# United States Patent

[11] 3,588,282

[72] Inventor David V. Chenoweth
Houston, Tex.
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[73] Assignee Baker Oil Tools, Inc.
Commerce, Calif.

[54] **FLUID SHOCK WAVE OSCILLATOR AND FLUIDIC PUMP**
**10 Claims, 13 Drawing Figs.**

[52] U.S. Cl. ........ 417/65
[51] Int. Cl. ........ F04f 7/00
[50] Field of Search ........ 103/1; 230/1; 103/75; 417/240, 241

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*Primary Examiner*—William L. Freeh
*Attorney*—Bernard Kriegel

**ABSTRACT:** A shock wave oscillator, such as a pump or pressure booster, in which fluid is pumped between a shock passage and a second fluid passage, there being a valve between the passages opening and closing at a comparatively rapid frequency, the valve in each cycle of its operation being closed suddenly by the pumped fluid so as to create a travelling fluid pressure rarefaction wave in the shock passage that develops either a positive or negative pressure pulse in the shock passage and thereby either increases or decreases the pressure in the shock passage over a time period equal to twice the length of the shock passage divided by the sonic pressure wave celerity in the field medium being pumped, the travelling pressure wave effecting reopening of the valve at the end of the time period, the cycle of operation repeating automatically. Two shock passages or tubes intercommunicating at one end are preferably used, with the valve alternately closing the flow between the second passage in each shock passage and then alternately opening to permit such flow, thereby obtaining continuity in fluid flow.

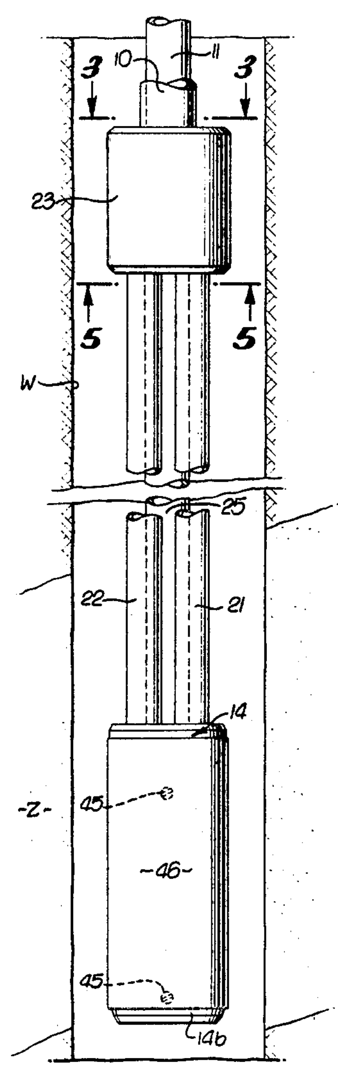


FIG. 4.

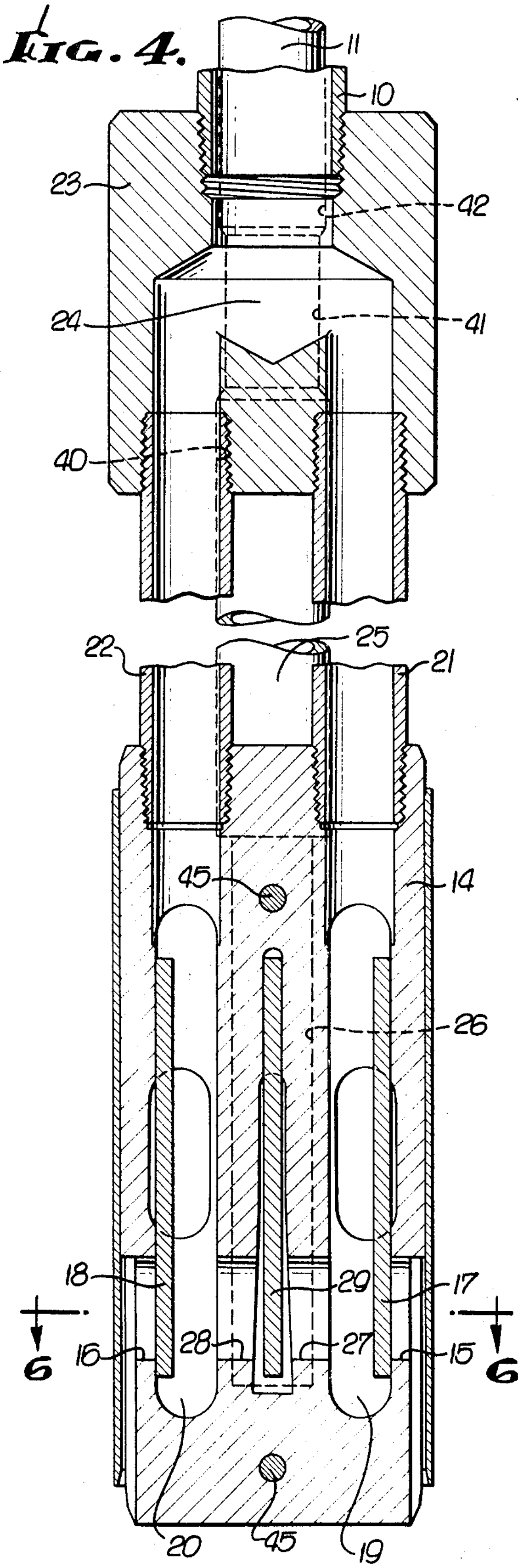
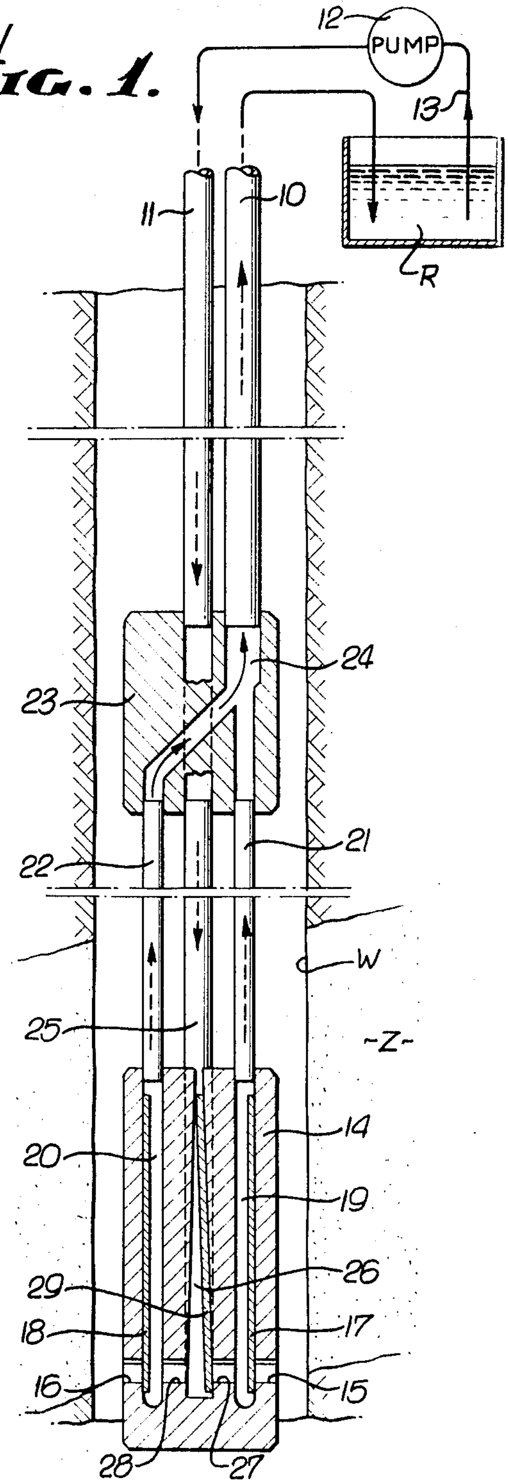



