Oct. 17, 1950 W. O. MILLER 2,526,388

CLOSED CIRCUIT FLUID APPARATUS FOR DEEP WELL PUMPING WITH COUNTERBALANCE CYLINDER

Filed July 30, 1945 4 Sheets-Sheet 1

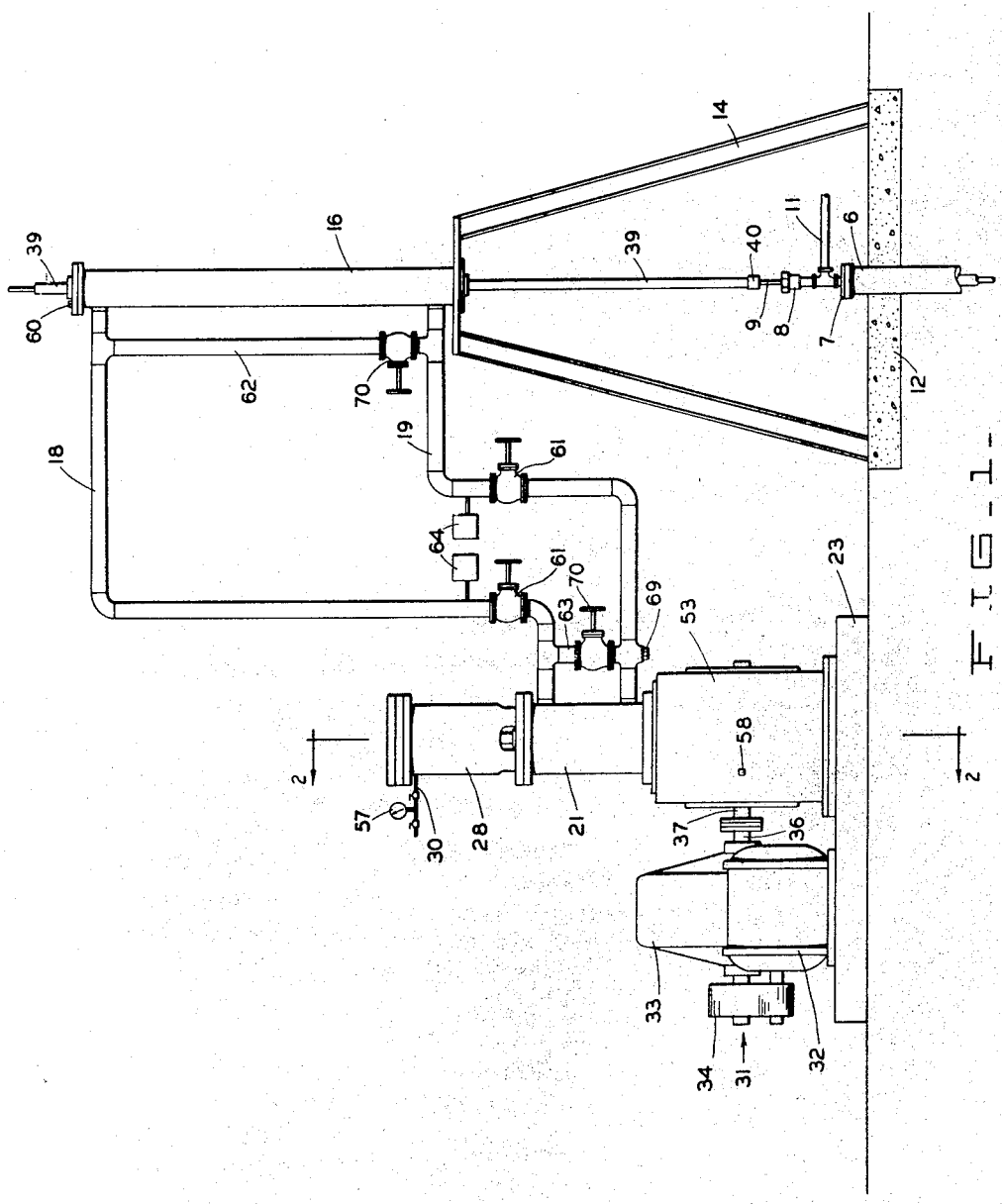


FIG-1-

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CLOSED CIRCUIT FLUID APPARATUS FOR DEEP WELL PUMPING WITH COUNTERBALANCE CYLINDER

