 1962 W. WELKOWITZ 3,019,660

ULTRASONIC TRANSDUCER

Filed April 26, 1956

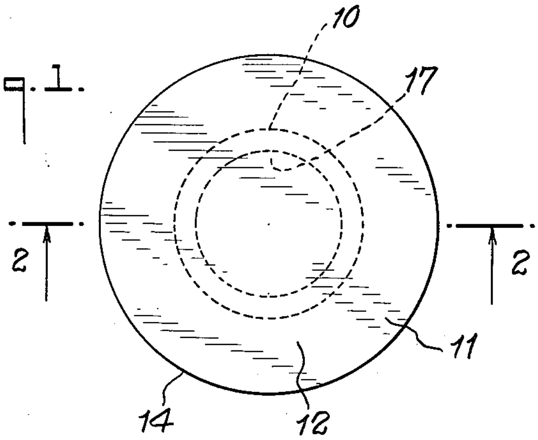

Fig. 1.

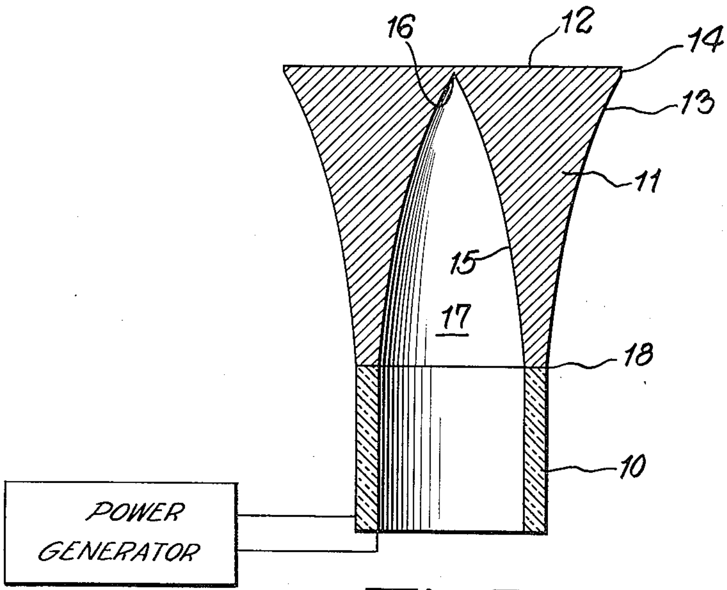

Fig. 2.

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ULTRASONIC TRANSDUCER

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My invention relates to ultrasonic transducers and in particular to those transducers whose active, driving element is a hollow cylinder with a small radiating surface and wherein a radiator is employed to acoustically transform the small radiating surface to a larger one.

When a hollow cylindrical electromechanical driving element vibrates in length mode (parallel to the axis of the cylinder), it is usually a very inefficient sound radiator. It is necessary to provide means for acoustically transforming the small radiating area into a much larger radiating area. Many other methods and techniques have been employed to obtain these results but up to now, it has been difficult to obtain good results using hollow cylindrical driving elements. The hollow cylinder is preferred since it is easy to cast the various ceramics in this shape. It is best to keep the driving element of reasonable size (neither very large nor very small) in order to produce the elements economically with little production shrinkage.

Accordingly, it is a principal object of my invention to provide an ultrasonic transducer wherein it is possible to acoustically transform a small radiating area into a greater radiating area.

It is a further object of my invention to provide an acoustic radiator whose acoustic resistance is substantially equal to that of the active driving element and which presents a much greater radiating area to the transmission medium than the radiating area of the active driving element.

It is a still further object of my invention to provide an ultrasonic transducer whereby it is possible to obtain more than the usual amount of energy from the active driving element.

Other objects and advantages of my invention will be apparent during the course of the following description.

In the accompanying drawings, forming a part of this application, and in which like numerals are employed to designate like parts throughout the same,

FIGURE 1 is a plan view of a preferred embodiment of my invention in which the driving element is a hollow cylinder formed of polarized electrostrictive material, to one end of which is affixed a solid radiator, and

FIGURE 2 is a cross-sectional view along the line 2—2 of FIGURE 1.

In the drawings, wherein for the purpose of illustration is shown a preferred embodiment of my invention, the numeral **10** designates a polarized electrostrictive driving element. I prefer to fashion the driving element **10** of material composed largely of barium titanate but any other material or type of electromechanically sensitive body, which can be formed in the shape of a hollow cylinder and driven in its length mode, parallel to the axis of the cylinder, may be employed with equally good results. Radiator **11** is joined to **10** at joint **18** using a high strength thermo-setting plastic adhesive of epoxy resin and having a very low compliance. I prefer to fashion radiator **11** of brass which has an acoustic resistance approximating that of barium titanate but other solid materials such as various aluminum alloys may also be used. If materials other than barium titanate are used for the driving element, it is conceivable that a solid other than brass will have an acoustic resistance more closely approximating that of the material of the driving element. The front face of **11** is designated by **12**. I

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prefer to fashion face **12** as a flat face in a single plane but I have found that those having a slight curvature may also be utilized with equally good results. Curve **13** generates the outer surface of revolution and is seen to taper outwardly from where radiator **11** is joined to element **10** as shown in FIGURE 2 and curve **14** generates the cylindrical portion of the outer surface of **11**. Curve **15** generates the inner surface of revolution which terminates in point **16**. Point **16** is substantially in the same plane as the plane of the junction between the surfaces of revolution generated by curves **13** and **14**. **17** designates the air space within element **10** and radiator **11**.

