July 13, 1948. A. G. BODINE, JR 2,444,912

METHOD AND APPARATUS FOR PUMPING

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Fig. 1

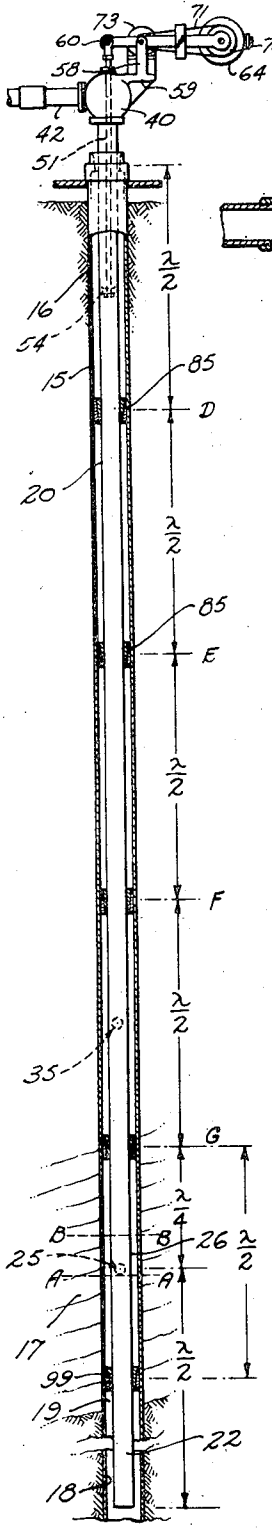


Fig. 2

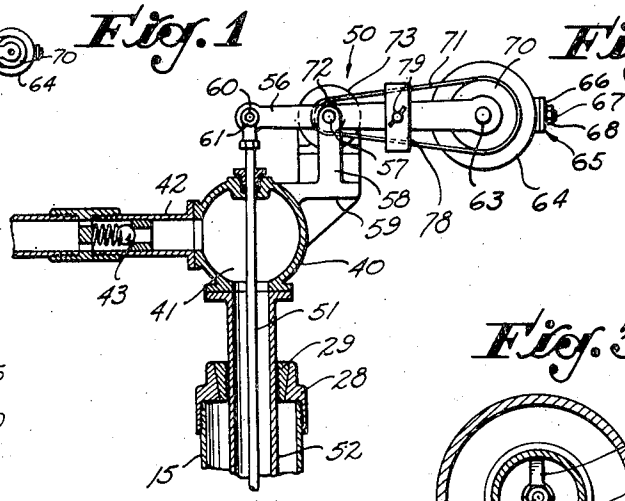
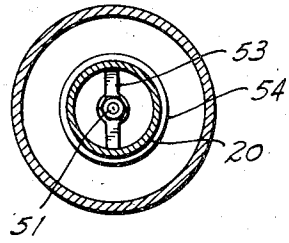


Fig. 3



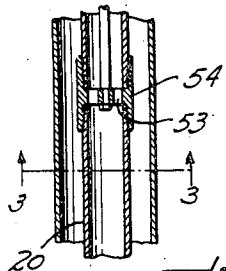


Fig. 6

Fig. 4

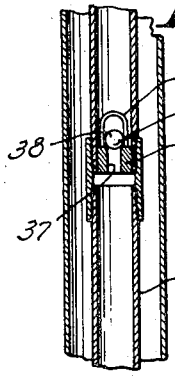


Fig. 5

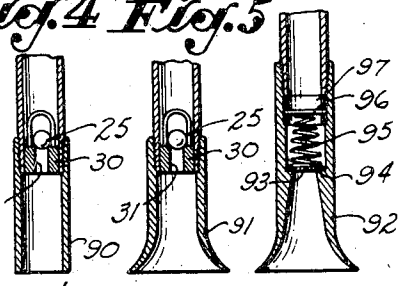
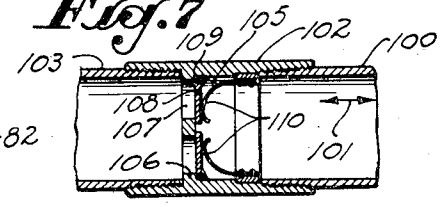
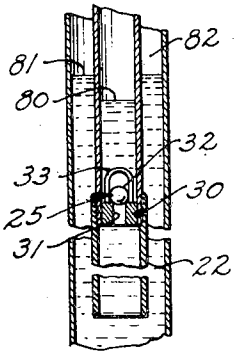


Fig. 7





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Fig. 8

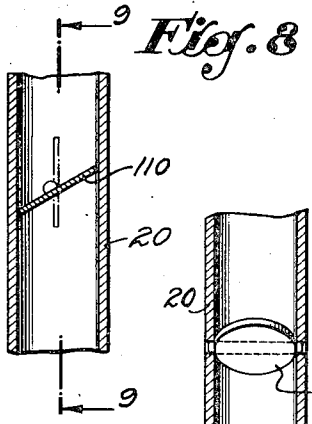
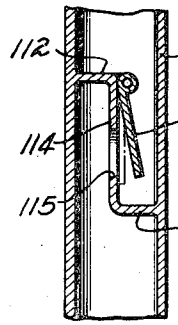


Fig. 10



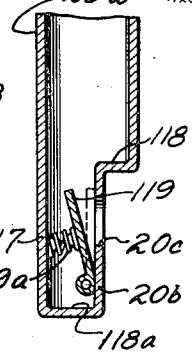
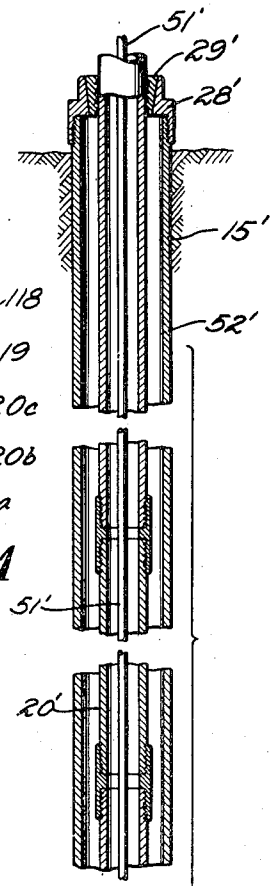


Fig. 9

Fig. 11



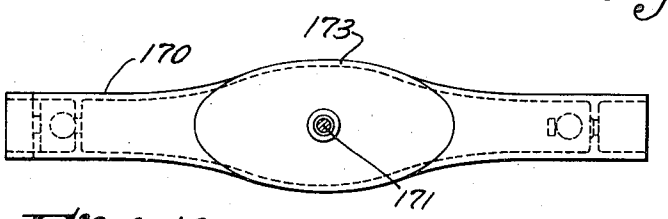
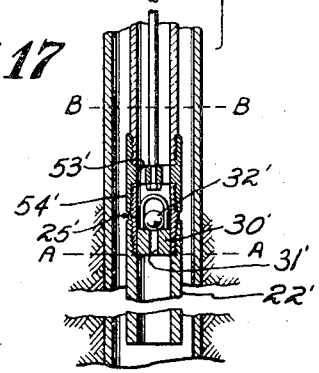


Fig. 19

Fig. 17



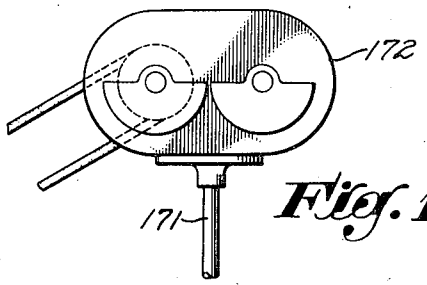
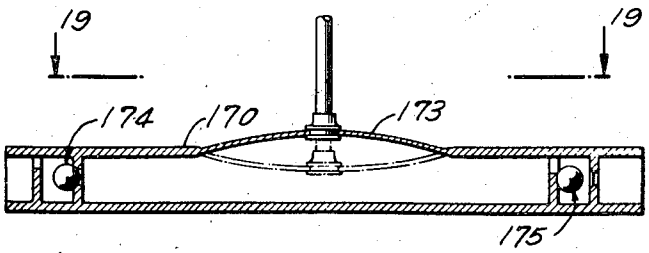


Fig. 18



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Fig. 12

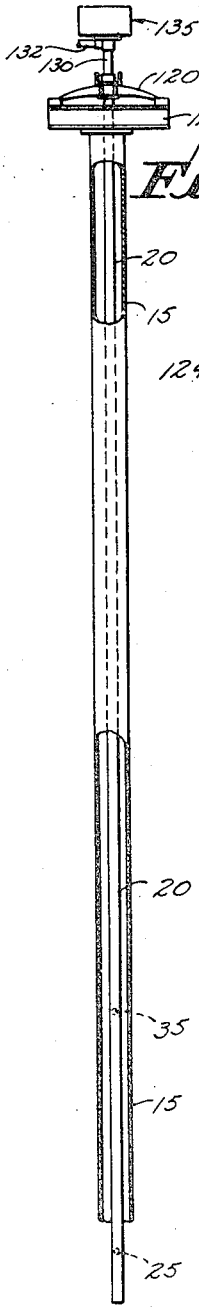


Fig. 13

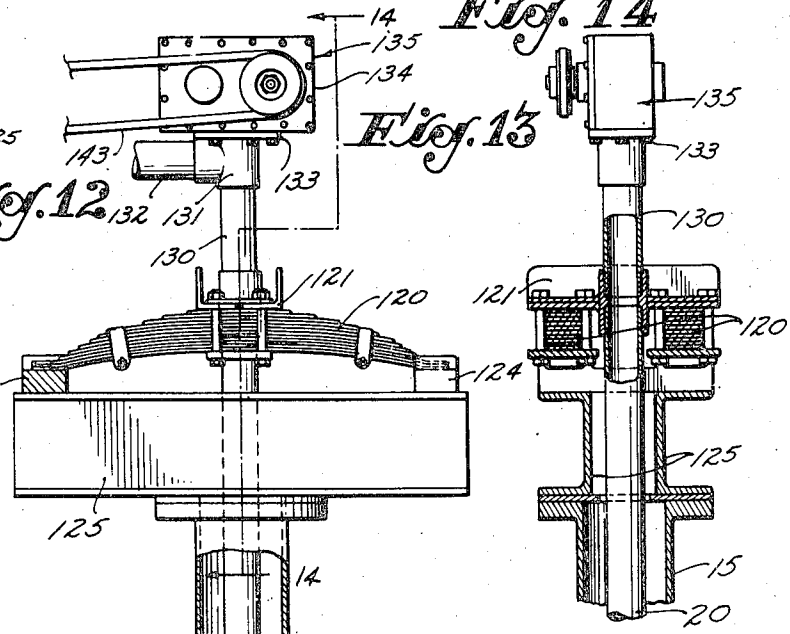


Fig. 14

Fig. 15

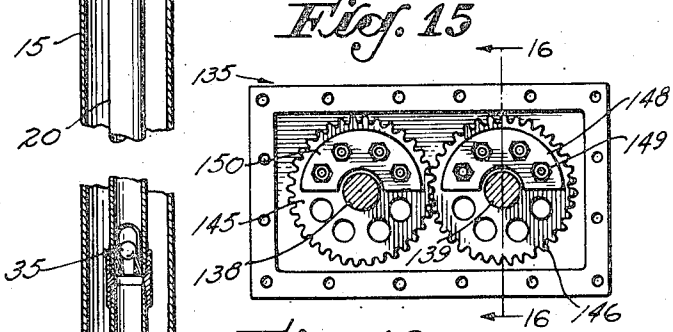
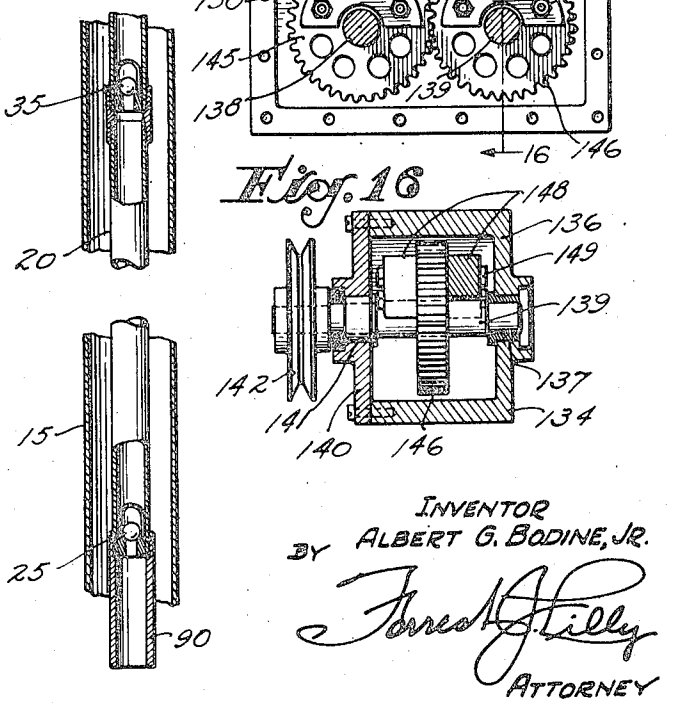