Filed July 30, 1945 4 Sheets-Sheet 2

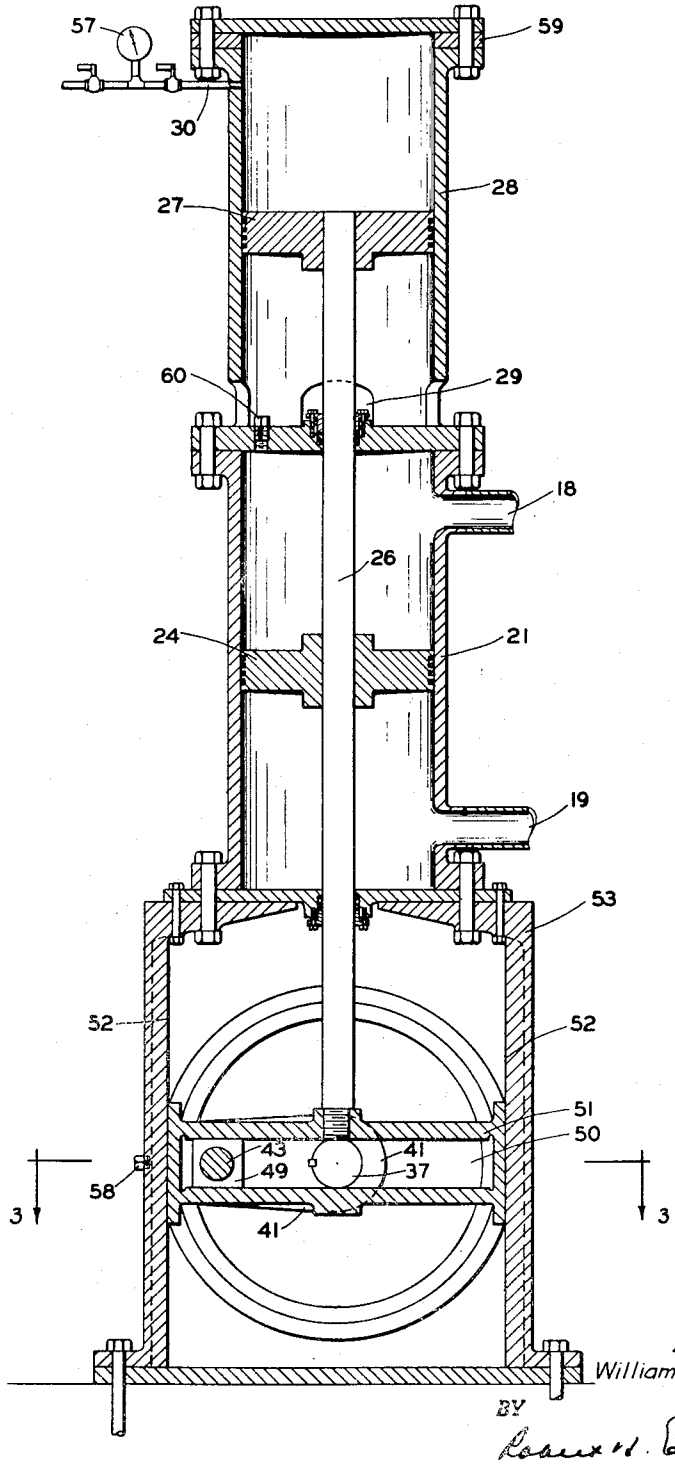


FIG_2_

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Oct. 17, 1950 W. O. MILLER 2,526,388

