

[54] **STANDING WAVE PUMP**

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[58] Field of Search **331/176; 417/53, 417/240, 241, 322, 437, 557**

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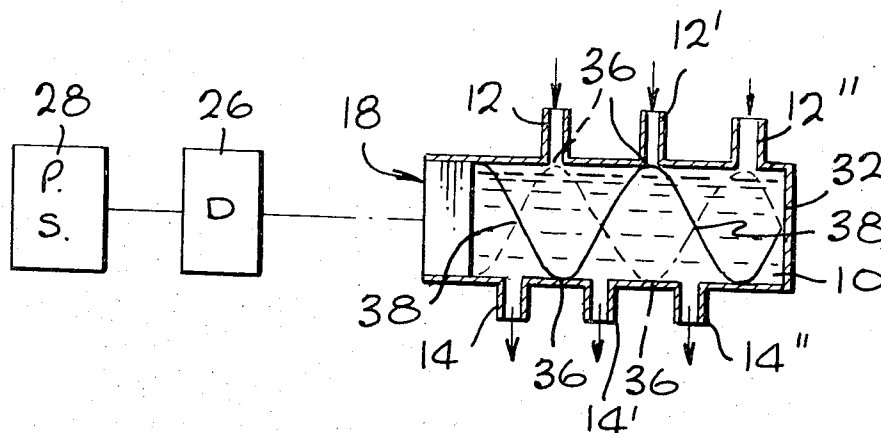
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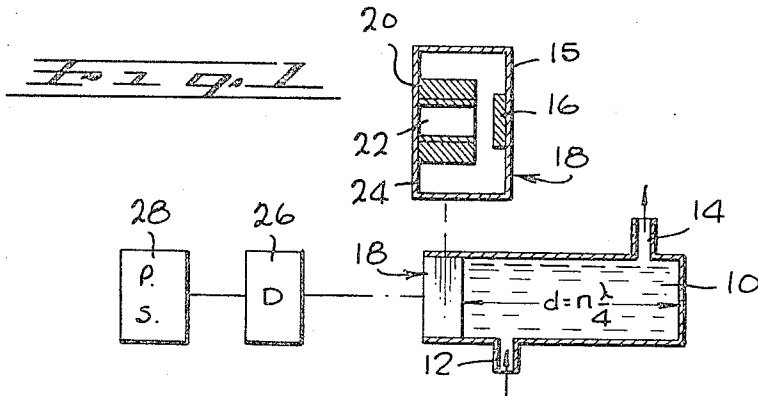
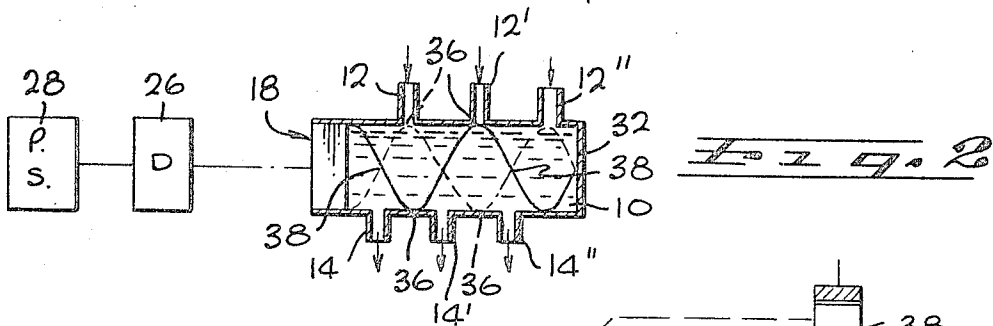
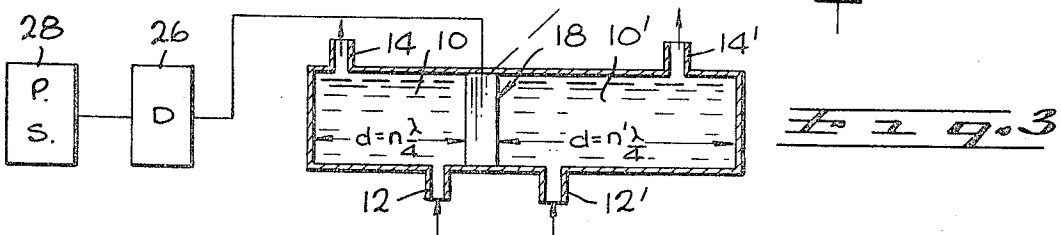
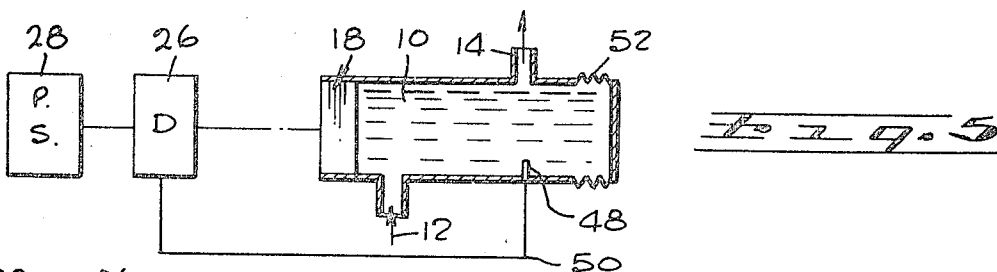
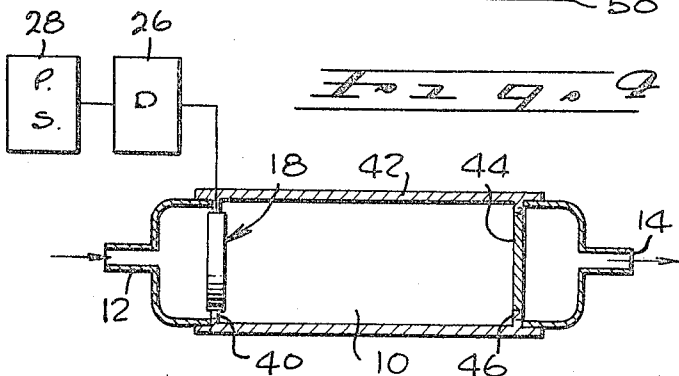
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[57] **ABSTRACT**