Element **10** is driven by the usual power generator **19** which applies excitation voltage to the electrodes (not shown) such that element **10** is driven in its length mode, parallel to the axis of the cylinder. The vibration of element **10** causes radiator **11** to vibrate and thereby transmit an acoustical wave from the whole area of face **12** into the transmission medium.

In use, the combination is mounted so that face **12** is in contact with the liquid and the balance of radiator **11** and all of element **10** are in air. The transducer may be mounted in the hull of a vessel or in the side of a tank so long as the above conditions are maintained.

If it is desirable to submerge the combination in liquid, it is necessary to enclose all of the unit except face **12** in a liquid-tight container (not shown). This container may be of metal or other suitable material and is attached to the unit at the outer surface of revolution generated by curve **14**.

Ultrasonic transducers of my invention may be utilized at frequencies from approximately 10 kc. to approximately 200 kc.

By way of example and without limiting the scope of my invention, I have found the following dimensions to produce excellent results at an excitation frequency of 40 kc.:

Length of **10**=2″, outside diameter of **10**=2¼″, thickness of **10**=¼″, length of **11**=4″, diameter of **12**=4″, length of **14**=1⁄16″ and diameter of **11** (at its midlength) =2¾″. These dimensions are for a driving element composed largely of barium titanate and a radiator of brass. For these materials, and for a 2″ diameter cylinder, the following formulas will give excellent results: for the driving element

$$l=\frac{80}{f}$$

where f is in kilocycles and l is in inches; for the radiator

$$l=\frac{140}{f}$$

where f is in kilocycles and l is in inches.

I have had excellent results: when curve **13** is of the form $y=y_0e^{ax}$ and **15** is its mirror; when curve **13** is of the form

$$y=y_0\left(l+\frac{x}{x_0}\right)$$

and **15** is its mirror; and when curve **13** is of the form $y=y_0 \cosh ax$ and **15** is its mirror; where x is distance along axis, y is distance away from axis, e is an exponential number, and a is a constant. However, other curves, which will produce surfaces of revolution with similar characteristics to those described, may also be employed as the generating curves **13** and **15**.

Radiator **11** possesses cylindrical symmetry and its inner and outer surfaces generated by curves **13** and **15** are mirrors of each other, referred to a cylindrical mirroring surface.

While I have described my invention by means of specific examples and in a specific embodiment, I do not wish to be limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit of my invention or the scope of the subjoined claims.

Having thus described my invention, I claim:

1. An ultrasonic transducer comprising a hollow, cylindrical, polarized electrostrictive, electromechanically sensitive body; a radiator; and power generating means; said radiator being affixed to one end of said electromechanicallly sensitive body by means of a high strength, thermo-setting adhesive of low compliance, said radiator having a face opposite said electromechanically sensitive body greater in area than that of the portion of said radiator affixed to said electromechanically sensitive body so that the outer surface of said radiator tapers outwardly from said electromechanically sensitive body toward the face of said radiator, said outer surface being a surface of revolution which terminates a small distance from said face, where said surface of revolution becomes a cylinder, said radiator having an inner surface of revolution smaller in area than said outer surface, said inner surface being generated by a curve which is the mirror of the curve generating said outer surface, said inner surface terminating in a point which is substantially in the same plane with the points at which said outer surface becomes a cylinder, said radiator having approximately the same acoustic resistance as said electromechanically sensitive body, said electromechanically sensitive body being vibrated in length mode by said power generating means.

2. An ultrasonic transducer as described in claim 1 wherein said face of said radiator lies in a plane.

3. An ultrasonic transducer as described in claim 1 wherein the curve generating said tapered outer surface is of the form $y=y_o e^{ax}$, where x is distance along axis, y is distance away from axis, e is an exponential number, and a is a constant.

4. An ultrasonic transducer as described in claim 1 wherein the curve generating said tapered outer surface is of the form

$$y=y_o\left(l+\frac{x}{x_o}\right)$$

where x is distance along axis, and y is distance away from axis.

5. An ultrasonic transducer as described in claim 1 wherein the curve generating said tapered outer surface is of the form $y=y_o \cosh ax$, where x is distance along axis, y is distance away from axis, and a is a constant.

6. An ultrasonic transducer as described in claim 1 wherein said electromechanically sensitive body is composed largely of barium titanate.

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