CLOSED CIRCUIT FLUID APPARATUS FOR DEEP WELL PUMPING WITH COUNTERBALANCE CYLINDER

Filed July 30, 1945 4 Sheets-Sheet 3

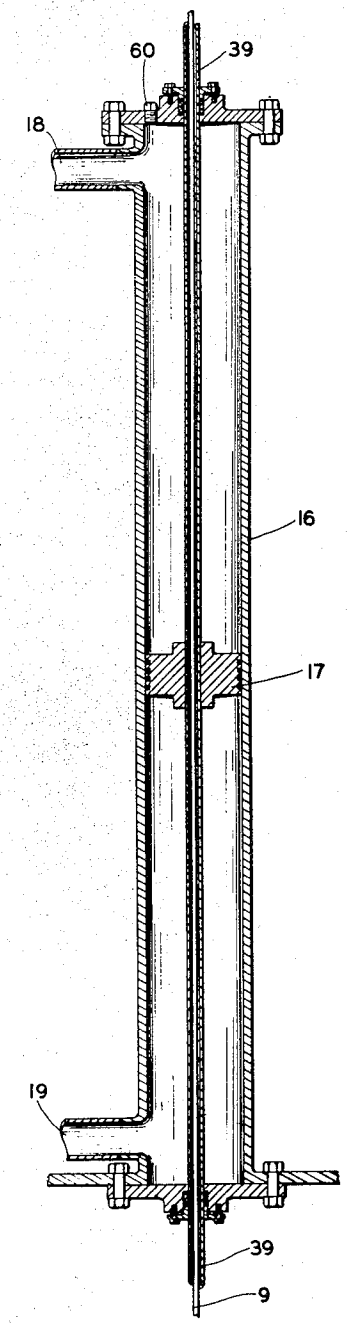


FIG_5_

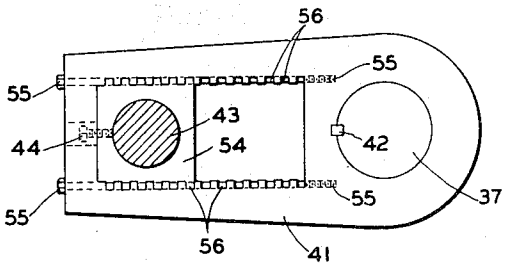


FIG_4_

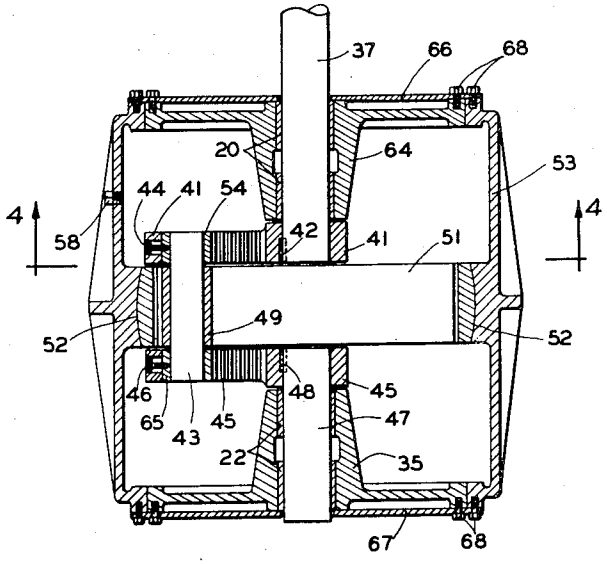


FIG_3_

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CLOSED CIRCUIT FLUID APPARATUS FOR DEEP WELL PUMPING WITH COUNTERBALANCE CYLINDER

