

Aug. 11, 1970

A. J. LAST ET AL

3,524,083

DEVICE FOR THE CONCENTRATION OF VIBRATIONAL ENERGY

Filed Dec. 16, 1968

2 Sheets-Sheet 1

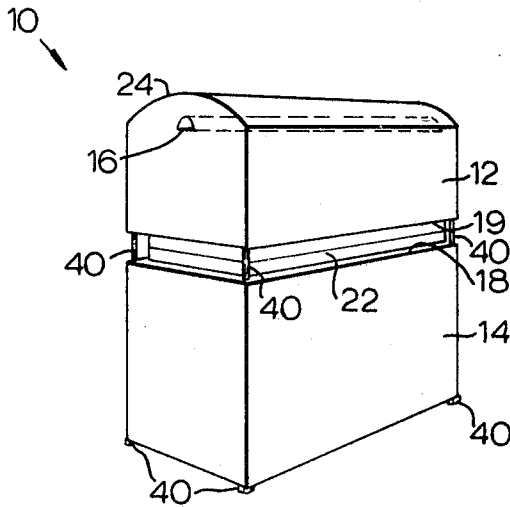


FIG. 1.

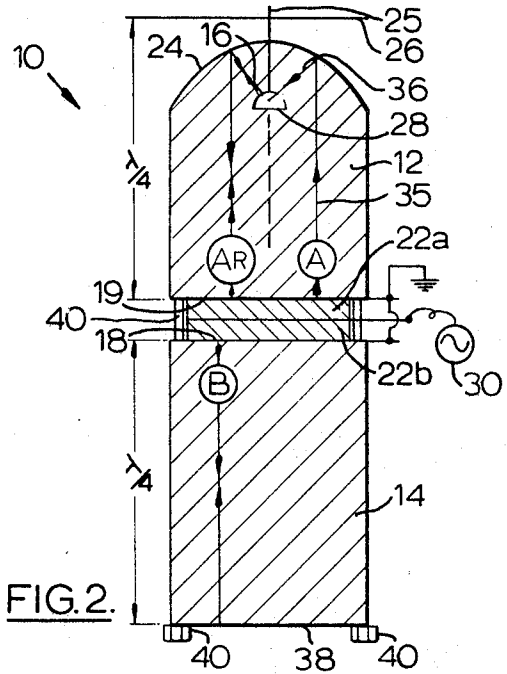


FIG. 2.

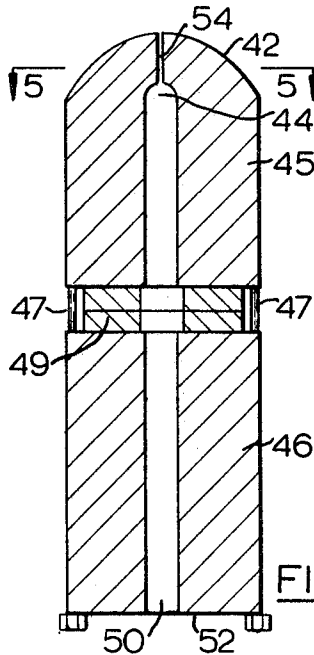


FIG. 3.

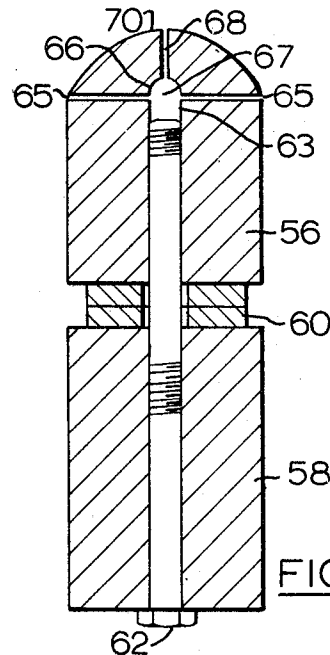


FIG. 4.

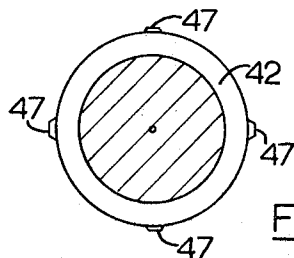


FIG. 5.

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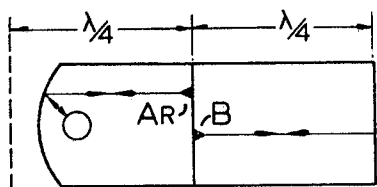


FIG. 6.

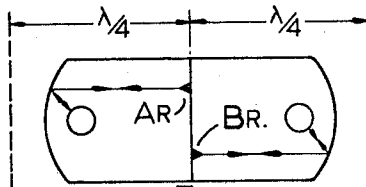


FIG. 7.

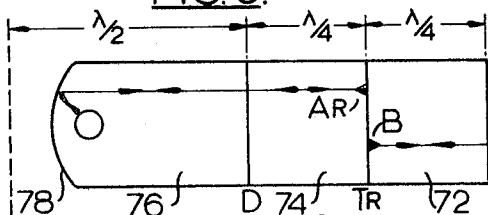


FIG. 8.