FIG. 1.




INVENTOR.
DAVID V. CHENOWETH
By Bernard Kriegel
ATTORNEY.

FIG. 2.

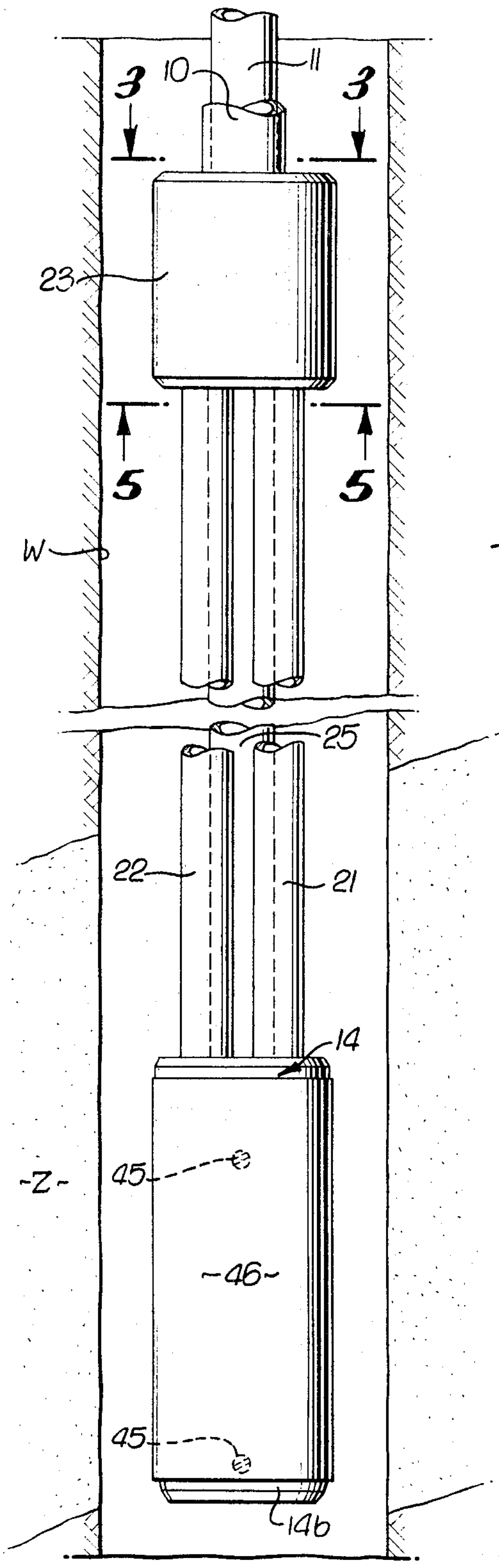



FIG. 3.

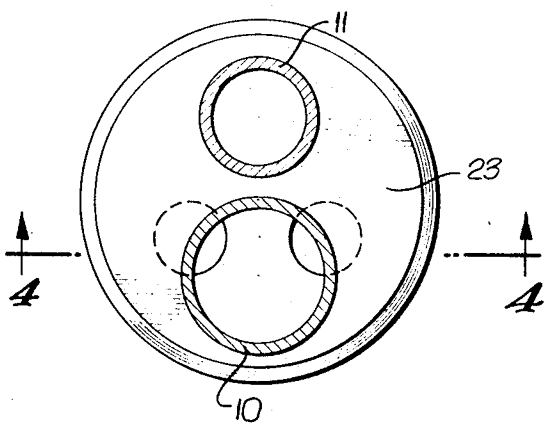



FIG. 5.

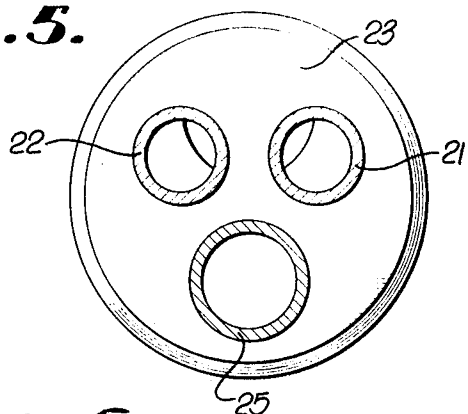
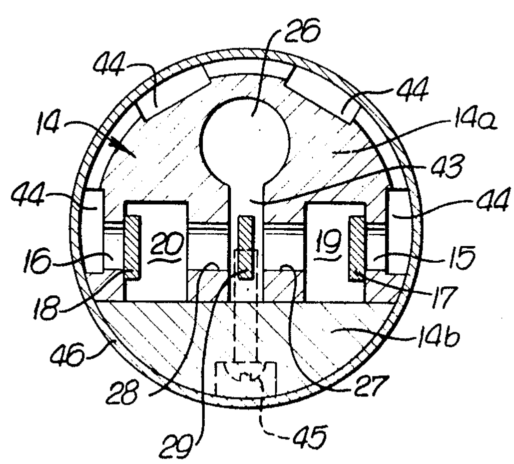



FIG. 6.