Fig. 16



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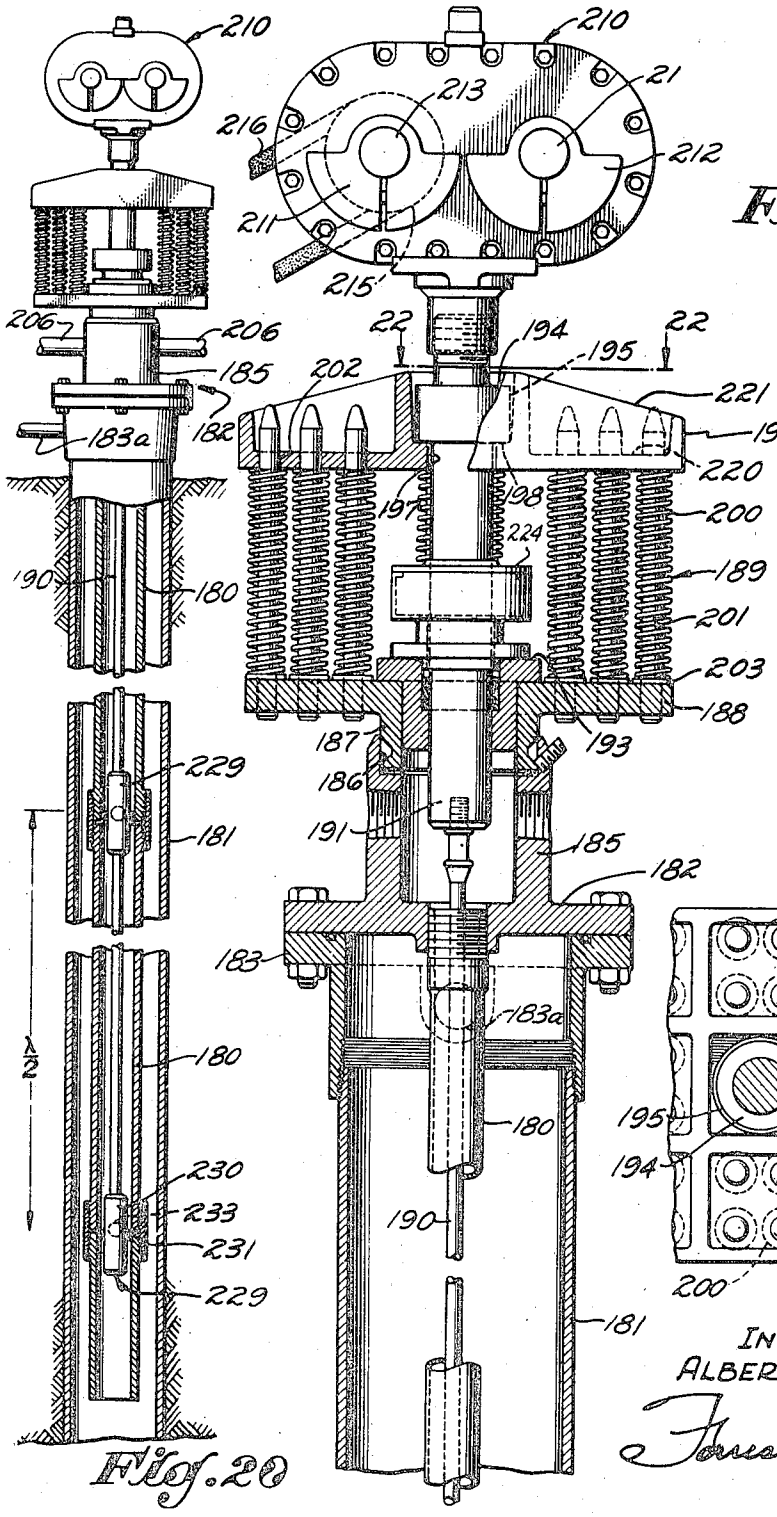


Fig. 21

Fig. 22

Fig. 20

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Fig. 23

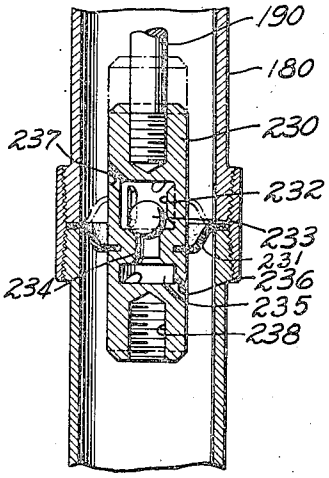


Fig. 25

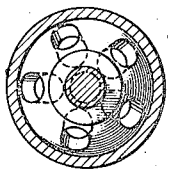


Fig. 26

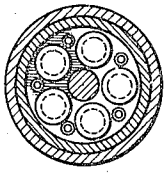


Fig. 28

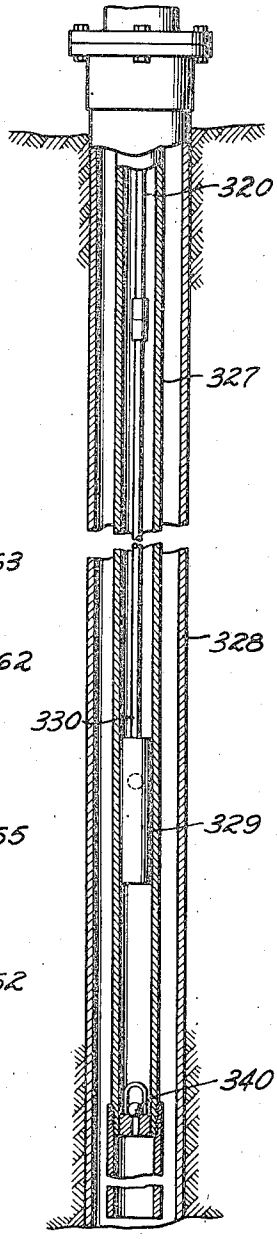
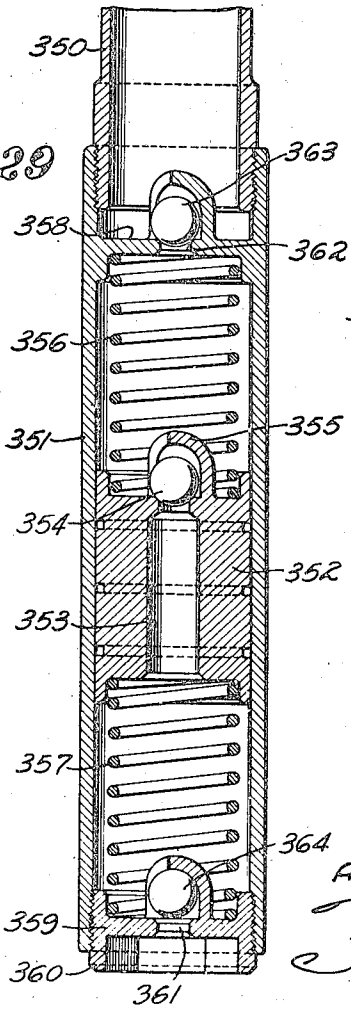


Fig. 29



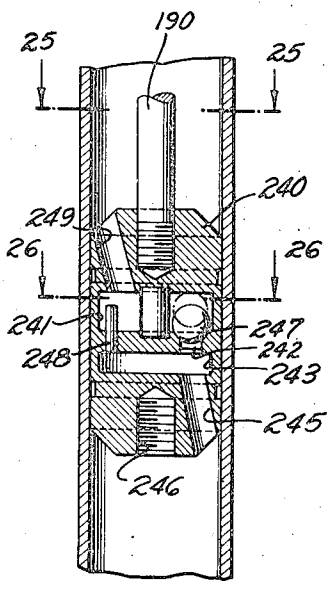


Fig. 24

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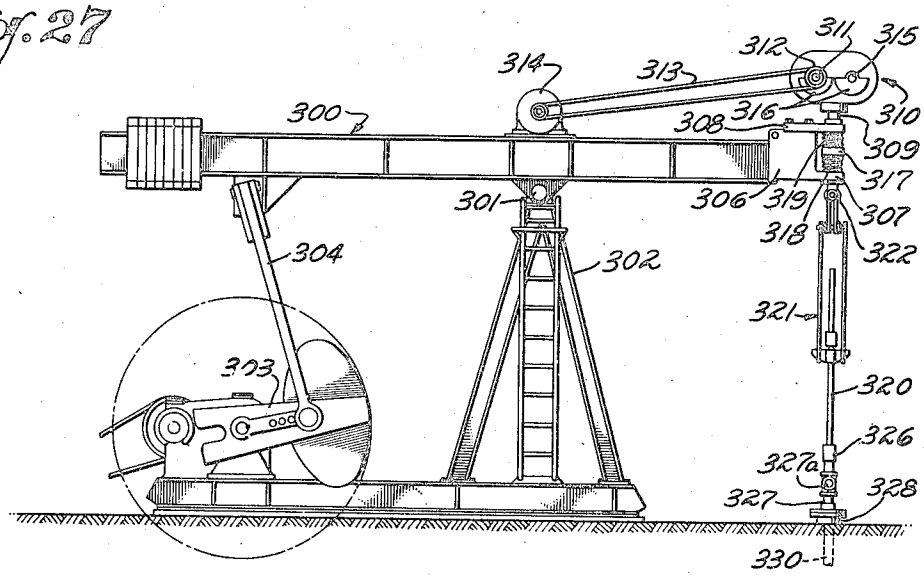
ATTORNEY

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Fig. 27



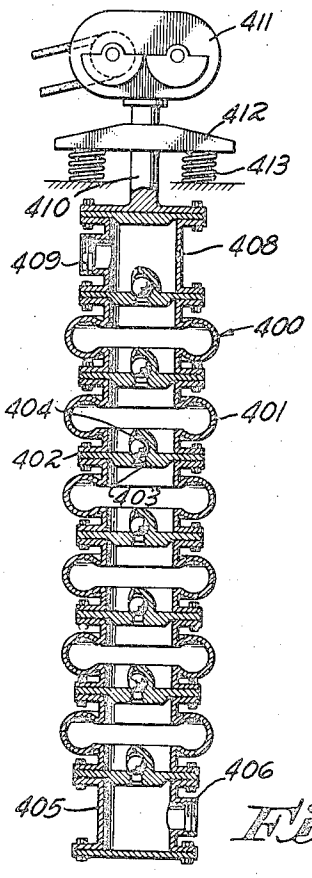


Fig. 31

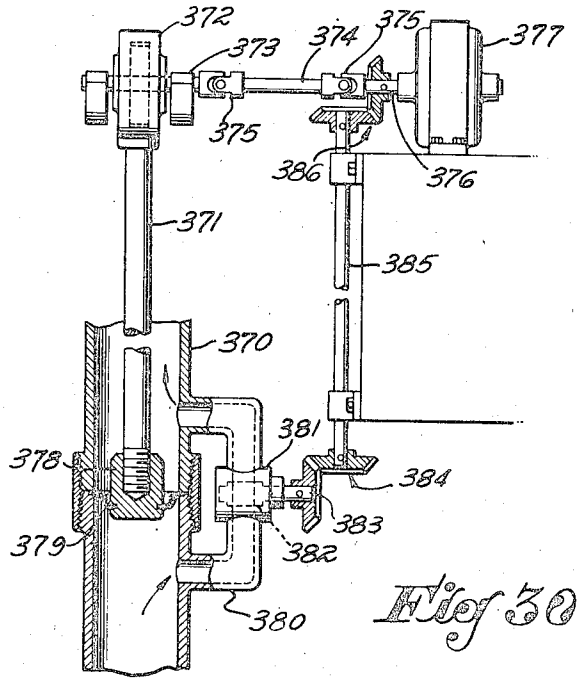


Fig. 30

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Patented July 13, 1948 2,444,912

UNITED STATES PATENT OFFICE

2,444,912

METHOD AND APPARATUS FOR PUMPING

Albert G. Bodine, Jr., Van Nuys, Calif.

Continuation of application Serial No. 521,576, February 8, 1944. This application July 17, 1947, Serial No. 761,456

16 Claims. (Cl. 103—1)

1

My invention relates to a novel method and apparatus for pumping and, more particularly, to a pumping system particularly applicable to the pumping of liquids from wells by employment of sonic principles.

This application is a continuation-in-part of my prior application Serial No. 521,576, filed February 8, 1944, entitled Method and apparatus for pumping, allowed March 18, 1947, now abanboned. Reference is made to my divisional and continuation-in-part applications as follows: Deep well pump, filed March 6, 1948, Serial No. 13,422; Pumping apparatus, filed March 15, 1948, Serial No. 14,959; Sonic system for augmenting the extraction of oil from oil bearing strata, filed February 17, 1948, Serial No. 8,799.

The present invention is applicable to various types of pumps, but may be illustrated in a simple adaptation to a class of pumps having the ability to pump from a body of displaceable liquid, by which I have reference to a body of liquid displaceable into some space other than that into which the valve discharges if the valve and its associated structure is moved slowly into the body of liquid. For example, such a pump may include a relatively short tubular member extending downwardly a slight distance into a body of liquid in a well cavity, the tubular member being smaller than the well cavity so that the well liquid tends to assume equal levels inside the tubular member and the walls of the well cavity. Assume that the surfaces of the liquid within and around the tubular member are in contact with air at atmospheric pressure and that the tubular member carries a working valve, of the usual ball type common in oil well pumping, in submerged position. Such a body of well liquid below and around the tubular member forms a displaceable body of liquid insofar as any downward movement of the tubular member, with the spherical valve member held against its seat, will displace liquid upward in the annular space around the tubular member, and this will be true irrespective of the rate at which the tubular member is lowered. If the spherical valve member is released, any slow and extensive downward motion of the tubular member will tend to admit fluid into the interior of the tubular member as soon as there is a sufficient differential head between the internal and external columns to overcome the gravitational bias of the spherical valve member. If the tubular member is then pulled slowly upward an equal distance, the level of the internal column may be raised above the level of the external column. However, during the next

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downward stroke, no additional liquid will enter the inner column through the valve.