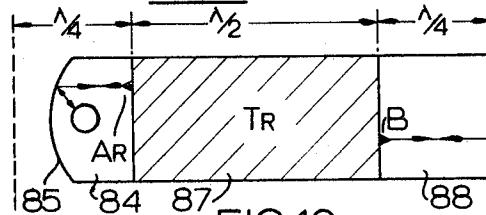


FIG. 10.

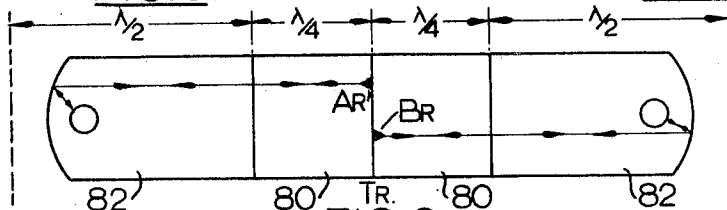


FIG. 9.

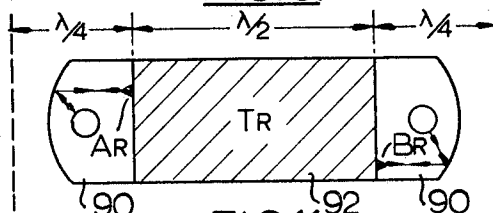


FIG. 11.

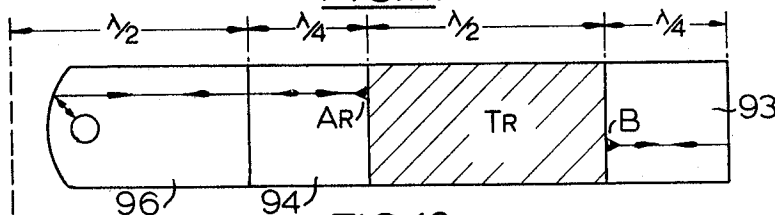


FIG. 12.

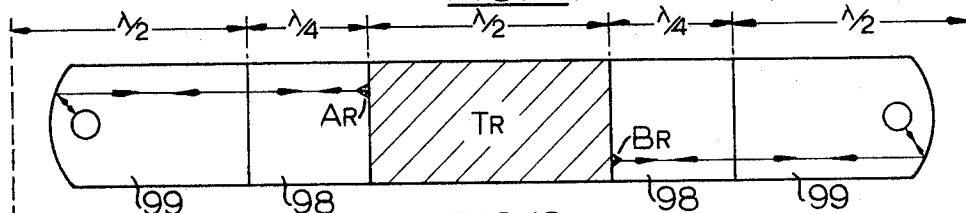


FIG. 13.

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DEVICE FOR THE CONCENTRATION OF VIBRATIONAL ENERGY

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Int. Cl. H01v 7/00

U.S. Cl. 310—8.1

14 Claims

ABSTRACT OF THE DISCLOSURE

A device which utilizes a parabolic interface to concentrate initially parallel vibrations at a single point or line, corresponding to the focus of the parabolic interface. A transducer sandwiched between two solid elements is used to generate vibrations emanating in opposite directions through the two solid elements, and the solid elements are dimensioned such that any portion of the vibrations reflected back to the transducer arrives in phase with the transducer's motion. A passageway is provided in one of the solid elements through the focus of the parabolic surface, such that, for example, two liquids can be passed through the passageway and emulsified or mixed by the concentrated vibrations.

This invention relates generally to devices for concentrating vibrational energy in a small volume, and has to do particularly with devices adapted to cause violent agitation of a liquid passed through the vicinity of energy concentration. Such agitation could be used, for example, to emulsify two immiscible liquids, or to effect the dispersion of a solid in a liquid.

GENERAL BACKGROUND OF THE INVENTION

It is well known to utilize ultrasonic vibrations to cause emulsification or to disperse solids in a liquid. The following patents may be referred to in this connection: U.S., 2,606,174, Aug. 5, 1952, Kolthoff et al.; U.S., 3,165,299, Jan. 12, 1965, Balamuth et al.; German, 712,216, Oct. 14, 1941, Hertz et al.; German, 716,231, Jan. 15, 1942, Hertz et al.; German, 960,893, Mar. 28, 1957, Hertz; German, 718,744, Mar. 19, 1942, Schöfer; German, 994,667, June 21, 1956, Sauter.

Those skilled in this art will be familiar with the various methods of generating ultrasonic vibrations. These methods may be classified as electrostrictive, magnetostrictive, or mechanical. The present invention is particularly adapted to utilize either the electrostrictive or the magnetostrictive method of vibration generation. Of the two types of electrostrictive effects known as "piezoelectric" and "ferroelectric," it is the former effect which is preferably used in the electrostrictive application of this invention. The "piezoelectric" effect is a phenomenon exhibited by materials such as quartz, Rochelle salt, and tourmaline, wherein the crystal changes its length over certain crystallographic axes by a differential varying directly with an electric field placed across the crystal. Thus, a high-frequency alternating electric field placed across the appropriate axis of a crystal of quartz will cause the crystal to vibrate at the same frequency as that of the electric field. Generally, natural crystals have been replaced in modern practice by artificial crystals, and such materials as barium titanate and lead zirconate titanate can be made to act in a piezoelectric manner by prepolarization.