INVENTOR.
DAVID V. CHENOWETH
By Bernard Kriegel
ATTORNEY.

FIG. 7.


FIG. 8.

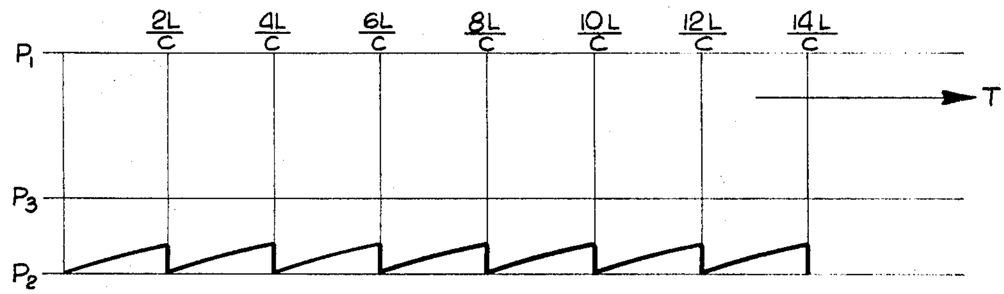
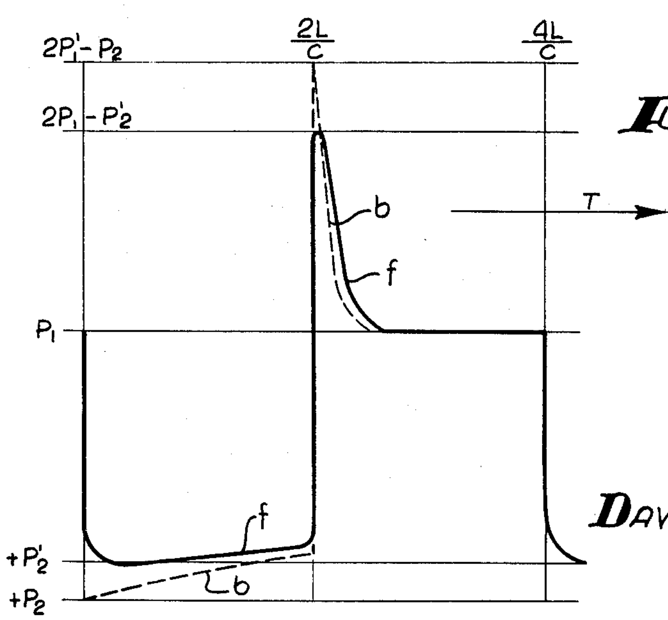



FIG. 9.




INVENTOR.
DAVID V. CHENOWETH
By Bernard Kriegel
ATTORNEY.

FIG. 10.

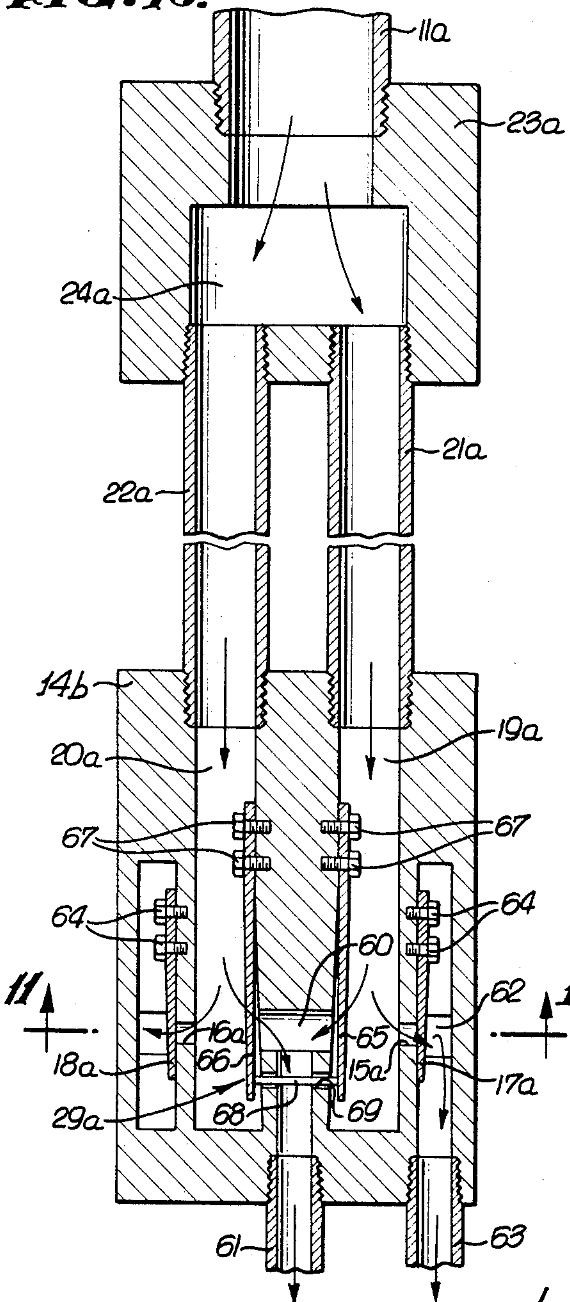



FIG. 12.