A sufficiently rapid vertical oscillation of such a tubular member, however, will cause pumping, depending in part upon the inertia effects of the liquid. For example, if the tubular member is moved downwardly with sufficient rapidity, the well liquid does not have time to displace into the annular space and an increment of liquid will flow through the valve. In fact, at the frequencies at which I propose to oscillate the tubular member, the inertia of the body of well liquid is such as to prevent the surface thereof in the annular space around the tubular member from substantially rising and falling with the reciprocation of the tubular member. The result is that the column of liquid in the tubular member increases in height by the supply of additional increments of liquid through the one-way valve.

Another inertia effect used to advantage in a pump of this type is the inertia of the column of liquid within the tubular member above the valve. During any slow downward motion of the tubular member and its associated valve, there would be no incremental intake through the valve, as noted above, and, furthermore, the internal column of liquid would move downwardly with the tubular member, the weight of this column being supported by the now-closed valve. However, if the tubular member is forced downwardly in the body of displaceable liquid rapidly and if the downward acceleration exceeds that of gravity for any instant of time, the valve seat moves from supporting relationship with the internal column, and, for an instant, the inertia of this internal column tends to retain it suspended in space. During this instant of time, the only downward force on the internal column of fluid is that imposed by gravity and by the very small frictional force or drag between the internal surface of the tubular member and the internal fluid column caused by downward movement of the tubular member at a velocity greater than any gravity-induced downward motion of the column.

In other words, if the valve seat is moved downwardly with an acceleration greater than about 32 ft./sec./sec., a "void" or zone of reduced pressure tends to appear immediately above the valve seat to establish a pressure differential thereacross. This pressure differential is sufficient in itself to cause flow of an increment of liquid through the valve and into the tubular member. Such flow is aided by the inertia effect of the body of liquid below the valve, as pointed out

above, which gives rise to an impacting and ramming effect tending additionally to force liquid through the passage into the zone of lowered pressure immediately above the valve seat. Such ramming effect can be accentuated by employment of a flared or trumpet-like passage facing downwardly and extending to the valve.

Not only does the downward acceleration greater than that of gravity tend to separate the inner column from the valve seat but it also tends to separate the spherical valve member from its seat as this valve member tends to be moved downwardly only by the accelerating force of gravity. Thus, in such a system, the spherical valve member forms no substantial impediment to upward flow of an increment of liquid into the tubular member. On the other hand, an additional bias, produced by a spring for example, can be imposed on the valve member so long as this bias does not prevent the desired pumping action.

In pumps of this class as heretofore known, the pump tubing has been reciprocated "bodily" or as a whole by suitable reciprocating mechanism located at the ground surface, the reciprocation being transmitted to the valve by the pipe functioning simply as a link. For example, see British Patent No. 130,332 (1920) to Denis, French Patent No. 850,942 to Moineau, also United States Patent No. 2,056,513 to Gambarini. In oil well practice, depths run to thousands of feet, the well holes are crooked, and the weight of a pump tubing with a column of oil in it runs to the order of 18 tons. These conditions bar use of a bodily reciprocating pump tubing, since the friction between the tubing and the earth for such depths, particularly for crooked holes, would be far beyond tolerance, and the loads involved (even if sufficiently strong tubing could be found) would require reciprocating mechanism of enormous bulk and power.

An object of the invention is accordingly to provide a pump of the general type mentioned wherein motion can be transmitted down the pump tubing without the necessity of "bodily" moving the tubing.

A more general object of the invention is to transmit reciprocative motion from a source of power at the ground surface down a solid elastic column (such as a string of pipe or rod) to the fluid displacing pump member at the bottom of the well, making use of longitudinal deformation waves of compression and expansion set up in the structure of the elastic column.

Still another object of the invention is to provide a novel method and apparatus for sonically pumping, i. e., pumping by use of sound waves, and, in the preferred embodiment, to oscillate a valved tubular member with respect to the fluid to be pumped and by transmission to such a tubular member of sound waves, whereby the tubular member is oscillated by wave motion.

Previously-proposed sonic pumping of liquids from wells has involved transmission of sound waves down the column of well fluid. Such a pump system includes a vertical pipe filled with a column of the pumped liquid and carrying a check valve at its lower end, this pipe being supported in the well so that the check valve is submerged. The column of liquid within the pipe was employed as the wave-transmission medium, the upper end of the fluid column being in contact with the piston of a sound wave generator. The mean pressure on such a liquid column increases toward the bottom end, at any section, is substantially equal to the hydrostatic head of the column thereabove, assuming discharge of liquid from the top of the column at atmospheric pressure. To cause liquid to enter the bottom of such a column through the check valve requires the presence, immediately above the check valve, of a rarefaction of an intensity approaching or greater than the hydrostatic pressure at the valve. This imposes limitations on the depth from which liquids can be pumped by such a system, particularly in pumping crude oils containing dissolved gases which tend to be liberated from the oil during periods of rarefaction. Any such system employing a column of pumped liquid as the wave-transmission medium is also open to the objection that it must be carefully primed to establish a continuous liquid column between the sound generator and the valve.

It is an object of the present invention to provide a simple sonic pumping system which need not be primed before starting and which, in fact, does not require that the pipe or tubing be completely filled with a continuous column of liquid at any time during the pump operation.

It is a further object of the invention to provide a pump capable of pumping liquids from great depths or against high hydrostatic heads, and to provide a novel method and apparatus for pumping which employs sonic principles and which does not employ and hence is not limited by the wave-transmitting characteristics of the liquid being pumped.

In one of its simplest embodiments, the tubular member mentioned above can be a part of, or secured to, an elongated pipe extending to the point where discharge of fluid is desired. For example, the tubular member may be a lower portion of a pipe suspended from the surface of the ground. It is an object of the present invention to send sound waves to such a tubular member through a metallic wave-transmission element, for example through the pipe itself. It is another object to pump a well by applying sonic oscillations to one portion of a tubing extending in the well and to transmit wave energy through the tubing to a fluid displacing member associated with valve structure carried thereby; also, in some embodiments, to reciprocate the upper or intermediate section of such a tubing to send sound waves longitudinally therethrough in a manner to actuate or cause pumping by a fluid displacing member associated with a valve structure.

In many instances, I prefer to increase the wave energy transmission to the valve structure by establishing a condition of resonance in a pipe supporting the valve structure. I have found, for example, that, if the frequency of the wave energy is properly related to the length of the pipe, the pipe at a position adjacent the movable fluid displacing member can be made to oscillate, i. e., it will be a "free end," namely, an end that will move within the elastic range of the material of which the pipe is formed. By establishing a condition of standing wave resonance in the pipe, a velocity anti-node can be made to occur in the pipe at the location of the fluid displacing member, and maximum amplitude of oscillation will then be obtained for a given application of driving force. It is an object of the present invention to provide a pumping system employing one or more of such principles, and to provide novel means for generating the sound waves and delivering them to a metallic wave-

transmission medium through which they are transmitted to a remote point.

If sound waves are transmitted longitudinally through a pipe to establish a condition of resonance, the relationship between the frequency and the length of the pipe may be such as to establish along the pipe a plurality of zones of maximum or substantial velocity variation, with intervening zones of minimum or small velocity variations. At these intervening zones, longitudinal to-and-fro motion of the molecules of the pipe will be small or negligible, and the energy at such sections will be primarily potential or stress energy. It is an object of the present invention to anchor such a pipe by rigid or somewhat resilient means at such intervening sections. Another object of the invention is to dispose a valve structure at one or more positions near or at zones of maximum velocity variation.

Further objects of the invention lie in the provision of a pumping system which can be satisfactorily operated to pump through straight or curved paths, and to provide a well-pumping system which can be used successfully in crooked or inclined wells; also, to provide a well-pumping system in which the minimum amplitude of sound waves employed for pumping is not necessarily determined by the depth from which the fluid is pumped.

In one illustrative embodiment of my invention, a pipe or tubing carrying a check valve near its lower end is supported in the well, with the lower end of the pipe submerged in the liquid to be pumped. The pipe is of highly elastic material, capable of a range of elastic deformation which allows alternate longitudinal portions thereof to be alternately compressed and expanded. A source of powerful vibrations, consisting typically of a highly unbalanced flywheel driven at high speed, is connected to the upper end of the pipe so as to deform it in rapidly reversing longitudinal directions, thus causing an adjacent portion of the pipe to be alternately stretched and compressed. These deformations in the pipe wall are transmitted down the elastic pipe as a series of alternating compression and expansion waves travelling with the speed of sound in the material of the pipe. The waves are characterized by elastic deformations causing, in adjacent half-wave portions, alternating simultaneously opposed movements and forces. The pump includes an oscillatory fluid displacement member in the pipe, located adjacent the valve, or included in the valve. As each wave passes through the portion of pipe containing this fluid displacing member, that portion of pipe experiences a slight longitudinal reciprocation as a result of the expansion and contraction movements occurring within the pipe wall. Continuous reciprocation of the fluid displacing member results in the pumping of liquid past the check valve.

Although pumping may be achieved using a form of my invention with only one check valve in the pipe, I prefer to use a series of such check valves, preferably located a half-wave length apart along the pipe, at velocity anti-node regions, in order to accomplish stagewise pumping. Those which are approximately a half-wave length apart move first toward one another and then away from one another, the portion of pipe between them alternately increasing in length, thus taking in liquid through the lower check valve, and then decreasing in length, thus expelling liquid through the upper check valve.

Further objects and advantages of the invention will be evident to those skilled in the art from the following description of exemplary embodiments of the invention.

Referring to the drawings:

Figure 1 is a foreshortened utility view showing one embodiment of the invention as applied to the pumping of a well;

Figure 2 is a sectional view of the same pumping system showing details of upper, intermediate, and lower sections thereof;

Figure 3 is a horizontal cross-sectional view, taken on the line 3—3 of Figure 2;

Figures 4, 5, and 6 are fragmentary views disclosing a vertical section of various forms of intake members, Figure 6 also showing a modified valve structure;

Figure 7 is a vertical sectional view of an alternative valve structure which can be employed for horizontal or vertical pumping;

Figure 8 is a vertical sectional view of another alternative valve structure;

Figure 9 is a section on line 9—9 of Figure 8;

Figures 10 and 11 are vertical sectional views of two additional alternative forms of valve structure;

Figure 12 is a foreshortened utility view of another embodiment of the invention;

Figure 13 is an enlarged view, partially in vertical section, of the pumping arrangement in Figure 12;

Figure 14 is a view taken along the line 14—14 of Figure 13;

Figure 15 is a view of the oscillation generator of Figure 13, shown with the cover removed;

Figure 16 is a sectional view of the oscillation generator, with cover attached, this view being taken along the line 16—16 of Figure 15;

Figure 17 is a sectional view showing a modification of a portion of the pumping system of Figure 2;

Figure 18 is a longitudinal sectional view of another embodiment of the invention;

Figure 19 is a view taken as indicated by arrows 19—19 on Figure 18;

Figure 20 is a utility view, partly in section, showing another embodiment of the invention;

Figure 21 is a vertical sectional view through the upper front end portion of the pumping system of Figure 20;

Figure 22 is a view taken in accordance with arrows 22—22 on Figure 21;

Figure 23 is a vertical sectional view showing a valve unit which may be employed in the pumping system of Figure 20;

Figure 24 is a view similar to Figure 23 but showing a modification;

Figure 25 is a section taken on line 25—25 of Figure 24;

Figure 26 is a section taken on line 26—26 of Figure 24;

Figure 27 is an elevational view showing the surface equipment of another modification of the broad invention;

Figure 28 is a vertical sectional view of the under-ground portion of the pumping system of Figure 27;

Figure 29 is a fragmentary vertical sectional view of another modified embodiment of the invention;

Figure 30 is a view, partly in elevation and partly in vertical section, of another modified embodiment of the invention; and

Figure 31 is a sectionalized view of still another embodiment of the invention.

Throughout the specification and in the claims I will for convenience refer to the pump as operating in a vertical well bore. However, the pump in certain of its forms will work in a horizontal bore, and the use of such expressions as "upper" and "lower" are therefore to be taken as relative and not limitative.

Referring particularly to Figure 1, I show a casing 15 set in a well bore 16, this casing being understood as perforated adjacent liquid-bearing strata 17 from which flows the liquid to be pumped. The lower end of the casing or, if desired, the lower end of the well itself, provides a well cavity 18 into which the liquid percolates through the casing perforations to form a body of liquid 19.