The magnetostrictive types of generators are based on changes in shape that occur when certain substances are magnetized. Nickel and nickel-copper ferrites are magnetostrictive materials. When rods made from these substances are magnetized by sending a high-frequency alter-

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nating current through coil windings around them, the length of the rods varies with the changes in polarity, causing them to oscillate with the applied current. Just as in the case of electrostrictive materials, there are two magnetostrictive types. Those producing deflections directly proportional to the magnetic field are demonstrating the piezomagnetic effect, and this effect is preferably used in the magnetostrictive application of this invention. In order to act in a piezomagnetic manner, a bias polarization must be maintained on the material and this in fact is done for all power applications.

Devices such as the above, capable of transforming one form of energy into another form, are called transducers.

In the adaptation of the above effects to accomplish the objects of this invention, a "sandwich" construction is utilized throughout, wherein a transducer, either electrostrictive or magnetostrictive, is tightly sandwiched between two blocks, the latter usually of metal. This construction permits a selection of the resonance frequency at which efficiencies are highest.

OBJECTS OF THE INVENTION

One object of this invention is to provide a device for concentrating vibrational energy capable of generating and focusing high-frequency mechanical vibrations at a single point or along a single line.

A further object of this invention is to provide a device capable of violently agitating a liquid, by focusing high-frequency mechanical vibrations in the liquid at a single point or along a single line.

GENERAL DESCRIPTION OF THE INVENTION

Generally, the invention provides a device consisting of a sandwich in which a transducer, either electrostrictive or magnetostrictive, is firmly sandwiched between two blocks of metal in such a way that longitudinal mechanical vibrations can be propagated rectilinearly in mutually opposed directions away from the transducer into the two blocks of metal. At least one of the blocks has a convex parabolic surface of which the axis is parallel to the direction of vibration propagation, and this parabolic surface is adapted to concentrate the longitudinal vibrations at the focus of the parabolic surface. A passageway is provided in the block with the parabolic surface, the passageway containing the focus of the parabola.

The preceding paragraph sets out the basic proposition from which this invention proceeds: namely, the concentration of parallel longitudinal vibrations by focusing the said vibrations through reflection at a parabolic surface. Further investigation of the vibrational characteristics of the concentrating device, however, indicates that a portion of the vibrations converging at the focus of the parabola reflects off the passageway wall, reflects again from the parabola, and returns to the transducer. Also, in addition to the mechanical vibrations emanating directly from the interface between the transducer and the metal block having the parabolic surface, the transducer emits into the other metal block vibrations which could likewise be reflected back to the transducer having encountered a surface or surfaces of the other metal block. If any of the reflected vibrations were to arrive at the transducer at an angle to the original vibration direction, or parallel to the original vibrations but out of phase with the transducer, interference would take place at the transducer and the efficiency of the device would suffer.

In view of the above, this invention further provides a construction whereby any portion of the mechanical vibrations generated by the transducer which return after reflection to the transducer are in phase with the latter, or substantially so, in order to maximize the efficiency of the device.

More specifically, this invention provides a device for concentrating vibrational energy, comprising: a transducer sandwiched between a first and a second solid element, the first solid element having a first plane surface in contact with said transducer and a convex parabolic surface of which the parabolic axis is normal to said first plane surface, the directrix of said parabolic surface being parallel to said first plane surface, a passageway in said first solid element through which a fluid may be transmitted, said passageway containing the focus of said parabolic surface, the second solid element having a second plane surface in contact with said transducer, the transducer being adapted to transmit vibrations into said first solid element in the direction normal to said first plane surface, said vibrations being reflected from said parabolic surface to converge on said passageway, a first portion of said vibration passing through the wall of said passageway into the fluid, a second portion of said vibration being reflected from the wall of said passageway and then reflected from the parabolic surface toward said first plane surface in the direction normal to said first plane surface, said first solid element being dimensioned such that said second portion arrives at said transducer in phase therewith, the transducer also transmitting further vibrations into said second solid element in the direction normal to said second plane surface, said further vibrations being generated simultaneously with said first-mentioned vibrations, said second solid element being dimensioned such that any reflected part of said further vibrations returning to the transducer arrives at said transducer in phase therewith.

GENERAL DESCRIPTION OF DRAWINGS

Eight embodiments of this invention are shown in the accompanying drawings, in which like numerals denote like parts throughout the several views, and in which:

FIG. 1 is a perspective view of one form of the first embodiment of this invention;

FIG. 2 is a cross-sectional view of the embodiment shown in FIG. 1;

FIG. 3 is an axial sectional view of another form of the first embodiment of this invention;

FIG. 4 is an axial sectional view of yet another form of the first embodiment of this invention;

FIG. 5 is a cross-sectional view taken at line 5—5 in FIG. 3; and

FIGS. 6—13 inclusive are simplified diagrams representing axial sectional views, respectively, of the eight embodiments of this invention.