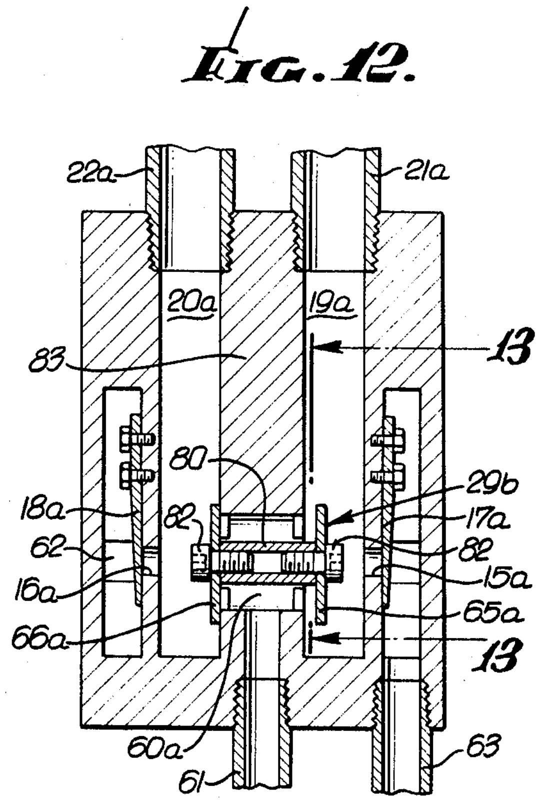



FIG. 13.

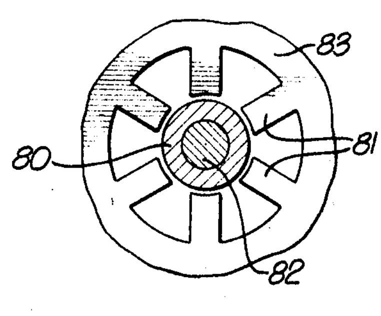
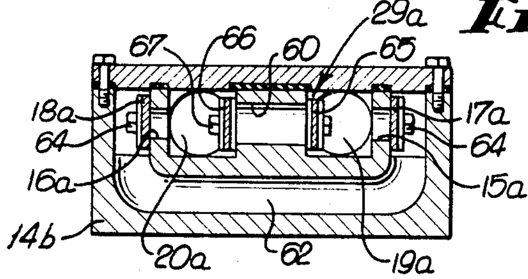



FIG. 11.




INVENTOR.
DAVID V. CHENOWETH
BY Bernard Kriegel
ATTORNEY.

## FLUID SHOCK WAVE OSCILLATOR AND FLUIDIC PUMP

The present invention relates to fluidic apparatus, and more particularly to apparatus for intermittently and suddenly arresting a moving fluid to create pressure waves capable of doing useful work, such as pumping fluids, boosting the pressure of fluids, delivering vibratory blows upon objects, and the like.

Fluid pressure mechanisms are known for pumping fluids, boosting the pressure of fluids, imposing vibratory or repeated impact motions on objects, and generating vacuums. Such mechanisms, however, are relatively complex and, therefore, costly to produce. They possess a comparatively large number of parts subject to wear and deterioration, thereby decreasing the useful life of the apparatus.

Apparatus embodying the present invention includes a shock tube oscillator which can operate to generate negative pressures or positive pressures, depending upon the particular embodiment of the invention which is used. In both instances, fluid flowing through a shock passage or tube is suddenly stopped by the closing of a valve, the kinetic or velocity energy in the moving fluid either generating a negative pulse in the shock tube or a positive pulse, caused by the pressure wave travelling along the length of the tube. The negative pulse aspect of the invention can be employed to function as a pump, as by drawing fluid in through a suitable inlet check valve and then discharging such fluid at a desired point. If desired, the motivating power fluid is used for pumping the fluid to the desired point. In the case of the generation of a positive pulse, the fluid under the increased pressure discharges through a discharge check valve into a suitable high pressure discharge passage. Preferably, a pair of shock tubes is employed of a desired length, which communicate with each other at one end portion, each shock wave becoming alternately effective upon the closing of the main valve of the apparatus. Such valve is closed automatically by the motivating fluid, its reopening being accomplished or assisted by the sonic pressure wave generated in one of the shock tubes. Thus, the motivating fluid and the shock tubes combine to close the passage leading to or from one of the shock tubes, while the passage leading to the other shock tube is open, and to automatically close the last-mentioned passage while automatically effecting opening of the first-mentioned passage, the main valve, in effect, being switched automatically between open and closed condition by the combination of the fluid moving through the system and the particular character of the pressure wave generated in each of the shock tubes as a result of sudden closing of the passage leading to or from such shock tube.

Apparatus embodying the present invention is comparatively simple and has very few moving parts. Such moving parts are only the main valve device that is intermittently opened and closed by the motivating fluid and the pressure wave in the shock tubes. If the apparatus is used as a fluid pump or fluid pressure booster, the only other parts are either an inlet check value in the case of the pump, or a discharge valve in the case of the pressure booster.

This invention possesses many other advantages, and has other purposes which may be made more clearly apparent from a consideration of several forms in which it may be embodied. Such forms are shown in the drawings accompanying and forming part of the present specification. These forms will now be described in detail for the purpose of illustrating the general principles of the invention; but it is to be understood that such detailed description is not to be taken in a limiting sense.

Referring to the drawing:

FIG. 1 is a diagrammatic view of a fluidic pump embodying the invention disposed in a well bore for pumping fluid therefrom;

FIG. 2 is a side elevation of a pump disposed in a well bore;

FIG. 3 is an enlarged section taken along the line 3–3 on FIG. 2;



FIG. 4 is a longitudinal section taken along the line 4–4 on FIG. 3;

FIG. 5 is an enlarged section taken along the line 5–5 on FIG. 2;

FIG. 6 is a section taken along the line 6–6 on FIG. 4;

FIG. 7 is a graph of a theoretical pressure profile developed in one of the pump branches;

FIG. 8 is a graph of the suction pressure profile provided by both branches of the pump;

FIG. 9 is an enlarged graph of part of the profile of FIG. 7, disclosing the actual pressure curve with friction in the system taken into account;

FIG. 10 is a longitudinal section through a pressure booster embodiment of the invention;

FIG. 11 is a cross section taken along the line 11–11 on FIG. 10;

FIG. 12 is a longitudinal section through a modified form of pressure booster; and

FIG. 13 is an enlarged section taken along the line 13–13 on FIG. 12.

