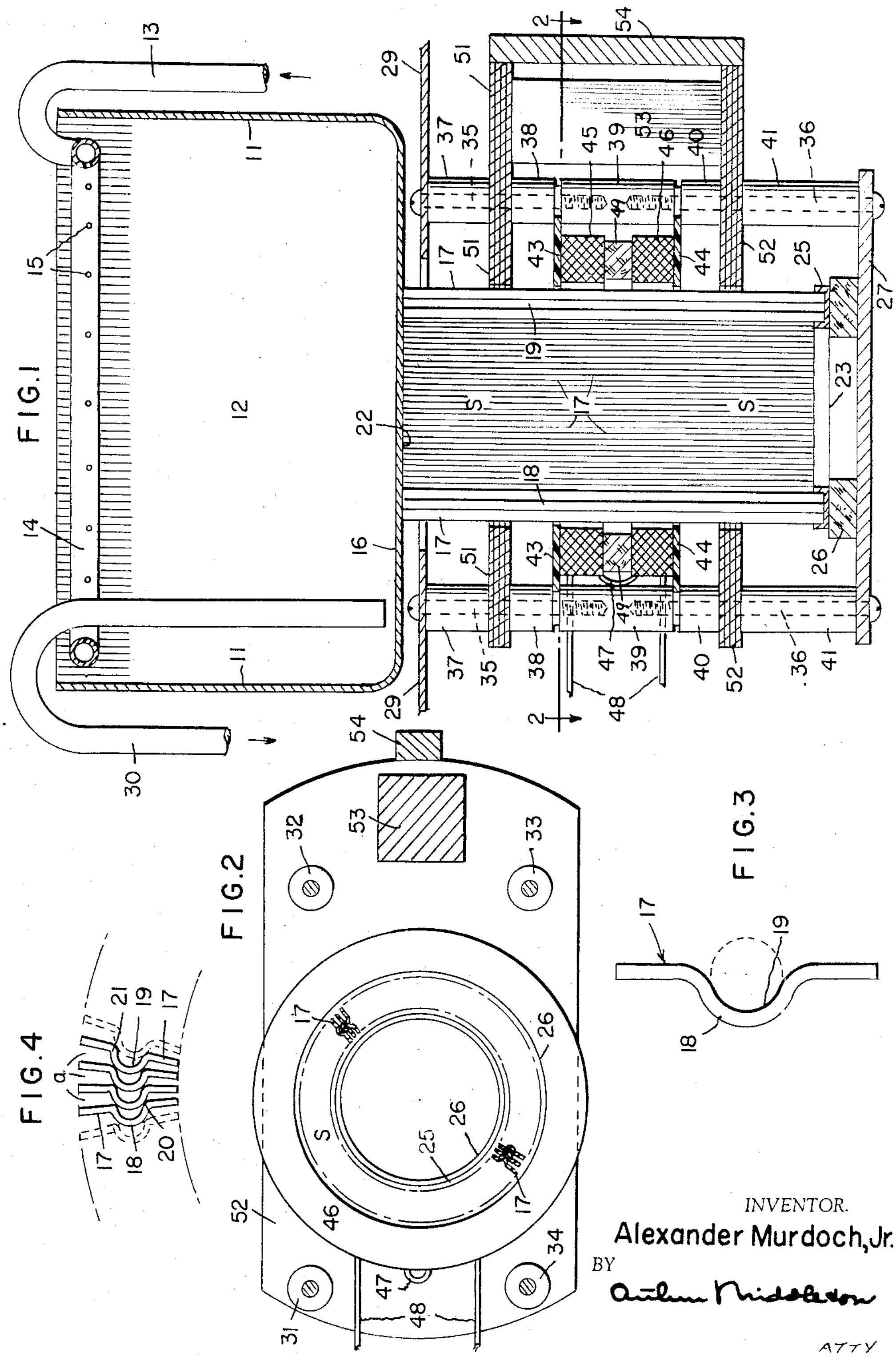
Feb. 17, 1959 A. MURDOCH, JR 2,874,316

ULTRASONIC TRANSDUCERS

