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MEANS FOR RAISING LIQUIDS FROM GREAT DEPTHS

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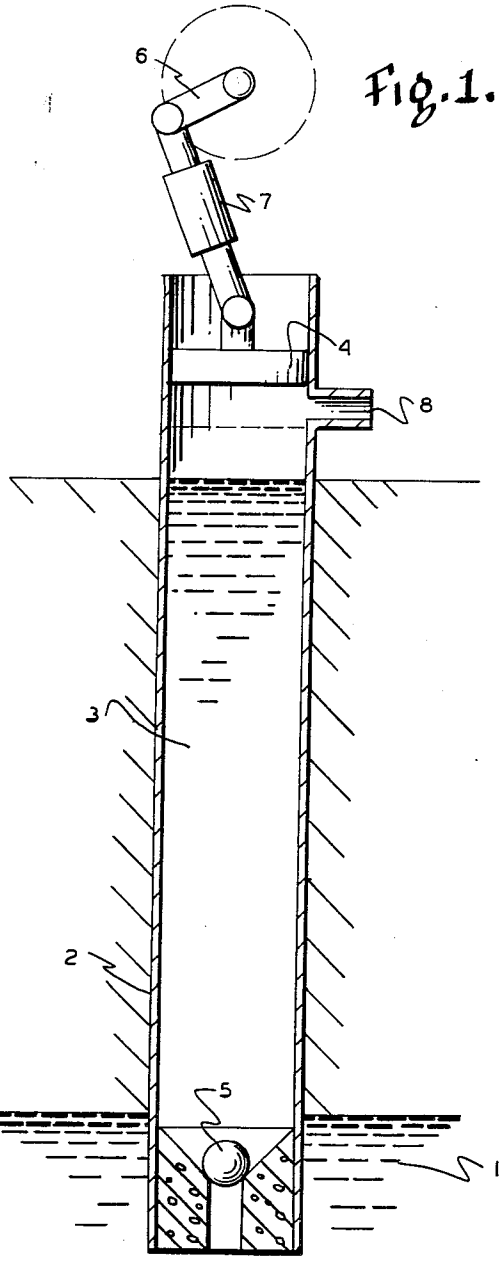


Fig. 1.

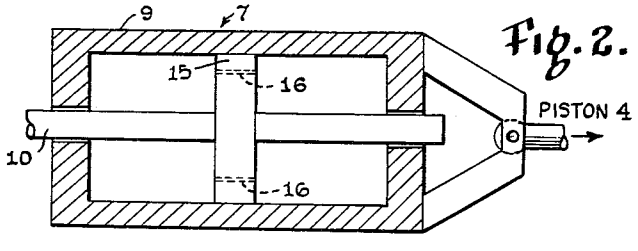


Fig. 2.

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MEANS FOR RAISING LIQUIDS FROM GREAT DEPTHS

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1 Claim. (Cl. 103—75)

The present invention relates to a means of improving the efficiency of removal of liquids from great depths as in pumping oil or water wells and the like.

While attempts have been made to use wave motion in a liquid column for this purpose, it appears that the principles have not been correctly applied to obtain the desired results.

In order to accomplish the desired result, it is necessary to use the natural resonance of the liquid column in which case the pressure node or nodes of the standing wave in the column are in the column of the liquid away from the end which must have velocity maxima in opposite directional phase. A further criterion in the easy operation of such a system is that in the initial transient state of operation, until the steady state resonance condition has been reached, the amplitude of motion applied at the outlet end or top end of the system must be slowly increased. In fact full amplitude should not be applied immediately since the forces and power required may be many times the natural operating forces and power.

By directional phase is meant that as the liquid in the column moves downward at the top, it must move upward at the bottom and vice versa. This means that the valve at the lower end of the column opens to admit liquid as the piston at the top end of the column is compressing the liquid so that after the liquid is drawn into the column at the base, it then flows off at the top during the next succeeding half cycle.

In the specification below, Figure 1 shows somewhat diagrammatically the invention which may be carried out in various construction forms by the use of well known standard elements which will be hereinafter mentioned and Figure 2 shows a detail of an element of Figure 1.