The apparatus exemplifying the invention and disclosed in the drawings is a fluidic pump, as disclosed in FIGS. 2 to 6, or a fluidic pressure booster, as disclosed in FIGS. 10 to 13. The pump mechanism is also illustrated diagrammatically in FIG. 1, wherein it is shown as a deep well or water well pump located in the well bore W immersed in the water flowing into the well bore from a water bearing zone Z. The water is to be lifted from the well to a suitable reservoir R at the top of the well bore, there being a fluid discharge line 10 connected to the upper end of the pump and running to the reservoir at the top of the well bore, and a power fluid line 11 connected to the upper end of the fluidic pump mechanism and running to a suitable centrifugal or other pump 12 at the top of the well bore, which has a suction line 13 disposed in the water reservoir.

The fluidic pump mechanism includes a lower housing 14 having a pair of inlet ports 15, 16, each of which is opened or closed by a suitable check valve 17 or 18 disclosed as a reed suitably secured to the housing and adapted to shift in a lateral outward direction across the port 15 or 16 to prevent return flow of fluid from a discharge passage 19 or 20 extending from an inlet port and upwardly through the housing. Each passage communicates with a shock tube 21, 22 extending upwardly from the housing to an upper housing or sub 23. The two shock tubes communicate with each other within the housing or sub, the point of communication, in effect, constituting a fluid reservoir 24 that, in turn, communicates with the fluid discharge line 10.

The fluidic pump further includes a single power tube 25 extending between and connected to the housings 23, 14, its upper end communicating with the power fluid line 11 and its lower end with a power fluid passage 26 in the housing. The lower end of the passage 26 communicates with opposed outlet ports 27, 28, which, in turn, communicate with the discharge passages 19, 20 through which fluid can flow into the shock tubes 21, 22. A check valve device 29 is disposed in the housing passage 26, being in the form of a reed that can be shifted laterally to one side of the passage 26 to close one of the outlet ports, such as the port 27, or to the other side of the passage 26 across the other outlet port 28, such shifting being effected by the power fluid in the power tube 25 and passage 26, and also by the sonic pressure wave developed in each of the shock tubes 21, 22, as described hereinbelow. When the check valve 29 is closing one of the outlet ports 27 or 28, the other is open and the power fluid can flow therethrough into one of the discharge passages 19 or 20 and upwardly through one of the shock tubes 21 or 22. When the check valve 29 is shifted across the previously open outlet port to close the same, the other outlet port is open and the power fluid can then flow therethrough into the other discharge passage branch and upwardly through the shock tube communicating therewith.

The shock tubes 21, 22 have a suitable length, depending upon the frequency at which the system is to operate. By way of example, each of them may be from about 3 feet to about 20 feet in length.

In the operation of the pump disclosed in FIG. 1, let it be assumed that the centrifugal pump 12 at the top of the well bore is drawing fluid from the reservoir R and pumping it down through the power fluid line 11, and that the water in the well bore is to be pumped back up through the fluid discharge line 10 to the reservoir. At the start of the operation, the main reed valve 29 will be in a central position within the power passage 26, both of the outlet ports 27, 28 being open. Assuming that the valve remains in this central position, the result would merely be the circulating of the power fluid through its passage 26 and the outlet ports 27, 28, and back up through the discharge passages 19, 20 and shock tubes 21, 22, through the fluid discharge line 10 to the reservoir. However, the fluid pumped downwardly through the power passage 26 will shift the reed valve element 29 to one side and across one of the outlet ports 27, 28, as, for example, the right outlet port 27 disclosed in FIG. 1. When this occurs, the pressure in the right shock tube 21 drops suddenly, because of the velocity of the fluid moving upwardly therethrough, caused by the pressure wave travelling from the outlet port 27 upwardly to the reservoir portion 24 in the top sub 23, and then back again to the outlet port 27. If the pressure drops below the hydrostatic pressure of the water in the well bore W, the back check valve 17 opens, and the water flows inwardly through the inlet port 15 and into the discharge passage branch 19, flowing up into the shock tube 21. During the time that the pressure wave is travelling up the shock tube 21 and then downwardly again, the pressure at the inlet port 15 remains below the hydrostatic head of water, or other fluid, in the well bore. As a result, the inlet check valve 17 remains open and the water will flow through the inlet port into the discharge passage 19 and tube 21. However, when the pressure wave returns to the lower part of the discharge branch passage 19, its pressure increases above the hydrostatic pressure, the back check valve 17 closing across its port 15. The intermittent opening and closing of the port 27 by the main valve 29 would cause the foregoing cycle to be repeated indefinitely.

In the water well pump illustrated, the disadvantage in using a single shock tube 21 and inlet check valve 17 is that the single branch will remain inactive for half the time. The use of the two parallel branches 19, 21 and 20, 22 illustrated in the drawings eliminates the inactivity, since they each operate alternately for half the time. In addition, the two branches eliminate the need for a reservoir at their intercommunicating ends. As shown, the main valve 29 shuts off the outlet ports 27, 28 alternately so that first one branch 19 has a negative pressure developed therein, while the power fluid is being pumped through the other outlet 28 and upwardly through the other branch 20, 22 and into the discharge line 10. Alternately, when the other outlet port 28 is closed by shifting of the valve 29 thereacross, a negative pressure wave develops in the other branch 20, and the power fluid then flows through the outlet port 27 into the first-mentioned branch 19, 21 to force the fluid therein upwardly through such branch and into the fluid discharge line 10 for delivery to the top of the well bore.