Reference is made first to FIG. 1, in which an emulsifying device 10 is seen to include a first solid element 12, and a second solid element 14. The word "solid" is used in this context to distinguish "solid" from "liquid" or "gas," and does not necessarily mean that the elements 12 and 14 are not cavitated. In the preferred form of the first embodiment shown in FIGS. 1 and 2, the second solid element 14 is in fact free of cavities, but the first solid element contains a passageway 16, later to be described in detail. The second solid element 14 has an upper plane surface 18, and the first solid element 12 has a lower plane surface 19. The surfaces 18 and 19 bear against the opposite surfaces of an electrostrictive transducer 22, which is preferably a piezoelectric crystal such as pre-polarized lead zirconate titanate.

The lower solid element 14 is in the shape of a rectangular parallelepiped. Referring to the upper solid element 12, the lower plane surface 19 and the four vertical walls are those of a rectangular parallelepiped, but opposite the plane surface 19 is a convex parabolic surface 24 of which the parabolic axis 25 (see FIG. 2) is normal to the plane surface 19. The directrix 26 of the convex parabolic surface 24 is a plane, and is parallel with the plane surface 19. As best seen in FIG. 1, the convex parabolic surface 24 is a cylindrical surface. The word "cylindrical" is here used in its broadest sense, i.e. to define a surface which is the locus of a straight line

moving curvilinearly in a direction normal to its length. Thus, all intersections of the parabolic surface 24 with planes parallel to the vertical section plane of FIG. 2 are identical.

As is well known, a parabolic curve is defined as the locus of a point moving so as always to be equidistant from a straight line and from a point not on the straight line. Looking at FIG. 2, the directrix 26 is the "straight line" in the foregoing definition (actually a plane due to the cylindrical characteristic of the parabolic surface 24), and a point shown at 28 is the "point" in the definition. It is also known that a reflective parabolic surface has the property of reflecting to a single point longitudinal mechanical vibrations travelling parallel with the parabolic axis. The point upon which the reflective rays converge is the same point as that mentioned in the definition of the parabolic surface, and will be hereinafter referred to as the focus 28 of the parabola 24. The reflection phenomenon at a given surface is due to a great acoustic impedance mismatch between the solid element and the gas (in this case air) contacting the surface.

Attention is again directed to the piezoelectric crystal system (transducer) 22, as seen in FIG. 2. The piezoelectric crystal system 22 is adapted to be excited by a high-frequency electric field produced by a generating device of conventional nature shown schematically at 30. The electrical drive connections to the crystals 22a and 22b, which are carefully matched, follow normal techniques which are well known to those skilled in the art to which this invention pertains. Multiple crystal systems may also be used, or a magnetostrictive transducer can also be substituted.

When the generating device 30 applies an alternating electric field symmetrically across the two crystals 22a and 22b of the transducer 22 (synonymous with crystal system 22), it causes these crystals to expand and contract in the axial direction in phase with the alternating electric field. The resulting mechanical vibrations are transmitted to the solid elements 12 and 14, and travel through them in a direction perpendicular to the plane surfaces 18 and 19 at a speed determined by the physical characteristics of the material from which the solid elements 12 and 14 are constructed.

Looking particularly at the vibrational disturbance A in FIG. 2, this disturbance is shown to travel upwardly along the path 35, and reflect off the parabolic surface 24, a metal-air interface, along the line 36 in the direction of the focus 28. The A-path is the direct route taken by vibrational disturbances emanating from the upper portion 22a of the crystal and converging on the focus 28. The A-path involves a single reflection at the parabolic surface 24, and this reflection results in a 180° phase shift for the disturbance A.

If the passageway 16 is filled with liquid and the solid element 12 is made of steel, about 88% of the vibrational energy converging on the focus 28 is reflected at the metal-liquid interface constituted by the walls of the passageway 16. Lower reflection percentages would be encountered if the solid element 12 were made of another material with better acoustic matching characteristics. The reflected portion of the energy converging at the focus 28, denoted by A_R , travels back along substantially the same path, because it is preferred that at least the upper surface of the passageway 16 be cylindrical, with its axis coincided with the focus 28. The reflected portion A_R of the energy travels back to the transducer 22, and is in phase with and reinforces the negative disturbance emanating from the transducer one-half wavelength later. If the reflected portion A_R does not return to the transducer 22 in phase with the transducer, interference will take place with a resultant loss of efficiency.

There is also generated a mechanical vibration travelling initially downwardly in the solid element 14 from the upper plane surface 18. This path is denoted by the letter B. The B-path involves a reflection from the remote

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plane surface 38 of the solid element 14, and vertical travel back to the transducer 22. It is, of course, also necessary that the B disturbance arrive at the transducer 22 in phase with the latter, in order to maximize efficiency.