The sense in which the expression "efficiency" is used in the present instance can best be understood from the following. Suppose, for example, that a liquid such as water is to be pumped from a pool at the bottom of a well 1000 feet as shown in the drawing 1 where 1 represents the pool and 2 the well casing.

Suppose now that the water is brought to the surface under atmospheric pressure by filling and raising a container to the surface by a cable or the like. The amount of energy required per gallon of water so lifted will be the weight of the water times the distance through which it is raised. Thus if the water being pumped weighs 62.5 pounds per cubic foot, one gallon would weigh 8.35 pounds and the energy required to raise one gallon to the surface would be 8350 foot pounds, neglecting of course the weight of the container and cable.

Normally of course, such a procedure would not be followed as in general a pump would be placed at the bottom of the well to force the water to the surface. Under such conditions an entirely different situation prevails because the pump must not only provide the energy to lift one gallon to the surface, but in addition must do so against a 1000 foot head of water. In such a case the pressure per square inch at the bottom of the column would be approximately 434 pounds per square inch and zero at the top. Therefore it will be apparent that the pump, in raising a unit volume of water to the surface must not only supply the energy required to physically raise the water from the depth, but must in addition do so against an average pressure of 217 lbs./sq. inch.

If we assume, for simplicity sake that the casing has an internal cross section of one square inch, the work required to raise one gallon of water through it will be 217,000 foot pounds to overcome the head of water plus 8350 foot pounds to raise the gallon of water. It will be clear therefore, that of the total of 225,350 foot pounds of energy required to raise a gallon of water up from the bottom of a 1000 foot well under the above conditions, over 96% is wasted in simply overcoming the pressure head.

The means whereby this situation is alleviated in the present invention can best be understood from the following.

If one end of a closed pope, as for instance the well casing 2, full of liquid 3 is fitted with a close fitting reciprocating piston or fluid displacement member 4, a wave of alternating pressure and rarifaction is produced, which travels along the liquid in the pipe at a velocity which is determined by the constants of the liquid, in the case of water approximately 1500 meters per second. If the frequency of reciprocation is adjusted to the point where it corresponds to a one-half wavelength in the liquid in the column, the column will expand and contract in length in unison with the motion of the piston.

Let us now consider the case of such a pipe set vertically in the ground as in the case of a deep water or oil well as shown in the drawing and that the bottom of the pipe is fitted with a ball check valve 5 opening inwardly.

Normally of course, the column of liquid in the pipe will exert a pressure on the valve tending to keep it closed. If now the piston is set into reciprocation a similar standing wave is established in the column of liquid and if the speed of reciprocation is chosen as above indicated the column will tend to elongate and contract in unison with the piston. During the portion of the cycle when the piston is in its most downward position, assuming that steady state conditions have been established, the bottom of the column will be in its most upward position and oil or water, as the case may be, can flow into the bottom of the column filling in the space created by the contraction of the column.

As the oscillating column starts to elongate again, pressure will be exerted on the liquid just drawn in and simultaneously the piston will be beginning the upward portion of its travel as will also the top of the column of liquid. Normally of course, the complete expansion of the column when added to the depth of liquid drawn in at the bottom would be more than the piston travel in the upward direction. It will be noted however, that as the piston rises past the normal neutral level of the top of the column, a port 8 is opened allowing the excess liquid to be forced out, the amount thus forced out being equivalent to what was taken in at the bottom of the column. When the excess liquid is forced out the piston starts downward again on a new cycle, the port 8 is closed by the piston and the cycle is repeated.

In this way the energy required to lift to the top the liquid drawn in at the bottom at each stroke is substantially only the energy required to lift the same weight through the height of the column.

The validity of this statement can perhaps best be appreciated from a consideration of the fact that when the column expands from the base provided by the liquid

drawn in at the bottom, some of the potential energy resident in the contracted column is employed in raising the whole column. Thus if liquid is drawn in at the bottom to a depth of one foot, some of the potential energy resident in the contracted column will be used to raise the whole column one foot. It is clear that from an energy standpoint there is no difference between raising a one foot deep layer of liquid through 1000 feet than there is in raising a 1000 foot column by one foot. The energy input from the piston at each stroke is therefor that required to raise to the surface at each stroke the amount of liquid drawn in at the bottom during the same period.