In understanding the operation of the system, it might be well to analyze the pressure profiles in one branch. In the following discussion:

$P_1$ = flowing pressure of the power fluid

$P_2$ = pressure at the branch outlet from the reed (main valve) immediately after it shuts off the branch outlet

$P_3$ = the hydrostatic pressure of the well at the inlet check valve

C = wave celerity

$T_1$ = time period, which is 2L/C

L = length of the branch

Assuming, as above, that the power fluid is flowing through both of the branches, and the main valve 29 suddenly shuts off branch 19, 21, as shown in FIG. 1, the pressure $P_1$ in the branch drops to $P_2$, and since $P_2$ is a lesser pressure than the hydrostatic pressure $P_3$ of the well fluid, a suction head is created in the branch 19, the inlet check valve 17 opening and water from the well rushing in and increasing the pressure in the branch 19, 21. At the instant of T=O, the pressure drops to $P_2$ and the pressure remains below the pressure $P_3$ of the hydrostatic head until the pressure wave has travelled up the branch 19, 21 to the reservoir 24, and then back down to the inlet port 15, which takes a time $T_1$ equal to 2L/C. At that time, the pressure has increased to a new value $P_4$, and then suddenly rises to $2P_1—P_2$, or $P_5$, lowering back down to $P_1$, as disclosed in the graph on FIG. 7. During the time period of from $T_1$=2L/C to $T_2$=4L/C, the branch 19, 21 is inactive. However, the main valve 29 has been shifted over to close the opposite outlet port 28 by the increased pressure $P_5$ in the branch 19, 21 at $T_1$=2L/C. The above pressure relationship and flowing cycle of operation then takes place in the branch 20, 22, which is drawing water in from the well through its inlet port 16 during the time period 2L/C to 4L/C. Thus, the pump is drawing in water continuously, one branch 19, 21 being under a suction condition while the power fluid is forcing the liquid in the other branch 20, 22 upwardly into the fluid discharge line 10. When the other branch 20, 22 is under a suction condition, power fluid is forcing liquid through the branch 19, 21 into the discharge line. Thus, the suction head profile with two branches operating is represented by the sawtoothed curve illustrated in FIG. 8.

The profile of the pressure wave disclosed in FIG. 7 is substantially a rectangular wave pattern. Actually, the rectangular wave is not obtained in the form disclosed in FIG. 1, because friction losses have not been taken into consideration. When such losses are considered, the rectangular wave profile is not secured exactly. Instead, the pressure wave is as represented in the full line *f* on FIG. 9, deviating from part of the wave profile disclosed in FIG. 7, which portion is represented in FIG. 9 by the broken line *b*. However, the time for the valve to switch over from one port to the other is not shown.

A preferred embodiment of the pump aspect of the invention illustrated diagrammatically in FIG. 1 is disclosed in FIGS. 2 to 6. In this specific device, the lower housing 14 has a power passage 26 extending downwardly from its upper end, the lower portion of the power tube 25 being secured to the housing and communicating with the passage 26. The upper end of the power tube is attached to a lower box 40 of the upper housing 23, communicating with a passage 41 therein opening into a threaded housing box 42 into which the power fluid line 11 is threadedly attached, this latter line extending to the top of the well bore and being connected to the pump 12. The lower portion of the power passage 26 is communicable through a lateral passage portion 43 with the outlet ports 27, 28 extending between such branch and the discharge passage branches 19, 20, each of which has an inlet port 15 or 16 communicating with intercommunicating longitudinal inlet grooves or passages 44 in the exterior of the housing body 14. For purposes of facilitating production, the housing 14 is composed of a main section 14*a* and with a second section 14*b* that is disposed across the power passage branch 43 and the discharge passage branches 19, 20, being suitably secured to the main section by screws 45, or the like. A sleeve 46 surrounds the housing sections 14*a*, 14*b* and the inlet passage grooves 44 to enclose and protect the housing.

Shock tubes 21, 22 are connected to the upper portion of the housing 14, one shock tube or branch 21 communicating with one of the discharge passage branches 19 and the other shock tube or branch 22 communicating with the other shock tube or passage 20. The upper ends of the shock tubes are secured to the upper housing 23 in communication with a common reservoir 24, which, in turn, communicates with the fluid discharge line 10 threadedly or otherwise suitably secured to the upper housing and extending to the top of the well bore W for discharge at a suitable point, as into the reservoir R.

The power passage branch **43** has a switching valve **29**, which is specifically disclosed in the form of a reed, attached to the housing at its upper end and being able to move laterally in one direction into engagement with the housing across one of the outlet ports **27**, or in the opposite direction into engagement with the housing against the other outlet port **28**, to alternately close such outlet ports, as described above in connection with FIG. **1**, thereby alternately shutting off the flow of power fluid through one outlet port and then the other. The flow of fluid through the inlet ports **15, 16** in one direction only is controlled by check valve elements **17, 18**, specifically illustrated as being in the form of reeds, disposed in the discharge branch passages **19, 20** and suitably secured to the housing **14**, the lower portions of the reeds being movable laterally outwardly against the housing to close the inlet ports **15, 16** against lateral outward flow of fluid therethrough from the discharge passage branches **19, 20** into the inlet passages **44**, and thence into the well bore, but which permits inward flow of fluid through each inlet port **15** or **16** when the pressure in its branch passage drops below the pressure in the well bore externally of the housing **14**.

As described above in connection with the diagrammatic view (FIG. **1**), the power fluid will first switch the switching reed **29** across one of the outlet ports **27**, causing the pressure wave in the associated branch passage **19, 21** to effect a negative pressure in such passage, thereby drawing the well bore fluid through the inlet **15** past the valve **17** into the discharge passage branch **19**. At this time, the power fluid is flowing through the other open outlet port **28** into the discharge passage branch **20**, and upwardly through the shock tube **22** and into the fluid discharge line **10**. When the pressure pulse in the fluid discharge branch **19** and shock tube **21** increases, the fluid pressure shifts the switching valve **29** in the opposite direction across the other outlet port **28** to close the same, opening the outlet port **27** so that the power fluid then flows therethrough and up through its communicating discharge passage branch **19** and its shock tube **21** into the fluid discharge line **10**. While this is occurring, the other discharge passage branch has the pressure wave therein decrease its pressure below the external well pressure to cause well fluid to flow through the inlet port **16** and past the check valve **18** thereinto. The valve **29** switches alternately into closed engagement with the outlet ports **27, 28** at a fairly rapid rate, depending upon the design and equipment. By way of example, the switching may be at a frequency of about 15 to 30 cycles per second. The reed valve **29** itself preferably has a normal frequency of vibration of about 80 cycles per second, the reed being made of a suitable material, such as polyvinylchloride or stainless steel. With the normal frequency of vibration of the reed higher than the frequency of operation of the system, shuttling of the valve **29** between positions closing the ports 27, 28 is facilitated. The apparatus has a relatively high efficiency, being capable of pumping relatively large volumes of fluid from the well bore to its surface.