Filed July 30, 1945 4 Sheets-Sheet 4

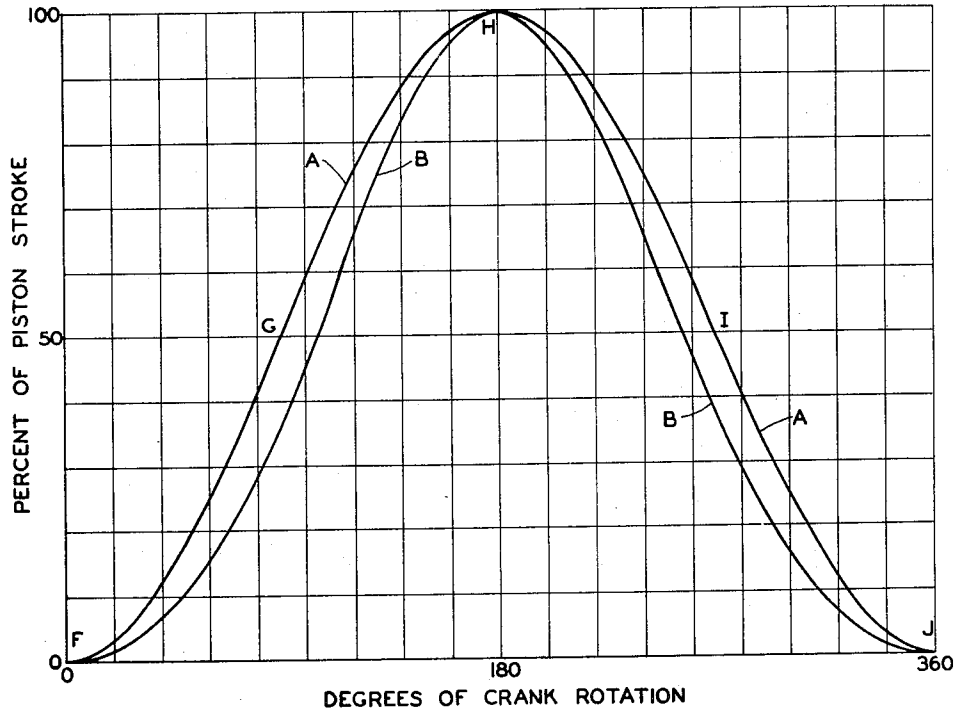


FIG. 6.

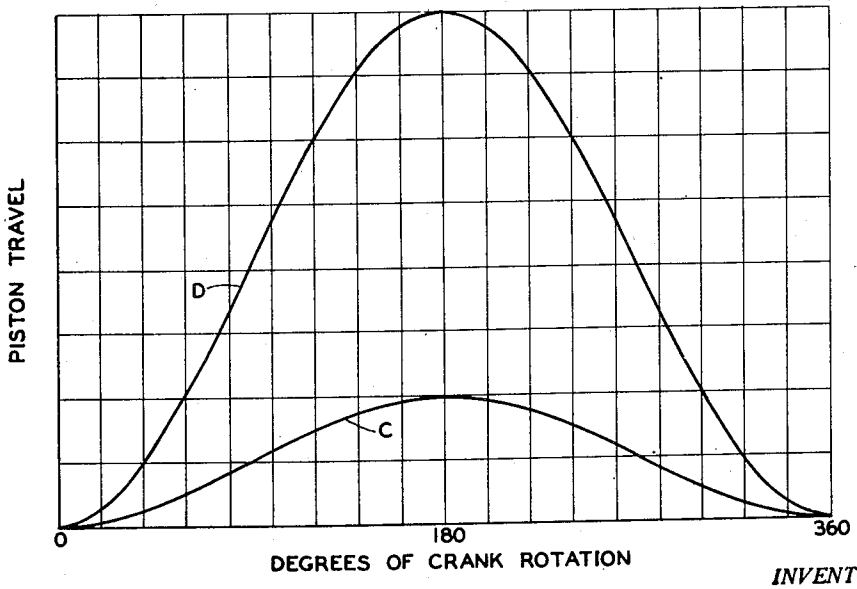


FIG. 7.