An efficient fluid pump which has a chamber for receiving the fluid to be pumped and a transducer for establishing a travelling wave in the fluid. The length of the chamber and the frequency of the transducer are adjusted so that a standing wave pattern is set up in the fluid having one or more pressure nodes and one or more pressure antinodes in it. At least one entrance port is provided in the chamber at the pressure nodes and at least one exit port is provided in the chamber at the pressure antinodes so that fluid will be drawn into the cylinder at the pressure node and will be forced out of the cylinder at the pressure antinode to achieve a pumping action.

8 Claims, 5 Drawing Figures





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STANDING WAVE PUMP

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus for pumping fluids.

2. Description of the Prior Art

The art of pumping fluids so that they may be transported from one place to another is extremely old, starting with such pumping devices as the water wheel and the Archimedes screw. More recently there have been developed reciprocating pumps of the type comprising an enclosure or chamber communicating through intake valves with a source of fluid under an initial pressure and through delivery valves with a space constituting a receiver for a fluid under a final pressure, the chamber including a movable wall to which a reciprocating movement is imparted to expand the capacity of it to fill it through the intake valves and then to contract the capacity and to evacuate it through the delivery valves. Many other variations on this technique of providing a chamber which is expanded to receive fluid and then contracted to force it out through the delivery valves have been devised, such as providing the pumping action by means of a flexible membrane to change the configuration of the chamber, a flexible tube which allows the fluid to enter and then squeezes it out, and a two-chamber system separated by a diaphragm in which an actuating fluid in the first chamber means causes the diaphragm to periodically pulsate and to displace a portion of the actuated fluid from the second chamber means. In a somewhat different form of pumping device, a diaphragm is actuated to cause a flow of fluid to be pumped across the throat of an orifice and thus to establish a zone of low pressure; due to this venturi effect, a fluid is pumped through the throat into the main body of the system and then is ultimately forced out of the system to achieve a pumping action.

As can be seen from the construction and operation of these prior art devices, these devices are subject to mechanical failure and fatigue where reciprocating pistons and valves or flexible diaphragms are used to draw fluid into a chamber and to force it out of the chamber and suffer from a low efficiency due to the amount of power required to operate the moving pistons, diaphragms and valves to achieve the pumping action and due to the presence of the unpumped or residual volume left in the pumping chamber at the end of the compression stroke. In addition, the pump system utilizing the venturi effect necessitates a very fast flow of a large bulk of fluid across the throat in order to achieve a satisfactory zone of low pressure and thus causes a large amount of strain and fatigue on the pumping diaphragm and the damping diaphragm used in the construction of the pump, along with a large amount of power input for a relatively small flow of output fluid.

OBJECTS AND SUMMARY OF THE INVENTION

The principal object of the present invention is to provide a new and improved pump for pumping fluids which avoids the pumping deficiencies of the prior art apparatus.

