

Dec. 3, 1957

G. G. BROWN

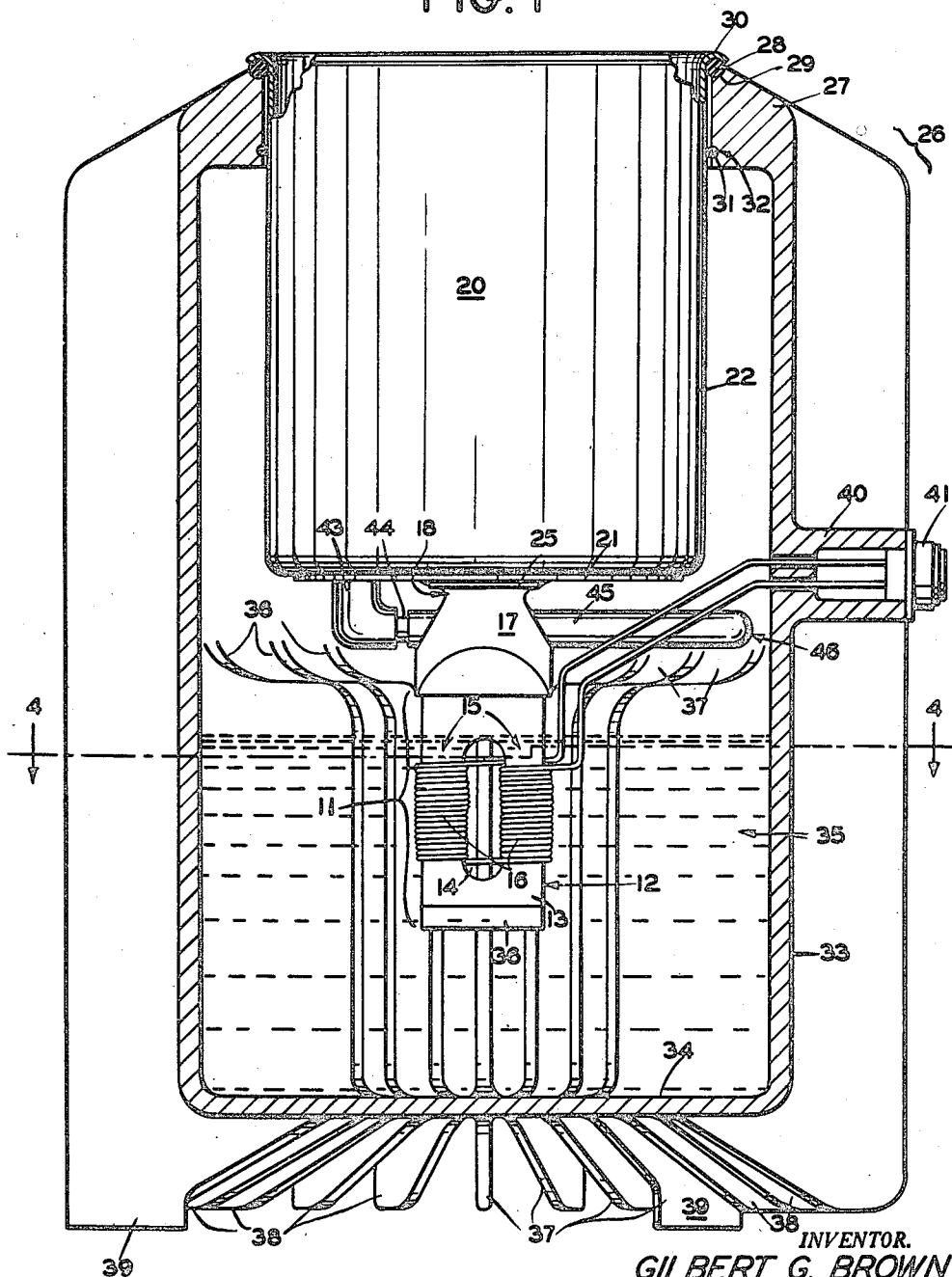
2,815,193

ULTRASONIC CLEANING SYSTEM

Filed Jan. 25, 1954

4 Sheets-Sheet 1

FIG. 1



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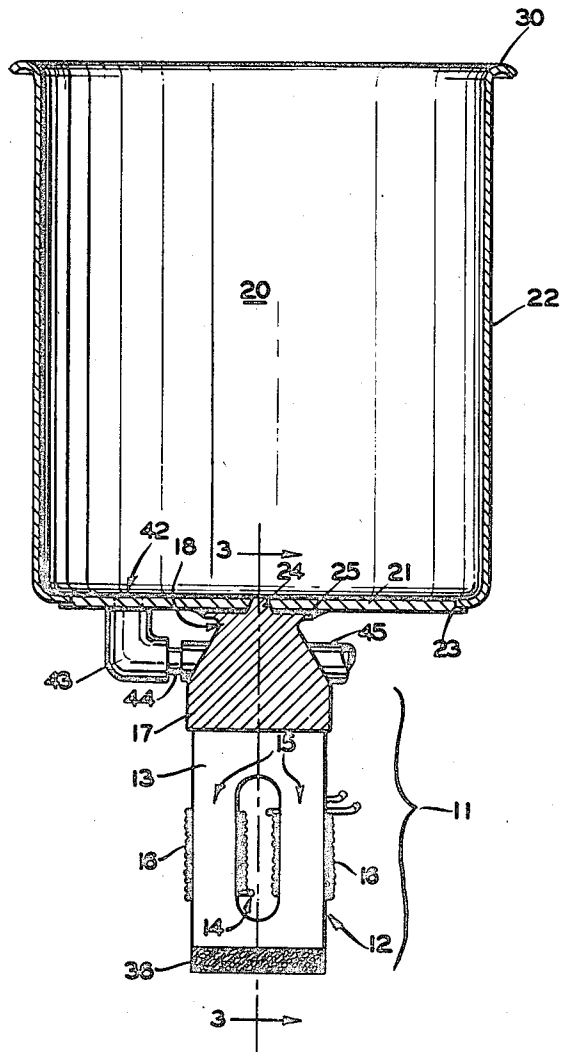
2,815,193

ULTRASONIC CLEANING SYSTEM

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4 Sheets-Sheet 2

FIG. 2



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2,815,193

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4 Sheets-Sheet 3

FIG. 3

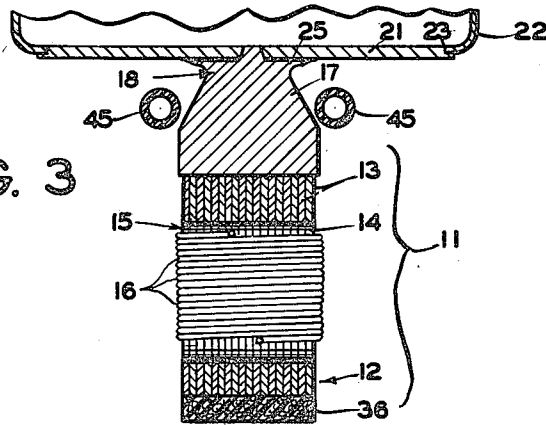
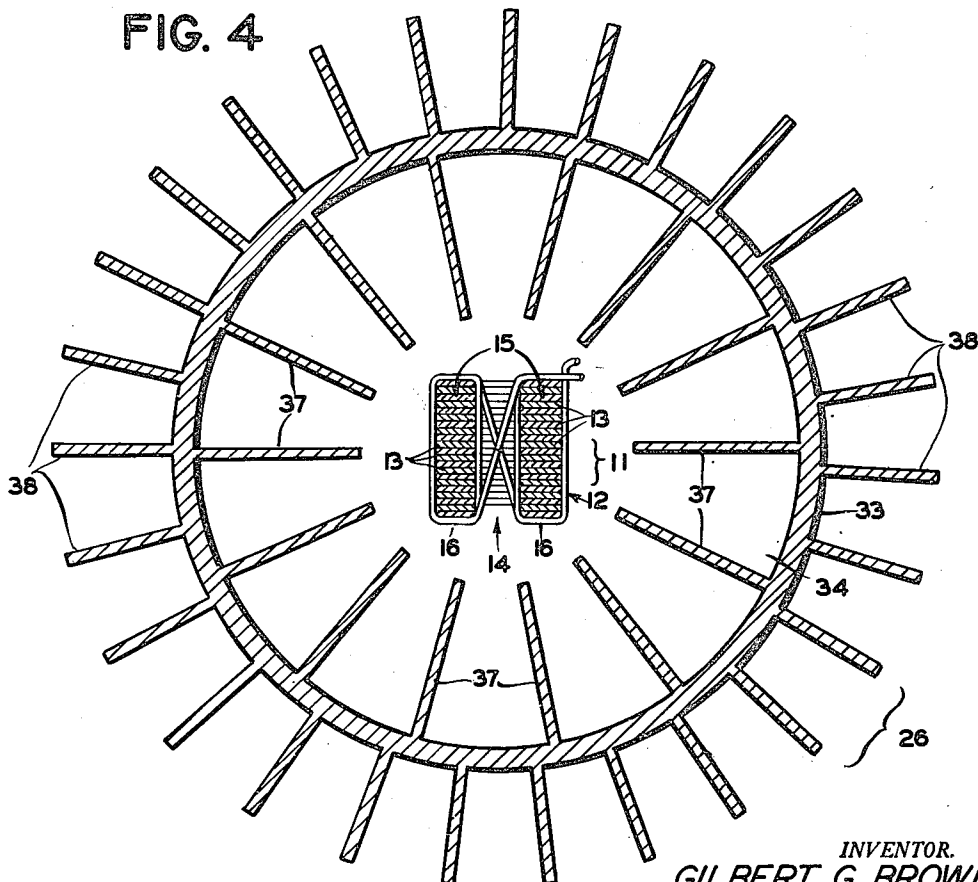


FIG. 4



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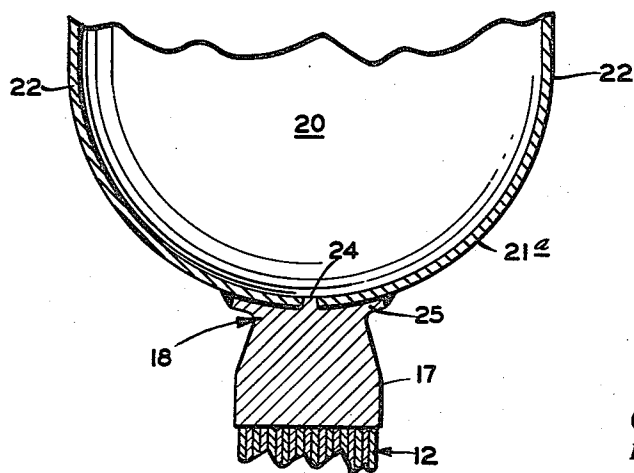
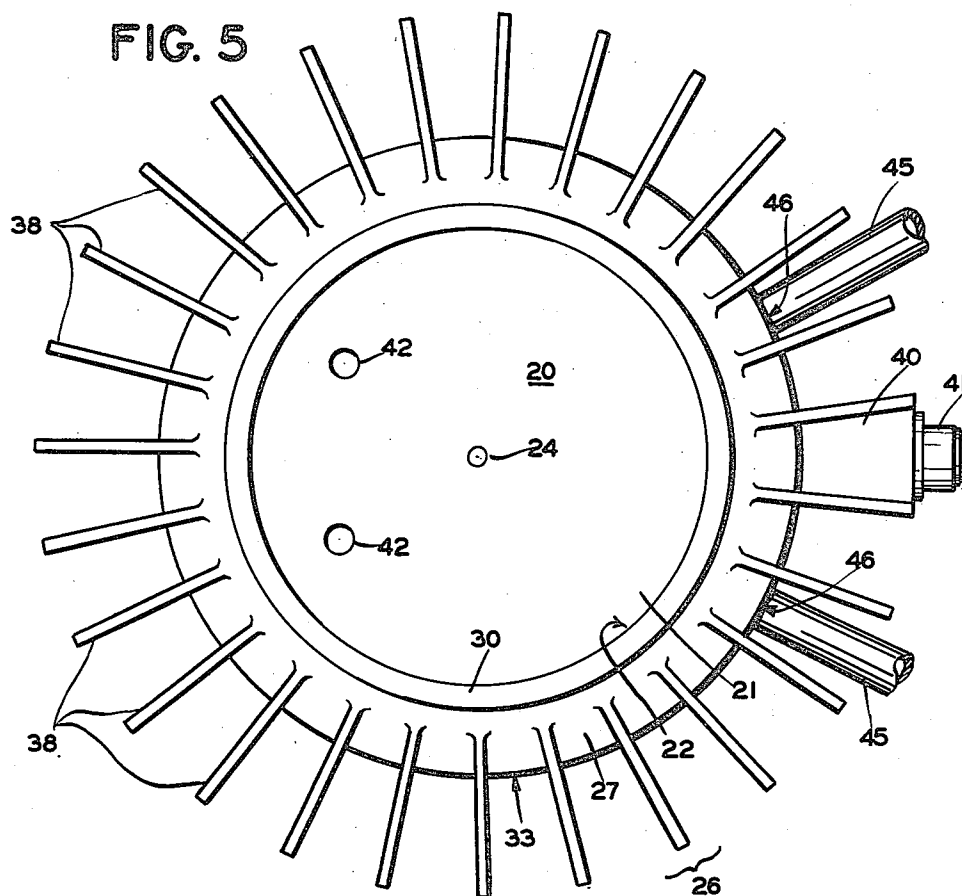
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ULTRASONIC CLEANING SYSTEM

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4 Sheets-Sheet 4



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2,815,193

ULTRASONIC CLEANING SYSTEM

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Application January 25, 1954, Serial No. 405,756

20 Claims. (Cl. 259—72)

This invention relates to vibratory apparatus, and especially to apparatus for the efficient generation, transmission and utilization of vibrations in the sonic and ultrasonic range (also known as the supersonic range), adapted for treatment of articles and substances by the action of acoustic waves. It is particularly directed to improvements in apparatus and methods for the creation, in a body of liquid, of waves suitable for promoting the cleaning of articles immersed in the liquid, as well as for other purposes.

While the use of such waves in liquids for various operations is known, previous apparatus for this purpose has had limited utility because it has not been capable of producing useful cavitation in a sufficiently large body of liquid to be commercially practical on an adequate scale. While assertions and claims to the contrary have been made in patents and literature, they have not been borne out in practice.

A main purpose of the invention is to provide effective wave action in the sonic-ultrasonic range in a larger body of liquid with adequate energy to accomplish the desired effect on articles in the liquid, or on the liquid itself, throughout the liquid body. A further object is to provide a system for introducing effective ultrasonic energy into larger bodies of liquid than has heretofore been practicable. A more specific object is to provide effective cleaning of solid objects by the effect of sound waves in all parts of such a larger body of liquid.

In seeking to accomplish these results, it was found that sonic-ultrasonic energy was dissipated in a number of ways not heretofore properly recognized. When a glass container was placed on a transducer, with the contacting surfaces carefully ground to produce a maximum contact, there was a large loss of energy at the junction, even when oil was used to bridge any slight gaps. Even when the container was held in apparently tight engagement with the transducer by weights, springs, screws, bolts, or the like, a similar energy loss occurred.

It is believed that these losses are due to the reflection of energy which takes place at the junction between two mediums of different acoustic impedance, or by discontinuities caused by the presence of oil, air or other acoustically different medium, even though the thickness of the latter medium is so extremely small that it would not normally be considered as creating a gap or discontinuity. The significance of this condition has not heretofore been appreciated in this type of apparatus. When waves in the indicated range arrive at such a junction, a proportion of the energy is reflected which bears a definite functional relationship to the difference in acoustic impedance, and is dissipated as heat. When the waves pass from the metal of a magnetostrictive transducer to oil, over four-fifths of the energy is reflected. When they pass to glass, about a third is reflected and lost. When a threaded connection is employed, as much as three-quarters of the energy may be lost, believed to be due to the presence of a very thin layer of air over a substantial part of the contiguous areas of the threads. This

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effect has been masked by the fact that enough energy is passed to produce a recognizable action as well as by the surprising extent to which even extremely thin layers of oil or air, for instance, reflect the waves and thereby reduce their transmission through the layers.

An object of the invention is therefore to improve the efficiency of wave energy transmission from the transducer in the indicated range by providing an effective transmission path through mediums of similar acoustic impedance.

Another purpose is to provide improved joints between the transducer and the elements through which the waves are transmitted to the liquid or other material or object to be treated, that will minimize the loss of wave energy at the joints, including loss by wave reflection. This is in general accomplished by providing a continuous path through metal elements connected to each other by metallic joints formed by welding, brazing or soldering with suitable bonding metals. The connection is made so that there is continuity through solid metal between said elements, without any interface with a non-metallic substance. A joint of this type is referred to herein as a solid joint.

It has been found that solid joints may be formed with the various known bonding alloys, provided they have the requisite resilient qualities and strength for particular installations. Silver and copper brazing metals have been found to be especially suitable for such joints. The composition of these and other soldering or brazing metals is known, being given, for instance, in Technical Bulletin T-34 (revised February 1953) published by The International Nickel Company, Inc., 67 Wall Street, New York, New York.

When the magnetostrictive stack itself is bonded to a coupling member or directly to a load, however, the temperature required for making a solid joint must be below that at which the magnetostrictive properties of the metal forming the stack are adversely affected, which limits the metals that can be used, silver brazing metal having been found especially desirable for this purpose.

An important purpose is to improve the efficiency with which the sonic energy produced by a magnetostrictive transducer is transmitted to the vibration-applying element. The magnetostrictive action of the transducer involves reciprocating physical movement as the stack changes in length. A feature of the invention is the provision of a novel arrangement for translating this reciprocating motion into waves, and then transmitting the waves to the vibration-applying element. With this arrangement the energy can be transmitted through a large metal element having relatively low acoustic impedance to the waves and a mass which could not be reciprocated by the transducer at the sonic-ultrasonic frequencies here involved, but which will readily and efficiently transmit the waves.

This is in general accomplished by connecting a metal wave transmission block, having relatively high conductance for said ultrasonic waves, to a vibrating end of the transducer by a solid joint, as already indicated. The block advantageously extends across the entire end of the magnetostrictive stack, so that all of the reciprocating motion of said end is directly translated into acoustic wave motion in the transmission block.

Another object is to provide an arrangement that will increase the amplitude of the acoustic waves. This is in general accomplished by tapering the block from the end joined to the stack, thereby forming a zone of reduced area in which the wave energy is concentrated, the angle of taper being sufficiently gradual to avoid substantial loss of energy by reflection. A feature of the preferred arrangement is the connection of the block to the wave-applying element, such as the bottom of a metal

container or other metal diaphragm or sheet, at a point immediately beyond the reduced area zone, advantageously with a lip on the block at the junction, arranged to provide a degree of marginal flexibility at the joint which will reduce the tendency to separate at the joint margin under the stress of intensive wave action.

Moreover, this construction improves the efficiency of wave transmission from the block to a diaphragm, container bottom or other element joined to the block. It has been found that with this construction the wave energy is effectively transmitted laterally along the element to marginal portions thereof, so that useful vibrations are transmitted over a substantial radial distance and are also transmitted transversely from substantially the entire area of said element to superposed liquid, whereas previous constructions were able to produce such vibrations only for a very limited distance from the area directly coupled to the stack, and only to a limited portion of such liquid immediately adjacent to said area. This is believed to be the result, at least in part, of the transmission block construction which flares outwardly above the restricted zone, thereby not only forming a more flexible lip as indicated, but also a continuous path along which waves traveling upwardly in the block, and guided or deflected transversely by the tapering sides, have an unbroken continuous path for lateral movement above said zone, so that they can travel laterally into and along the connected element with reduced loss of energy due to change in direction.

Another important object is to provide a novel acoustic wave generator comprising a magnetostrictive transducer and a wave transmission block connected by a solid joint. In addition to the features already mentioned, one important characteristic of this generator involves the length of the transmission block. It has heretofore been believed that important advantages are obtained by designing the element connected to the transducer so that its acoustical length is half of the wave length of the operating frequency of the transducer, or a multiple thereof, these presumed advantages being attributed to the establishment of a loop or antinode at the point of connection. A feature of the invention is the use of a transmission block that is not a half wave length long. It has been discovered that highly efficient wave transmission through the block is obtained, and that the block length affects the operating frequency of the magnetostrictive stack, even though the block has substantially no magnetostrictive action, as already indicated. The frequency of the transducer stack will in general be reduced, and a block length indicated by physical requirements of design and arrangement may be used in combination with a magnetostrictive stack whose natural frequency is selected to produce the desired resultant frequency of the transducer unit comprising the stack and the coupling block. One advantage of this arrangement is due to the fact that the stack length decreases with increases in the resonant frequency of the transducer, so that shorter stacks may be used to produce a desired frequency of generated acoustic waves. In one practical embodiment, for instance, a transducer having a natural frequency of 25 kc. was connected to a suitable block of substantially less than a half wave length to obtain the desired frequency of 18 kc.

A further object is to provide an improved liquid container having characteristics which cooperate with the features already indicated to produce enhanced wave action on the contents of the container. One characteristic is the provision of a metal container bottom having the proper degree of stiffness to transmit from its entire surface a proportionate degree of wave energy applied to its central portion.

This stiffness may be provided by selecting a metal having the requisite rigidity and thickness. It should furthermore have characteristics required for efficient transmission of the wave energy. These include proper

acoustic impedance and the optimum combination of a high modulus of elasticity with low density resulting in a maximum value of C in the equation:

$$C = \sqrt{E/d}$$

where:

C =Velocity

E =Modulus of elasticity

d =Density

It may also be aided by stiffening the margin of the bottom, as by providing a transverse circumferential flange. This is conveniently accomplished by a rigid connection between the container walls and the bottom. Such a construction does not utilize as a source of ultrasonic energy in the liquid the "piston action" heretofore used in such devices, according to which the margin should be connected to the container walls by a flexible joint that would leave the bottom free to vibrate with all sections of the bottom vibrating in phase, and to transmit more wave energy, since damping by the side walls is avoided. It has however been found unexpectedly that a rigid connection between the bottom and walls produces in fact a better transmission of the energy to the container and to its contents. The walls and bottom may be integral, but preferably the walls are separately formed and connected by a solid joint to the periphery of the bottom.

Another way in which the desired rigidity may be imparted to the container bottom is to provide a convex or concave bottom, which possesses inherent stiffness even when made of thin metal. This construction has been found to be efficient in transmitting acoustic waves from the transducer unit, and provides a curved path along which the waves may travel from the transmission block without any sharp change in direction.

A principal problem in obtaining efficient transmission of wave energy from the transducer to the point of application is to minimize the damping effect of supports or other parts contacting the transducer or the elements through which the energy is transmitted. It has therefore been proposed to arrange the transducer and the elements connected thereto so that nodes will exist at predetermined points, and to support the structure at these points, where theoretically there is no motion. Such arrangements have not been effective, since nodal points are in effect so narrow that joints having structural strength would overlap into adjacent active metal portions beyond the nodal points. Moreover, they impose difficult design requirements in order to obtain the proper conditions for nodal support, since the elements generally must be a half wave length long, or a multiple thereof. This imposes serious limitations on the size and arrangement of the parts.

A feature of the invention is the elimination of lateral supports for the magnetostrictive transducer stack and wave transmission block, which together form a resonant unit having a characteristic frequency. This unit according to the invention has only endwise support, and advantageously is supported from only one end, which transmits the acoustic waves to the supporting element. This element may be the wave-applying member, such as a container bottom. With this arrangement the endwise movement of the magnetostrictive stack is free from damping by lateral engagement. When the unit is supported entirely by the transmission block, the end of the stack joined to the block is free to transmit energy by wave motion, while energy from the other end is not lost, as said end is free for movement in a medium having an entirely different acoustic impedance, such as air, so that only a small amount of energy, or none at all, is transmitted from the free end.

The support of the unit is advantageously pendulous, a convenient arrangement when the unit is attached to the bottom of a liquid container. In this embodiment a similar object is accomplished by pendulously supporting the container from its upper portion, so that the body of the

container as well as the transducer supported thereby are free from energy-dissipating contacts below the upper part of the container.

A specific object is to provide a container suspension that will have a minimum damping effect. This is attained by supporting the container entirely on a resilient or elastic mount engaging the upper part of the container. This mount advantageously comprises a resilient element, which may be rubber or other elastomer, which permits the container to vibrate freely at the selected frequency while providing adequate support.

Magnetostrictive transducers have been found to generate heat, and require cooling during operation. This has been generally accomplished by employing streams of water; but cooling in this manner requires a special arrangement for this purpose, including the provision of pumps, motors and piping, and restricts the location and use of the apparatus, since a plentiful water supply and discharge facilities must be provided. Moreover, water is also objectionable because some magnetostrictive metals rust very readily; also, the danger of shorting the high voltage winding is increased.

An object of the invention is to provide an air-cooled unit. This is accomplished by submerging the transducer in a heat-transmitting liquid, and providing an improved fin arrangement for dissipating the heat, especially suited for use with a pendulously supported transducer.

In an arrangement of this type, in which a vibrating end of the transducer is immersed in liquid, a substantial amount of energy is lost by transmission from said end to the liquid. An object of the invention is to minimize this loss by covering said end with material that provides acoustic insulation, that is, material that substantially prevents transmission of acoustic waves to the liquid. For this purpose the material should have acoustic impedance differing substantially from that of the stack, so that the maximum amount of wave energy is reflected back into the stack toward the opposite end where it will be useful. Elastomers have been effectively employed; and where the material is submerged in oil, it should be of a type not affected thereby, silicone rubber having been found satisfactory.

Since an air interface will produce substantially total reflection of acoustic waves, the insulation is advantageously arranged to provide such an interface. This may include an air space or spaces at the junction, from which the oil is excluded; but a simple and effective arrangement comprises a sheet of cellular rubber of proper type, having a sufficiently large number of sealed air cells so that all parts of waves entering the rubber will encounter such cells and be reflected. When suitable acoustic insulation is provided, there is substantially no loss of energy from this end of the stack, when otherwise the loss may run over ten percent.

An important purpose is to provide a magnetostrictive transducer that will operate continuously for long periods at substantially lower temperatures than previous transducers of this type. The tendency to heat up excessively has been a principal objection to such transducers, and at the best has required the use of an excessive amount of circulating liquid coolant. Moreover, such heating may raise the stack temperature to the Curie point at which it loses magnetostrictive properties. With the present invention the stack can operate efficiently without any danger of approaching its Curie point, and can be cooled much more easily, in many cases by air cooling. Moreover, this feature makes it practical to use magnetostrictive metals that have lower Curie points, such as nickel, and which may be more attractive because of price, rust-resisting properties or other considerations.

In many instances it is desirable to provide arrangements for circulating the cleaning liquid, or liquid under treatment, in the container, which presents a problem in avoiding damping of the vibrations. An object is to provide a circulation system that is practical and con-

venient, and does not damp vibrations to any substantial extent.

The waves referred to herein are acoustic or sound waves. As far as effective generation and transmission of these waves in accordance with this invention are concerned, they may be of any frequency capable of generation by a magnetostrictive transducer, which includes a range extending from the lowest tones to frequencies well above 150 kilocycles per second. However, there are two practical limitations on the frequencies that are advantageous. The low frequency limit is imposed by the fact that up to about 15 kilocycles the waves are audible, and with a powerful generator the sound produced is highly objectionable. The high frequency restriction is due to the fact that the magnetostrictive stack becomes shorter as the frequency rises, with a corresponding reduction in the ability to dissipate heat generated in the transducer, as well as a loss in stack activity due to the lower amplitude of stack movement, and loss of space required for the necessary winding, while the stacks required to produce the lower audible frequencies are so large as to be unwieldy and impractical for ordinary purposes. Consequently, in the present state of the art, it is advantageous to use a frequency only slightly above the highest frequency that produces objectionable audible sound, as stacks of the proper dimensions for generating acoustic waves in this frequency range are sufficiently long to produce an effective amount of energy, and sufficiently short for practical use.

For convenience, acoustic waves in the range pertinent to this invention are referred to herein as "ultrasonic," though they may include waves audible to human ears.

The invention therefore comprises a number of features which cooperate to produce substantially greater effective wave energy at the point of application, and especially greater cavitation, for cleaning or other purposes, in a substantially larger body of liquid than has heretofore been accomplished. Moreover, while previous magnetostrictive vibration-generating arrangements have been ineffective in producing useful cavitation in more than about a pint of liquid per kilowatt of ultrasonic power, apparatus embodying the present invention has produced cavitation of very much greater intensity than any previously obtained, throughout thirty quarts of liquid, using only one kilowatt of power.

The invention therefore comprises also the combination of features which cooperate to produce these novel results. These features include the transmission of vibrations in the indicated range from a magnetostrictive transducer through members of similar acoustic impedance connected by solid joints; the use of an improved wave-transmitting member connecting the transducer and the vibration applying member, including the provision of a zone of reduced area and a lip at the output joint; endwise, and preferably pendulous support of the transducer; a transducer and wave transmission block unit free from lateral contacts; pendulous support of the container, and particularly a resilient support; a container with a bottom arranged for vibration transmission, and rigidly connected to the side walls; an improved air-cooling arrangement including fins and liquid; vibration-blocking insulation on the submerged end of the transducer; and a circulation system for liquid in the container, arranged to avoid damping of the vibrations.

The foregoing and other objects and advantages of the invention will appear more fully hereinafter from a consideration of the detailed description which follows, taken together with the accompanying drawings, wherein one embodiment of the invention and a single modification are illustrated. It is to be expressly understood, however, that the drawings are for the purposes of illustration and description, and are not to be construed as defining the limits of the invention.

In the drawings:

Fig. 1 is a side view of an embodiment adapted for

treatment by acoustic waves generated by a magnetostrictive transducer, of liquid or articles in liquid, and particularly for the cleaning of metallic or other solid articles in this manner, the casing being shown in central vertical section;

Fig. 2 is a central vertical section through the liquid container and the attached magnetostrictive wave generating unit;

Fig. 3 is a similar fragmentary central vertical section on line 3—3 of Fig. 2;

Fig. 4 is a horizontal section on line 4—4 of Fig. 1;

Fig. 5 is a top view of the entire unit; and

Fig. 6 is a fragmentary central vertical section through a modified form of container bottom.

In the illustrated embodiment the wave generating element is a magnetostrictive transducer 11, comprising a stack 12 made up of laminations 13 and having a longitudinal central opening 14 arranged to form two stack legs 15 energized by windings 16. The transducer 11 may be constructed in known manner, with laminations 13 formed of appropriate magnetostrictive metal cemented together. One satisfactory metal is composed of two to four percent vanadium, the remainder consisting substantially of about equal parts of iron and cobalt, though the cobalt percentage may be as high as 60%.

A connecting vibration-transmitting block 17 is fixed to the upper end of stack 12 by a solid joint. The joint is advantageously formed by soldering or brazing with a metal to produce a solid joint, the metal being selected so that the joint-forming temperature will not be as high as the minimum temperature at which the magnetostrictive characteristics of the stack would be adversely affected.

The metal employed should also have an acoustic impedance as close as is practical to the acoustic impedances of stack 12 and block 17. Silver brazing alloys have been found especially effective in forming this joint. It has been found that a solid joint of this type transmits vibrations with negligible loss of energy.

Block 17 may be made of stainless steel, though Monel metal or nickel may be used.

Its base extends across the entire end of stack 12, and preferably is of substantially the same area as said end at the joint, but is upwardly tapered to a neck 18, substantially smaller in cross section than the lower end of the block, and advantageously substantially circular when used to transmit vibrations to a circular element, as in the form illustrated.

Neck 18 is connected to a vibration applying unit which pendulously supports the block 17 and transducer 11. In the form shown, this arrangement comprises a container 20 having a bottom 21 and a side wall 22, both formed of metal. The illustrated container is cylindrical, and the bottom 21 is flat and circular, connected at its periphery to the side wall 22 by a solid joint, preferably by silver or copper brazing. The bottom 21 is sufficiently thick and rigid to transmit vibratory movement to its periphery without serious loss of energy. When made of stainless steel or Monel, a thickness of one-eighth inch with a diameter of twelve inches has been found satisfactory. The side wall 22 is connected to bottom 21 along a line substantially in alignment with the vertical portion of the side wall, so that vibrations from the bottom 21 are transmitted substantially along wall 22 rather than transversely thereto. The lower edge of side wall 22 may be curved and soldered into a rabbet 23 at the edge of bottom 21 with a solid joint to provide a particularly rigid connection.

Connecting block 17 engages the center of bottom 21, and may have a positioning stud 24 fitting a central opening in the bottom. Block 17 is advantageously provided with a lip 25 immediately above neck 18, shaped to give sufficient flexibility at this point to reduce the strain on the joint during operation, and to transfer waves to the bottom with minimum deflection. The upper end of block 17 is advantageously connected to the container

bottom 21 by a brazed solid joint, which may be formed with silver or copper solder.

The container 20 is pendulously supported from its upper end. This is conveniently accomplished by providing a casing 26 having an inwardly extending upper end 27 with an opening slightly larger than the container 20 and carrying a resilient support for the container. As illustrated, this comprises a readily compressible elastic ring 28 of rubber or similar elastomeric material, seated in an annular recess 29 and projecting upwardly and inwardly from the casing end 27. Container 20 is formed with an outwardly projecting lip 30 extending over and bearing against the top of ring 28, which preferably fits the curve of lip 30 and also bears laterally against side wall 22. A centering ring 31, also made of resilient material such as rubber or the like, is seated in recess 32 in casing end 27 a substantial distance below ring 28, and bears lightly against the container side wall 22, being arranged to maintain the side wall out of contact with the casing end 27 without material damping of vibrations.

Casing 26, as illustrated, forms a container with a cylindrical side wall 33 and a bottom 34 located below the bottom of transducer 11. The lower portion of the casing is filled with a liquid 35 having good heat transferring properties, transformer oil or silicone oil being especially suitable. The liquid level is maintained close to or above the top of the transducer 11, but below the container 20. The lower end of transducer 11, submerged in liquid 35, is of course vibrated by the magnetostrictive action of the transducer, and would normally transmit vibrations to the liquid 35. To prevent this loss of energy an acoustic insulating element extends across said end in contact therewith. For this purpose insulating sheet 36 of vibration-blocking material is firmly attached to the entire lower end of stack 12, as by cementing. Sheet 36 is formed of material that will reflect the vibrations of the stack end, and will prevent acoustic waves generated thereby from reaching the oil or other fluid surrounding the stack end. Rubber or other elastomer may form the body of sheet 36, and of course must be of a type unaffected by the fluid. When oil is used, silicone rubber is satisfactory. The sheet should consist principally of closed air spaces, sealed from the liquid, sufficiently numerous and overlapping to block acoustic waves, which will be reflected back to the stack without material loss of energy.

An arrangement may be provided for improving the heat transfer to the casing 26. For this purpose, vertical heat conducting fins 37 connected to the casing 26 extend radially inward through liquid 35 to points adjacent to but spaced from transducer 11. As shown, fins 37 are in heat-transferring engagement with the side wall 33 and the bottom 34 of the casing, and extend to points above the level of liquid 35 but below the container 20. Since the liquid immediately surrounding the transducer will of course be heated to a higher temperature than the surrounding liquid, it will rise, being replaced by cooler liquid from below the transducer. This will produce an upward flow along the transducer that will result in a downward flow between the fins 37, which serve to prevent turbulence and form vertical channels for the circulation of the liquid by convection.

Casing 26 is also provided with external heat radiating fins. In the form illustrated, these fins 38 extend vertically in a radial direction at equally spaced intervals around the side wall 33; and certain fins 38 at spaced intervals are downwardly extended to form feet 39 which support the unit. The leads from winding 16 are brought out above the liquid level through side wall 33, to a standard connecting plug 41 fixed to block 40 which is connected to side wall 33 and to contiguous fins 38.

The casing 26, including the projecting upper end 27, side wall 33, bottom 34, fins 37 and 38 and block 40 are constructed and arranged so that they may be formed from a single integral casting, and are made from a suit-

able relatively light metal that is a good heat conductor, aluminum or one of the well known aluminum alloys being suitable.

An arrangement for conveniently supplying liquid to and removing liquid from container 20 without damping vibrations is advantageously provided, and may be arranged for continuous circulation of the liquid if desired. For this purpose inlet and outlet openings 42 in container bottom 21 each connect with a pipe L 43 fixed to the container bottom 21 by a solid joint, as by silver or copper brazing, the L 43 carrying a connecting nipple 44. A flexible hose 45, which may be of synthetic rubber or similar material unaffected by the hot oil, fits over each nipple 44 and extends through a snugly fitting opening 46 in the casing wall 33 between fins 37 and above the level of liquid 35.

The container bottom may likewise be transversely curved, a construction which imparts rigidity even when thin metal is used; and when the bottom is curved, it provides a path for the waves along the container bottom and walls that is free from the sharp change in direction at the junction of the bottom and the side wall that is present in the embodiment heretofore described. A modified container construction of this type is illustrated in Fig. 6, having a convex bottom 21a integral with side walls 22 of the container 20, the upper end of transmission block 17 being shaped to conform to the contiguous surface of the bottom 21a, and fixed thereto by a solid soldered joint, the construction and arrangement of container 20, block 17, stack 13 and associated elements being otherwise the same as that already described.

In operation, the windings 16 of the magnetostrictive transducer 11 are connected through plug 41 to a generator of standard type which applies to said windings a polarizing direct current and an alternating current having a frequency corresponding to the natural frequency of vibration of the transducer 11 and block 17 combined. The resulting acoustic waves are transmitted from stack 12 through block 17 to the container bottom 21 and container walls 22. The efficiency of this arrangement is substantially higher than was heretofore attainable; and to this end the stack 12, block 17 and container 20 are constructed of metals having similar acoustic impedance, and are connected by solid joints, advantageously by silver or copper brazing as already indicated. Liquid in container 20 is thereby subjected to vigorous cavitation throughout its entire volume. The cavitation will be sufficiently vigorous for the effective loosening and removal of dirt on objects immersed in the liquid, and in particular will effectively remove grease, abrasives, oxidation and other objectionable material from the surface of objects immersed in liquid in the container. In practical operation, this has been successfully carried out under plant conditions with a volume of liquid amounting to twenty-four quarts and only one kilowatt of ultrasonic energy, effective results being obtained in an exceptionally brief period of time owing to the vigor and good distribution of the cavitation.

Because of the exceptional wave energy that may be applied to the liquid, excessive cavitation may be obtained which will interfere with effective cleaning or other operation in the liquid; and the power applied to winding 16 should be regulated for optimum action in each instance. When the apparatus is used for cleaning solid objects, and especially for removing oxidation or other incrustation or dirt from metal objects, the best results have been obtained by operating at the threshold of cavitation. This condition is identified by the fact that cavitation takes place and can be observed, but the surface of the liquid is not sufficiently agitated to produce turbulence resulting in visible surface flow of the liquid.

The heat generated by the transducer 11 is effectively dissipated by radiation into the air, so that the unit can be located wherever desired without reference to a source

of water supply or drain, or the use of an expensive heat exchanger. When the unit is used for cleaning or other purposes where a change in the liquid in container 20 during operation is desirable, the liquid can be fed through one pipe 45 and removed through the other, carrying solid contaminants which may be filtered out. The arrangement is also useful for continuous treatment of liquids by acoustic waves for any of the various known purposes for which such treatment is effective. Articles can be readily introduced into and removed from the container 20, and said container and the attached transducer 11 may be easily removed from casing 26 simply by disconnecting pipes 45 and plug 41.

For simplicity and clarity, acoustic waves within the effective ranges heretofore indicated are referred to in the claims as in the sonic-ultrasonic range, and endwise supported portions of the container and transducer unit that are not in lateral vibration-damping contact with supports or other structural elements are described as free.

The term "liquid" as used herein includes normally solid materials in fluent state, such as molten metals, plastics or other substances rendered fluent by heat, solvents, plasticizers or otherwise, and solid particles so finely divided that they have fluent characteristics.

Although but one embodiment of the invention has been illustrated and described in detail, it is to be expressly understood that the invention is not limited thereto. Various changes can be made in the design, arrangement and constituents of the parts without departing from the spirit and scope of the invention, as the same will now be understood by those skilled in the art.

I claim:

1. Vibratory apparatus, comprising a generator of vibrations in the sonic-ultrasonic range, a vibration transmitting member fixed to a vibrating surface of the generator by a solid joint, and a vibration applying member fixed to the transmitting member by a solid joint, the acoustic impedance of the generator, transmitting member and applying member being similar.

2. Vibratory apparatus, comprising a magnetostrictive transducer, a vibration transmitting member fixed to a vibrating surface of the transducer by a solid joint, and a vibration applying member fixed to the transmitting member by a solid joint, the acoustic impedance of the generator, transmitting member and applying member being similar.