Each of the eight embodiments of this invention constitutes a different way in which the in-phase arrival of reflected vibrations at the transducer 22 can be effected.

In the first embodiment of this invention, shown in FIGS. 1 and 2, the A_R and B disturbances are made to arrive at the transducer 22 in phase with the latter by dimensioning the device 10 in such a way that the transducer 22 is spaced from the surface 38 by a distance representing $\lambda/4$, and is spaced from the directrix 26 of the parabolic surface 24 also by a distance representing $\lambda/4$, where λ represents the wavelength of mechanical vibrations in the device 10. It has been found that a satisfactory mathematical model of the physical device can be represented in the manner of FIG. 6, wherein the thin transducer crystal has been reduced to a line of zero thickness, labelled TR.

The in-phase arrival at the transducer 22 of disturbances A_R and B in FIG. 2 is established as follows. Disturbance A_R , considered to originate at the transducer surface, travels to and reflects from the parabolic surface 24, reflects from the surface of the passageway 16, again reflects from the parabolic surface 24, and returns to the transducer 22, having travelled a total distance of $\lambda/2$. Three phase-reversals occur at the three reflections, and their distance equivalent is $3\lambda/2$. Thus, the effective acoustical path length for disturbance A_R is

$$\frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

Disturbance B emanating downwardly from the lower transducer surface covers a distance $\lambda/4$, is reflected once, and returns to the transducer 22, having travelled a distance of $\lambda/2$. One phase-reversal occurs at the surface 38, such that the acoustical path length for disturbance B is

$$\frac{\lambda}{2} + \frac{\lambda}{2} = \lambda$$

It is thus seen that, in order for reflected disturbances to return to the transducer 22 in phase with the latter, the effective acoustical path length must be a multiple of a whole wavelength.

It will also be clear from the above discussion that the in-phase arrival at the transducer 22 of disturbances A_R and B will also be assured if the distance from the transducer to either the directrix 26 or the surface 38, or both, is increased by some multiple of one-half wavelength. For example, increasing this distance to $2\frac{1}{4}\lambda$ would not disturb the in-phase arrival at the transducer 22 of disturbances A_R and B.

In the first embodiment of this invention, shown in FIGS. 1 through 5, the force maintaining the solid elements 12 and 14 in pressure contact with the transducer 22 is provided by four bolts 40 which extend loosely through appropriate boreholes in the lower solid element 14, and which are tightly threaded into tapped bores in the upper solid element 12 extending upwardly from the plane surface 19.

Turning now to FIG. 3, a second form of the first embodiment of this invention is shown, in which the parabolic surface 42 is a paraboloid of revolution, having a single point focus 44, rather than a linear focus as does the first form of this invention shown in FIGS. 1 and 2. Because the surface 42 is a paraboloid of revolution, the section 5—5 is circular, as seen in FIG. 5. The device shown in FIG. 3 is likewise provided with a first solid element 45, a second solid element 46, and bolts 47 securing the two solid elements 45 and 46 in sandwiching relation to a piezoelectric crystal 49, the latter being identical in its function with the piezoelectric crystal shown in FIGS. 1 and 2.

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Whereas in FIGS. 1 and 2 the liquids to be emulsified are passed along passageway 16 parallel with the plane surface 19 of the solid element 12, in the FIG. 3 form of this invention, a central, axial passageway 50 is provided for the liquids to be emulsified, the passageway 50 extending upwardly from the lower surface 52 of the solid element 46, centrally through the piezo electric crystal 49 (which is suitably bored), upwardly through the solid element 45 to encompass the focus 44, and from there a reduced extension 54 of the passageway 50 extends to the upper, central point of the surface 42. The liquids to be emulsified enter the bottom and the emulsified mixture is ejected at the end of the extension 54.

FIG. 4 shows another form of the first embodiment of this invention, which consists of the same basic components as the devices shown in FIGS. 1-3. An upper solid element 56 and a lower solid element 58 are tightly secured together in sandwiching relation about a transducer 60 by a single bolt 62 which extends loosely through an appropriately sized bore-hole in the lower solid element 58, and is tightly threaded into a tapped bore 63 in the upper solid element 56. Two or more radial passages 65 extend inwardly and communicate with a central cavity 66 which contains the focus 67. The cavity 66 is merely the termination of the bore 63. A vertical passageway 68 extends upwardly from the cavity 66. The liquids to be emulsified are introduced at the radial passages 65, travel inwardly to be emulsified at the focus 67, and are ejected as an emulsion upwardly through the passage 68. The parabolic surface 70 in FIG. 4 is also a paraboloid of revolution.