A more specific object of the invention is to provide a pump in which the moving elements are not utilized to provide a pumping pressure to the fluid to be pumped.

Another object of the invention is to provide a pump which has a high efficiency of operation.

A further object of the invention is to provide a pump in which the pumping pressure is provided by a nearly motionless actuating fluid.

In accordance with one embodiment of the present invention, a pump is provided which has a cylindrical chamber having as one end wall a fluctuating diaphragm. The diaphragm is caused to oscillate at a preselected frequency by means of a power supply and driver to set up a travelling wave in the fluid in the chamber. The frequency of oscillation of the diaphragm and length of the chamber are configured that the chamber is a resonant chamber and thus a standing wave is set up in the fluid having a pressure antinode or node at the wall opposite the diaphragm and a series of pressure nodes and pressure antinodes spaced along the length of the chamber, the particular number depending upon the length of the chamber and the frequency of vibration of the diaphragm. An entrance port is located in the chamber at one of the pressure nodes and an exit port is located in the chamber at one of the pressure antinodes. Due to the pressure differential between the pressure node and the pressure antinode, fluid outside the chamber at the pressure node will be forced into the chamber and fluid outside the chamber at the pressure antinode will be forced out, thus achieving a pumping action.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partly schematic, partly sectional view of a pumping device embodying the novel features of the invention;

FIG. 2 illustrates a second embodiment of the invention showing more fully the principles of the pumping action;

FIG. 3 illustrates a third embodiment of the present invention;

FIG. 4 illustrates a fourth embodiment of the present invention;

FIG. 5 illustrates another embodiment of the invention in which the high efficiency of the pump is maintained.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, an embodiment of the present invention is illustrated. A chamber 10 is provided which has an entrance port 12 and an exit port 14 whose positions are determined, as explained more fully hereafter, by the location of the pressure nodes and antinodes of a standing wave generated in the chamber 10. Forming one wall of the chamber 10 is a transducer element 18 comprising a flexible diaphragm 15 which has a magnetic slug 16 attached thereto, a coil 20 and a core 22 attached to the opposite wall 24 of the transducer 18. The coil 20 of the transducer 18 is energized by a driver 26, such as an oscillating circuit, which in turn is energized by a power supply 28.

In operation, the driver 26 causes the coil 20 to be cyclically energized at a predetermined frequency and thus causes the diaphragm 15, by means of the coil's

attraction on the magnetic slug 16, to vibrate at such preselected frequency and to cause a travelling wave to be generated in the fluid in the chamber 10. If the length of the chamber 10 is made to be equal to an integer times the wave length of the travelling wave in the fluid divided by 4, i.e. $n\lambda/4$, the chamber 10 will act as a resonant cavity and will have a standing wave pattern set up in it. As is well known, the wave length of the wave in the fluid is equal to the velocity of the wave in the fluid divided by the frequency of the wave pattern. Thus if the fluid is water and the diaphragm 15 is excited by a five thousand cycle signal, the minimum length of the chamber 10, that is the wave length divided by 4, would be 0.246 feet since the velocity of a 5,000-cycle wave in water under standard conditions is 4,920 feet per second. If the frequency of excitation were reduced to 1,000 cycles per second, then the length of the chamber 10 would be 1.23 feet. If, on the other hand, the fluid in the chamber 10 were air, then for a 1,000-cycle excitation signal, the minimum length of the chamber would be 0.28 feet since the velocity of the wave in air under standard conditions is 1,130 feet per second.

The placement of the entrance port 12 and the exit port 14 in relation to the operation of the invention is best illustrated with reference to FIG. 2. When the transducer 18 is excited by the driver 26, it causes an initial wave, shown by the solid line, to travel in the fluid in the chamber 10. When this wave hits the far wall 32 of the chamber 10 it is reflected back, shown by the dashed wave, 180° out of phase with the initial wave. If the chamber 10 has been configured so as to be an integral number of quarter wavelengths long, the reflected wave, when it reaches the diaphragm wall 15, will be reflected 180° out of phase and thus coincident with the initial wave. In addition, the reflected wave will be reinforced by the motion of the diaphragm since it is in synchronization therewith. Thus a standing wave pattern, as shown in FIG. 2, is set up in the chamber 10 which has a displacement node or a pressure antinode at the end wall 32, a pressure node or displacement antinode at the diaphragm 15 and a series of such nodes and antinodes between the two end walls of the chamber. Since the pressure nodes, indicated by the numeral 36, are points of minimum pressure in the fluid, a series of entrance ports 12, 12', 12'' are placed in the wall of the chamber 10 at such pressure nodes, while since the pressure antinodes, indicated by the numeral 38, are points of maximum pressure in the fluid, a series of exit ports 14, 14', 14'', are placed in the wall of the chamber 10 at such pressure antinodes. Thus, when the fluid in the chamber 10 is excited by the action of the transducer 18 and a standing wave pattern is set up therein consisting of pressure nodes and antinodes, the fluid immediately outside the chamber 10 at the entrance ports 12, 12', 12'' will be drawn into the chamber 10 and the fluid inside the chamber 10 at the exit ports 14, 14', 14'' will be forced out of the chamber 10 due to the pressure differentials at the pressure nodes and the pressure antinodes. Thus the apparatus shown in FIGS. 1 and 2 produces a pumping action due to the differential pressure in the fluid in the chamber 10.