FIGS. **10** and **11** illustrate a fluidic pressure booster apparatus as another embodiment of the generic invention. In this embodiment, a shock tube manifold or housing **23*a*** has a reservoir or chamber **24*a*** therein communicating with an inlet line **11*a*** threadedly or otherwise suitably secured to the manifold. A pair of shock tubes **21*a*, 22*a*** is threadedly secured to the manifold, being in communication with the reservoir **24*a*** therewithin. The opposite ends of the shock tubes or branch lines are threadedly or otherwise secured to the housing **14*b*** of a pulse generator, each tube communicating with a branch passage **19*a*, 20*a*** in the generator housing. Fluid may flow from both branch passages into a central lateral port in the housing, communicating with an exhaust port **60** from which the fluid flows into an exhaust pipe or tube **61** threadedly or otherwise suitably secured to the housing, this exhaust pipe extending to any suitable source for the discharge of a portion of the power fluid.

Each branch passage **19*a*** or **20*a*** communicates through a lateral port **15*a*** or **16*a*** in the housing with a high pressure chamber **62** formed in the housing, this chamber being in communication with a high pressure discharge line **63** threadedly or otherwise suitably secured to the housing. Return flow of fluid from the high pressure chamber **62** to each of the branch passages **19*a*; 20*a*** is prevented by a back pressure valve **17*a*** or **18*a***, which is disclosed, by way of example, as a reed secured by screws **64**, or the like, to the housing and being adapted to close over its discharge port to prevent flow of fluid from the chamber back into the branch passage. However, the reed **17*a*** or **18*a*** can deflect outwardly away from the housing surrounding the port to permit fluid to flow through the port **15*a*** or **16*a*** and into the high pressure chamber **62**.

The flow of fluid from the shock tubes and their associated branches into the exhaust port and the exhaust line is controlled by a switching valve mechanism **29*a*** adapted to alternately prevent fluid from flowing from one branch, as the branch **19*a***, into the exhaust port **60**, and then from the other branch, as the branch **20*a***, into the exhaust port **60**. This switching valve is illustrated as in the form of a pair of reeds **65, 66**, each of which is disposed in a branch passage **19*a*** or **20*a*** and being secured at one end portion to the housing in any suitable manner, as by means of screws **67**. The free ends of the reeds are interconnected by a tie bar **68** extending freely through passages **69** in the housing, the tie bar being of a length preventing the reeds **65, 66** from simultaneously engaging the housing and simultaneously closing the exhaust port **60**. Only one reed can move laterally into engagement with the housing to close the port **60**, the reed also closing the passage **69** through which the tie bar extends. When one reed moves to its closed position, the other reed is shifted away from the housing so that it is in its open position, and vice versa.

In the operation of the pressure booster, let it be assumed that the reed shuttle valve **29*a*** is in its open position, as dislodged in FIG. **10**. Fluid then flows from the power tube or line **11*a*** into the reservoir **24*a*** and then downwardly through both shock tubes **21*a*, 22*a*** into both branches **19*a*, 20*a***, and tends to flow into the exhaust port **60** and the exhaust line **61**. The flowing fluid under pressure will effect a shifting of one of the reed valves, such as valve **65**, across the exhaust port **60** to close the latter, and thereby prevent fluid in one of the shock tubes **21*a*** from passing into the exhaust port. The sudden closing of the valve against the port creates a pressure wave pulse in the closed branch **19*a*** and shock tube **21*a***, which increases the pressure therewithin for the time required for the pressure wave pulse to traverse upwardly to the reservoir **24*a*** and then downwardly to the location of the exhaust port **60** closed by the reed **65**, this increased fluid under pressure then being discharged through the port **15*a*** and past the discharge check valve **17*a*** into the high pressure chamber **62**. During this short interval, the power fluid is flowing through the other shock tube or branch **22*a*** and its associated branch passage **20*a*** into the exhaust port **60** and into the exhaust line **61**, since the opposed reed **66** is in the port opening position. However, when the pressure pulse has travelled in one direction through the shock tubes to the reservoir and then down to the location of the switching valve reed **65** in the time $T=2L/C$, the pressure wave then moves back towards the reservoir **24*a***, decreasing the pressure in the branch **19*a*** below that of the fluid pressure in the other branch **20*a***, the fluid pressure therewith then acting on its reed **66** to shift it against the housing, closing the port **60** and the second branch **20*a***, but shifting the other reed valve **65** to its open position. The pressure in the first branch **19*a*** is then less than the pressure in the chamber **62**, so that the check valve **17*a*** is forced inwardly against the housing to close the discharge port **15*a*** against return flow of fluid.

The sudden closing of the reed valve **66** over the exhaust port **60** and passage **69** then stops movement of the power fluid column through the exhaust port **60**, causing the shock wave to travel from the reed valve **66** up the second shock tube **22*a*** towards the reservoir **24*a*** in the manifold **23*a***, and then downwardly, increasing the pressure in the second shock tube **22***a* and its branch **20***a*, such fluid under pressure then being forced through the discharge port **16***a* and past the check valve **18***a* into the high pressure chamber **62**. After the pressure wave makes its round trip, it again diminishes below the pressure in the chamber **62**, the discharge check valve **18***a* for the second branch **20***a* closing, and the shuttle valve reed **65** again being closed over the exhaust port **60** and passage **69** by the fluid pressure flowing through the first shock tube **21***a* and first branch **19***a*, whereupon the foregoing cycle of operation repeats.

A comparatively great increase in the fluid pressure can be achieved with the apparatus illustrated, depending upon the specific design of the equipment. By way of example, the pressure can be boosted as much as 20 times the pressure of the power fluid flowing in the line **11***a*. The high pressure fluid discharging into the high pressure chamber **62** and the discharge line **63** flows comparatively continuously, since the flow of the high pressure fluid alternates between one of the shock tubes **21***a* and its branch **19***a* and the other shock tube **22** and its branch **20***a*.