The passageway 16, the upper termination of the passageway 50 and the cavity 66 are preferably all curved so as to be normal to the converging disturbance A as the latter is reflected toward the foci of the three forms by the respective parabolic surfaces. If this were not the case, the portion of the disturbance being reflected from the liquid-metal interface would not retrace its original path, and would not necessarily reach the transducer 22 in phase. This is particularly important where the passageway is of substantial width. Where the passageway therefrom in random directions will not have a serious effect on the angles at which the vibrations pass through the crystal 60. Generally speaking, however, where the focus is a straight line as in FIG. 2, it is preferable that at least the upper portion of passageway 16 be cylindrical with the focus at the cylindrical axis. The lower portion can be flat as shown, whenever the focus is not within the volume defined by the parabolic surface, since in this case the converging vibrations do not impinge upon the lower side of the passageway. Where the focus is a single point, as in the forms shown in FIGS. 3 and 4, it is preferable that at least the upper portion of the passageway be spherical with the focus at the centre of spherical curvature.

In FIGS. 3 and 4, the transducers 49 and 60 are excited in exactly the same way as the piezoelectric crystal in FIG. 2. This has not been shown, because it is conventional.

Attention is now directed to FIGS. 6 through 13, showing the eight separate embodiments of this invention. The first four embodiments shown in FIGS. 6, 7, 8 and 9 all utilize electrostrictive crystals for vibration generation, and since these are small compared to one wavelength, they are represented as a single, hypothetical plane of vibration generation, and are denoted by the letters TR. The remaining embodiments of this invention, shown in FIGS. 10, 11, 12 and 13, utilize magnetostrictive transducers, and these are always one-half wavelength long, and are designed for a specific resonance frequency. For this reason, the transducer is represented in FIGS. 10 through 13 as a block of material whose length is equal to one-half wavelength. It will be appreciated that the speed of transmission through the magneto-

strictive transducer is not necessarily the same as the speed of transmission through the solid elements at either end of the magnetostrictive transducer, and that the actual length of the transducer, and of the solid elements, is a function of the speed of transmission. In the embodiments shown in FIGS. 10 through 13, the entire magnetostrictive transducer block is labelled TR. FIGS. 6 to 13 show only the paths of the reflected vibrations.

FIG. 6—EMBODIMENT 1—ELECTROSTRICTIVE

$$\text{Effective acoustical path length } LA_R = \frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

$$\text{E.A.P.L. } LB = \frac{\lambda}{2} + \frac{\lambda}{2} = \lambda$$

FIG. 7—EMBODIMENT 2—ELECTROSTRICTIVE

In this embodiment both of the solid elements have a parabolic surface remote from the transducer TR, and the following formulas will show that, at the transducer TR, the two disturbances arrive substantially in phase.

$$\text{E.A.P.L. } LA_R = \frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

$$\text{E.A.P.L. } LB_R = \frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

(B_R is the reflected portion of disturbance B.)

FIG. 8—EMBODIMENT 3—ELECTROSTRICTIVE

It is possible to insert transition layers of one-quarter wavelength or one-half wavelength between the transducer and the solid element containing the parabolic surface and the focus of the latter. These one-quarter wave or one-half wave studs may be considered as transmission lines which can be constructed on the basis of transmission line theory to provide matching of high to low impedances.

(a) Ignoring internal and surface reflectivity losses, a half-wave stub adds a resonant section to the resonant crystal and does not change the phase relationships in the creation of a standing wave condition. It acts as though it is not present, i.e. the resonant crystal (or magnetostrictive transducer) "sees" as its load only the medium which loads the half-wave stub.

(b) A quarter-wave stub, however, acts as an "acoustic impedance transformer." Applying transmission line equations, we get eventually

$$Z_i = \frac{(Z_m)^2}{Z_l} = \frac{Z_l Z_t}{Z_l} = Z_t$$

where Z_i is the acoustic impedance seen looking into a transmission line of characteristic acoustic impedance Z_m and where $Z_m = \sqrt{Z_l Z_t}$. Z_l is the load impedance and Z_t is the transducer impedance. In other words, it is possible to transform the impedance of the loading medium in such a way that the crystal sees a perfect match. The selection of transmission lines is very important and has a direct effect on the amount of sound energy reflected at the metal-liquid interface constituted by the wall of the passageway.

Naturally, a number of layers or "stubs" may be used for matching, but the increased absorption with extra layers must be balanced with the increased transmission. This absorption is due to both the extra interfaces and the extra material in the transducer.

Turning to FIG. 8, the transducer is represented as TR, on the right of which is a quarter-wave solid element 72, and on the left of which is, first, a quarter-wave stub 74, and then a one-wave element 76 having a parabolic surface 78.

The following formulas apply to the third embodiment of this invention, shown in FIG. 8:

$$\text{E.A.P.L. } LA_R = \frac{3\lambda}{2} + \frac{3\lambda}{2} = 3\lambda$$

$$\text{E.A.P.L. } LB = \frac{\lambda}{2} + \frac{\lambda}{2} = \lambda$$

FIG. 9—EMBODIMENT 4—ELECTROSTRICTIVE

In this embodiment, the device is symmetrical about the transducer TR, and consists of two quarter-wave stubs 80 adjacent the transducer, and two half-wave parabolic elements 82 fixed to the remote surface of the quarter-wave stubs 80.