Extending downwardly in the casing 15 is a tubing or pipe 20 formed in sections coupled together either by welding or by use of conventional threaded collars. The lower end of this tubing extends into the body of liquid 19. As shown in Figures 1 and 2, the lowermost end of this tubing is open and forms an intake pipe 22 terminating at a valve structure 25 adjacent a section indicated in Figure 1 by the line A—A, this valve structure, functionally considered, comprising both fluid impelling and check valve means. That portion of the tubing 20 between the section A—A and a section B—B a short distance thereabove comprises the vertically-movable tubular member or fluid conduit previously mentioned and indicated by the numeral 26. This tubular member may be formed as a part of, or suitably connected to, the lower end of the remaining portion of the tubing 20 which extends to the surface of the ground. The junctures of this tubular member or conduit 26 with the tubing below section A—A and above section B—B may thus be regarded as the inlet and outlet, respectively, of the tubular member 26. In this embodiment of the invention, the upper end of the tubing 20 extends through a collar 28 secured to the upper end of the casing 15. Suitable attachment means is provided for anchoring the tubing to the casing at this point, for example internally-toothed and externally-beveled slips 29. If desired, the entire weight of the tubing 20 may be suspended from such an attachment means.

The valve structure 25, or fluid impelling and check valve means, includes in this instance, first: a sleeve 30 rigidly mounted in or with respect to tubular member 26 and providing an oscillatory fluid displacing member, a fluid conducting passage 31 and a valve seat; and second: a movable valve member 32, shown in this embodiment as comprising a rather massive ball urged downwardly by the force of gravity and confined in its relative movement with respect to the seat formed by the upper end of sleeve member 30 by a suitable cage 33. As will later become more apparent, the fluid displacing member 30 and the valve element 32 are not necessarily mutually exclusive in function. Thus, the valve element 32 functions as an oscillatory fluid displacing member to the extent of its vertically projected area on the upstroke, and it therefore cooperates with the end areas of sleeve 30 in the performance of that function. The larger its area relative to the diameter of the pump tubing, the more of the function of the fluid displacing member it takes over. Thus the valve element may also be a fluid displacing member. The expression fluid impelling and check valve means is hence used herein and in the claims to denote the valve element and its seat together with the means for

impelling fluid therepast, whether or not the valve element and the actual fluid displacing member (sometimes referred to herein as included in the fluid impelling and check valve means) are structurally one and the same. While it is desirable that the movable valve member 32 engage the seat portion of member 30 during a portion of each cycle to close the opening 31 against downward flow of liquid, this is not necessary in all instances and the use of the term "one-way valve" herein is not limited in this respect as the pump can be made to operate even if there is some reverse leakage so long as the members 30 and 32 move into a relative position to permit flow of liquid at one instant of time in the cycle and restrict or impede flow of liquid in a reverse direction at another period of time in the cycle. The sleeve or fluid displacing member 30 functions on each downstroke to displace fluid below it, causing such fluid to enter and travel upwardly through the valve controlled pasage 31, and on each upstroke to elevate the fluid above it, all as will be more fully described presently.

In the embodiment shown in Figures 1 and 2, a second valve structure 35 is shown as disposed above the valve structure 25, a section 34 of the tubing 20, of selected length, joining the two valve structures. The valve structure 35 is formed similar to that previously described and includes a sleeve member 36 secured to the tubing 20 and providing a fluid-conducting passage 37, as well as a valve seat and a fluid displacing member. A movable valve member 38 of spherical form may move with reference to the seat member 36, as determined by the confines of a cage 39.

The uppermost end of the tubing 20 is flange-connected to a head member 40 providing a discharge chamber 41 in open communication with the interior of the tubing. The pumped liquid may discharge from this chamber directly into the atmosphere or this discharge may be through a pipe 42 leading to the desired point of delivery of the pumped liquid. The discharge may be against an additional hydrostatic head. If desired, a spring-loaded check valve 43 may be disposed in the pipe 42, though this is not necessary to the operation of the invention. Particularly if the fluid being pumped includes large amounts of gas dissolved in liquid, the pump operates more satisfactorily if some such valve is provided to maintain a minimum back pressure.

Sound waves are delivered to the tubing 20 to traverse the tubing in a longitudinal direction. In the embodiment of Figures 1 and 2, this is accomplished by use of an oscillation or sound wave generator 50 connected to a rod 51 which is, in turn, connected to the tubing 20 at any suitable position below the attachment means 29. The point of connection of the rod 51 with the tubing 20 should be sufficiently below the attachment means 29 so that an intervening section of the tubing shall comprise a resilient member 52, which will be periodically compressed and expanded slightly when the sound wave generator 50 is in operation. This point of connection, may, in fact, be lowered sufficiently to make direct connection with the section of pipe 26 between the planes A—A and B—B, though in such case the wave path to pipe section 26 is down the rod 51 rather than via the tube 20. This illustrates the fact that the wave path need not be in the tubing, but may be in a solid rod. Any suitable metallic elastic column, hollow or solid, will serve as the wave transmission medium. As shown, the lower

end of the rod 51 is connected to the hub of a spider 53 which, in turn, forms a part of a coupling 54 for adjacent sections of the tubing 20. It is preferred that the hub and arms of the spider 53 be small in comparison with the internal cross-sectional area of the tubing 20, both to give a maximum-area passage for upward flow of the liquid and to avoid the transmission of sound waves directly to the liquid column within the tubing 20.

The oscillation or sound wave generator 50 is of novel construction. It includes a beam or lever 56 pivoted about an axis 57 by a heavy-duty bearing provided by the upper end of a post 58 extending upwardly from a platform 59, shown as secured to the head member 40. One end of the lever 56 carries a pin 60 extending between bifurcations of a connecting member 61 attached to the upper end of the rod 51. The other end of the lever 56 carries a pin 63 on which is journalled an unbalanced flywheel 64. The unbalance may be obtained in any suitable way but I prefer to accomplish this by use of a small adjustable mass 65 located eccentrically relative to the fly-wheel center. For example, a plurality of washer-like means 66 may surround a bolt 67 extending radially from the periphery of the flywheel 64, being held in place by a suitable nut 68. Such a system facilitates adjustment of the mass 65, and thus the unbalance of the flywheel 64, by changing the number of washer-like means 66.

The flywheel 64 carries a pulley 70 connected by a belt 71 to a pulley 72 driven by a variable-speed electric motor 73 or other drive means. The pulleys and the interconnecting belt member may desirably be of the V-type. The motor 73 is supported on the platform 59 and it is preferred, though not necessary in all instances, that the axis of the motor pulley 72 be aligned with the axis 57, though the pulleys 72 and the motor shaft are spaced laterally from the bearing journalling the lever 56.

It is usually desirable to maintain the rod 51 in tension sufficient to prevent compressive stresses therein during the operation of the generator 50. This may be accomplished by controlling the overall weight of the unbalanced flywheel 64, supplemented, if desired, by a weight 78 slidable along the flywheel-end of the lever 56 and connected thereto by any suitable clamping 79.

When the motor 73 is energized, the unbalanced flywheel 64 is rotated about the pin 63. Due to the eccentricity of the mass 65, rotation of the flywheel 64 causes vertical oscillation of the right-hand end of the lever 56, this lever pivoting about the axis 57. This causes the lever 56 to rock through a small locus of motion to impart longitudinal wave vibrations to the rod 51, this rod tending to be oscillated vertically in step with the rotation of the flywheel 64. The longitudinal vibrations of the rod 51 are substantially sinusoidal and are imparted to the tubing 20 through the spider 53. The tension in the rod 51, created by the flywheel 64 and the weight 78, is preferably sufficient to prevent compression forces in this rod which might tend to cause it to strike against the interior of the tubing at a free wave zone. The resilient member 52, comprising in the preferred embodiment an upper section of the tubing 20, is of sufficient length to permit slight vertical oscillation of the spider 53. A small vertical oscillation is thus imparted to the tubing 20 at a position between the attachment means 29 and the valve structure 25. This establishes a series or train of longitudinal waves traversing the tubing 20 from the spider to the lowermost end of this tubing. The speed of the motor 73 is preferably adjusted to establish a condition of standing wave resonance in the tubing 20. A standing sound wave is thus established in the tubing and utilized for transmitting substantial amounts of energy to the fluid displacing member 30 adjacent the valve structure 25. The wave length of the sound waves moving longitudinally through the tubing 20 will be a function of the rate of oscillation and the speed of sound in the metal of which the tubing is formed.

At properly selected frequencies of the generator 50, the valve seat and fluid displacing member 30 will be moved up and down in step with the oscillations imparted to the tubing through the spider 53. Under such conditions, the valve structure 25 is at a "free end" of the tubing and its vertical oscillations will pump liquid into and up the tubing 20 to discharge through the pipe 42. Consider, for example, that the pumping system has been newly installed in the well and that a short column of liquid has entered the tubing through the valve structure 25, this liquid column having a surface 80 slightly below a surface 81 assumed by the well liquid in an annular space 82 between the tubing 20 and the walls of the well cavity. For the time being, assume that no intake pipe 22 is attached so that the valve structure 25 is at the extreme lower end of the tubing 20. Slow vertical oscillations of the valve structure 25 will not exert a continuous pumping action for reasons noted above. However, when the fluid displacing member 30 is moved downwardly with an acceleration greater than that of gravity, it will displace the liquid in its path and an increment of liquid will be forced through the passage 31 to the upper side of the member 30.

If the vertical oscillation of the member 30 is sinusoidal, it is quite apparent that the downward stroke will include an acceleration period and a substantially equal deceleration period. During the first portion of the downward stroke, the acceleration will build up to a value greater than the acceleration of gravity. When this occurs, the member 30 is moving downwardly at a rate faster than the rate of fall of the spherical valve member 32 and the internal column of liquid. An increment of liquid thus enters the column. Depending upon the length of this greater-than-gravity acceleration and upon the laving action of the liquid stream on the lower surface of the spherical valve member 32, this valve member will assume a position either at the extreme upper end of the cage 33 or at a somewhat intermediate position. During the decelerating portion of the downward stroke, the valve member 32 will move closer to the seat portion of member 30. The greatest amount of pumping will take place if the valve member 32 engages the seat portion of member 30 at or near the extreme lower end of the stroke. However, some degree of pumping will be obtained so long as the valve member 32 seats or restricts return flow before the time that the member 30 reaches the extreme upper end of the following upward stroke. In other words, one way of operating the invention is to start the member 30 on its upward stroke even before the valve member 32 has been seated, in which instance there may be a slight return or downward flow through the passage 31 until the member 30 moves upward to engage the valve member 32 dropping under

gravitational force. Any remaining portion of the upward stroke, after seating of the valve member **32**, lifts the internal column of liquid. It will thus be apparent that the pump acts somewhat as a ratchet. Each oscillation of the valve seat **30**, which in this embodiment not only serves to seat the movable valve member but also, as a fluid displacing element, pumps, by displacement, a small increment of well liquid into the tubing above the valve structure **25**. These increments will, of course, raise the surface **80**. When this surface rises to the valve structure **35**, a very similar pumping action will take place. In fact, the valve structure **35** can be considered as a second stage of the pumping system. As its fluid displacing member **36** oscillates in step with the member **30**, it will be understood that it will accelerate downwardly at the same rate. The column of liquid inside the tubing **20** between the valve structures **25** and **35** cannot drop by gravity at the same rate as the member **36** is moving downwardly, thus accentuating the ramming effect at the valve structure **35**, following principles previously noted with reference to the valve structure **25**. Further, as the column of liquid rises above the valve structure **35**, the inertia of the upper column prevents its dropping under gravitational influence at a rate corresponding to the downward motion of the valve member **36**. Correspondingly, both valve structures aid in the pumping. If desired, any number of such valve structures can be disposed along the tubing **20** at appropriate points in the sonic system.

In practice, the actual vertical movement of the fluid displacing member **30**, for example, can be quite small, being usually from a small fraction of an inch to somewhat more than one inch. The actual velocity of the member **30** at the midpoint of its upstroke and its downstroke is relatively high. The peak wave amplitude and the amplitude of the oscillations of the member **30** are readily adjustable by changing the degree of unbalance of the flywheel **64**, as by adding or removing washer-like members **66**. This also controls the acceleration of the member **30** and, correspondingly, the pumping rate. Another method of controlling the pumping rate is by choosing a rotative speed of the flywheel **64** to cause oscillation of the member **30** at a harmonic frequency rather than the fundamental frequency hereinafter referred to. Resonance at fundamental or harmonic frequencies can be established by adjusting the speed of the driving motor **73** and this controls the frequency of oscillation of the member **30**.

I have found that a sonic drive for such a fluid displacing member is admirably suited to establishment of the desired oscillations, and that vertical accelerations far greater than the acceleration of gravity can be obtained. For example, with a frequency of 50 pulses per second and an amplitude of motion of the member **30** of one inch, the peak acceleration approaches 8600 ft./sec./sec., as determined by the sonic acceleration formula:

$$A=\omega 2_R$$

where A is the acceleration, $\omega=2\pi$ times frequency, and R equals stroke amplitude. From this, it will be seen that a stroke amplitude of one inch is many times that required for reasonable pumping rates. In practice, the frequency of oscillation of the fluid displacing member **30** can be from a few pulses per second to several hundred pulses per second.

Considering now the relationships between frequency and length of the tubing **20**, it is desirable that the distance between the attachment means **29** and the valve structure **25** shall be equal to an odd multiple of one quarter wave length of the sound waves employed. This disposes the valve structure **25** at a "free end" or anti-node of the system and insures its vertical oscillation in step with the sound wave generator, as well as providing maximum amplitude of oscillation for a given generator drive. In using the term "in step with" the sound wave generator, I have reference to movement of the fluid displacing member **30**, for example, and the lever **56** at the same fundamental or overtone frequency, irrespective of phase differences.