In considering the detailed application of the present invention to a specific instance the following may be helpful. Suppose that we have a situation such as is depicted in the figure where it is desired to pump water from a pool at the bottom of a well 1000 feet deep. It will be understood that the same procedure would be followed for pumping other liquids, such as oil, except that the details might differ somewhat because of differences in the constants of the oil as compared to water.

In accordance with the invention it will be supposed that the piston is to be operated at a frequency corresponding to a one-half wavelength in the water. The frequency and wavelength of the transmitted pulse are connected to the velocity of transmission by the relationship.

$$f\lambda=c$$

where f, λ, and c are respectively the frequency, wavelength and velocity of transmission.

In this particular instance, 1000 feet is to be taken as $\frac{1}{2}\lambda$ and furthermore the velocity of sound in water may be taken as 4920 feet/second.

Therefor,

$$f(2000)=4920$$

or

$$f=\frac{4920}{2000}=2.46 \text{ cycles/sec.}$$

The necessary frequency of operation having now been determined it will next be appropriate to determine the elastic modulus of the water as a preliminary to determining the amplitude of motion of one end of the column for a given maximum operating pressure. This factor may be arrived at from the velocity of pulse transmission in water and its density which are connected by the relationship

$$c=\sqrt{\frac{E}{\rho}}$$

where E is the elastic modulus and ρ is the density.

Converting into metric units, we have

$$4920 \text{ feet/sec}=150{,}000 \text{ cm/sec.}$$
$$62.5 \text{ lbs/cu. ft.}=1 \text{ gram/cc}$$

and

$$150{,}000=\sqrt{\frac{E}{1}}$$

or

$$E=225(10)^8 \text{ dynes/cm.}^2$$
$$=327{,}000 \text{ lbs./sq. in.}$$

The maximum operating pressure in the column, which tends to elongate and contract it, is to a certain extent a matter of choice although it is desirable to keep it reasonably low consistent with the desired pumping rate because of cavitation problems should the water contain dissolved gas.

We can now proceed either by determining the operating pressure for a given piston stroke or vice versa. Suppose we decide on a piston stroke of 4 inches remembering that in a half wave oscillating column the total compression of the column will be twice the compression

at either end. The operating pressure per square inch will then be

$$P=\frac{\alpha AE}{l}$$

where α is the compression, l is the length of the column, and A its cross sectional area.

Substituting we have

$$P=\frac{8(1)(327{,}000)}{1000(12)}$$
$$=218 \text{ lbs. sq. in.}$$

In considering this figure it should be remembered that it is the maximum internal pressure exerted in the oscillating column tending to increase and decrease its length and is not the pressure which must be exerted by the piston which is many times less than this amount. If the column were simply contracting and elongating as a half wave oscillator no energy would need be put in by the piston after the column was once set in oscillation if it were not for the viscous losses in the liquid, friction losses on the pipe walls, etc. plus the energy required to raise the water being pumped. Neglecting such losses for the moment, the amount of work required to raise 1 gallon of water from this depth, as we have already seen is 8350 foot pounds. Since the piston frequency will be 2.46 cycles per second as already determined this means

$$8350\ (2.46)=20{,}550 \text{ ft. lbs./sec.}$$
$$=3.74 \text{ horsepower}$$

In other words, 3.74 H. P. to pump 147.5 gals./min.

Mention has already been made of the fact that the maximum pressure exerted on the column of water by the piston is many times less than the pressure internal in the column which tends to elongate and contract it during operation.

As an example, suppose we wish to design the pump required to give a capacity of 50 gallons per minute using the operating pressures just computed.

$$50 \text{ gallons/min}=78.2 \text{ cu. in./stroke}$$

Using our assumed amplitude of 4 inches, the area of the piston would then be 19.55 square inches and the piston diameter, 5 inches.