In FIG. 3 a third embodiment of the invention is shown. In this embodiment there are two chambers 10 and 10' having entrance ports 12 and 12' and exit ports 14 and 14'. The two chambers 10 and 10' are separated by a transducer 18 excited by driver 26, which trans-

ducer 18 is in this particular instance shown as a piezoelectric crystal. Upon receiving alternating voltages from the driver 26, the piezoelectric crystal alternately expands and contracts to cause standing travelling and then standing waves to exist in the chambers 10 and 10'. As should be noted from FIG. 3, the chambers 10 and 10' are of unequal length but with each one being an integral number of quarter wavelengths in overall length. In this particular embodiment, the piezoelectric crystal is in a loaded condition and acts with greater efficiency to pump the fluid in chambers 10 and 10'. In addition, chambers 10 and 10' could originally have been formed as a single chamber with the piezoelectric crystal being inserted at any point therein to effect a separation of chambers, as long as the length of each of the chambers remains an integral number of quarter wavelengths in length. The standing wave patterns on either side of the transducer 18 may be in phase or out of phase with each other depending on the operation of the transducer 18.

In FIG. 4 a fourth embodiment of the invention is shown. In this embodiment one wall of the chamber 10 is formed by the transducer 18 supported by a webbing 40 coupled to the outer wall 42 of the chamber 10, while the opposite wall of the chamber 10 is formed by an end plate 44 supported by a webbing 46 coupled to the outer wall 42 of the chamber 10. The entrance port 12 in this configuration is formed between the transducer 18 and the outer wall 42 of the chamber 10 and the exit port 14 is formed in a similar manner between the end plate 44 and the outer wall 42 of the chamber 10. The electrical coupling between the driver 26 and the transducer 18 is achieved through a hollowed out portion of the webbing 40.

It should be noted that in FIGS. 1 to 3 the transducer need not be a diaphragm or a piezoelectric crystal, but may be a series of magnets or coils driven to produce a wave in the chamber by magneto hydrodynamic forces and that in such case the end walls could be identical with the transducer operating through or as a part of the outer wall 42 of the chamber 10. Thus the fluid itself in the chamber 10 would act as a diaphragm. In addition, while it may be preferable to have the chamber 10 an exact number of quarter wavelengths in length, nonetheless by the introduction of reactive elements into the chamber 10, such as a deformation or bulge in the outer wall 42, or a side chamber connected to the outer wall 42, the actual length of the chamber 10 may be shorter or longer than the effective length of the chamber 10 which is kept at an integral number of quarter wavelengths in length.

Since the efficient operation of the pump requires that it be operated in a resonant condition, it is necessary that the length of the chamber 10 be maintained at an integral number of quarter wavelengths independent of the velocity of the wave in the fluid in the chamber 10. Thus, since the velocity of the wave in the fluid is temperature dependent, the embodiment shown in FIG. 5 illustrates the use of a temperature sensor 48 which has a feedback path 50 coupled to the driver 26. The temperature sensor 48 may, for example, be a thermocouple which sends back a voltage dependent on the temperature of the fluid, which voltage serves to vary the frequency output of the driver 26 and thus to alter the frequency of the wave in the fluid such that the chamber 10 remains an integral number of quarter wavelengths in length. As an alternative to using such

a temperature sensor, the chamber 10 shown in FIG. 5 has also provided therein a bellows-type section 52 which serves to expand and contract depending on the temperature of the fluid in the chamber 10. In this manner as the velocity of the wave in the fluid changes due to temperature changes, so does the length of the chamber so as to keep the length of the chamber an integral number of quarter wavelengths in length for a fixed frequency of excitation of the transducer 18 by the driver 26.