It is important to understand that the tubing **20** does not, in any such system, move up and down with equal amplitude at all sections. If the distance between the attachment means and the valve structure **25** is one quarter wave length, there will be an intervening section of the pipe, near attachment means **29**, in which substantially no vertical oscillations are present, this section being a zone of minimum velocity variation in the wave-transmitting medium, namely, the tubing **20**. Correspondingly, it becomes feasible to anchor the tubing **20** to the casing **15** by use of the attachment means **29**. Such anchoring may be rigid or resilient and serves the desirable function of centralizing the tubing **20** with respect to the casing **15**.

If the distance between the attachment means and the valve structure **25** is an odd multiple, greater than one, of the wave length, there will be, in fact, a plurality of such zones of minimum velocity variation disposed along the tubing **20**. These are zones in which the tubing **20** experiences little or no vertical oscillation—zones suitable for anchoring the tubing to the casing. It will be understood that such zones are spaced from each other by a distance of one half wave length. It will be understood, also, that a zone of maximum vertical oscillation will lie midway between each of the previously-mentioned zones. For example, in Figure 1 I have shown a system in which the attachment means **29** and the valve structure **25** are separated a distance of 2¼ wave lengths (wave length being indicated by λ). This gives rise to four intermediate zones of minimum oscillation of the tubing **20**, indicated in Figure 1 at the sections D, E, F, and G, where the tubing can most advantageously be anchored to the casing **15**, for instance, by anchoring means **85** (Figure 1) surrounding the tubing and in engagement with the casing wall, said means incorporating resilient bearing means to damp transverse movements of the pump tubing and prevent loss of energy into the casing. For the provision of means capable of transmitting sufficient vibratory energy to the casing to be transmitted to the surrounding formation to do useful work, and for claims made thereto, see my aforementioned application Serial No. 8,799. At low frequencies, the anchoring means **85** may be disposed several hundred feet apart but, if the system is designed for higher frequencies, they may be correspondingly closer together.

From a further study of Figure 1, it will be apparent that the valve structure **25** and the tubular member **26** are located at or near a zone of maximum vertical oscillation of the tubing **20**, i. e., at a velocity anti-node of the system. The same is true as regards the valve structure **35**, shown as intermediate sections F and G and as spaced one

half wave length from the valve structure 25. As is well known in the art of sonic wave transmission, the velocity anti-node zones of maximum vertical oscillations move, because of their half-wave spacing, 180° out of phase. In other words, this type of energy transmission relies upon the distributed elastance of the material; and is characterized by a form of elastic motion wherein zones spaced one-half wave length from each other move in relatively opposed directions. Therefore, assuming, for example, that a check valve is located at every velocity anti-node, as stated above, each check valve will move cyclically in a direction at any given instant which is opposite to the movement of the two check valves immediately above and below it. As a consequence, only half the total number of check valves are passing liquid at any one instant—the alternately spaced intervening valves moving at this instant in a direction opposed to that for passing liquid flow. I have found this new form of pumping motion to be especially advantageous because even during the upward motion of a valve it is causing an upward compression and acceleration of the liquid which assists the pumping action of the oppositely moving valve one-half wave length above. Therefore, by locating the valves relative to the wave length at all intermediate sections of motion as stated above, the pipe column operates as a multi-stage series of volume displacement pump sections each with inlet and discharge check valves. This relatively opposed movement of the adjacent check valves is best accomplished by establishing standing wave resonance in the pipe. However, resonance must be recognized as associated with the speed of sound in the pipe material (approximately 1700 feet per second), and with the relation of wave length in the pipe to pipe length. "Bouncing" resonance associated with the total mass of pipe and the compliance of the supporting structure is irrelevant. In a pump using that type of resonance, the total reciprocating mass is "bouncing" or reacting as a lumped mass upon the support springs which thus become a lumped compliance or elastance, the two factors controlling the resonant frequency. There are no standing waves along the pipe in a system employing that type of resonance. Standing wave resonance, on the other hand, depends upon the distributed mass (pounds per foot) in cooperation with the distributed elastance of the structure, both properties being distributed along the path to be followed by the wave. By use of wave motion in the pipe itself I have been able to more efficiently transmit longitudinal oscillations over large distances and also accomplish a form of pumping which is entirely distinct from prior art systems in which the pipe is oscillated as a whole with valve members moving substantially in unison. It will be understood, also, that similar valve structures can be disposed throughout the tubing 20 at corresponding intermediate sections, if this is desired, and that, if desired, the valve structures, such as 25 and 35, may be spaced a full wave length apart without departing from the spirit of the invention.

I have now described the pumping system of Figures 1 and 2 in a form wherein the effective length of the elastic column (in this instance the length between the point of attachment 29 and the valve 25) is one-quarter wave length, and in another form wherein the length of the column may be an odd multiple, greater than one, of quarter-wave lengths. The first example represents nearly the maximum wave length relative to column length that can be effectively used in accordance with the invention. Preferably, the wave length should thus be not much longer than substantially four times the length of the elastic column, amplitude of motion being rapidly lost as a quarter-wave length of the wave generated is extended beyond the length of the column. The matter may be better visualized when it is realized that a distinguishing feature of the present invention is use of a wave length sufficiently short relative to column length that parts of the elastic column will have appreciable and useful longitudinal movement relative to other parts of the column.

Thus far, the operation of the system has been described without reference to employment of the intake pipe 22 or any other intake member for the valve structure 25. Such an intake member is often desirable and the simplest embodiment is a relatively short intake member 90 depending from the valve structure 25, and shown in Figure 4. This tends to increase the ramming effect of the liquid below the valve structure 25 by partial confinement thereof, but does not change the fundamental mode of operation noted above. It is recognized that this short intake member 90 encompasses a lower column of liquid below the valve structure 25. As the member 30 moves downwardly at an acceleration greater than gravity, the inertia of this lower column tends to force liquid through the passage 31. A further ramming effect can be obtained by use of a flared or trumpet-shaped intake member 91, shown in Figure 5. Figure 6 shows another flared intake member 92 of slightly different form employed in conjunction with a different type of valve structure. As shown, the intake member 92 provides a seat member 93 engaged by a disc-like movable valve member 94 which is, in turn, urged resiliently into engagement with the seat member by a light spring 95 compressed between the valve member 94 and a pin 96 traversing a collar 97. The type of valve shown in Figure 6 is often advantageous as it has less inertia than the spherical-type shown in Figures 2, 4, and 5. The valve member 94 is actuated more in response to fluid displacement action causing pressure differences thereacross than by the inertia or gravitational effects on the valve member and as previously described with reference to the spherical-type valve member 32. Usually, it is desirable to provide a valve member 94 of sufficiently light mass and a spring member 95 of sufficient tension that the natural frequency of vibration of the member 94 will be substantially above the pumping frequency, thus assuring quick response of the valve member 94 to hydraulic pressure differences, and prevention of out-of-phase resonant motion.

Another type of intake member, often very desirable, is a long pipe, represented in Figures 1 and 2 as the intake pipe 22. It is desirable that this intake pipe be of such length as to be tuned with the remainder of the tubing 20, i. e., its length should be in some definite relationship to the wave length of the sonic vibrations. If this intake pipe is made of a length equal to one half the wave length of the sound wave in the pipe material, as suggested in Figure 1, the intake pipe will resonate in a particularly desirable manner, aiding in forcing the liquid upward through the valve structure 25. Such an arrangement insures that the valve structure 25 will be at a zone of maximum motion as the extreme lower end of the intake pipe 22, if unrestrained in its vertical

motion, will also be a zone of maximum motion if the system is in resonance.

If the intake pipe 22 has a length corresponding to one half wave length, an anchor 99 of the type previously disclosed may be disposed halfway between the valve structure 25 and the lower end of this intake pipe, as suggested in Figure 1. It will be understood, further, that the intake pipe 22 may be any multiple of one half wave length, though excessively long ontake pipes are usually not desired as the lowermost valve structure 25 should be in submerged position to insure self-priming of the system.

The tubular member 26 cooperates with the valve structure 25 and with the adjacent end of the intake pipe 22, or any of the intake members of Figures 4, 5 and 6, in defining a tubular structure containing two columns of liquid separated by the valve structure. Vertical oscillation of such a tubular structure will produce the pumping action previously described. It will also be recognized that the tubing portions immediately above and below the valve structure 35 form a similar tubular structure aiding in the upward pumping of the liquid. Stagewise pumping is often desirable as the pumping action exerted by the oscillations of one valve structure need be only sufficient to raise the liquid to the next valve structure.

The dimensional relationships of the rod 51 and the resilient member 52, with reference to the existing wave length of the sound waves, are not of controlling importance. The spider 53 may be disposed at a section of the tubing 20 which normally would have a maximum amplitude of vertical oscillation. On the other hand, this disposition of the spider 53 is in nowise necessary as vertical oscillations imparted to the tubing 20 at any position above the section D can be made to establish a standing wave therein under conditions of resonance noted above. The rod 51 need not be tuned to the system. However, considering that the extreme upper end of the rod 51 is a zone of maximum velocity variation, there are certain advantages in making the length of this rod substantially equal to one eighth wave length and making the total distance from the top of the rod, measured downwardly therethrough and thence upward through the resilient member 52 to the attachment means 29, substantially equal to one quarter wave length, in which event the attachment means 29 will be at a zone of maximum pressure variation and minimum velocity variation.

It should be understood that my pumping system is not limited to employment in a well nor to vertical pumping. For example, the tubing 20 can be disposed horizontally to extend into a mine shaft or through a slightly sloping opening penetrating a hill or substantially horizontally into any body of liquid. Such horizontal disposition of the tubing 20 is suggested in Figure 7, where the tubing is indicated by the numeral 100, the tubing oscillating in the direction of the double-headed arrow 101. A collar 102 connects the tubing to an intake member 103 of any of the forms previously described. The valve structure is indicated by the numeral 105 and is of a slightly different form, often desirable even in well pumping. For example, this valve member includes a seat member 106 providing a plurality of passages 107, respectively closed by flapper-type valve members 108 pivoted at 109. A small resilient force biasing the flapper valves toward closed position is provided by any suitable means, such as flat springs 110. In a horizontally-disposed system, the biasing action of such springs takes the place of the gravitational bias imposed on the valve members of Figures 2 to 6, inclusive. Forward acceleration of the valve structure 105 may desirably be at such rate that the seat member 106 moves forward faster than the valve members 108 can be accelerated by their associated springs 110 or by fluid presure on the valve members. As to this fluid presure and related inertia effects, it will be clear that the liquid ahead of the valve structure has a ramming effect tending to move each of the valve members 108 toward open position by establishing a difference in pressure thereacross. Also, of course, the columns of liquid on opposite sides of the valve structure, while not tending to move toward or away from the valve structure by gravitional force, do have substantial inertia tending to maintain these columns stationary in space as the valve structure moves forward, and this aids in the opening and closing of the biased valve members 108.

It has already been mentioned that the larger the area of the valve member 32 relative to the diamater of the pump tubing 22, the more of the function of the oscillatory fluid displacing member it takes over. In Figures 8 and 9 I have shown a modified valve consisting of a slightly elliptical butterfly 110 fitted within and pivoted off-center to the pump tubing 20. It will be understood that such a valve installed in the pump of Figures 1 and 2 will open and close by pivotal action, and that the movable valve element 110 fully performs the two functions of check valve and fluid propelling member. The vertical projected area of valve element 110 will pump just as does the end area of the tubular member 31 of Figure 2, and as does the vertical projected area of the ball valve 32 of Figure 2. The valve element 110 will also have a check valve action equivalent to the check valve action of ball valve 32 of Figure 2.

Figure 10 shows a modification in which the check valve structure itself has no fluid propelling function, the latter function being delegated to associated members in the pump tubing. The pump tubing, again indicated by reference numeral 20, is divided by two horizontal, vertically spaced walls 112 and 113 and a vertical connecting partition 114, the latter having a port 115 controlled by a vertically hung flap valve 116 which is pivoted at the top to partition 114 as shown. This valve tends to close automatically by gravity. The fluid displacing members in this instance are the upper and lower faces of walls 112 and 113, and the valve 116 opens and closes in response to fluid propelled by the displacing members 112 and 113 when the pump tubing is oscillated vertically at a rapid rate. For the purpose of the claims, the members 112 to 116 may again conveniently be referred to collectively as fluid propelling and check valve means.

Figure 11 shows another modification in which the valve itself does not participate in the fluid propelling function as a fluid displacing member. The pump tubing 20a has a lower end portion 117 of reduced thickness, providing an upwardly facing shoulder 118 and an upwardly facing bottom end 118a. In vertical wall 20b is a port 20c controlled by pivoted flap valve 119 closed by spring 119a. On each downstroke of the lower end portion of the pump tubing (assuming acceleration greater than gravity) the

oil column descends slower than said lower end of the pump tubing, and a void tends to be created therein causing outside well fluid to enter port 20c past valve 119. On the succeeding upstroke the valve 119 closes, and the well fluid is propelled upwardly by the fluid displacing members 118 and 118a. Again, the fluid displacing members 118 and 118a, and the valve 119, may be referred to collectively as fluid propelling and check valve means.