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Patented Oct. 17, 1950 2,526,388

UNITED STATES PATENT OFFICE

2,526,388

CLOSED CIRCUIT FLUID APPARATUS FOR DEEP WELL PUMPING WITH COUNTER-BALANCE CYLINDER

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Application July 30, 1945, Serial No. 607,713

5 Claims. (Cl. 60—54.5)

1

The present invention relates to pulsator devices and particularly to one suited to the pumping of oil wells, particularly those of great depth. The invention will be particularly described as it has been applied to the pumping of oil wells, but the pulsator device can be used for providing pulsating movement to other mechanism, particularly those which present the problem of vertically reciprocating a relatively long rod having such weight that this is a factor in the pulsating of the rod and any system utilized in conjunction with the rod.

In wells of a few thousand feet in depth, no particular problem is involved and conventional rigs suffice. However, as the length of the sucker rod in the well increases, its weight, plus the weight of the fluid lifted from the well, produces such an elongation or stretch in the sucker rod that in many cases a relatively large movement of the rod at the top end of the well must occur before any movement is applied to the piston system in the region of the fluid in the well. For example, and to give specific values, in one oil well pumping system it was necessary to have a stroke at the top of the well of approximately 192 inches to provide a lift stroke at the end of the sucker rod of 48 inches. The difference of 144 inches was taken up in stretching of the sucker rod and pump tubing.

It is my observation that to provide for proper motion and to secure the greatest fluid output from the well per unit of power input, one must provide a cycle of motion of the sucker rod such that both ends of the sucker rod system operate in phase with each other. Stated differently, I have observed that it is necessary that (*a*) the stretching of a sucker rod and (*b*) the amplitude and frequency cycle of the stretch be in a state of motion known as "harmonic motion." In other words, the optimum cycle of sucker rod performance is such that both ends of the sucker rod system must operate in phase with each other.

It is difficult, in long stroke straight line pumping operations, to impart harmonic motion to the sucker rod system. Even though harmonic motion has been imparted to the top end of the sucker rod system in deep wells the bottom end is extremely difficult to keep in phase with the upper end due primarily to the stretch in the sucker rod and tubing system. This troublesome condition is further amplified by the fact that both the sucker rod system and the deep well pump tubing have their own natural periods of vibration. The stretch and natural period

2

of vibration of each system can be determined from which the optimum frequency and amplitude of sucker rod stroke can be determined. By optimum frequency and amplitude, I refer to the length of stroke and number of strokes per minute in addition to the type of motion imparted to the top of the polish rod in the sucker rod system to satisfy the engineering and economic factors involved in any given case.

It is in general the broad object of the present invention to provide an improved device for the pumping of deep oil wells and the like.

A further object of the present invention is to provide means for imparting harmonic reciprocating motion to a sucker rod system.

The present invention contemplates utilization of a closed fluid system including the use of two cylinders and a movable piston in each cylinder. One piston is mounted upon the top end of the sucker rod system, i. e., on the end of the polish rod, while the other piston is adapted to be moved in a pulsator cylinder in a manner which I will presently discuss in further detail. Corresponding ends of each cylinder are connected one to another so that when the piston in the pulsator cylinder is moved in one direction a non-compressible fluid is forced positively into the other cylinder to cause the other piston to move the sucker rod in an opposite direction, the fluid on top of the piston in the sucker rod cylinder being displaced. The means employed for moving the pulsator piston imparts a harmonic reciprocating motion to that piston. Since the fluid system provided on each side of each piston is of constant volume, it will be obvious that harmonic motion will be applied from the pulsator piston to the piston in the sucker or polish rod cylinder. Also, by employing a pulsator piston of large area moved over a relatively short distance one can move a fluid volume sufficient to provide a long stroke on a sucker rod piston of a suitable and a small area. In this way, the practical requirements of pump design can be observed while the long stroke required to pump the well is made available. Further, and in accordance with this invention, the pulsator piston is moved at such a rate that the requisite harmonic motion is applied to the sucker rod piston and the sucker rod system.

