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ULTRASONIC PUMPS

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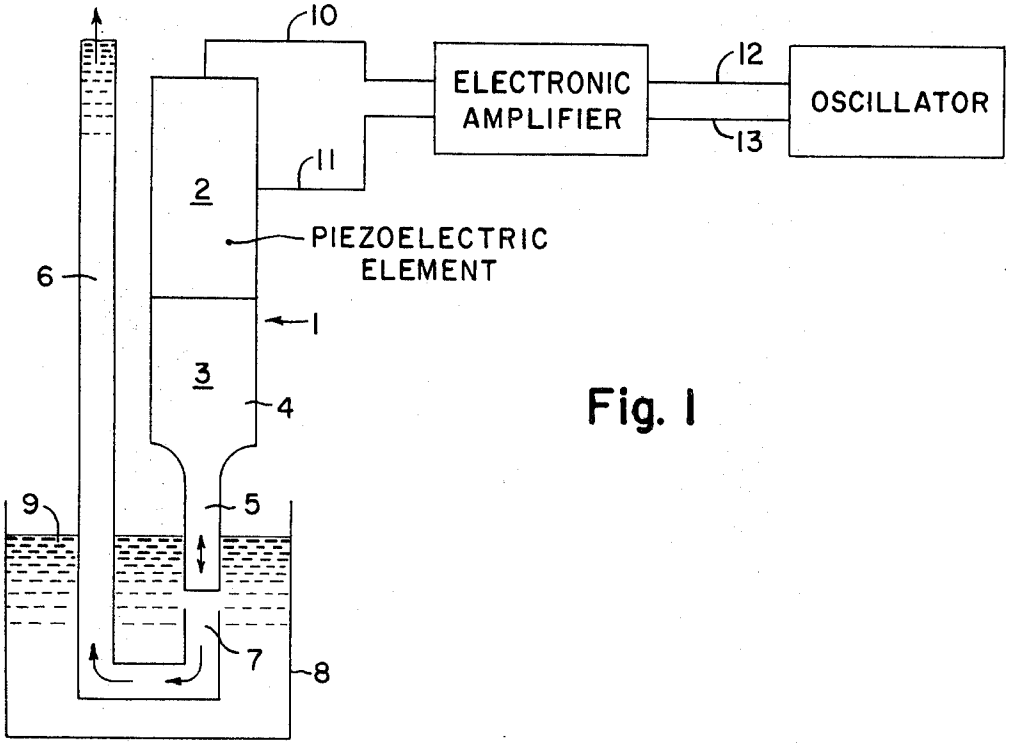

Fig. 1

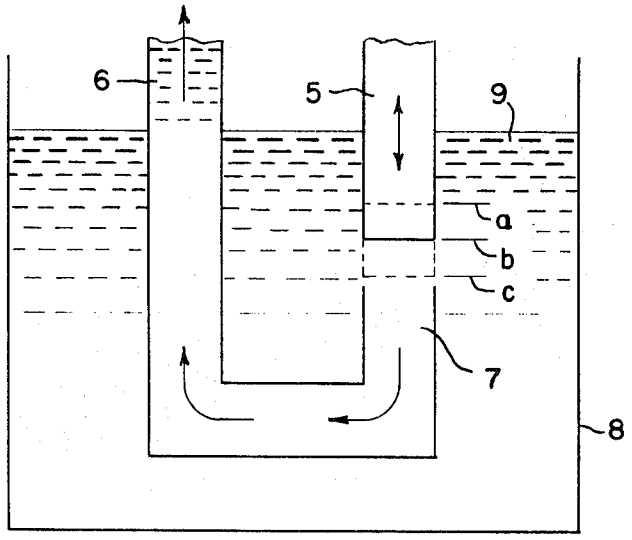

Fig. 2

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ULTRASONIC PUMPS

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ABSTRACT OF THE DISCLOSURE

A pump for ultrasonically pumping liquids has a stepped ultrasonic resonator, a conduit and means to vibrate the resonator. The tip of the resonator is submerged in the liquid to be pumped, wherein the tip is disposed adjacent to and facing the open mouth of the conduit through which the liquid is to be pumped. The vibrating tip of the resonator forces the liquid into the mouth of the conduit. A succession of impulses, caused by the vibrating tip, pumps the liquid through the conduit.

BACKGROUND OF THE INVENTION

The majority of the prior art pumps, for example, reciprocating piston pumps and rotary pumps, rely for their operation upon a plurality of mechanically moving elements that are expensive to manufacture and to maintain in operating condition, as well as creating a great deal of noise. Accordingly, there has been a long felt need for a pump that is substantially free of mechanically moving parts and is silent in operation.