Another embodiment of the invention, employing a somewhat different oscillation generator, is suggested in Figures 12 to 16, inclusive. Here, the tubing 20 is provided with a short-type intake member 90 feeding the valve structure 25 which, in turn, is spaced from the valve structure 35 by one half wave length. The upper end of the tubing 20 is free to move with reference to the upper end of the casing 15, as best shown in Figures 13 and 14. The entire weight of the tbing 20 is supported by two leaf springs 120 disposed on opposite sides thereof and clamped thereto by a support structure 121. The ends of the springs are retained in saddles 124 mounted on a pair of channels 125 spaced a sufficient distance to receive the tubing 20. It will be understood that, if the support 121 is oscillated vertically, a standing wave can be established in the tubing 20 in accordance with the principles previously outlined. In this instance, however, the support 121 is resilient and is at or near a zone of maximum velocity variation, so far as concerns resonant vertical oscillations in the tubing 20, so that the distance between this support and the valve structure 25 should preferably be a multiple of one half wave length to insure that the valve structure will be at a free end of the system.

The upper end of the tubing 20 comprises a nipple 130 connected to an elbow fitting 131, from which extends a discharge pipe 132. The upper end of this elbow fitting carries a flange 133 to which is secured a box-like housing 134 of a novel type of oscillation generator, indicated generally by the numeral 135.

The details of this oscillation or sound wave generator are best shown in Figures 15 and 16. As there shown, the housing 134 provides a bottom wall 136 carrying two bearings 137 for respectively journalling axially-aligned shafts 138 and 139. The forward portion of the housing 134 is closed by a removable cover 140 which, in turn, carries two bearings 141 for respectively journalling the shafts 138 and 139. The shaft 139 carries a pulley 142 driven by a V-belt 143 extending to any adjustable-speed drive means, not shown.

Within the housing 134 are two intermeshing gears 145 and 146, respectively rotating with the shafts 138 and 139. Each of these gears is dynamically unbalanced by attachment of suitable off-center weights. For example, the gear 146 is shown as including arcuate weights 148 clamped to opposite faces thereof by bolts 149. The gear 145 carries similarly-connected weights 150. The gears 145 and 146 have an equal number of teeth and rotate in opposite directions. These gears are intermeshed in such relationship that the centers of gravity of the off-center weights are vertically above the shaft axes when in the position shown in Figure 11. When the gear 146 turns clockwise through 90°, the centers of gravity of the weights are in horizontal alignment with the shaft axes, the weights being on opposite sides of the shafts. Another 90° rotation will bring both sets of weights directly beneath the shaft axes, and a further 90° rotation will bring the centers of gravity of the weights between the shaft axes and in horizontal alignment therewith. Rotation of the unbalanced gears will thus establish vertical oscillatory forces which are applied to the bearings 137 and 141, thence to the housing 134, and thence to the upper end of the tubing 20.

It is a feature of this type of oscillation generator that any tendency for one unbalanced gear to establish horizontal oscillations is exactly opposed by the equal and opposite tendency of the other unbalanced gear to establish horizontal oscillations. Each of the shafts 138 and 139 tends to oscillate horizontally with corresponding forces delivered to the housing 134 but, as will be readily apparent, these oscillatory forces cancel each other, and that portion of the housing between the shafts is subjected to tension and compressive stresses. However, the housing 134 experiences no net horizontal oscillation, whereby there is no tendency for the upper end of the tubing 20 to be oscillated sidewise. Rather, the housing 134 oscillates vertically with substantial sinusoidal motion. This motion is transmitted to the upper end of the tubing 20 to establish the longitudinal waves therein. The resilient support, provided by the springs 120, permits the upper end of the tubing 20 to oscillate slightly in a vertical direction, and this oscillation will appear at the valve structure 25, having large amplitudes particularly when under conditions of standing wave resonance, to effect the type of pumping action previously described.

The force exerted on the upper end of the tube by the wave generator need not be sufficiently prolonged to result in bodily movement of the tube. Indeed, it is preferable that the tube experience little or no translation as a whole. It is desired that the applied force on the tubing serve primarily to slightly deform the upper portion thereof while the center of gravity of the tubing remains substantially stationary. A slight elongation strain of the tube, for instance, causes a wave of tensile stress to begin traveling down the tube (at about 17,000 feet per second in the case of an elastic metal). When a series of such waves are dispatched down the tube, the tension at any point will be periodically first somewhat greater, then somewhat less than existed when the tubing was merely hanging from its upper end in a static condition. As with other pumps, this static stress (upon which I add a stress wave) will be at a maximum in the upper portion of the tube immediately below the point of suspension and will decline uniformly to a minimum in the fibers at the lower end.

In many known pumps, a displacement force is applied and all portions of the tubing are translated simultaneously for a substantial distance. But in the present device a force need be briefly applied only to initiate a strain wave in the tube; after a peak force is reached it is immediately reversed in order that the first wave may be followed by another of opposite kind. The point in the tubing at which the center of gravity may be said to be located under static conditions experiences no reciprocating movement but other parts of the tube are at the same time moving longitudinally in opposite directions and the tube does not, in the operation of my invention, have to undergo any translation as a unitary body. I do find, however, that my wave transmission

invention will work while the tubing is being moved bodily.

In connection with this explanation it may be be observed that the spring supports of the tubing, in certain embodiments of my invention, provide for some longitudinal freedom of movement of the tubing wall at the point of support in order to permit the passage of an elastic wave past the point of support without appreciable damping. Spring characteristics of the support are not relied upon to return the section of tubing from its displaced position. The fibers of the tubing wall which are stressed in the process of being deformed provide the restoring force and the spring type support is used in the embodiments of Figures 13 and 14 solely to give these fibers freedom of action and to prevent the dissipation of energy through the support into the surroundings.

By use of sonic pumping systems such as hereindisclosed, I have been able to pump from depths far greater than possible in other sonic pumping systems. For example, I have pumped water from depths of 1500 ft. or more by a pumping system arranged as indicated in Figures 12 and 13, employing as the drive for the generator a ¾ H. P. electric motor. No preliminary priming of the system is necessary and high pumping efficiencies can be obtained.

While the invention desirably comprehends the transmission of longitudinal waves through at least a portion of the tubing **20**, it does not exclude transmission through other metallic wave-transmission paths such, for example, as might be provided by extending the rod **51** downwardly into operative connection with the tubular member **26**. Figure 17 (wherein members corresponding to similar members of Figures 1 and 2 are identified by like reference numerals but with primes added) shows such a modification. The rod **51'** thus extends downward to the tubular conduit member or section **26'** between the planes A—A and B—B, to which it is operatively connected by spider **53'** and coupling **54'** forming a part of said section. The rod **51'** thus becomes the elastic column providing the wave transmission path leading from the wave generator to the tubular member **26'**.

Figures 18 and 19 show another modification wherein the sonic vibrations are transmitted via a path other than the pump tubing. In this instance, the pump tubing **170** is horizontally disposed, and the metallic elastic column **171** extends transversely thereto. For instance, the tubing **170** might be a substantially horizontal pipe in a mine, and the column **171** might be a rod string extending down to it from the ground surface. Or, the tubing **170** might be intended to carry an explosive fluid, making it desirable that the generator be substantially removed from any part thereof, so that the transversely extending column becomes useful. An elastic wave generator **172**, typically of the type of Figures 14 and 15, is mounted on the upper end of column **171**, and the latter, while not shown with supports in Figure 18, may be supported in a fashion resembling the arrangements for the pump tubing **20** of Figure 13, if desired. The pump tubing is laterally widened opposite the column **171**, and provided with a flexible wall **173** to the center of which the column **171** is attached. On opposite sides of wall **173**, the tubing **170** is fitted with check-valves **174** and **175**.

The generator **172** transmits longitudinal vibrations down the elastic column **171**, causing the flexible plate or wall **173** to vibrate in and out. On each inward movement, valve **175** closes and valve **174** opens to permit fluid to be propelled therepast. On each outward movement, valve **174** closes, and the resulting suction developed behind it opens valve **175** and draws fluid into the space between the two valves. The flexible wall **173** thus constitutes in combination with the check valves **174** and **175** the fluid propelling and check valve means of this form of pump, the elastic waves being transmitted thereto from the generator **172** down the elastic column **171**. It is of course understood that the frequency of operation of the generator is sufficient to establish wave action in the column such that a portion of the column will have a substantial longitudinal movement relative to another portion of the column.

Reference is next directed to Figures 20 to 26, inclusive, showing another modification of the invention in which the vibrations are transmitted from the wave generator down a string of sucker rods to the fluid displacing member in the lower portion of the pump tubing, the fluid displacing member in this instance, however, not being affixed to the pump tubing, but on the contrary having relative movement within the pump tubing. Here, the pump tubing **180** is suspended within casing **181**, the upper end of tubing **180** being screwed into a central opening through tubing head **182**, to which is secured casing head **183** carrying casing **181**, the latter being provided with gas outlet pipe **183***a*. Upstanding from tubing head **182** is a tubular extention or cup **185**, the upper end of which is counterbored at **186** to receive the tubular lower end portion **187** of the base plate **188** of spring supporting means **189** for the sucker rod string **190** that extends downwardly through pump tubing **180**. The sucker rod string will be understood to be of elastic material, ordinarily steel of good fatigue properties. The upper end of string **190** is screwed into a suspension rod **191** which projects up through base plate **188** and top plate **192** of spring supporting means **189**, being slidably fitted in stuffing box **193** carried by base plate **188**. Rod **191** has near its upper end an enlarged head **194** received within a recess **195** formed in the top of top plate **192**, the bottom defining wall of recess **195** being bored through, as at **197**, on a diameter just sufficient to pass the rod **191**, so as to afford an upwardly facing shoulder **198** which is engaged by head **194**. Between the base member **188** and top member **192** are a plurality of coil springs **200**, which are positioned on vertical pins **201** set tightly into base **188** and projecting with working clearance through bores **202** in top member **192**. Preferably, the pins **201** are provided near their lower ends with washers **203**, which are welded both to the pins and to the plate **188**.

The weight of the sucker rod string **190** is thus transferred by rod **191** to top member **192** of spring supporting means **189**, and thus to the springs **189** which are in turn supported through base member **188** from tubing head **182**. The casing head **183** which carries tubing head **182** will be understood to be suitably supported to carry the load thus placed upon it by any appropriate supporting means, not shown. Tubing head member **185** will be seen to receive the flow from pump tubing **180**, and is provided with flow pipes **206**.

Mounted on the top end of rod **191**, above spring supporting means **189**, is a wave generator

210 which may be of the same general character as that disclosed in Figures 15 and 16. The wave generator 210 may differ from that of Figures 15 and 16 in that its two unbalanced weights 211 and 212 are mounted exteriorly of the generator housing, but it will be understood that the shafts 213 and 214 carrying said unbalanced weights are geared together inside the generator housing in the same manner as illustrated in Figure 15. One of the shafts, as 213, is provided with pulley 215 driven by belt 216. It will be understood that the function of this wave generator thus connected to the elastic sucker rod string is to transmit longitudinal waves down said string.

The top member 192 of spring supporting means 189 consists preferably of a plate 220 and webs 221 forming pockets within which oil-soaked waste may be lodged in order to maintain lubrication of the portions of the pins 201 that reciprocate in the bores 202 in plate 220 during the operation of the pump. For the purpose of lubricating rod 191 where it passes through stuffing box 193, an oil cup 224 may be supported on and above the stuffing box, and when filled with oil, will maintain proper lubrication of the parts for an extended period.

The lower end of rod string 190 is screwed into a fluid impelling and check valve unit 229 (Figure 20) which may be, for instance, of the type shown in either of Figures 23 or 24–26. Referring first to the form of Figure 23, rod 190 is screwed into cylindrical valve body 230, to which is fitted a flexible diaphragm 231 peripherally clamped by or to the surrounding pump tubing 180. Within valve body 230 is a valve chamber 232 containing valve ball 233 adapted to seat at the upper end of bore 234 leading upwardly from annular recess 235, the latter receiving fluid by way of a plurality of upwardly inclined passage ways 236 opening through the side of valve body 230. Leading upwardly and outwardly from valve chamber 232 are a plurality of fluid passageways 237 opening through the side of valve body 230. The valve body 230 is shown formed in its lower end with a screw threaded socket 238 adapted to receive a lower sucker rod section. For the check valve unit at the lower end of the rod string, the socket 238 is not needed and might have been omitted. Just as in the embodiments of Figures 2 and 9, however, for multi-stage pumping a plurality of the check valve units 229 may be employed in the sucker rod string, spaced apart preferably a half-wave length of the wave generated by the generator 210, as has been indicated in Figure 20. For the one or more additional valves above the lowermost one, the socket 238 must thus be provided.