In this embodiment, the following equations apply:

$$\text{E.A.P.L. } LA_R = \frac{3\lambda}{2} + \frac{3\lambda}{2} = 3\lambda$$

$$\text{E.A.P.L. } LB_R = \frac{3\lambda}{2} + \frac{3\lambda}{2} = 3\lambda$$

FIG. 10—EMBODIMENT 5—MAGNETOSTRICTIVE

In this embodiment, a quarter-wave element 84 having a parabolic surface 85 is fixed to one surface of the transducer block 87, while a rectangular block 88 is fixed to the other surface of the transducer block 87.

The magnetostrictive transducer block 87 can be made of solid ferrite, solid permendur, or nickel laminations, inter alia.

The applicable formulas are as follows:

$$\text{E.A.P.L. } LA_R = \frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

$$\text{E.A.P.L. } LB = \frac{\lambda}{2} + \frac{\lambda}{2} = \lambda$$

FIG. 11—EMBODIMENT 6—MAGNETOSTRICTIVE

In this embodiment, two parabolic solid elements 90 sandwich between them the magnetostrictive transducer 92.

The applicable formulas are as follows:

$$\text{E.A.P.L. } LA_R = \frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

$$\text{E.A.P.L. } LB_R = \frac{\lambda}{2} + \frac{3\lambda}{2} = 2\lambda$$

FIG. 12—EMBODIMENT 7—MAGNETOSTRICTIVE

In this embodiment, a quarter-wave solid element 93 is fixed to the face E of the transducer, a quarter-wave stub 94 is fixed to the face F of the transducer, and a half-wave element 96 bearing the parabolic surface and the focal passageway is in turn fixed to the quarter-wave stub 94.

The applicable formulas are as follows:

$$\text{E.A.P.L. } LA_R = \frac{3\lambda}{2} + \frac{3\lambda}{2} = 3\lambda$$

$$\text{E.A.P.L. } LB_R = \frac{\lambda}{2} + \frac{\lambda}{2} = \lambda$$

FIG. 13—EMBODIMENT 8—MAGNETOSTRICTIVE

This embodiment is symmetrical about the transducer. A quarter-wave stub 98 is fixed to each face of the transducer, and a half-wave element 99 is in turn fixed to each quarter-wave stub 98.

The applicable formulas are as follows:

$$\text{E.A.P.L. } LA_R = \frac{3\lambda}{2} + \frac{3\lambda}{2} = 3\lambda$$

$$\text{E.A.P.L. } LB_R = \frac{3\lambda}{2} + \frac{3\lambda}{2} = 3\lambda$$

Generally speaking, the higher is the effective acoustic path length, the greater is the absorption of energy by the device. Practically speaking, this limits the system to one, or at most three, quarter-wave stubs.

While preferred embodiments of this invention have been disclosed herein, those skilled in the art will appreciate that changes and modifications may be made therein without departing from the spirit and scope of this invention as defined in the appended claims.

What we claim as our invention is:

1. A device for concentrating vibrational energy comprising:

a transducer sandwiched between a first and a second solid element,

the first solid element having a first plane surface in contact with said transducer and a convex parabolic surface of which the parabolic axis is normal to said first plane surface, the directrix of said parabolic surface being parallel to said first plane surface,

a passageway in said first solid element through which a fluid may be transmitted, said passageway containing the focus of said parabolic surface,

the second solid element having a second plane surface in contact with said transducer,

the transducer being adapted to transmit vibrations into said first solid element in the direction normal to said first plane surface, said vibrations being reflected from said parabolic surface to converge on said passageway, a first portion of said vibrations passing through the wall of said passageway into the fluid, a second portion of said vibrations being reflected from the wall of said passageway and then reflected from the parabolic surface toward said first plane surface in the direction normal to said first plane surface, said first solid element being dimensioned such that said second portion arrives at said transducer in phase therewith,

the transducer also transmitting further vibrations into said second solid element in the direction normal to said second plane surface, said further vibrations being generated simultaneously with said first-mentioned vibrations, said second solid element being dimensioned such that any reflected part of said further vibrations returning to the transducer arrives at the transducer in phase therewith.

2. A device as claimed in claim 1, in which said parabolic surface is cylindrically parabolic, such that the focus is a straight line parallel with said first plane surface, said passageway being rectilinear and containing said straight line defining the focus.

3. A device as claimed in claim 1, in which said parabolic surface is a paraboloid of revolution, such that the focus is a single point, the portion of the passageway containing said single point having a spherical surface remote from said first plane surface, the single point lying substantially at the centre of curvature of said spherical surface.

4. A device as claimed in claim 1, in which said second solid element has a further plane surface parallel with said second plane surface and opposite thereto.

5. A device as claimed in claim 1, in which the length of the effective acoustic path for vibrations leaving and returning to the transducer in either solid element, calculated as the sum of the actual geometric distance covered plus the distance equivalent of reflection phase changes, is one wavelength or a multiple of one wavelength.