The invention includes other objects and features of advantage some of which, together with the foregoing, will appear hereinafter wherein, referring to the drawing, a preferred form of a harmonic motion sucker rod system is disclosed,

Referring to the drawing accompanying and forming a part hereof,

Figure 1 is a side elevation showing the pulsator and sucker rod installation.

Figure 2 is a section taken through the pump mechanism along the line 2—2 in Figure 1.

Figure 3 is a section taken along the line 3—3 in Figure 2 and showing a Scotch yoke or crosshead, crank, crankpin and shaft assembled in the crankcase.

Figure 4 is a section taken along the line 4—4 in Figure 3 and showing details of the crank.

Figure 5 is a section through the center line of the sucker rod piston and cylinder assembly.

Figure 6 is a graph showing the comparison between the reciprocating motion produced by a Scotch crosshead and a conventional crank and connecting rod.

Figure 7 is a graph showing the comparison between the travel of the pulsator piston and the sucker rod piston.

Referring to the drawing, an oil well casing is generally indicated by numeral 6, the casing being closed as at 7 and being provided with a packing gland 8 through which issues the polish rod 9. An oil outlet 11 is also provided from the casing. Mounted upon a suitable foundation 12 is a support structure 14 upon which is mounted sucker rod cylinder 16.

Polish rod 9 extends into hollow piston rod 39 and is clamped thereto by clamp 40. Piston rod 39 carries a suitable piston 17. In the event that the sucker rods are to be pulled from the well, the internal diameter of piston rod 39 is such that the rods may be pulled through the piston rod and removed without dismantling the pumping equipment that stands directly over the well. This installation lends itself to the possibility of utilizing the power made available by cylinder 16 in lifting the several sucker rod lengths from the well.

Pipes 18 and 19 extend from opposite sides of sucker rod cylinder 16 to pulsator cylinder 21 mounted upon the crankcase 53 and which, in turn, is mounted upon a foundation structure 23. The pulsator cylinder includes a piston 24 therein mounted upon a piston rod 26. The piston rod 26 extends beyond cylinder 21 and carries upon its upper end a second piston 27 slidable in a cylinder 28, the latter being open at its lower end as at 29, and closed at its upper end except for a lead-off line 30. The function of cylinder 28 on piston 27 will be presently discussed.

To move pulsator piston 24, a suitable prime mover assembly 31 is provided including electric motor 32 or other suitable prime mover driving a gear reducer 33 through drive 34, shaft 36 from the reducer driving a shaft 37 in the crankcase 53, and which is shown particularly in Figures 3 and 4. A crank 41 is fixed to shaft 37 by key 42 while a slotted crank block 54 is fixed to the crank 41 by machine screws 55. Crank block 65 is fixed similarly to auxiliary crank 45. Crank pin 43 is fixed to crank block 54 by set screw 44 and to auxiliary crank block 65 by set screw 46. Auxiliary crank 45 is fixed to auxiliary shaft 47 by key 48. Crank pin 43 revolves in crosshead block 49 which slides in slot 50 of crosshead 51.

As shaft 37 is rotated by the prime mover assembly 31, crank 41 imparts circular motion to crank pin 43. This forces block 49 to reciprocate in slot 50, in turn imparting reciprocating motion in a vertical plane to cross head 51 which slides between guide surfaces 52 of crankcase 53. Crosshead 51 is fixed to shaft 26 thereby imparting its motion to piston 24. As crank 41 revolves, the distance which crankpin 43 moves, measured in a horizontal direction, is the same as the vertical movement of the crosshead 51. This is a simple and well known mechanism for producing true harmonic motion, as contrasted with the common crank and connecting rod which combination does not produce harmonic motion.