The power required would be

$$\frac{78.2}{231}(8350)=2830 \text{ ft. lbs/stroke}$$
$$=6950 \text{ ft. lbs/sec.}$$
$$=1.264 \text{ H. P.}$$
$$=944 \text{ watts/50 gals/min}$$

Since the piston is describing sinusoidal motion the power which it is delivering may be expressed as

$$P=\frac{F\alpha\omega}{2(10)^7}$$

where F, α and ω are respectively the maximum force in dynes the amplitude in centimeters, and 2π times the frequency. The maximum force exerted therefor will be

$$F=\frac{2(944)(10)^7}{4(2.54)(2\pi)}(2.46)$$
$$=120.5(10)^6 \text{ dynes}$$
$$=271 \text{ pounds maximum}$$

$$\frac{271}{19.55}=13.9 \text{ lbs/sq. in. of piston surface}$$

Neglecting viscous and friction losses, the maximum pressure which must be exerted by the piston to keep the column in oscillation as a ½ wavelength oscillating column is only about 6.3% of what would be required to compress or elongate the column under static conditions.

To summarize then, the method of operation would be to operate the piston at a speed corresponding to the half

wave frequency of the liquid column (or an odd harmonic of it). In so doing a standing wave is established in the liquid column which has the effect of shortening and elongating the column from both ends toward or away from the middle, i. e. the piston amplitude is reproduced at the bottom of the column. In so doing it removes the pressure periodically which would normally act to open the check valve at the bottom and allow liquid to flow into the limit of the displacement. On the reverse half of the cycle the column will descend against the liquid so drawn in thus closing the check valve.

Normally of course this would mean that the whole column would rise by a similar amount. In the present instance, however, the valve or port at the top of the column allows the liquid to escape. Under these conditions the pump simply supplies the energy required to lift the liquid to the top which is drawn in at the bottom on each stroke, plus friction losses of course, and the necessity of pumping against a 1000 foot head is avoided.

In putting such a system in operation certain special precautions must be taken because of the resonant nature of the operation. Attention has already been called to the fact that the pressures required on the piston surface may be only 6% or thereabouts, of the actual internal pressures in the column. In other words, the piston pressure which would be needed to start the column in oscillation at the amplitude discussed above, from rest, could well be many times that required for normal operation once the column was oscillating at resonance.

In fact, unless special precautions are taken, it would be nearly impossible to start the column in oscillation at all by means of a piston directly connected to an eccentric giving the desired amplitude unless the motor driving the eccentric were enormously larger than would be needed under running conditions. For this reason it is practically essential to provide some means whereby the stroke of the piston can be reduced until resonant conditions have been established. This may be accomplished by introducing in the crank arm **6** connecting the piston to the eccentric an hydraulic arrangement **7**, such as is shown in my Patent No. 2,541,112 which will permit the piston to operate at reduced amplitude until such resonance conditions have been established. Figure 2 shows somewhat diagrammatically the element **7** which comprises a cylinder **9** having a partitioning piston wall **15** reciprocated by a shaft **10** which may extend through both ends of the cylinder **9**. Small connecting passages **16** through the piston permit the building up of the amplitude of motion of the piston to a resonant point after the system has once been started in operation when connected as shown in Figure 2 of my Patent No. 2,541,112 referred to above.

I am cognizant of the fact that various attempts have been made in the past to utilize somewhat the general principles described herein, but, so far as I am aware, they have not been successful. This has undoubtedly been due in the main to the lack of two major improvements disclosed herein; one, the operation of the column at its natural period of oscillation to avoid the pressures which would otherwise be present at the bottom of the column, and secondly, the provision of means whereby the piston amplitude may be automatically reduced initially to permit the column to be supplied with energy at its resonant frequency until steady state conditions of oscillation have been established.

While resonance of the liquid column may be established for the whole column from the top of the shaft to the check valve at the bottom, it is intended that the reference to top and bottom is to include a section of the column used to establish the half or multiple half wave length resonance.

Having now described my invention, I claim:

In combination with a well casing having a wall providing an enclosed confined liquid well column, means for drawing the liquid from the top of the well casing comprising a one way valve at the bottom of the well casing permitting liquid to flow in the well casing, an outlet in the well casing above the top of the liquid well column, a fluid displacement member at the top of the liquid well column, means connected to said member for periodically applying motion to the member at the resonant frequency of the liquid well column wherein the liquid well column is one half wave length and odd number of half wave lengths referred to the frequency and means for gradually increasing the magnitude of the applied aforesaid motion to said fluid displacement member until full resonance in the liquid well column of the well has been built up to the desired value, said last mentioned means comprising hydraulic coupling means having two opposing sections connected between the displacement member and the means for periodically applying motion to said member and further having pressure release means between the opposing sections of said coupling means.

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