In lieu of either of the above methods for maintaining the pump in a resonant condition, the chamber 10 itself may be used as the frequency determining element in an oscillator circuit. In this embodiment a voltage generated by a crystal oscillator circuit is applied to a piezoelectric crystal which is part of such circuit and which forms one wall of the chamber 10, as in FIGS. 1 or 3. The deformation of the crystal, which is acoustically coupled to the fluid in the chamber 10, causes a wave to be propagated the length of the chamber 10 and to be reflected back to the crystal. The amount of time required for the wave to return to the crystal automatically determines the resonant frequency of the chamber 10, and the presence of the return wave front at the crystal causes a positive feedback therefrom which is used, as in any standard oscillator circuit, to excite the crystal oscillator circuit to reinforce the original wave. In this manner then the entire system behaves as an oscillator circuit with the chamber 10 acting as the frequency determining element. If the length of chamber 10 changes or the temperature of the fluid, and thus the velocity of propagation of the wave, changes, the frequency of the wave automatically changes to keep the chamber 10 in a resonant condition. A loosely coupled frequency ranging element may be coupled to the system to limit its operation to the fundamental frequency or the desired harmonic.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art. Thus, for example, chamber 10 could be excited from both ends thereof by a pair of synchronized transducers in order to obtain a greater pressure differential in the nodes and antinodes. In addition, if the fluid to be pumped is air, one end of the chamber 10 could be left open with the chamber 10 then being an integral number of half wavelengths in length. If desired the chamber 10 could be closed at both ends and still be an integral number of half wavelengths in length with an entrance or exit port being provided in the center and exit or entrance ports being provided at either or both ends thereof. Finally the chamber 10 need not be tubular so long as it is resonant in some mode with the shape and position of the entrance and exit ports being determined by the position of the nodes and antinodes of the resonant chamber. Consequently, it is intended that the claims be interpreted to cover such modifications, variations, and equivalents.

What is claimed is:

1. A pump comprising:

a chamber for receiving a fluid to be pumped; driver means, including transducer means, for establishing travelling waves in said fluid in said chamber, said transducer means being positioned within said chamber to create travelling waves on both sides of said transducer;

means including said driver means and said chamber for converting said travelling waves to standing wave patterns in said fluid in said chamber on both sides of said transducer having one or more pressure nodes and one or more pressure antinodes therein;

at least one entrance port in said chamber at said pressure nodes; and

at least one exit port in said chamber at said pressure antinodes.

2. The pump of claim 1 wherein entrance and exit ports are positioned in said chamber on both sides of said transducer means.

3. A pump comprising:

a chamber for receiving a fluid to be pumped;

driver means for establishing a travelling wave in said fluid in said chamber;

means including said driver means and said chamber for converting said travelling wave to a standing wave pattern in said fluid in said chamber having one or more pressure nodes and one or more pressure antinodes therein, said chamber, said driver means and said aforesaid means forming an oscillator circuit and said travelling wave generating a positive feedback in said oscillator circuit to adjust the frequency of said driver means at the resonant frequency of said chamber;

at least one entrance port in said chamber at said pressure nodes; and

at least one exit port in said chamber at said pressure antinodes.

4. A pump comprising:

a chamber for receiving a fluid to be pumped;

driver means for establishing a travelling wave in said fluid in said chamber;

means including said driver means and said chamber for converting said travelling wave to a standing wave pattern in said fluid in said chamber having one or more pressure nodes and one or more pressure antinodes therein;

at least one entrance port in said chamber at said pressure nodes, said entrance port comprising a valveless opening in said chamber; and

at least one exit port in said chamber at said pressure antinodes.

5. The pump of claim 4 wherein said driver means includes a pair of synchronized transducers each one positioned at one end of said chamber to obtain a greater pressure differential in said nodes and antinodes.

6. The pump of claim 4 wherein said chamber includes a bellows-type section operable to expand and contract with temperature variations.

7. The pump of claim 4 wherein said driver means includes a transducer and said transducer is supported by a webbing coupled to the sides of said chamber, said entrance or exit port being formed between said transducer and said chamber sides.

8. A pump comprising:

a chamber for receiving a fluid to be pumped;

driver means for establishing a travelling wave in said fluid in said chamber;

means including said driver means and said chamber for converting said travelling wave to a standing wave pattern in said fluid in said chamber having one or more pressure nodes and one or more pressure antinodes therein;

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at least one entrance port in said chamber at said pressure nodes; and
at least one exit port in said chamber at said pressure antinodes;
said driver means including a transducer and said 5

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transducer being supported by a webbing coupled to the sides of said chamber, said entrance or exit port being formed between said transducer and said chamber sides.

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