Filed Jan. 4, 1957 3 Sheets-Sheet 1



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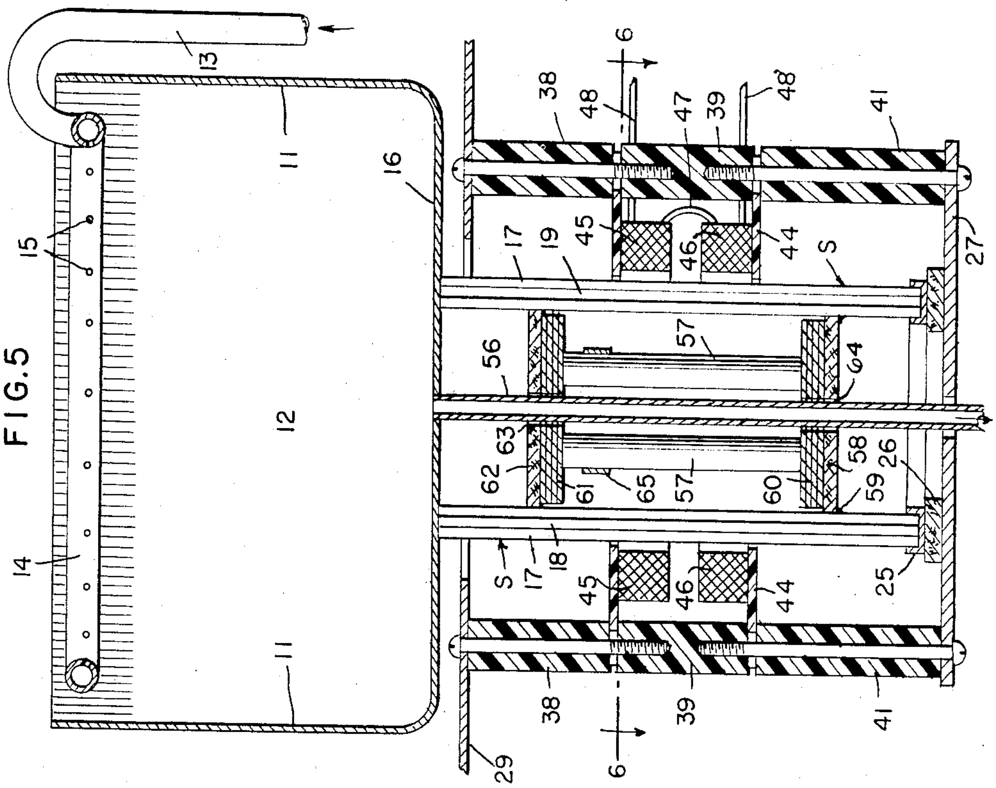