3. Vibrating apparatus, comprising a magnetostrictive transducer, a vibration transmitting member fixed to a vibrating surface of the transducer, and a vibration applying sheet member of rigid material extending transversely to the transducer and centrally fixed to the vibration transmitting member by a solid joint, the transmitting member being provided with an integral relatively flexible lip extending laterally from the sides of the transmitting member, terminating in a thin margin and attached to the sheet member from the margin inwardly by said solid joint.

4. Vibratory apparatus, comprising a magnetostrictive transducer, a vibration transmitting member fixed to a vibrating surface of the transducer, said member having a zone spaced from the transducer of less cross-sectional area than its cross-sectional area at the transducer, and an outwardly extending lip beyond said zone, and a vibration applying sheet member of rigid material extending transversely to the transducer and centrally fixed to said lip by a solid joint.

5. Vibratory apparatus having a selected vibrating frequency, comprising a magnetostrictive transducer, including a metal stack having a natural frequency of vibration higher than said selected frequency, and a vibration transmitting member of similar acoustical impedance fixed to the generator stack by a solid joint and forming with the stack a unitary vibrating element having the selected frequency of vibration.

6. Vibratory apparatus comprising a magnetostrictive transducer including a stack, and a metal vibration-transmitting member fixed to the stack by a solid brazed joint having low vibration-damping characteristics, formed substantially from a brazing metal having a brazing temperature below the minimum temperature at which the magnetostrictive action of the stack is permanently affected by the brazing.

7. Vibratory apparatus, comprising a support, a container for material to be treated by vibration pendulously carried by the support, including a rigid vibrating diaphragm in contact with said material, and an acoustic transducer pendulously supported by the diaphragm in vibration transmitting relationship.

8. Vibratory apparatus, comprising a support, a container for material to be treated by vibration pendulously carried by the support, including a rigid vibrating diaphragm in contact with said material and a magnetostrictive transducer pendulously supported by the diaphragm in vibration transmitting relationship.

9. Vibratory apparatus, comprising a metal container for material to be treated by vibration, a support engaging the container only adjacent the upper margin of the container and extending along said margin in supporting engagement therewith for at least a major part of its periphery, the remainder of the container being free, and a magnetostrictive transducer pendulously supported by the container, arranged to transmit vibrations to the container.

10. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container including a bottom and side walls rigidly connected to the bottom, said bottom and side walls being formed of rigid wave-transmitting material, and a magnetostrictive transducer centrally connected to the container bottom by a solid joint in vibration-transmitting relationship to said bottom and walls.

11. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container having rigid side walls and a bottom integral with the side walls, and a magnetostrictive transducer having an end connected to the container in vibration-transmitting relationship to said bottom and side walls, the other end of the transducer being free.

12. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container including a relatively flat bottom and side walls of sheet material rigidly connected to the bottom, said bottom and side walls being formed of rigid wave-transmitting material, the bottom being thicker than the side walls, and a magnetostrictive transducer in central vibration transmitting engagement with the bottom.

13. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container including side walls and a bottom formed of separate pieces of rigid wave-transmitting material joined at the periphery of the bottom by a solid vibration-transmitting joint, and a magnetostrictive transducer centrally connected to the bottom in vibration-transmitting relationship to the bottom and side walls.

14. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container having integral side walls and convex bottom of sheet material having a continuous transverse wave-transmitting curvature, and an acoustic transducer in vibration-transmitting engagement with the bottom.

15. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container and a magnetostrictive transducer centrally connected to the bottom of the container in vibration-trans-

mitting position, the container and transducer being free from vibration-damping contacts between the upper part of the container and the bottom of the transducer.

16. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a support, a liquid container of rigid wave-transmitting material having a laterally extending flange resting on the support, and a magnetostrictive transducer connected to and supported by the container in vibration-transmitting relation thereto.

17. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a liquid container of rigid wave-transmitting material having a marginal rim, a yieldable supporting element engaging the rim, and a magnetostrictive transducer supported by the container in vibration-transmitting relation thereto.

18. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a support, an annular yieldable supporting member on the support, a liquid container of rigid wave-transmitting material having a circular flange resting on the supporting member, and a magnetostrictive transducer attached to and supported by the container in vibration transmitting relation thereto, said combined container and transducer being free except adjacent to said flange.

19. Vibratory apparatus for liquid treatment with vibration in the sonic-ultrasonic range, comprising a support, an annular yieldable supporting member on the support, a liquid container of rigid wave-transmitting material having a circular flange resting on the supporting member, and a magnetostrictive transducer attached to and supported by the container in vibration transmitting relation thereto, said container and transducer being free except adjacent to said flange, and a yieldable positioning element carried by the support and laterally engaging the container, arranged to maintain the container out of contact with the support.

20. Vibratory apparatus, comprising an outer casing having continuous sides and bottom forming an outer container for a body of heat transmitting liquid, an inner container located within the casing above the liquid and supported at the top of said inner container by the casing, a magnetostrictive transducer centrally fixed to the container bottom with one end in vibration transmitting relation to said bottom and the other end submerged in the liquid, heat-conducting fins extending inwardly from the casing toward the transducer in the liquid, and heat radiating fins extending outwardly from the casing.

References Cited in the file of this patent

UNITED STATES PATENTS

1,380,869	Fay	June 7, 1921
1,923,678	Lowell	Aug. 22, 1933
2,143,610	Muller et al.	Jan. 10, 1939
2,336,438	Evans	Dec. 7, 1943
2,467,668	Hallberg	Apr. 19, 1949
2,498,990	Fryklund	Feb. 28, 1950
2,521,136	Thuras	Sept. 5, 1950
2,632,858	Calosi	Mar. 24, 1953
2,636,998	Davis et al.	Apr. 28, 1953
2,638,577	Harris	May 12, 1953
2,651,148	Carwile	Sept. 8, 1953
2,714,303	Bodman	Aug. 2, 1955

FOREIGN PATENTS

511,682	Germany	May 22, 1931
581,123	Great Britain	Oct. 2, 1946
852,150	France	Jan. 24, 1940
870,238	Germany	Mar. 12, 1953