The fluidic pressure booster illustrated may have an appropriate frequency of vibration depending upon the specific design of the equipment, such as the length of the shock tubes **21***a*, **22***a*, the material of which the shock tubes are made, and the natural frequency of vibration of the shuttle valve reeds. By way of example, the frequency of operation may be about 15 to 30 cycles per second, while the reeds **65**, **66** may have a natural frequency of vibration of about 80 cycles per second.

The effective operation of the system is not dependent upon the natural frequency of vibration of the shuttle valve **29***a*. In fact, it may have virtually a zero frequency of vibration. As disclosed in FIGS. **12** and **13**, a shuttle valve **29***a* is illustrated of a spool type. Specifically, it consists of a sleeve **80** shiftable axially in the exhaust port **60***a* and slidable in inwardly extending boss segments **81** integral with the housing. Valve discs **65***a*, **66***a* are attached to the sleeve by screws **82** threaded into the sleeve at opposite ends of the latter, each disc being located in a passage branch **19***a* or **20***a* communicating with a shock tube **21***a* or **22**on opposite sides of the housing partition wall **83**.

The spool **29***b* may shift in one direction to move its valve disc **65***a* across the exhaust port **60***a* to close the latter, while the other valve disc **66***a* is moved away from the housing to open the exhaust port to flow of fluid from its branch **20***a* into the exhaust port **60***a* and line **61**, or the spool will shift in the opposite direction to bring the second disc **66***a* against the housing to close the port **60***a* against flow of fluid thereinto from its associated branch passage **20***a* while the other disc **65***a* is removed from contact with the housing, so as to allow the fluid to flow from its branch passage **19***a* into the exhaust port **60***a*.

With the spool valve **29***b* shuttling back and forth to alternately close the branches **19***a*, **20***a* and their shock tubes **21***a*, **22***a* against flow of fluid into the exhaust port passage **60***a*, a pressure increase occurs in each branch passage and its shock tube, the high pressure fluid passing through the discharge ports **15***a*, **16***a* and past the discharge check valves **17***a*, **18***a* into the high pressure chamber **62** and line **63**. The spool valve has no resonant frequency, which increases its switching time in shuttling from a position closing one branch to a position closing the other branch. The switching time affects the pressure boost, and the longer it is the greater is the forward velocity of fluid in a branch before the valve closes the exhaust port leading from such branch, and, consequently, the pressure increase in such branch. With a valve of the spool type, its natural frequency of vibration is virtually zero, or substantially less than the pressure pulse wave travelling within the branches **19***a*, **20***a* and their shock tubes **21***a*, **22***a*.

I claim:

1. A fluid shock wave oscillator apparatus comprising means providing a reservoir, a passageway including a shock tube secured to said reservoir means and open at its inlet end to said reservoir, said passageway having an opening at the outlet end of said shock tube, and a shuttle valve in the path of fluid flow through said passageway shiftable by the fluid flowing in said passageway to a position closing said opening to generate a positive fluid pressure pulse wave travelling between said reservoir and opening and through said shock tube, that first holds said valve closed and then facilitates opening of said valve.

2. In apparatus as defined in claim 1; wherein said shuttle valve has a natural frequency of vibration substantially greater than the frequency of said pulse wave.

3. In apparatus as defined in claim 1; said passageway having a second opening leading therefrom, and a check valve adapted to close said second opening against fluid flow into said passageway, but permitting fluid flow therefrom through said second opening.

4. A fluid shock wave oscillator apparatus comprising a pair of shock passageways intercommunicating at their inlet ends, a pulse generator communicating with the opposite outlet ends of said shock passageways and having an outlet fluid passage therein, said generator including an outlet opening between each shock passageway and fluid passage for the flow of fluid therebetween, and a shuttle valve device in the path of the fluid flow through said openings for alternately closing a first opening while opening the second opening and then closing said second opening while opening said first opening to alternately generate a positive fluid pressure pulse wave in each shock passageway travelling through each shock passageway between its associated opening and said intercommunicating end.

5. In apparatus as defined in claim 4; wherein said shuttle device has a natural frequency of vibration substantially greater than the frequency of said pulse wave.

6. A fluidic pressure booster comprising a pulse generator having first and second passages therein, exhaust openings leading from said passages, and first and second discharge openings leading from said passages and communicating with a high pressure discharge passage, a housing spaced longitudinally from said generator, first and second shock tubes extending between said generator and housing and communicating with each other in said housing and with said first and second discharge passages, respectively, means for conducting fluid to said housing and said shock tubes, a shuttle valve device in said passages shiftable alternately across said exhaust openings to close the same, and check valves permitting fluid flow from said passages through said discharge openings into said discharge passage, but preventing return fluid flow from said discharge passage through said discharge openings.

7. A fluidic pressure booster as defined in claim 6; said shuttle valve device comprising a reed in each of said first and second passages and fixed at one end portion to the generator, means securing said reeds together for oscillation as a unit between a position in which a first reed closes its exhaust opening while the second reed opens its exhaust opening and a position in which said second reed closes its exhaust opening while said first reed opens its exhaust opening.

8. A fluidic pressure booster as defined in claim 6; said shuttle valve device comprising a reed in each of said first and second passages and fixed at one end portion to the generator, means securing said reeds together for oscillation as a unit between a position in which a first reed closes its exhaust opening while the second reed opens its exhaust opening and a position in which said second reed closes its exhaust opening while said first reed opens its exhaust opening, each reed having a natural frequency of vibration substantially greater than the frequency of the pressure pulse wave generated in a shock tube when the reed closes an exhaust opening communicating with the shock tube.

9. A fluidic pressure booster as defined in claim 6; said shuttle valve device comprising a reed in each of said first and second passages and fixed at one end portion to the generator, means securing said reeds together for oscillation as a unit between a position in which a first reed closes its exhaust opening while the second reed opens its exhaust opening and a

position in which said second reed closes its exhaust opening while said first reed opens its exhaust opening, each of said check valves comprising a reed.

**10**. A fluid pressure booster as defined in claim **6**; said shuttle valve device comprising a central member extending through said exhaust openings and first and second valve heads secured to said member and disposed in said first and second passages, respectively, whereby said shuttle valve device is oscillatable between a position in which said first head closes its exhaust opening while said second head opens its exhaust opening and a position in which said second head closes its exhaust opening while said first head opens its exhaust opening.