FIG.5

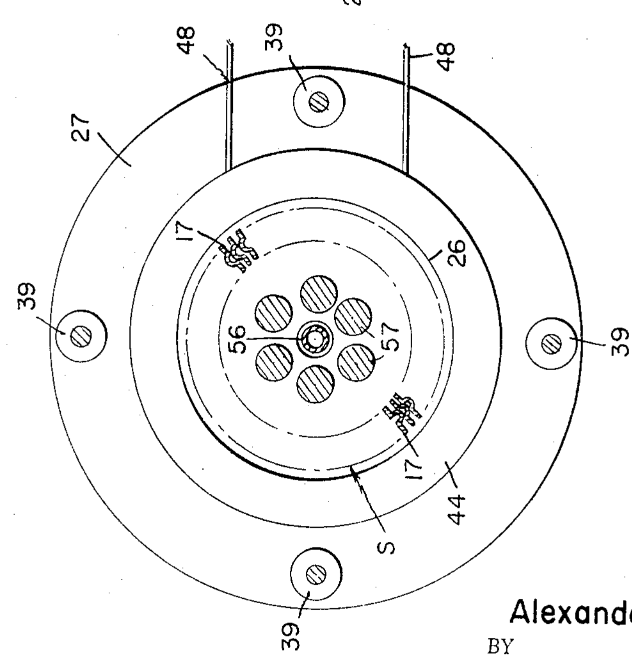

FIG.6

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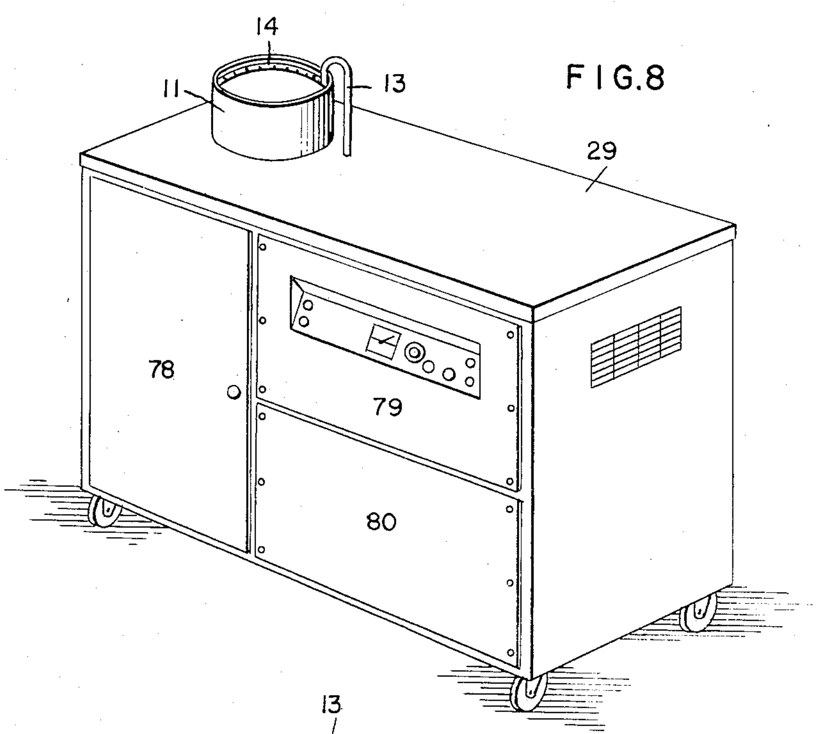

FIG.8

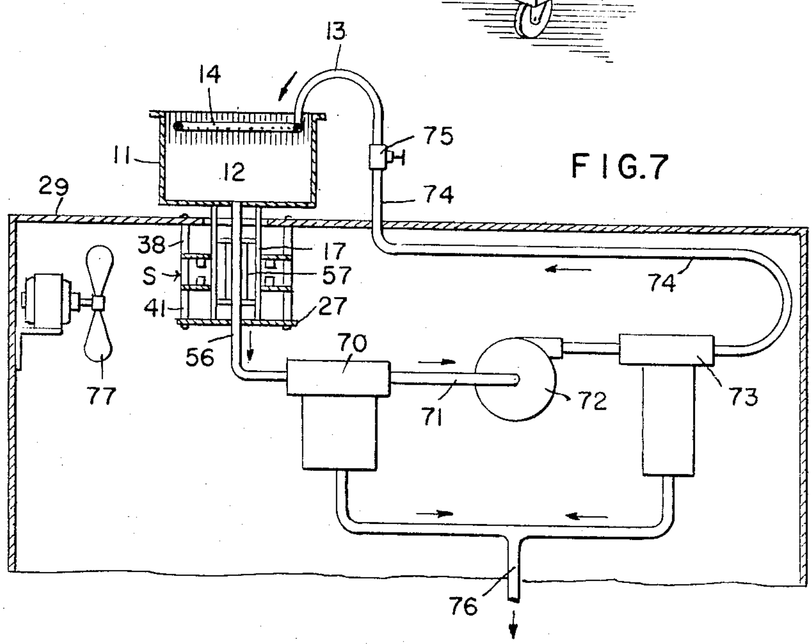

FIG.7

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United States Patent Office

2,874,316

Patented Feb. 17, 1959

2,874,316

ULTRASONIC TRANSDUCERS

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Application January 4, 1957, Serial No. 632,582

12 Claims. (Cl. 310—26)

This invention relates to ultrasonic transducers for use in producing cavitation in a bath of liquid in a liquid-holding container, and more particularly to the construction, arrangement, and operation of the transducer and its associated parts. The transducer changes electrical energy input thereto into high frequency compressional waves that are projected through the container into the liquid held therein, and these waves are of such regulatable character as to produce in the liquid the effects of cavitation which in turn are useful in cleansing solid articles and for a variety of other purposes. The basic part of the transducer is a plurality of parallel strips of magnetrostrictive material called a stack.

It is among the objects of this invention to improve present-day transducers as to their efficiency in the use of electricity; to lower their cost of manufacture; to make them dependably operable for long periods of time; to reduce the hysteresis losses by proper heat treatment of the magnetostrictive material; to reduce the eddy currents by using multiple strips of magnetostrictive material of particular shape and particular array thereof conjointly into an annular shape; to arrange the coil adapted to excite the transducer stack in such a manner as to be readily replaceable; to provide a greater magnetostrictive mass for insuring a greater factor of safety for operation of the transducer at high power levels; to provide for better radiation of heat losses by the transducer strips; to provide for greater ease in obtaining dependable joints between the transducer and the container; to provide for lowering the cost of making individual strip elements of the transducer; to minimize inert metal associated with the transducer; to maximize the vibrational amplitude transmitted by the transducer to the container; to arrange all the parts as to be neatly encaseable; and to combine the co-operating parts so as to provide the maximum degree of regulatability of all aspects of the cavitation effected in the container. Another object is to devise and arrange the parts so that the bottom of the container can be controlled to vibrate near but not at its present frequency for thus avoiding erosion of the container. And a further object is to devise and arrange the parts together with controls whereby the cavitation can be so regulated that discrete particles submerged in the container for cleansing can be caused to move slightly with respect to each other for thus exposing fresh surfaces for cleansing. And other objects will appear as this specification proceeds.

These objects can be attained by a transducer whose magnetostrictive element is made in the form of a hollow cylinder by using rectangular strips of nickel radially disposed in the cylinder, with the strips bearing longitudinally thereof a rib along one face and a corresponding depression along the other. The annular transducer is supported from cushioning means mounted from a cabinet or casing and the container with its bath of liquid in which cavitation is to be effected has its bottom axially secured to the other end of the magnetostrictive element or stack. Coil means encircle the stack for regulatable exciting the stack to produce desired magnetostrictive effects. Other features from which advantage is derived include mounting rod-shaped magnets in the bore of the annular transducer.

The invention is shown in the accompanying drawings in which Fig. 1 is a vertical sectional view through the transducer. Fig. 2 is a sectional plan view taken along the line **2—2** in Fig. 1. Fig. 3 is an end view of one of the magnetostrictive strips of this invention. Fig. 4 is a partial detailed end view of a few of the strips showing their relative positioning when put together to form the annular cylindrical form of the stack thereof. Fig. 5 is a view like Fig. 1 except of a modification of this invention. Fig. 6 is a transverse view taken along the line **6—6** in Fig. 5. Fig. 7 is a partial vertical sectional view showing the transducer in a cabinet with a filtering system. And Fig. 8 is an isometric view of one form of cabinet for housing the transducer of this invention.

This invention is capable of several embodiments but one has a container or bowl **11** having bottom and side walls adapted to hold a pool or bath of liquid solvent **12**, supplied thereto through a feed pipe **13** terminating in an annular spray pipe **14** having spraying apertures **15**, through which the liquid solvent is pressure-fed by a suitable pump. The liquid solvent is drained from the bowl through drain pipe **30**. The bowl **12** has depending from its bottom **16** a magnetostrictive annular stack S, now made of from 1 to 3 inches outside diameter, made up of radially disposed rectangular unitary strips **17** of magnetostrictive material such as grade A nickel, satisfactorily $17/64$ of an inch wide and .012 inch thick, carrying a longitudinally extending projecting rib **18** on one face and a corresponding depression or groove **19** on the opposite face. The rib and groove are formed to be substantially semi-circular with a radius shown in the dotted line, satisfactorily $1/16$ of an inch, in Fig. 3. The unitary strips **17**, in length equal to one-half the wave length at the desired frequency of vibrations of the stack are then disposed in an annular or hollow cylindrical form of shape as shown in the partial detailed view of Fig. 4. The angle "*a*" made between two adjacent strips varies with the diameter selected for the stack S, but in general adjacent strips only touch at one or two points such as **20** and **21** taken in plan view but these contacts are normally line contacts extending the length of the contacting strips. The less contacts the better for the more ready radiation and dissipation of heat generated in the strips. The strips must be insulated from each other, and particularly along these line contacts, and I have found that satisfactory insulation comprises nickel oxide yielded in situ on the nickel strips by merely heating the strips to oxidizing temperature in air or steam, and then cooling them. The ends of the assembled strips are fastened together by being cemented with resin as at **22** and **23**. The top area **22** of the strips is fastened with respect to the bottom **16** of the container or bowl **11**, preferably by brazing or welding. For mechanical protection of the strips, the free bottom area **23** thereof may be cemented together and fastened to a flanged metallic ring or gasket **25** that is supported from an annular cushioning means **26** such as cork, which, in turn, is supported from a bottom plate **27** held in place from the top of a table or casing **29** by means of a plurality of rods **31, 31, 33** and **34**, each made of a plurality of screws **35** and **36** securing together a group of spools **37, 38, 39** and **41**.

Supported from the top and bottom of spools 39 are insulating plates of phenolic material 43 and **44**, from which are supported coils 45 and **46** in circuit with each other by wire **47**, and the coils are in circuit 48 with an appropriate oscillating or driver amplifier of a well-known type for producing vibrations in the stack S of magnetostrictive strips 17. Such devices comprise apparatus to produce the desired frequency of alternating current use and they may be, for instance, either an electron coupled oscillator in which oscillation and amplification is accomplished in the same electron tube or tubes, or, a separate oscillator buffer, and power amplifier. The coils may be spaced apart by the insulating spacer 49 to improve heat transfer from the coils. Supported between spools 37 and 38 is a laminated pole piece 51 and a similar laminated pole piece 52 is supported between spools 40 and 41. It can be seen from Fig. 1 that these pole pieces extend to the right sufficiently to hold between them a polarizing magnet 53, either round or square, and associated therewith are one or more that are proportioned in size or number to adjust the amount of polarization necessary for optimum performance. This embodiment just described is best characterized by the fact that its polarizing magnet is located externally of the magnetostrictive stack S, while the embodiment now to be described is characterized by the fact that the polarizing magnet means is located internally of the stack and a plurality of magnetized rods are used. Also that the return of the solvent from the bath thereof in the bowl is accomplished by locating the return pipe axially through the annular stack. This latter feature could also be used in the first embodiment.

In the embodiment shown particularly in Figs. 5 and 6, parts numbered like those in Figs. 1 to 3 are the same, or at least operatively so. Therefore, only parts that are rearranged or changed will now be described. A major change, which also could be embodied in the previous embodiment comprises substituting for the outside solvent drain pipe 30, a drain tube 56 leading from the center of the bottom 16 of the bowl 11 and passing axially through the bore of the annular stack S of magnetostrictive strips 17. If this pipe, located internally of the stack S, is used in the embodiment of Fig. 5, it must be of non-magnetic material, such as nylon. Characteristic of this embodiment is a plurality of rods 57 of magnetic metal, such as Alnico 5, selected in number and size to effect the correct amount of flux (so no keepers are needed), located planetarily within the bore of the annular stack S and supported therein as follows: A noise-deadening and insulating spacer 58 of cork and buna rubber is supported transversely of the bore of the stack by means of resilient cement 59, and on top of the spacer 58 are mounted a laminated circular pole piece 60, from which the magnet rods 57 in turn are topped with another laminated circular pole piece 61, and the latter is capped with another noise-deadening and insulating spacer 62. Located in the bore of the top pole piece 61 is a soft steel hub or sleeve 63 encircling the drain tube 56, to permit assembly of the laminations of the pole piece 61 as a unit and to center the laminations around the tube. 64 represents a similar soft steel sleeve on which is assembled the laminations of the lower pole piece 60. 65 represents a ring for holding the magnet rods 57 from inadvertent displacement. The word transducer will be used herein and when used it is intended to mean generally the annular stack of magnetostrictive strips with the coils and magnets needed to make them into an operative assembly.

Fig. 7 shows elements associated with the transducer to make an operative system for cleansing objects when immersed in the bath 12 of the bowl 11, therein to be subjected to the effect of cavitation produced by the high frequency vibrations delivered to the bath by operation of the transducer. The table or casing is indicated at 29 from which the transducer elements are supported as shown in Fig. 5, while the drain tube 57 leading down through the bore of the stack S passes to a coarse filter 70 from which filtrate goes through pipe 71 to pump 72 and thence through a fine filter 73 from which filtrate is pressure-flowed through pipe 74 and passed valve 75 into feed pipe 13. Suspended solids discharged by the filters 70 and 73 flow to discharge through pipe 76. 77 represents a fan in the casing for siding in keeping the transducer elements properly cooled. Fig. 8 shows the exterior of the casing or cabinet 29 for housing the transducer and its associated equipment. It has a door 78 leading to the place where is located the transducer, the filters and the pump as well as the fan. 79 shows an instrument panel for operating the driver amplifier that is behind it, and there may be a second driver amplifier behind panel 80. It is possible and sometimes desirable to have the bowl 11 and its transducer equipment mounted separate from the cabinet that houses the driver amplifier, especially if no filtering system is required.

The transducer embodying this invention is usable to produce compressional waves of high frequency in a bath of liquid held in a container thereof for producing in the liquid the effect of cavitation for any purpose to which such cavitation can be put but specially to include the purpose of cleansing of articles of their contaminating dirt or other undesirable or degrading component carried more or less by the surface of the article. The liquid in which the cavitation is effected can also be a solvent for the contaminant and thus can be water, aliphatic hydrocarbon, varsol, solvesso, deobase, TPC, as well as neutral or acidic detergents.

To produce the effect of cavitation in the bath of liquid 12 in the bowl 11, associated with the casing 29, the controls on the panel 79 are turned on to set in operation the oscillating driver that is behind it, which operating through the circuit wires 48 leading to the series-connected coils 45 and 46, set up magneto-strictive vibrations at high frequency in the annular stack S of magnetostrictive strips 17. The presence of the polarizing magnet 53, whose functioning is regulated by the flux-controlling keeper or keepers 54, operates through the pole pieces 51 and 52 that are insulated from each other and are maintained out of contact with or spaced from the strips 17, as shown in Fig. 1. This arrangement then produces in the stack S of strips 17 high frequency vibrations in that the strips alternately expand and relax. This expansion and relaxation of all the strips, since they are cushioned at the bottom ends by cushioning means 26, is all transferred upwardly through the flanged ring 24 to the bottom 16 of the bowl 11 and through it to the bath of liquid held therein, since it is to be noted that the bowl is supported solely through the medium of the strips 17, and they, in turn, are supported through their cushioning means or ring 26 that rests on the plate 27 that in turn is dependably supported from the casing or table top 29. Liquid can be supplied to the bowl 11 through infeed pipe 13 and sprayed into the bowl through the apertures 15 in the delivery pipe 14. Dirty liquid can be withdrawn from the bowl through drain pipe 30, as required.

Surprising advantages are to be derived from the shape of the rectangular strips 17 with the longitudinally extending rib 18 on one face thereof and the corresponding groove 19 on the other face thereof, with the strips radially arranged as shown in Fig. 4 to form the annular stack S. Normally, adjacent strips have a single line contact between them, but sometime two, although not as many as three, and the less contacts the better. At the points of contact the strips must be insulated against each other, and it has been found that an easy and cheap way of causing this insulation is to oxidize the nickel strips to yield thereon in situ a coating of nickel oxide since such nickel oxide is a good insulator, and does not tend to rub off or otherwise be diminished while the strips are in use. By this arrangement of strips, more strips can be included in an annular stack of lesser dimension so a greater magnetostrictive mass is provided in concentrated location, while at the same time providing for better radiation of heat as it is generated in the strips during their magnetostrictive functioning. The arrangement of the annular array of the strips insures all of their nickel being activated. This would not be the case with an arrangement of massive cross-section where undesirable effects are noted, reducing the performance and comprising a wasteful use of the nickel results. The heat treatment in yielding the coating of nickel oxide on the strips also has the effect of minimizing hysteresis losses in the strips. The shape of the strips makes for greater ease in obtaining a good cemented joint to the bowl. And since they can be cut from long lengths thereof, the cost of making them is low. The environmental arrangement of the multiple strips and of the magnet means reduces eddy currents that are undesirable.

In the embodiment shown in Figs. 5 and 6, the difference over that of Figs. 1 and 2, lies in the fact that the drain pipe leading from the bowl **11** comprises a drain tube **56** leading axially from the bottom **16** of the bowl **11** and passed through the bore of the stack S, as shown. Instead of the single polarizing magnet **53**, a plurality of magnet rods **57** are clustered around the drain tube, as shown, and are connected at their top with one laminated annular pole piece **61** as well as connected at their bottom with one laminated annular pole piece **60**. The bottom pole piece **60** is supported from a sound-deadening insulating spacer **58** cemented at its periphery **59** to the stack S while the top pole piece **61** carries on top of it another sound-deadening insulating spacer **62**. The spacers break up the electrical circuit that would be formed if the magnet pole pieces should touch the stack of nickel strips. It reduces noise by eliminating contact between these parts, as the nickel strips vibrate while the pole pieces do not. The plurality of magnet rods and their size can be selected to correct the amount of flux, so no keepers are required. The soft steel cylinder or sleeves **63** and **64** permit assembly of the laminations of the pole pieces into a unit and they center the laminations around the tube **56**.

Fig. 7 shows how the solvent can be continually circulated to and from the bowl, meanwhile having filtered therefrom, dirt picked up thereby from the articles being cleansed in the bath in the bowl.

The cavitation is controlled partly by the construction and arrangement of the parts and partly by control of the liquid level in the bowl as well as of the frequency of the oscillator activating the nickel stack.

As this invention may be embodied in several forms without departing from the spirit or essential characteristics thereof, the present embodiments are therefore illustrative and not restrictive, since the scope of the invention is defined by the appended claims and all changes that fall within the metes and bounds thereof or that form their functional as well as conjointly cooperative equivalents, are therefore intended to be embraced by those claims.

I claim:

1. A transducer assembly having a plate, a plurality of rectangular magnetostrictive strips secured together to hold them operatively as laminations in a hollow cylindrical form of which one end is adhered to the plate, coil means encircling the cylindrical form, a regulatable electrical circuit connected to the coil means through use of which the strips are excited to vibrate at a selected high frequency, and polarizing magnet means insulatingly supported from the strips, the strips being of nickel of irregular cross-section for avoiding face-to-face contact between adjacent strips while assuring at least one line contact therebetween with the strips being insulated from each other at their points of contact.

2. Apparatus according to claim 1, wherein the cross-section of the strips has a rib projecting from one face thereof and a corresponding channel depressed in the other, whereby adjacent ribs are spaced from each other and maximum heat-radiating surfaces are provided while the strips are disposed radially in the hollow cylindrical form.

3. Apparatus according to claim 1, wherein the magnet means comprise a plurality of rods insulatingly connectively supported within the hollow cylindrical form of the strips.

4. A magnetostrictive stack in the form of a hollow cylinder made up of a plurality of rectangular radially extending magnetostrictive strips fastened together insulatingly with each strip in transverse cross-section having a rib extending from one face thereof and on the other face a corresponding depression in cross-section smaller than the rib for preventing face-to-face contact between adjacent strips.

5. A magnetostrictive stack according to claim 4, wherein the strips are covered with a metallic oxide insulating coating for insulating the strips against each other along any line contact that may take place therebetween.

6. A magnetostrictive stack having a plurality of rectangular radially extending magnetostrictive strips insulatingly fastened together into the form of a hollow cylinder, coil means for exciting the strips encircling the cylinder, and polarizing magnet means located within the bore of the hollow cylinder comprising a plurality of magnetic rods, a metallic pole piece connecting the rods together at one end thereof, another metallic pole piece connecting the rods together at the other end thereof, a noise-deadening circular insulating spacer fixedly extending across the bore of the hollow cylinder for supporting one of the pole pieces, and a second similar spacer extending across the bore while secured to the other pole piece.

7. Apparatus according to claim 6, wherein the pole pieces are made of circular laminations, and a soft steel hub is provided for securing the laminations of each pole piece together as a unit.

8. Apparatus according to claim 6, with the addition of a plate cemented to the top of the hollow cylinder, and resilient cushioning means on which the other end of the cylinder is supported.

9. An ultrasonic transducer assembly having a container, a plurality of magnetostrictive strips secured together to hold them operatively as laminations in a hollow cylindrical form of which one end is secured to the container, coil means encircling the cylindrical form, a regulatable electrical circuit connected to the coil means through which the strips are excited to vibrate at a selected high frequency, polarizing magnet means insulatingly supported from the strips, and means for introducing liquid into and removing liquid from said container without damping vibrations imparted to said container, the means for introducing liquid into the container comprising a conduit extending into said container but spaced therefrom and discharging directly thereinto.

10. The assembly as defined in claim 9 wherein the means for removing liquid from the container comprises a conduit extending into and adjacent the bottom of the container but spaced at all points therefrom.

11. The assembly as defined in and by claim 9 wherein said means for removing liquid from the container comprises a drain tube connected to the bottom of the container and extending therefrom axially through said hollow cylindrical form, said drain tube being formed of non-magnetic material.

12. An ultrasonic transducer assembly having a container, a plurality of magnetostrictive strips secured together to hold them operatively as laminations in a hollow cylindrical form of which one end is secured to the container, coil means encircling the cylindrical form, a regulatable electrical circuit connected to the coil means through which the strips are excited to vibrate at a selected high frequency, polarizing magnet means insulatingly supported from the strips, and means for introducing liquid into and removing liquid from said container, said means for removing from the container comprising a drain tube connected to said container at the bottom thereof and extending substantially centrally through said

cylindrical form, said drain tube being constructed of nonmagnetic material.

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