In operation, the generator 210 is set into vertical oscillation, and transmits alternating longitudinal elastic deformation waves of compression and expansion down the length of the spring-supported elastic sucker rod string 190, the springs 200 oscillating in step with the vibration frequency of the generator, and the waves of compression and expansion being continuously transmitted down the sucker rod string to the one or more check valve and fluid impelling units 229 incorporated therein. From what has already been said of the earlier described embodiments of the invention, it will be understood that the sucker rod portion immediately adjacent each unit 229 will be set into vertical oscillation, and that the flexible diaphragm 231, which becomes a fluid displacing member, is oscillated accordingly. On each downward movement of the check valve body 230 and diaphragm 231, fluid within the pump tubing below the diaphragm is caused to flow inwardly through passageway 236 and upwardly past valve ball 233; and on each up stroke of the valve body 230 and diaphragm 231, the valve ball 233 seats, and liquid is propelled in an upward direction by the diaphragm 231 and the vertical projected area of the valve body 230 and ball 233 operating against the fluid column.

The reciprocable check valve unit shown in Figures 24 through 26 incorporates within its own structure the entirety of the fluid impelling and check valve functions. In this instance, the sucker rod string 190 is screwed into cylinder valve body 240, which is of a diameter to fit slidably within the pump tubing. Within a central region of the valve body is a valve chamber 241, and extending downwardly from the lower surface of this chamber are a plurality of passageways 242 leading to annular chamber 243, there being a plurality of fluid entrance passageways 245 extending upwardly into chamber 243 around the outside of the screw threaded sucker rod socket 246 formed in the bottom of the valve body. Valve balls 247 in chamber 241 seat at the upper ends of passages 242, and spacer pins 248 maintain them in proper position. A plurality of passageways 249 extend upwardly from valve chamber 241 around the upper sucker rod socket, and open through the upper end of the valve body as shown.

Assuming again vertical reciprocation of the end portion of rod 190 screwed into plunger 240 as a result of longitudinal deformation waves of compression and expansion transmitted down the sucker rod string from wave generator 210, the valve body 240 will be rapidly reciprocated at the frequency of operation of the wave generator, to pump fluid in an upward direction therethrough. On each down stroke fluid is displaced by the lower end area of the valve body 240 and caused to flow upwardly through passageways 245 and 242 to enter the valve chamber 241, past the unseated balls 247, and on each up stroke of the valve body, the increment of fluid thus pumped into chamber 241 is elevated by the vertical projected area of the valve body and balls 247 which are effective against the column of oil above, the valve balls 247, of course, seating at such time.

It will be evident that the check-valved body 240, oscillated vertically by the longitudinal elastic deformation waves transmitted down the rod string, becomes both fluid impelling and check valve means. As in the case of Figure 23, the valve assembly of Figures 24–26 may be used either at the lower end of the sucker rod string, in which case the bottom socket 246 is not used, or a plurality of such valves may be used in the rod spring, preferably at spacings of one-half wave length, in which case the lower sucker rod sockets in all units but the lowermost are used.

Modifications of the invention have now been disclosed wherein the pump plunger is rapidly reciprocated through a small amplitude stroke by means of alternating longitudinal elastic deformation waves of compression and expansion transmitted down a string of sucker rods as the elastic column. In a further modification, the sucker rod string may not only have longitudinal deformation waves thus transmitted down its length, but may also be slowly bodily reciprocated through a relatively long pump stroke. Such an embodiment is disclosed in Figures 27

and 28, to which reference is now directed. In said figures, numeral **300** designates generally a more or less conventional counter-weighted walking beam, which is pivotally mounted at **301** on a suitable supporting structure **302**, the walking beam being oscillated in a vertical plane by means of the usual crank **303** and connecting rod **304**, driven in any conventional manner. At the forward end of walking beam **300** is a head **306** having at its bottom a projecting ledge **307**, and having demountably secured to its top a projecting plate **308**, the ledge **307** and plate **308** being vertically perforated to receive a rod **309** that carries at its top end a vibrator **310** serving as a longitudinal wave generator. This generator may again be of the general type disclosed in Figures 15 and 16, being understood to have within its housing a pair of spur gears, the shaft **311** of one of said gears being provided with pulley **312** driven by belt **313** from electric motor **314** mounted on walking beam **300**, preferably immediately over supporting structure **302**. Shaft **311**, and the shaft **315** carrying the other spur gear of generator **310** are provided with unbalanced weights **316**, like those described in connection with the generator of Figures 15 and 16, the only difference being that the weights are outside the generator housing in the instance of Figure 27.

Rod **309**, which is vertically reciprocable in members **307** and **308**, has midway between said members a head or flange **317**, and a pair of coil compression springs **318** and **319** encircle rod **309** between said head **317** and the members **307** and **308**, respectively.

The lower end of rod **309** is connected to the upper end of the polished rod **320** of the well through any conventional means such as indicated at **321**, said means including a horizontal pivot joint at **322** to permit the rocking action of the walking beam.

Polished rod **320** extends downwardly through stuffing box **326**, into pump tubing **327** suspended inside casing **328**, a pump plunger **329** of any suitable character being connected to the lower end of the elastic sucker rod string **330** suspended from polished rod **320**. The column of oil in the tubing is delivered by way of flow pipe **327***a*. The plunger **329** might be of the character known in conventional well pumps employing sucker rods, or it might be of the type disclosed in Figures 24 to 26, or any other suited to the purpose. A standing valve **340** is shown in the bottom of the pump tubing.

The pump of Figures 27 and 28 might be operated with the walking beam stationary, in which case its operation is similar to that described in connection with Figures 20 to 26, the standing valve **340** being in this instance unnecessary. The vibration generator **310**, operated at suitable speed, transmits longitudinal deformation waves of compression and expansion down the sucker rod string to the check-valved pump plunger **329**, causing the latter to oscillate rapidly through a small amplitude, e. g., a fraction of an inch, such action being permitted by the springs **318** and **319** which support the sucker rod string and wave generator for vertical reciprocation relative to the walking beam. The oscillating plunger functions as check valve and fluid impelling means, in accordance with principles already disclosed, and the fluid column is elevated accordingly. In addition to this action, the walking beam **300** may be slowly reciprocated so as to give the sucker rod string not only a rapid wave motion causing portions thereof to reciprocate rapidly in a vertical direction through an amplitude of the order of a fraction of an inch, but also to have a slow vertical pumping stroke of the order of several feet. This long stroke action of the rod string and connected plunger, in conjunction with the standing valve **340**, will result in pumping in the manner of the conventional deep well plunger pump. When both types of movement of the sucker rod are used in combination, the result is additive. It should also be noted that pumping in accordance with the principles of the present invention can be accomplished by a sufficiently rapid, low-amplitude oscillation of the walking beam **300**. This would only require a shortening of the crank arm **303** so as to give a small amplitude reciprocation to the upper end of the sucker rod string. In order to give the necessary wave pattern in the rod string by which the invention is characterized, the walking beam will of course have to be oscillated or vibrated at a frequency comparable to that at which the wave generator **310** is otherwise driven. In other words, the walking beam in this case becomes the wave generator. It should also be noted that in such a version of the invention, the springs **318** and **319** are no longer necessary, it being sufficient that the sucker rod string is suspended from the walking beam in the ordinary way.

In certain of the previously described embodiments of the invention, the longitudinal wave action has been transmitted down the pump tubing, the pump tubing usually having rigidly connected thereto the fluid impelling and check valve means. In a modification, the longitudinal vibrations have been transmitted down an elastic rod string to a point adjacent the fluid impelling and check valve means, where an operative connection to the tubing is made (Figure 13). In other modifications, the longitudinal waves are transmitted down a sucker rod string directly to the pump plunger, which is reciprocable within the pump tubing, rather than rigidly connected thereto (see Figures 20–26). In Figure 29 is shown a further modification of the invention wherein the longitudinal vibrations are transmitted down the pump tubing, but wherein the fluid impelling and check valve means is not rigidly connected with the pump tubing but on the contrary is vertically reciprocable therewithin. There are various evident variations of this form of the broad invention, but that shown in Figure 29 may be taken as illustrative. The pump tubing **350** will be understood to serve as a means transmitting alternating longitudinal waves of compression and expansion from an elastic wave generator coupled to its upper end to the barrel **351** screwed to its lower end. The longitudinal wave motion in the tubing **350** may for this purpose be set up just as in the embodiment of Figure 13, where longitudinal wave motion is transmitted from generator **135** down the tubing **20**, the tubing being supported by spring means **120**. Just such an arrangement may be utilized in connection with the embodiment of Figure 29, it being understood that the pump tubing **350** of Figure 29 corresponds to the pump tubing **20** of Figure 13. Alternatively, the longitudinal vibrations may be transmitted down through the tubing **350** using such a rod string for the elastic column as the rod string **51'** of Figure 17, it being understood that such a rod string would be connected to the pump tubing **350** at a point adjacent the lower end thereof.

Whatever the specific arrangements adopted, it will be understood that longitudinal deformation waves of proper frequency are transmitted through an elastic column to reach and cause vertical oscillation of the barrel 351.

Mounted for sliding reciprocation within barrel 351 is a pump plunger 352, formed with a central fluid passage 353, extending vertically therethrough, and equipped at the upper end of said passage 353 with a check valve, here shown in the form of a valve ball 354 seating at the upper end of passageway 353, a suitable cage 355 for the ball 353 being provided on the upper end of plunger 352. Plunger 352 is mounted between a pair of coil springs 356 and 357, the former of which seats upwardly against a centrally perforated flange 358 formed in the upper end of barrel 351, and the latter of which seats against a flange 359 on a ring 360 screwed into the lower end of barrel 351, flange 359 being centrally perforated as indicated at 361. The port 362 in flange 358 and the port 361 in flange 359 may preferably be controlled by check valves 363 and 364, respectively, though such valves are not essential to operation of the pump.

Operation of the pump will first be considered without the valves 363 and 364, the ports 361 and 362 being assumed to be open. First assume that the mass of the plunger or piston 352 and the stiffness of springs 356 and 357 are tuned to a much lower frequency than the frequency of the longitudinal waves transmitted down the pump tubing to the barrel 351. That is to say, the natural resonant frequency of the plunger 352 mounted between the springs 356 and 357, is to be assumed as much lower than that of the waves in the pump tubing. It will of course be understood that the greater the mass of the plunger 352, and the less the stiffness of the springs 356 and 357, the lower will be the resonant oscillation frequency of the plunger 352; and with this understanding, the resonant frequency of the plunger 352 may readily be made less than that of the waves transmitted down the pump tubing. In this situation, the longitudinal waves transmitted down the pump tubing will result in vertical oscillation of the barrel 351 at the frequency of the wave generator coupled to the pump tubing, while the plunger 352 will stand substantially stationary in space. On each upstroke of the barrel 351 relative to the plunger 352, an increment of well fluid displaced by the wall or flange 359 (functioning as an oscillatory fluid displacing member) is forced upwardly through the passage 353 in plunger 352 and past the valve ball 354. On the succeeding down stroke of the barrel 351, the valve ball 354 seats, and a void is created in the space between the plunger 352 and the wall 359, causing inflow of well fluid into said space by way of the port 361. It will be seen that the result of reciprocating the pump tubing and the barrel 351 connected to its lower end is to impel successive increments of well fluid through the plunger member 352, elevating the oil column above accordingly. If the valve 364 is employed, additional well fluid is forced upwardly through the plunger 352 on each upstroke of the barrel 351 owing to the impossibility of some fluid escaping via port 361. Pumping also results from the action of the wall 359 in combination with the valve 364 since this combination, connected to the lower end of the barrel 351, will be recognized to be a pump of the character preliminarily described in connection with Figures 1 and 2.

Substantial improvement in the pumping rate is achieved by adjusting the mass of the plunger 352 relative to the stiffness of the springs 356 and 357 in a manner to tune the system to approximately the same frequency as the wave motion in the pump tubing. Reciprocation of the pump tubing and barrel 351 will then result in vertical oscillation of plunger 352 at the same frequency and in step with the barrel 351, but at increased amplitude. In other words, plunger 352 moves up and down with barrel 351, but with an amplitude which may be a number of times that of the oscillation of the barrel 351. Operation in this mode may first be considered with valves 363 and 364 disregarded. It should be evident that operation will be analogous to that of the embodiment of Figures 1 and 2, excepting that the increased amplitude of movement of the plunger 352 will result in a correspondingly increased pumping rate. On each downstroke of plunger 352, well fluid will be displaced thereby and forced upwardly through passage 353 and past valve ball 354. On each upstroke of plunger 352, valve ball 354 seats, and the column of oil is elevated. Use of valve 364 increases the fluid that will be forced upwardly through plunger passage 353 on each downstroke of the latter, since outflow by way of port 361 is prevented. Thus the pumping rate is increased. Use of the valve 363 is beneficial, since the column of oil above is prevented from descending with each downstroke of plunger 352. The void so created between valve 363 and the plunger 352 on each downstroke of the latter also helps in that the fluid flow upwardly through plunger 352 is increased because of the suction created immediately above it.

Figure 30 shows a modification of the broad invention in which the fluid impelling and check valve means embodies a fluid displacing plunger in the pump tubing and a power driven valve. Numeral 370 designates the usual pump tubing, and extending downwardly therein is a solid rod string 371 which forms the elastic column, the other end of said rod string having connected thereto wave generator 372, which again may be of the general type shown in Figures 15 and 16. In this instance, however, the belt drive of Figures 15 and 16 is substituted for by extending one of the generator shafts 373 and connecting it by means of transmission shaft 374 and suitable universal coupling 375 to the shaft 376 of electric drive motor 377.

The lower end of elastic column 371 carries plunger 378, to which is fitted flexible diaphragm 379 connected at its periphery to the pump tubing as diagrammatically indicated in the figure. A by-pass tubing 380 opens into pump tubing 370 above and below diaphragm 379, and contains power driven valve 381, the latter typically employing a ported valve rotor 382 having drive shaft 383 connected by bevel gears at 384, a vertical drive shaft 385, and bevel gears at 386, to the shaft 376 of drive motor 377.

Generator 372 establishes longitudinal deformation waves traveling downwardly in elastic column 371, causing the lower end portion thereof to oscillate vertically at the frequency of the wave generator 372. The rotor 382 is so timed as to open the tubing 380 on each downstroke of plunger 378 and flexible diaphragm 379, so that fluid displaced by said plunger and diaphragm at such time will flow upwardly in tubing 380 and be added to the fluid column above. On the upstroke of the plunger and diaphragm, valve

rotor 382 closes tubing 380 so as to prevent reverse flow. It should be evident that the pump of Figure 30 is a species of the broad invention disclosed herein, the primary difference being in the specific arrangement of the check valve means, which is placed in a by-pass tubing outside the main pump tubing, and which secures its check valve action by means of a synchronized power drive; thus impact of fluid or vibration of structure are unnecessary for valve operation. The specific fluid impelling means in Figure 30 is in the form of a combination plunger and diaphragm, but it will be evident that the plunger might be enlarged to slidably fit within the pump tubing, in which case the diaphragm would not be necessary, all as suggested by Figure 24.

Figure 31 shows still another modification, in which the elastic column is folded or corrugated in a bellows-like fashion to greatly shorten its length, as well as the wave length of longitudinal waves traversing its length. This construction makes possible a relatively compact, multi-stage, high pressure pump. The elastic column 400 is made up of a multiplicity of outwardly-folded bellows sections 401, each flange-connected to the next, and with intervening valve plates 402 having central ports 403 controlled by check valve balls 404. To the lower bellows section is connected a box section 405 formed with an inlet 406 to which a flexible intake pipe may be connected. To the upper bellows section is connected a box section 408 having outlet 409 to which a flexible outflow pipe may be connected. Box section 408 is suspended from vertical rod 410 having mounted on its upper end longitudinal vibration generator 411 of the usual character. Rod 410 is carried by transverse plate 412 supported on suitable springs 413. It should now be evident that the pumping system of Figure 31 is broadly equivalent to that of Figures 12 and 13, and operation will be in accordance with the principles previously disclosed in connection with said figures. The wave lengths along the elastic column made up of a plurality of bellows sections will, however, be very considerably shortened, so so that longitudinal wave action in the elastic column made up of the bellows section will result from vertical reciprocation of the suspension rod 410 by the generator 411. As the longitudinal waves pass the several valve plates 402 in succession, said plates function as oscillatory fluid displacing members to force the fluid upwardly through the valve controlled ports 403, the plurality of such check-valved plates 402 giving a multi-stage pumping action of the general character discussed in connection with the earlier described embodiments of the invention. The bellows construction, as already mentioned, makes possible a very compact arrangement, and adapts the principles of the invention to ground surface pumps where compactness is of importance.

While I have disclosed the invention with particular reference to the pumping of liquids and as it is particularly adapted thereto in view of the relatively large inertia effects of liquid bodies, it should not be understood that I am limited thereto. With sufficiently high accelerations, readily obtainable by sonic means, it is possible to pump other fluid, such as gases, or mixtures of liquids and gases. By the use of terms such as "sound," "sonics," "sound waves," etc., I have reference to wave transmission which proceeds with the speed of sound, without limitation to frequencies within human audible range. Further, as used in this specification and in the attached claims, the term "column member" refers to a structural member of solid material, e. g., a string of pipe or rod. It does not cover a column comprised of liquid. Hollow column members may be used to pipe fluid but the fluid therein is not employed as a means for transmitting the elastic waves. Liquid column wave transmission of power is expressly disclaimed.

Various changes and modifications can be made without departing from the spirit of the invention as defined in the appended claims.

I claim:

1. In a pumping system: a fluid conduit having an inlet and an outlet, fluid impelling and check valve means in said conduit between said inlet and said outlet, said means including an oscillatory fluid displacing member for pumping fluid in a forward direction in the conduit, an elastic column of solid material capable of a range of longitudinal elastic deformation allowing a portion thereof to be alternately longitudinally deformed in opposite directions relatively to another portion of the column by virtue of successive compression and expansion waves transmitted longitudinally through the structure of the column, an operative connection between said deformable portion of said column and said fluid displacing member by which said member is oscillated as a result of said deformation movement of the column, and an elastic-wave generator operatively connected to said column adapted to continuously transmit alternating compression and expansion waves longitudinally through the structure of the column to cause said alternating longitudinal deformation thereof.

2. In a pumping system: a fluid conduit having an inlet and an outlet, fluid impelling and check valve means in said conduit between said inlet and said outlet, said means including an oscillatory fluid displacing member for pumping fluid in a forward direction in the conduit, an elastic column of solid material capable of transmitting elastic deformation waves of compression and expansion longitudinally through the structure thereof, said column having a portion operatively connected to said fluid displacing member, and a wave generator operatively connected to the column in a manner to generate alternating longitudinal elastic deformation waves of compression and expansion therein for transmission through the structure of the column to alternately compress and expand the portion thereof connected to said fluid displacing member and thereby oscillate said fluid displacing member, said wave generator being operable at a speed to generate longitudinal waves in the structure of the column having a quarter wave length which is no longer than substantially the length of the column.

3. A pumping system as defined in claim 2, in which said generator operates at a speed sufficient to provide a plurality of quarter-wave lengths along the column.

4. A pumping system as defined in claim 2, having means substantially fixedly mounting said column at a point near its upper end, and in which said generator operates at a critical speed providing an odd number of quarter-wave lengths, greater than one, along the column, to establish in the column a condition of substantial standing wave resonance, with a velocity antinode near said fluid displacing member and a velocity node at said substantially fixed mounting means.

5. In a well pumping system: a fluid conduit having an inlet and an outlet, fluid impelling and check valve means in said conduit between said inlet and said outlet, said means including an oscillatory fluid displacing member for pumping fluid in a forward direction in the conduit, an elastic column of solid material capable of transmitting elastic deformation waves of compression and expansion longitudinally through the structure thereof, said column having a portion operatively connected to said fluid displacing member, means yieldingly supporting the upper end portion of the column for vertical oscillatory movement, and a wave generator operatively connected to the column in a manner to generate longitudinal elastic deformation waves therein for transmission through the structure of the column to said fluid displacing member, said wave generator being operable at a critical speed establishing a condition of substantial standing wave resonance in the column with substantial velocity antinodes at the region of said supporting means for the upper end portion of the column and the region of said fluid displacing member, and thereby effect alternating elongation and contraction of said portion of the column at maximum amplitude in the region of said fluid displacing member.

6. In a well pumping system: an elastic pipe suspended in a well and having an inlet at its lower end and an outlet at its upper end, said pipe being capable of a range of elastic deformation allowing a lower portion thereof to be alternately longitudinally deformed in opposite directions relatively to a higher portion of said pipe by virtue of alternating compression and expansion waves transmitted longitudinally through the walls of said pipe, fluid impelling and check valve means in said pipe between said inlet and said outlet, said means including an oscillatory fluid displacing member for pumping fluid in an upward direction in the pipe; said fluid displacing member being operatively connected to said deformable lower portion of said elastic pipe so as to pump as a result of elastic deformation movement of said lower portion of said pipe, and an elastic-wave generator operatively connected to said pipe adapted to continuously transmit alternating compression and expansion waves longitudinally through the walls of said pipe to cause said oscillatory longitudinal deformation of said lower portion of said pipe.

7. In a well pumping system: an elastic pipe suspended in a well and having an inlet at its lower end and an outlet at its upper end, means yieldingly supporting the uppr end portion of the pipe for vertical oscillatory movement, said pipe being adapted to transmit elastic waves of compression and expansion longitudinally through the walls thereof, fluid impelling and check valve means in said pipe between said inlet and said outlet, said means including an oscillatory fluid displacing member for pumping fluid in a forward direction in the pipe, said fluid displacing member being operatively connected to a portion of the pipe so as to pump as a result of elastic deformation movement of said portion of the pipe, and a wave generator operatively connected to the pipe in a manner to generate alternating longitudinal elastic waves of compression and expansion therein for transmission through the walls of the pipe to said portion thereof to alternately compress and expand and thereby oscillate the same, said wave generator being operable at a critical speed establishing a condition of substantial standing wave resonance in the pipe with substantial velocity anti-nodes at the region of said supporting means for the upper end portion of the pipe and the region of said fluid displacing member, all in such manner as to effect vertical oscillation of said portion of the pipe at maximum amplitude in the region of said fluid displacing member.

8. In a pumping system: a pump tubing adapted to be suspended in a well, said tubing having an inlet and an outlet, fluid impelling and check valve means in said tubing between said inlet and said outlet, said means including an oscillatory fluid displacing member for pumping fluid in an upward direction in the tubing, an elastic rod within said pump tubing, said rod being capable of a range of longitudinal elastic deformation allowing a portion thereof to be alternately longitudinally deformed in opposite directions relatively to another portion of the rod by virtue of successive compression and expansion waves transmitted longitudinally through said rod, an operative connection between said deformable portion of said rod and said fluid displacing member by which said member is oscillated as a result of said deformation movement of the rod, and an elastic wave generator operatively connected to said rod adapted to continuously transmit alternating compression and expansion waves longitudinally through said rod to cause said alternating longitudinal deformation thereof.

9. A method for operating a well pump having a tubular fluid conduit provided with fluid impelling and check valve means that includes an oscillatory fluid displacing member for pumping fluid through the conduit, and having also an elastic column of solid material supported in the well and operatively connected to said fluid displacing member, that includes: continuously transmitting alternating waves of compression and expansion downward through the material of said column at a sufficient frequency to provide quarter-wave lengths of elastic deformation in the column which are not substantially longer than the column length, thereby causing the portion of the column to which said fluid displacing member is connected to experience appreciable compression and expansion deformations and said fluid displacing member to oscillate at an amplitude sufficient to accomplish pumping of fluid.

10. A method as defined in claim 9, wherein the frequency of the deformation waves is made such as to establish standing wave resonance in the column.

11. A method for operating a well pump having an elastic pipe suspended in the well, said pipe carrying oscillatory fluid displacing and check valve means for pumping fluid upwardly in the pipe, that includes: continuously transmitting alternating waves of compression and expansion downward through the walls of the pipe to said oscillatory fluid displacing and check valve means at sufficient frequency to provide quarter-wave lengths of elastic deformation in the pipe which are not substantially longer than the pipe length, thereby causing the pipe to experience appreciable longitudinal compression and expansion deformations and said fluid displacing and check valve means to oscillate at an amplitude sufficient to accomplish pumping of fluid.

12. A method as defined in claim 11, wherein

the frequency of the deformation waves is made such as to establish a resonant standing wave along the pipe.

13. In a pumping system: an elastic pipe having an inlet and an outlet, said pipe being capable of a range of elastic deformation which allows alternate longitudinal portions thereof to be simultaneously longitudinally compressed and expanded by successive compression and expansion waves continuously transmitted therealong through the structure thereof, a plurality of fluid impelling and check valve means mounted within and spaced longitudinally along said pipe, said means including oscillatory fluid displacing members for pumping fluid in a forward direction in the pipe by virtue of longitudinal deformation movements of the pipe, and means for sending alternate compression and expansion waves along said pipe through the structure thereof to simultaneously compress and expand alternate longitudinal portions of the pipe and to alternately compress and expand the pipe portions in which said oscillatory fluid displacing means are contained, whereby said fluid displacing members are oscillated in response to said alternate compression and expansion of said pipe portions to pump fluid from said inlet toward said outlet in substantially a stagewise movement.

14. In a pumping system: a conduit having an inlet and an outlet, fluid impelling and check valve means in said conduit including an oscillatory fluid displacing member, an elastic column of solid material capable of a range of elastic deformation allowing portions of the column to be alternately shortened and elongated by longitudinal waves of compression and expansion transmitted longitudinally therethrough, an operative connection between a portion of said elastic column and said oscillatory fluid displacing member by which said member is oscillated in response to compression and expansion deformation movements occurring therein, means for continuously generating and transmitting longitudinal deformation waves of compression and expansion in and along said column, at a frequency to establish a standing wave therein having a velocity node, and supporting means for said column engaging said column at said velocity node.

15. In a pumping system: a conduit having an inlet and an outlet, fluid impelling and check valve means in said conduit including an oscillatory fluid displacing member, an elastic column of solid material capable of a range of elastic deformation allowing portions of the column to be alternately shortened and elongated by longitudinal waves of compression and expansion transmitted longitudinally therethrough, an operative connection between a portion of said elastic column and said oscillatory fluid displacing member by which said member is oscillated in response to compression and expansion deformation movements occurring therein, means for continuously generating and transmitting longitudinal deformation waves of compression and expansion in and along said column, and resilient bearing means for said deformable elastic column for damping transverse movements of said column.

16. A combination as defined in claim 1, in which said wave generator includes a pair of unbalanced oppositely-rotating members, bearing means for journalling said members, said bearing means being subjected to oscillatory forces due to the unbalance of said members, and means for operatively connecting said bearing means to said column.

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