6. A device as claimed in claim 4, in which the transducer is electrostrictive and is thin compared with said solid elements, whereby a hypothetical plane of vibration generation can be postulated between the two solid elements, the distance between said hypothetical plane and said further plane surface being equal to one-quarter of the wavelength of said vibrations, the distance between said hypothetical plane and the directrix of said parabolic surface being equal to one-quarter of the wavelength of said vibrations.

7. A device as claimed in claim 4, in which the transducer is electrostrictive and is thin compared with said solid elements, whereby a hypothetical plane of vibration

generation can be postulated between the two solid elements, the distance between said hypothetical plane and said further plane surface being equal to one-quarter of the wavelength of said vibrations, said first solid element being composed of a quarter-wave stub adjacent the transducer and a parabolic portion joined to said stub at an interface parallel with said hypothetical plane, the distance from said interface to the directrix of said parabolic surface being one-half of the wavelength of said vibrations.

8. A device as claimed in claim 4, in which the transducer is magnetostrictive and has a length equal to one-half of the wavelength of said vibrations between said first plane surface and said second plane surface, the distance between said second plane surface and said further plane surface being equal to one-quarter of the wavelength of said vibrations, the distance between said first plane surface and the directrix of said parabolic surface being equal to one-quarter of the wavelength of said vibrations.

9. A device as claimed in claim 4, in which the transducer is magnetostrictive and has a length equal to one-half of the wavelength of said vibrations between said first plane surface and said second plane surface, the distance between said second plane surface and said further plane surface being equal to one-quarter of the wavelength of said vibrations, said first solid element being composed of a quarter-wave stub adjacent the transducer and a parabolic portion joined to said stub at an interface parallel with said hypothetical plane, the distance from said interface to the directrix of said parabolic surface being one-half of the wavelength of said vibrations.

10. A device as claimed in claim 1, in which said second solid element has a convex parabolic surface of which the parabolic axis is normal to said second plane surface, the directrix of said last-mentioned parabolic surface being parallel to said second plane surface, a passageway in said second solid element through which fluid may be transmitted, said last-mentioned passageway containing the focus of said last-mentioned parabolic surface.

11. A device as claimed in claim 10, in which the transducer is electrostrictive and is thin compared with said solid elements, whereby a hypothetical plane of vibration generation can be postulated between the two solid elements, the distance between said hypothetical plane and the directrix of said last-mentioned parabolic surface being equal to one-quarter of the wavelength of said vibrations, the distance between said hypothetical plane and the directrix of said first-mentioned parabolic surface being equal to one-quarter of the wavelength of said vibrations.

12. A device as claimed in claim 10, in which the transducer is electrostrictive and is thin compared with said solid elements, whereby a hypothetical plane of vibration generation can be postulated between the two solid elements, said first solid element being composed of a first quarter-wave stub adjacent the transducer and a first parabolic portion joined to said first quarter-wave stub at a first interface parallel with said hypothetical plane, the distance from said first interface to the directrix of said first-mentioned parabolic surface being one-half of the wavelength of said vibrations, said second solid element being composed of a second quarter-wave stub adjacent the transducer and a second parabolic portion joined to said second quarter-wave stub at a second interface parallel with said hypothetical plane, the distance from said second interface to the directrix of said last-mentioned parabolic surface being one-half of the wavelength of said vibrations.

13. A device as claimed in claim 10, in which the transducer is magnetostrictive and has a length equal to one-half of the wavelength of said vibrations between said first plane surface and said second plane surface, the distance between said first plane surface and the directrix of said first-mentioned parabolic surface being equal to one-quarter of the wavelength of said vibrations, the distance between said second plane surface and the directrix of said quarter of the wavelength of said vibrations.

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14. A device as claimed in claim 10, in which the transducer is magnetostrictive and has a length equal to one-half of the wavelength of said vibrations between said first plane surface and said second plane surface, said first solid element being composed of a first quarter-wave stub adjacent the transducer and a first parabolic portion joined to said stub at a first interface parallel with said hypothetical plane, the distance from said first interface to the directrix of said first-mentioned parabolic surface being one-half of the wavelength of said vibrations, said second solid element being composed of a second quarter-wave stub and a second parabolic portion joined to said second quarter-wave stub at a second interface parallel with said hypothetical plane, the distance from said second interface to the directrix of said last-mentioned parabolic surface being one-half of the wavelength of said vibrations.

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References Cited

UNITED STATES PATENTS

3,165,299	1/1965	Balamuth et al.	259—1
2,738,172	3/1956	Spiess et al.	259—1
3,379,902	4/1968	Harris et al.	310—8.5
3,331,589	7/1967	Hammitt et al.	310—8
2,855,526	10/1958	Jones	259—1

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259—1; 310—8.3, 8.7

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,524,083

August 11, 1970

Anthony J. Last et al.

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

Column 7, lines 50 to 55, the formula should appear as shown below:

$$z_i = \frac{(Z_m)^2}{Z_1} = \frac{Z_1 Z_t}{Z_1} = Z_t$$

Signed and sealed this 23rd day of February 1971.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents