March 2, 1971 F. W. ROSS ET AL 3,567,185

FLUID RESONATOR SYSTEM

Filed Oct. 3, 1968 2 Sheets-Sheet 1

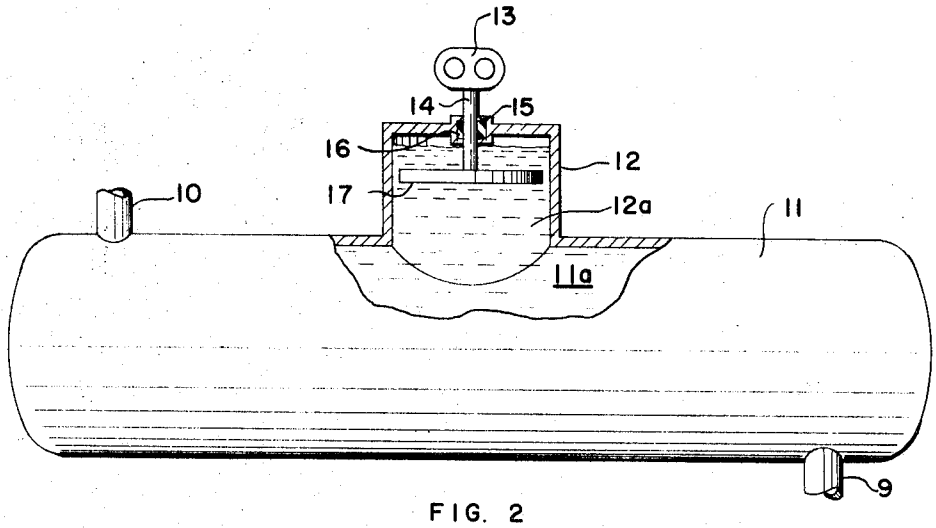


FIG. 2

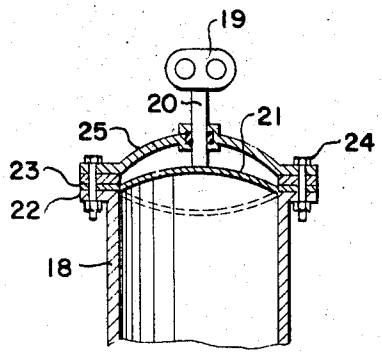


FIG. 3

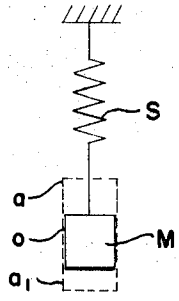


FIG. 1

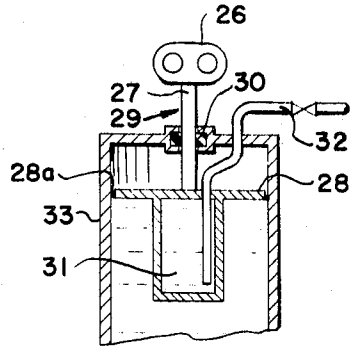


FIG. 4

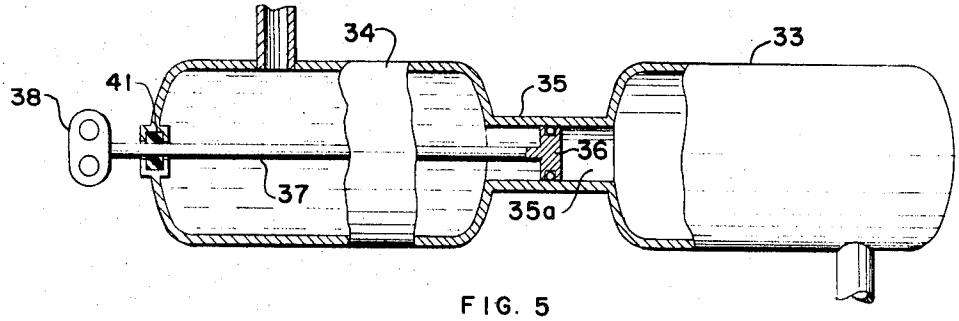


FIG. 5

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FLUID RESONATOR SYSTEM

Filed Oct. 3, 1968 2 Sheets-Sheet 2

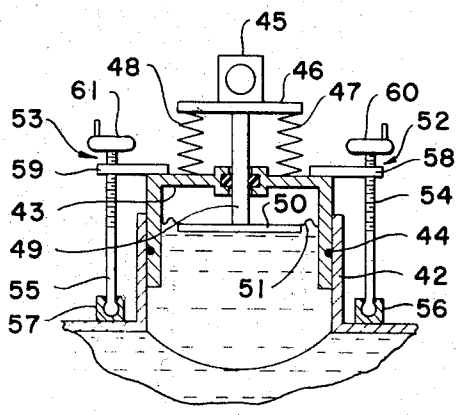


FIG. 6

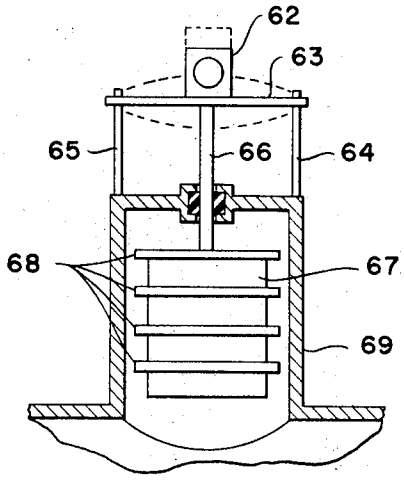


FIG. 7

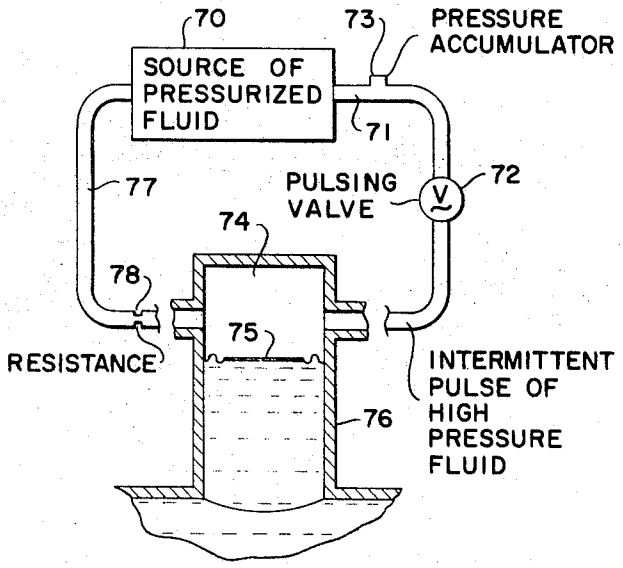


FIG. 8

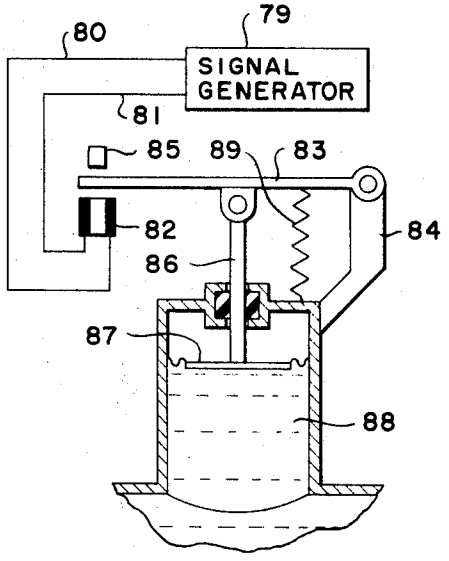


FIG. 9

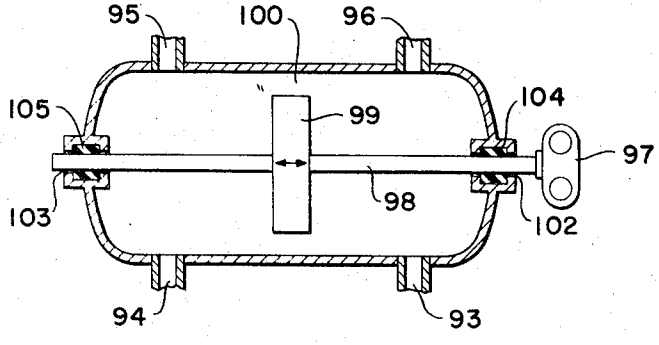


FIG. 10

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3,567,185

FLUID RESONATOR SYSTEM

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Int. Cl. B01f 11/02
U.S. Cl. 259—1 8 Claims

ABSTRACT OF THE DISCLOSURE

A sonic treatment vessel for liquids is arranged so that a body of liquid confined therein is functionally divided so that one portion of the body of liquid serves as a mass and the remainder serves as a spring in a resonant vibratory system so that resonant frequency vibrations generated therein distributes pressure energy substantially equal throughout the liquid.

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to the introduction of sonic or ultrasonic energy into a body of liquid and pertains more particularly to methods and apparatus for introducing high levels of sonic energy into bodies of liquid with substantially equal pressure and/or energy distribution throughout the body of liquid.

Description of the prior art

The potential benefits of introducing sonic or acoustic energy into liquids in reactors and mixing vessels are well known. The introduction of such energy is useful for such purposes as treatment of liquids, mixing of materials, in liquids, increasing of chemical reaction rates, emulsification of immiscible liquids, increasing heat transfer rates, cleaning of vessels and other articles, and other such purposes requiring sonic or ultrasonic energy in a body of liquid. Many of the prior known devices have generally been successful in transmitting acoustic energy into a liquid in the immediate vicinity of the coupling of the sonic or ultrasonic generator or transducer to the body of liquid, but have been ineffectual to transmit the sonic energy with equal pressure pulses to remote areas of the body of liquid. For this reason, prior known sonic or ultrasonic devices are either limited to small liquid masses or are quite expensive.

The introduction of high-level sonic or ultrasonic energy into a liquid produces large amplitude oscillations in the body of liquid. That is, the pressure in the liquid varies above and below the static pressure of the liquid. These high-pressure oscillations cause particle displacement and may also cause what is known as cavitation. Cavitation in liquid results when the negative pressure swings are great enough to reduce the hydrostatic pressure locally below the local vapor pressure of the liquid during the dilational phase. The large amplitude oscillations may be useful in themselves, without the presence of cavitation, to induce high-turbulent mixing of the liquid throughout the vessel.

Cavitation may be induced in a body of liquid by the introduction of high-level energy, sonic or ultrasonic, above a certain level, usually about ⅓ watt per square centimeter for water at room temperature and near atmospheric pressure. Cavitation is generally understood to be the formation of many relatively tiny or small cavities or voids in the liquid when the liquid is unable to fill the local region of space at generally high power sonic rarefactions through the liquid. The formation and subsequent

collapsing of these voids or cavities as the sonic compression acts in rapid time sequence after each rarefaction act as tiny implosions releasing intense localized pulses of energy manifested by high localized pressure which may be as much as several hundred atmospheres. These localized pulses of energy in the liquid causes intense fluid flow rates and physical agitation which is useful to increase chemical reactions and to perform sonic cleaning and to cause erosion damage. The intense agitation of the particles or molecules of the liquid accompanying the cavitation also makes the process very well suited to the mixing of various liquids and also the mixing of solids in liquids.

The present invention was developed to put the maximum amount of sonic energy into a liquid and to distribute this energy more equally throughout the body of liquid. The term "sonic energy" as used herein is not intended to be limited to the range of audible frequencies for a vibrating system but may also include subsonic as well as ultrasonic. It is well known that the most effective method of producing large amplitudes in a vibrating system is to drive the system at its resonant frequency. At resonance, the amplitude of vibration is limited only by the energy dissipation in the system; the inertial energy alternately stored and released by the moving mass of the system is exactly balanced by elastic energy stored and released by the compliant members (springs) of the system. Prior art systems for the introduction of sonic or acoustic energy into liquids have attempted to use this resonance phenomena. These prior art systems, however, utilized standing wave techniques for developing resonance in the vibrating system. These standing wave techniques. although known to operate at resonant frequencies, are incapable of producing equal pressure variations and energy distributions throughout the body of liquid. These prior art systems develop areas known as nodes and antinodes which are areas of minimum and areas of maximum pressure variations. These systems are unsuited for many types of liquid treatments for which the present system is developed.

The present invention, however, is based on the discovery that a system for introducing sonic energy into a liquid can be constructed to operate at resonant frequencies without the use of a standing wave technique. The system of the present invention is effective to produce substantially equal pressure variations throughout a body of liquid while operating at resonant frequency.

The liquid resonator of the present invention comprises a vessel or container having a neck or at least a portion thereof which serves to functionally isolate or separate a portion of the liquid in the container from the remainder of the liquid therein. The separated portion thereof is driven or excited so as to move a great deal relative to the remaining portion thereof so as to serve as a mass or inertia member or element while the remainder of the liquid therein is alternatively compressed and dilated and serves as a spring for the system.

SUMMARY OF THE INVENTION

It is primarily the object of the present invention to provide method and apparatus for the introduction of sonic energy with substantially equal pressure variations throughout a body of liquid.

It is a further object of the present invention to provide method and apparatus for the resonant vibration of a body of liquid while inducing equal pressure variations throughout the body of liquid.

It is a still further object of the present invention to provide a system for the sonic treatment of a liquid wherein substantially equal amounts of energy are transmitted throughout the body of liquid.

A still further object of the present invention is to provide a system for resonantly vibrating a body of liquid which results in the efficient transmission of sonic energy throughout the body of liquid regardless of the shape of the vessel.

Still another object of the present invention is to provide improved means for coupling a sonic or ultrasonic energy generator to a body of liquid. It is a still further object of the present invention to provide apparatus for introducing high-level sonic energy into a body of liquid.

In accordance with one aspect of the invention, a resonant system is formed which comprises an enclosed liquid vessel which serves as a resonator chamber to which a neck or second chamber containing a column of liquid is attached in fluid communication therewith. The column of liquid is excited by a sonic generator to resonate the system, thereby transmitting sonic energy throughout the vessel at substantially equal levels.

The above and other objects of the present invention are carried out by means of a system which functionally isolates a body of liquid into a spring mass vibrating system. Means are then provided for coupling a sonic or ultrasonic generator to the liquid system to move the mass portion of this system and to alternately compress and dilate the spring portion of the system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a simple spring-mass oscillating system;

FIG. 2 is a side elevation partially in section of a preferred embodiment of the present invention;

FIG. 3 is a side elevation in section of a second embodiment or modification of the sonic transmitting apparatus of the present invention;

FIG. 4 is a side view in section of a third modification of the sonic transmitting apparatus of the present invention;

FIG. 5 is a side view partially in section of a modification of the system of the present invention;

FIG. 6 is a schematic elevational view partially in section of an alternate form of driver and coupling system with the resonant system of the present invention;

FIG. 7 is a schematic elevational partially in section of a further modification of the power coupling for the present invention;

FIG. 8 is a schematic elevational view partially in section of an alternate form of sonic generator or pulser for the apparatus of the present invention;

FIG. 9 is a schematic elevational view partially in section of a further form of sonic or pulse generator for the apparatus of the present invention; and

FIG. 10 is a schematic side view of a further modification of the system of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to more fully understand the fluid resonator of the present invention, an analogy may be drawn between the resonator of the present invention and a conventional mass spring resonant system. The simple, well-known mass spring system is schematically illustrated in FIG. 1. In this system, the mass M is supported by the spring S and when set in motion oscillates between the marks or levels designated a and a_1. The spring S exerts an oppositely-directed force on the mass M proportional to its displacement from the centerline or static position marked O during each oscillation. In the fluid resonant system of the present invention a portion of a body of fluid contained in a vessel is functionally separated from the remainder of the liquid, acts as the mass of the system whereas the remainder of the liquid contained in the main body of the vessel acts somewhat as a spring. A separate chamber extending off the main vessel may be used to functionally separate this portion or mass of liquid from the main body of liquid. This chamber will

hereinafter be referred to as the mass chamber. The mass of liquid in the mass chamber serves as an inertia element in the system and moves up and down as a unit compressing the liquid in the resonator chamber during each downstroke. The liquid in the resonator chamber has sufficient compressibility to serve the function of a spring in a properly designed system. This compressibility is primarily due to the compressibility of the fluid itself but may be due in part to the compressibility of gas or air trapped therewith. Also, some incidental spring effect will normally be attributable to the elasticity of the vessel itself.

Illustrated in FIG. 2 is a preferred embodiment of the present invention. As illustrated therein a vessel **11** forms a resonator cavity or chamber **11***a* and has a cylindrical appendage or neck **12** connected thereto which forms a second chamber **12***a* having an opening communicating with the interior of the vessel or resonator cavity **11***a*. Chamber **12** serves to functionally separate the portion of liquid contained therein from the remainder of the liquid in the vessel. Inlet and outlet conduits **9** and **10** are provided through which liquid flows into and out of the vessel. These conduits preferably have external flow control means such as valves, not shown, to control the flow of fluid to and from the vessel. The vessel or resonator cavity **11***a* and the mass or inertia chamber **12***a* are designed to form a resonant system that will have a resonant frequency that is suitable for the particular liquid treatment desired. The liquid contained in chamber **12***a* is cyclically driven so as to move up and down as a unit, alternately compressing and dilating the liquid in cavity **11***a*, and alternately storing energy in this liquid and receiving energy thereform.

The resonant frequency of the system is established principally by the choice of dimensions for chamber **11** and **12**, but is influenced by the amount of gas or air dissolved in or trapped with the liquid filling the chambers, the rigidity of the vessel, the mass of the sonic energy generator **13** and the elasticity of the members supporting the sonic energy generator. The resonant frequency of the system may be adjusted by making the value of one or more of the above parameters adjustable.

We have devised numerous different apparatus which may be utilized to excite or drive the resonator of the present system at the desired frequency. These include sonic generators as well as means to couple the generator to the system.

One such apparatus as illustrated in FIG. 2 comprises a sonic or ultrasonic energy generator **13** which is coupled in any suitable manner to an elongated member **14** which extends through opening **15** and may have seal member **16**, if needed, and is connected at its other end to a coupling disc **17**. The sonic energy generator may be of any suitable type which produces a sinusoidal vibration. For example, the generator may be a rotating eccentric mass type or it may be the orbiting rotor type, both types of which are illustrated in U.S. Pat. No. 3,123,843. The disc member **17** is of slightly less diameter than the internal diameter of the mass chamber **12** providing an annular spacing therebetween. The predetermined annular spacing between disc member **17** and coupling or mass chamber **12** is selected so as to obtain the maximum transmission of power to the liquid with a minimum of friction losses and viscous damping. Furthermore, the annular spacing between disc **17** and the wall of chamber **12** is arranged to be low to provide good coupling without friction and also to allow restricted passage of liquid around the disc **17** through the annular opening (between disc **17** and wall of chamber **12**). This passage, although restricted to increase the tendency of the surrounding liquid in chamber **12** to be carried therewith it is not overrestricted so that the motion of the liquid can still move relative to it to allow the liquid vibratory motion (vertically as shown in FIG. 2) to seek its natural phase relative to that of the vibrating or oscil-

lating disc 17, a condition essential to making the mass of fluid in chamber 12 and the spring of the liquid in chamber 11 resonate as desired as described hereinbefore.

The chamber 12 can be located vertically as shown in FIG. 2 with a free liquid surface (liquid to air or some other gas) or it can be connected as at the top with more of the same liquid. For a vertical arrangement as shown in FIG. 2 with a free liquid surface, the height of liquid in chamber 12 offers an excellent means for tuning this liquid resonator. This has been set up in the laboratory and demonstrated. Changing the height of liquid in 12 changes the effective mass resonated (see FIG. 1) and thereby changes the natural frequency or tuning. Also in the latter case (with interconnected liquid) the neck or chamber 12 need not be vertical or above, but it could be below or on the side of the vessel.

The disc or cylinder, or chamber 12*a* do not have to have circular plan form but need only fit the criterion that a particular portion of the mass of the liquid must be confined or separated from the remainders to move generally together as a "plug" to serve as a mass or inertial element and that the "plunger or disc" restrict partially as discussed the flow around the plunger, but only partially, so the fluid "plug" can move about it to seek the necessary phase relation for resonance. FIG. 7 embodiment is an alternate version of the plug. These elements, generator 62, member 66, and multiple disc 68, make up a system for driving the resonant system comprising the liquid confined in resonator cavity 11*a*, serving as a spring or elastic cushion and the liquid in chamber 12*a* serving as a mass for the system. The former system may be referred to as a driving system which drives the latter, driven resonant system.

FIG. 3 illustrates an alternate means of coupling the excitation force from a sonic vibration generator to a liquid resonant system of the present invention. In this embodiment the mass chamber 18 is suitable connected to a vessel or resonator chamber (not shown). A sonic generator 19 is coupled to a rod member 20 to which is connected a flexible diaphragm 21. The flexible diaphragm 21 is connected over the end of chamber 18 by any suitable means such as by clamping between flange 22 and ring 23 which are connected together by means of bolts 24. The member 20 is supported by support bracket or cover 25 extending upward from ring 23. The diaphragm 21 contacts the upper surface of a body or mass of liquid in chamber 18 and transmits alternately directed sinusoidal forces thereto from generator 19.

In the embodiment of the driving or excitation means of FIG. 4, means are provided for changing the effective density of the fluid in the mass chamber which changes the effective mass and hence the resonant frequency of the system. In this embodiment a sonic generator 26 is coupled by means of rod member 27 to cylindrical piston means 28, sealed by means such as a ring 28*a* within cylinder 33. The rod member 27 extends through an opening 29 and is supported by sealing and vibration isolation means 30. The piston means 28 has attached thereto a container 31, the interior of which may be supplied with a fluid of predetermined density via conduit 32 which leads to suitable supply of external fluid (not shown). The container 31 becomes effectively a part of the body or mass of fluid in the cylinder or mass chamber 33. A change in the level of fluid in container 31 changes the effective density of the fluid in the mass coupling chamber and thus the effective resonance of the system of which it forms a part. Thus, this provides an alternate method of tuning the system.

FIG. 5 illustrates an alternate embodiment of the present invention comprising a pair of vessels 33 and 34 serving as resonator chambers and connected together by means of a conduit member 35 which serves or functions as a mass chamber. Suitable energy coupling means such as a piston 36 and a rod 37 serve to couple an oscillator 38 to the liquid in chamber 35*a*. This embodiment can operate in any position if the vessels 33 and 34 are closed. For example, the vessels may be positioned side by side or they may be positioned with one above another. Also, the vessels need not be the same size or shape.

In the embodiment of FIG. 6, the volume of the mass chamber may be varied, which varies the effective mass of the system which in turn varies the frequency of the system. As illustrated in FIG. 6, a variable volume mass chamber is formed which comprises a neck portion 42 into which is fitted, in sealed sliding relationship, a tubular chamber member 43. Suitable seal means such as an O-ring 44 assures a fluid-tight seal between members 42 and 43. A suitable sonic vibration generator 45 is mounted on support member 46 which is in turn supported by suitable vibration isolating means such as springs 47 and 48. The sonic vibration generator 45 is coupled by means of link member 49 to suitable energy coupling means such as disc 50. The disc 50 is sealed to the walls of the cylindrical chamber 43 by means of suitable flexible annular diaphragm means. The volume of the mass chamber may be varied by raising or lowering cylindrical chamber member 43 with respect to the cylindrical neck portion 42. Suitable adjusting means such as screw jacks 52 and 53 are provided for movement of cylindrical chamber member 43 with respect to the cylindrical neck member 42. The screw jacks comprise an elongated screw member 54 and 55, rotatably journaled in bearing means 56 and 57 and threadably engaging nut members 58 and 59. The screw members 54 and 55 are rotated by suitable means such as hand wheels 60 and 61.

In the embodiment of FIG. 7 a suitable vibration generator 62 is mounted on flexible support member 63 such as a leaf spring which in turn is supported by upright support members 64 and 65. The vibration generator 62 is connected by means of elongated link members 66 to fluid coupling means 67 which comprise but are not limited to a cylindrical member having annular disclike ribs 68 extending radially therefrom into close proximity of the internal wall of the power coupling chamber 69. The cylindrical portion of the fluid coupling means may be hollow and may be filled with a fluid of different density from the density of the fluid in the mass coupling chamber in order to vary the frequency of the system. A plurality of annular disclike ribs or rings may be utilized to provide a more effective coupling between the fluid coupling means 67 and the fluid in the mass chamber.

In FIG. 8 is illustrated a modification or an alternate embodiment of means for introducing the sonic energy into the sonic or fluid resonant system. The sonic vibrational energy in this embodiment is generated by means of a pulsing fluid. The pulsing may be intermittent or sinusoidal.

As illustrated in FIG. 8, a source of pressurized fluid 70, which fluid may be either a liquid or a gas, communicates via conduit 71 which includes a pulsing valve 72 and a pressure accumulator 73, if needed, with pressure chamber 74. The pressure chamber may be separated by means such as a diaphragm 75 from a mass chamber 76. The return conduit 77 which may contain a resistance or a restriction 78 returns the fluid back to the source. In operation of this embodiment of the invention, intermittent pulses of high-pressure fluid are injected into the pressure chamber to alternately force the diaphragm against the body of liquid contained in the mass chamber, thus forcing this liquid downward and compressing the liquid in the resonator chamber. The fluid in the pressure chamber is drained off between pulses permitting the compressed fluid in the resonator chamber to force the diaphragm 75 back to the other limit of its stroke. The diaphragm 75 may be omitted where the pulsing fluid is the same as the liquid to be treated, or mixing is not objectionable.

Illustrated in FIG. 9 is an electromechanical sonic pulse generator of the present invention. In the embodiment of FIG. 9 an electrical signal generator 79 is connected by

means of conductors **80** and **81** to an electromagnet **82**, a lever or plate **83** constructed of a magnetically responsive material pivotally mounted on support member **84** extends into a space between the electromagnet and stop means **85**. The lever **83** is connected by means of link member **85** to disc and diaphragm member **86** which is in intimate contact with the fluid in the mass chamber **88**. Energizing electromagnet **82** pulls lever **83** downward to force the liquid in the mass chamber downward to compress the liquid in the resonator chamber. The power coupling disc would be driven only toward the liquid in the mass chamber under the influence of the electromagnet and would be driven away from the fluid or in a reverse direction by the pressure of the fluid itself acting on the power coupling disc. Means may be provided, such as spring **89**, for returning lever **83** and disc **87** to the uppermost position.

In FIG. 10 is illustrated a further system embodying the principles of the present invention in which a conventional processing vessel **92** is provided with suitable openings **93**, **94**, **95**, and **96** to which are connected suitable flow lines not shown for the introduction and removal of liquids and other materials to be mixed or treated. Oscillator **97** is operatively coupled by means of a rod **98** through a disc **99**, positioned near the center of the vessel **92**, dividing the vessel into a pair of chambers **100** and **101**. The connecting rod **98** extends through openings **102** and **103** and are supported therein by suitable bearings and seal means **104** and **105**. The disc **99** serves to functionally separate an annular portion of liquid indicated by numeral **106** from the remainder of the liquid in the vessel. This annular portion of liquid serves as the mass or inertia element in the system and is activated or set in motion to reciprocably vibrate back and forth, under the influence of a movement of disc member **99**, and alternately compress and release the liquid contained in chambers **100** and **101**.

It should be pointed out here that the couplings are of two basic types. These may be referred to as either loose type or rigid type. The loose type couplings (e.g., FIGS. 2, 7 and 10) substantially isolate the mass of the oscillator from the inertial mass of the system. On the other hand the more rigid type coupling, such as a piston (FIGS. 4 and 5) or a diaphragm (FIGS. 3, 6 and 9) would provide a more positive coupling of the oscillator to the liquid serving as the inertial mass of the system. With the more positive type coupling, the mass of the oscillator and coupling means must be taken into consideration as a portion of the inertial mass of the system.

While the present invention has been described with reference to specific illustrated embodiments, it will be apparent to those with skill in the art that changes may be made in the methods and apparatus described without departing from the scope of the present invention as defined in the appended claims.

We claim as our invention:

1. A system for resonantly transmitting sonic energy at uniform pressures throughout a body of liquid comprising:

a vessel forming a compressive resonator chamber for containing a body of liquid to be cyclically compressed so as to function as a spring;

a mass chamber communicating with the interior of said vessel for containing a mass of liquid to function as a mass to oscillate against said body of liquid;

said mass chamber and said vessel being at least partially filled with liquid;

sonic energy coupling means in energy transmitting engagement with the mass of liquid in said mass chamber; and

sonic energy generating means in operative engagement with said sonic-energy coupling means for transmitting sonic energy to said mass of liquid to move said mass against said body of liquid within a resonant frequency range that is determined by the mass and spring of said system.

2. The system of claim **1** wherein:

said energy transmitting means comprises a substantially circular disc having at least one side thereof in contact with the liquid in said mass chamber.

3. The system of claim **2** wherein:

said disc is of a diameter that is slightly less than the internal diameter of the energy coupling chamber.

4. The system of claim **1** wherein:

said energy transmitting means comprises a diaphragm having one surface thereof in contact with said body of liquid.

5. The apparatus of claim **1** wherein:

said sonic energy generating means comprises a pulsing fluid.

6. A method of sonically treating a body of liquid, said method comprising the steps of:

confining said body of liquid in a vessel to function as a mass and compressive spring resonant system;

separating a portion of said body of liquid to function as a mass from the remainder of said body of liquid which functions as a spring; and

inducing said portion of said liquid to move en masse relative to the remainder of said liquid whereby said portion of liquid functions as a mass and said remainder of said liquid functions as a spring as in a resonantly vibrating mass and spring system.

7. A system for transmitting sonic energy throughout a body of liquid comprising:

a vessel forming a resonator chamber for containing a body of liquid;

a mass chamber communicating with the interior of said vessel;

said mass chamber and said vessel being at least partially filled with a body of liquid;

means to change the effective mass of the fluid in said mass chamber;

sonic energy coupling means in energy transmitting engagement with the portion of liquid in said mass chamber; and

sonic energy generating means in operative engagement with said sonic-energy coupling means for transmitting sonic energy to said body of liquid within a desired frequency range.

8. A system for the sonic treatment of a liquid, said system comprising:

a vessel for containing a body of liquid;

separation means for separating said vessel into a plurality of resonator chambers and forming a chamber extending between said resonator chambers to functionally separate a portion of said body of liquid from the remainder of said body of liquid;

a sonic vibration generator; and

coupling means operatively coupling said generator to said portion of said body of liquid.

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ROBERT W. JENKINS, Primary Examiner

U.S. Cl. X.R.

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