Pumping devices which are actuated electrically and do not have relatively movable parts are disclosed in U.S. Pat. No. 2,317,166, granted Apr. 20, 1943 to Abrams and U.S. Pat. No. 3,150,592, granted Sept. 29, 1964, to Stec, Abrams teaches the use of a chamber having a magnetostrictive element which causes the chamber to contract and expand in response to a variation in a magnetic field in which the magnetostrictive element is disposed, thereby causing the chamber, by varying the capacity of the chamber, to act as a pump. Stec teaches the use of an inner sphere formed of a piezoelectric material and positioned in an outer sphere. When the voltage applied to the surface of the inner sphere is periodically reversed, alternate radial expansion and contraction of the inner sphere occurs, while the outer sphere remains fixed in size, thereby causing the pump space between the inner and outer sphere to contract and expand, and thus providing a pumping action.

As stated above, the usual manner for these electrical devices to pump liquids is to utilize the dimensional change characteristics of a material as a volume changing element to provide the pumping action of the device.

A stepped ultrasonic resonator, similar to the resonator of this invention, is disclosed in U.S. Reissue Pat. No. 25,033, granted Aug. 29, 1961 to Balamuth et al. The resonator of Balamuth et al. is used for ultrasonic machining of materials, that is, for cutting, grinding, boring or otherwise altering the configuration of materials by means of a tool vibrated at ultrasonic frequencies.

SUMMARY OF THE INVENTION

This invention relates to a fluid pump, and more particularly to a pump that utilizes an ultrasonic resonator as the pumping element to force the fluid into and through a conduit. The vibrating tip of the resonator, facing the open mouth of the conduit, sets up a succession of impulses occurring at high frequencies, which enables the resonator to pump the fluid through the conduit. The ultrasonic cavitation also cleans the mouth of the conduit to maintain the proper operation of the pump.

Accordingly, an object of the present invention is to provide a device for pumping or delivering increments of the fluid by means of an ultrasonic resonator to overcome the disadvantages of the prior art pumping devices.

Another object of this invention is to provide a pumping device which is extremely simple and includes no parts which can get out of order through operation or continued use, whereby the pump can be readily produced and maintained with relatively little expense.

A further object of this invention is to provide a pump that is free of mechanically moving parts which require close machining or adjustment to obtain proper operation, whereby in the present invention the factor of wear is virtually eliminated, thereby reducing the maintenance problems arising from wear, breakage and noise such as are present in the moving parts of conventional prior art pumps.

An added object of this invention is to provide a pump that cleans its own inlet by cavitation, thereby eliminating the clogging of valves when pumping impure or corrosive liquids, which has always been a problem of the prior art pumping devices.

BRIEF DESCRIPTION OF THE DRAWINGS

Having in mind the above and other objects that will be evident from an understanding of this disclosure, the invention comprises the devices, combinations and arrangements of parts as illustrated in the presently preferred embodiment of the invention which is hereinafter set forth in such detail as to enable those skilled in the art readily to understand the function, operation, construction and advantages of it, when read in conjunction with the accompanying drawings in which:

FIG. 1 illustrates diagramatically the essential elements incorporated in the pump of the present invention;

FIG. 2 illustrates diagrammatically an enlarged view of the region where the pumping action of the present invention occurs.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, the ultrasonic resonator **1**, hereafter called a horn, has a cylindrical body and is formed with a piezoelectric element **2** on one end and a stepped member **3** having a body portion **4** and a tip portion **5** on the other end. The piezoelectric element **2** is bonded to the body portion **4** with each part having the same diameter, where the tip portion **5** has a reduced diameter. The horn **1** may be made in any suitable shape which has the cross-section of tip portion **5** smaller than the cross-section of body portion **4**, where the cylindrical body is the preferred shape.

The horn **1** is positioned above a container **8** so that the free end of tip portion **5** is immersed in a liquid **9** being held in the container **8**. The means for holding the horn **1** in the above position do not form an essential part of the present invention, and therefore have not been shown, whereby such holding means are well known in the art as disclosed in U.S. Reissue Pat. 25,033 to Balamuth et al. For example, one method of holding the horn **1** would be to constrain the horn radially near a vibration nodal plane. A ring bolted on a support and lying in the nodal plane would surround the horn, whereby three nylon tipped set screws radially threaded through the ring and spaced 120° apart would engage the horn **1** at the nodal plane to provide the holding force. Usually, a vibration nodal plane is located at the stepped portion between the body portion **4** and the tip portion **5**, where the length of the tip portion **5** is equal to one-fourth of the wavelength of the vibration created along the length of horn **1**, with a vibration antinode occurring at the free end of the tip portion **5**.

A conduit 6, in the form of a tube or a pipe, has one end submerged in the liquid 9. The open mouth of conduit portion 7 is disposed adjacent to and facing the free end of tip portion 5. As shown in FIGS. 1 and 2, the tip portion 5 is spaced from and vertically positioned above the open mouth of conduit portion 7. If desired, the entire horn 1 may be submerged, whereby the relative position between the tip portion 5 and the open mouth of conduit portion 7 should be maintained by suitable holding means as stated above. If the entire horn 1 is submerged, it is understood that any electrical components of the horn 1 would have to be shielded from electrical conductive or corrosive liquids, which could be done by any one of numerous protective means well known in the art. For example, the electrical components could be enclosed in a liquid tight stainless steel housing, wherein the housing would be attached to the horn 1 at a vibration nodal plane.

As is well known in the art, certain piezoelectric materials such as for example quartz crystals, rochelle salt, barium titanate and compounds of barium titanate have piezoelectric properties. Many of these materials are adapted to be formed into configurations whose opposite faces can be or are polarized with respect to one another. When a piezoelectric material is so polarized and has a voltage applied to its faces, the material will change shape and/or dimension. It is this latter phenomenon that is taken advantage of in the instant invention. As shown in FIG. 1, a conventional oscillator and a conventional electronic amplifier are connected to the piezoelectric element 2 by electrical means 10, 11, 12, and 13 to regulate the ultrasonic frequency and voltage, respectively, to apply a varying voltage which causes the piezoelectric element 2 to vertically expand and contract with respect to its normal condition or dimensions when no voltage is applied.

The vertical expanding and contracting of the piezoelectric element 2 causes the stepped member 3, which is bonded thereto, to move up and down whereby a very high acceleration is produced at the free end of the tip portion 5 of the horn 1. As shown in FIG. 2, position *b* indicates the location of the tip portion 5 with no electrical power applied to the horn 1. When the electrical power is applied to the piezoelectric element 2, the tip portion 5 moves vertically back and forth from position *a* to position *c*. The acceleration of the tip portion 5 is many times greater than gravity, perhaps a million times greater, wherein this phenomena is used to pump liquids in the present invention.

The basic method of pumping of this invention is a ramming motion of the tip portion 5 of the horn 1 against the liquid 9 which forces the liquid 9 into the open mouth of conduit portion 7. The inertia of the liquid in the conduit 6 after it is given an impulse by the tip portion 5 of the horn 1 is sufficient enough to keep it from returning until the liquid is struck again. This succession of impulses, occurring at high frequencies, enables the horn 1 to pump the liquid 9 up the conduit 6, where it is understood that the acceleration of the tip portion 5 must be greater than gravity.

On half of the cycle of the tip portion 5, that is the forward thrust of the tip portion 5 from position *a* to position *c*, the liquid 9 is forced into the open mouth of conduit portion 7. Because the liquid 9 is basically incompressable, the collision between the liquid 9 and the tip portion 5 may be considered perfectly elastic. Therefore, the time during which the tip portion 5 acts on the liquid 9 is one fourth of the cycle, or one half of the forward stroke. After this time the tip portion 5 begins to decelerate while the liquid 9 continues to move forward at essentially the same speed. Because of the high deceleration of the tip portion 5, the tip portion 5 stops at position *c*.

On the other half cycle, the tip portion 5 withdraws from position *c* to position *a* creating a cavity in the liquid 9 that is essentially at zero pressure, or at most, the vapor pressure of the liquid 9. The pressure drop across the liquid 9 to the cavity, forces the liquid 9 into the cavity. On the next forward thrust, the liquid 9 in the cavity is rammed into the conduit 6.

The momentum imparted to the liquid 9 on the forward thrust causes the liquid 9 to continue up the conduit 6. The acceleration of the liquid 9 tends to be reduced due to the gravity acting on the liquid column of the conduit 6. But, because of the great acceleration of the tip portion 5, the liquid 9 in the conduit 6 does not have time to flow back down into the cavity before it is again rammed by the following pumping cycle. This action occurs over and over again at the repetition rate of the horn 1.

A pump based on the cavitation-inertia phenomena of this invention and arranged as shown in FIG. 1 was able to produce a flow rate of 650 cc./min. of water at a pressure head of one foot, which is a height of one foot in conduit 6 above the surface level of the liquid 9 in the container 8, wherein the surface level is called the supply level. The same pump was able to raise the water to a height of more than six feet above the supply level. The pump had a metal stepped member 3 and a crystal piezoelectric element 2. The body portion 4 and the crystal diameter was 1½ inches, wherein the tip portion 5 had a ⅜ inch diameter. Tubing of ⅛ inch diameter was used for the conduit 6. The repetition rate of the tip portion 5 was 20.5 kilocycles per second.

The distance of the free end of the tip portion 5 below the liquid surface in the container 8 affects the flow rate. If the free end is too near the liquid surface, a large amount of the energy from the horn 1 goes into increased surface activity. This was avoided in the above pump by keeping the free end of the tip portion 5 at least 1½ inches below the water surface.

The distance between the free end of the tip portion 5 and the open mouth of the conduit portion 7 is also critical to the operation of the pump. Too large a separation distance gives a very small flow rate and a low pressure head, whereby the liquid displaced by the free end of the tip portion 5 is not directed into the open mouth of the conduit portion 7 but is dissipated throughout the surroundings. As the separation distance is decreased, the flow rate increases to a maximum rate, with the pressure head increasing steadily. Too small a separation distance gives a much smaller flow rate than the maximum, but a high pressure head is obtained, whereby at a close position the liquid can not enter the open mouth of the conduit portion 7 at a fast enough rate to allow a large flow rate. It is also possible that at close positions the sound waves, and therefore the energy, are not focused correctly into the mouth of the conduit portion 7 to facilitate large flow rates, even though there is good energy coupling which shows itself in higher pressure heads, however a significantly long time is required to achieve these higher pressure heads. The optimum separation distance for the above pump was about 1/16 inch, which gave the largest flow rate.

It is interesting to note that performance is obtained from the pump only when the diameter of the free end of the tip portion 5 is at least as large as or larger than the diameter of the open mouth of the conduit portion 7. Also, the selected resonant frequency of the horn 1 has a larger effect on the performance of the pump than does the selected power input.

It is also noted that the pump need not be only vertically positioned, but can be oriented in any position so long as the relative position between the tip portion 5 and the open mouth of conduit portion 7 remains unchanged. However, any change in the orientation of the pump may affect the flow rate and the pressure head. As mentioned above, the spacing between the tip portion 5 and the open mouth of conduit portion 7, the orientation of the pump, the resonant frequency of the horn 1, and the power input affect the flow rate and the pressure head, and therefore

each of these means can be used to control the flow rate and the pressure head.

One of the most striking characteristics of the pump is its quick response time. For example, once a pressure head of four feet is established for normal operation of the pump, the power to the unit is cut off. When the same power is again turned on, the liquid initially at rest will shoot back up to the four foot mark in a matter of a second, provided all settings and adjustments remained unchanged.

Many advantages come from the inherent simplicity of the pump of the present invention. The horn is used as the driving force in the pump. There are no mechanically moving valves which have been causing problems in conventional pumps up to the present day. The factor of wear is virtually eliminated. Clogging of valves when pumping impure or corrosive liquids has always been a problem, but this ultrasonic pump cleans its own inlet by cavitation. This pump could also be used to simultaneously mix and pump liquids.

Numerous alterations of the structure herein disclosed will suggest themselves to those skilled in the art. However, it is to be understood that the present disclosure relates to a preferred embodiment of my invention which is for purposes of illustration only and not to be construed as a limitation of the invention.

Having thus set forth the nature of the invention, what we claim herein is:

1. A method of pumping a liquid comprising the steps of immersing an open end of a conduit in a body of liquid, immersing a tip portion of a member in said body of liquid, maintaining a submerged free end of said tip portion in spaced relation to said open end, and vibrating said member at an ultrasonic frequency toward and away from the open end of said conduit between a first position adjacent to but spaced from the open end of the conduit and a second position wherein the tip portion is spaced a greater distance from the conduit, whereby the tip portion forces the liquid into said open end to pump the liquid through said conduit.

2. A method of pumping a liquid according to claim 1 wherein said steps include forming a substantially flat surface on said free end of said tip portion and arranging said flat surface facing towards said open end of said conduit.

3. A pump comprising a conduit having an open end, a member having a tip portion positioned in spaced relation to said open end, and means to reciprocate the tip portion of said member at an ultrasonic frequency toward and away from the open end of said conduit, said reciprocating tip portion having a first position adjacent to but spaced from the open end of the conduit and a second position wherein the tip portion is spaced a greater distance from the conduit so that when said open end and said tip portion are submerged in a body of liquid, said tip portion will force the liquid into said open end and pump the liquid through said conduit.

4. A pump according to claim 3, wherein a free end of said tip portion is formed with a substantially flat surface which faces toward said open end of said conduit.

5. A pump according to claim 3, wherein said tip portion and said conduit are cylindrical, and the diameter of a free end of said tip portion is at least as large as the diameter of said open end of said conduit.

6. A pump according to claim 3, wherein said member is stepped along its longitudinal length with said tip portion having the smallest cross section and the means to vibrate said member at an ultrasonic frequency being connected remote from said tip portion.

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U.S. Cl. X.R.

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