The length of stroke of crank 41 may be adjusted by inserting slotted blocks 54 and 65 in any desired set of slots 56 in crank 41 when screws 55, which hold blocks 54 and 55 in position, are removed. Any change in length of crank stroke will change the stroke of piston 24 by an equal amount. This change is then reflected in the stroke of piston 17 by an amount proportional to the ratio of the respective piston net areas. For proper lubrication, crankcase 51 is partially filled with lubricating oil through plug 58. Shafts 37 and 47 revolve in bearings 20 and 22, respectively, which are mounted in openings in bearing housings 64 and 35, respectively, and held by plates 66 and 67, respectively, and screws 68. If a more uniform application of force to block 49 is desired, power may also be applied to an extension of shaft 47.

The area of the pulsator piston 24 and its stroke in the pump cylinder 21 is such that the same volume of fluid is displaced from the pump on each stroke as is displaced in the sucker rod cylinder.

Through the use of different cylinder diameters it is possible to obtain a long sucker rod stroke while maintaining a short pulsator stroke. Since the value of fluid handled remains constant regardless of stroke or cylinder diameter ratios, it is axiomatic that the actual displacement of each piston is always equal.

For purposes of illustration I offer the following:

Let S equal length of stroke of sucker rod piston
Let A equal net area of sucker rod piston
Let X equal length of stroke of pulsator
Let Y equal net area of pulsator piston

In every case the product of the values of S multiplied by A must be equal to the product of the values of X multiplied by Y. The greatest value of this invention is attained when the value of S is greater than the value of X. However, engineering considerations enter into the choice of the value of X for any given value of S—for example:

S equals 20 ft.—assumed for a hypothetical case
A equals 1 sq. ft. net area—assumed for a hypothetical case.

For the above values of S and A, good engineering has established a value of X to be of the order of 5 ft.

Since S times A must always be equal to X times Y, Y equals S times A divided by X or, substituting values,

$$Y=\frac{20\times 1}{5}=4$$

For practical application, the values of S—A,—X and Y may be determined attention being given to the required value of S for any given pumping operation. In every case the product of the value of S multiplied by the value of A must be equal to the product of the value of X times the value of Y as was borne out by the values given in the apparatus above described.

In one structure the net area of the pulsator piston was 500 square inches while that of the

ram piston was 100 square inches. The stroke of the pulsator piston was 20 inches while the stroke of the ram piston was 100 inches. It will be observed that 10,000 cubic inches were displaced from each cylinder upon movement of each piston from one end of the associated cylinder to the opposite end. Depending upon the direction of movement, the displaced fluid was transferred from one cylinder to the other through lines 18 and 19.

Energy loss upon fluid transfer is kept to a minimum by using conduits of a suitable size. Thus the system provides for imparting a straight-line motion to the sucker rod, but the rate of supply of this motion is such as to impart the generally desired harmonic motion to the sucker rod system. The equipment required for this is quite simple and of standard construction.

Cylinder 28 and piston 27 provide a pneumatic counter-balance, air being compressed upon the upstroke of the piston which is utilized on the downstroke to help raise the sucker rod system. The weight of the sucker rod system on the upstroke of the pulsator piston 24 assists in compressing air in the cylinder so that some advantage is gained from this energy.

The pneumatic counterbalance is adjustable to any desired initial and terminal pressure. The desired initial air pressure is applied to cylinder 28 through air supply line 30 as measured by gauge 57 when piston 27 is at the bottom of its stroke. The cylinder volume required above the piston at the top of its stroke to produce the desired terminal pressure is then computed. This volume is acquired by adding or removing a spacer 59 of required thickness or a flanged length of cylinder (not shown), or by suitably adjusting the position of piston 27 on shaft 26.

All free space in cylinders 21 and 16, conduits 18, 19, 62, and 63, and valves 61 and 70 are completely filled with a suitable non-compressible fluid, suitable plugs 60 being provided for purposes of filling the system with fluid and permitting air to escape during the filling operation. A suitable plug 69 being provided for purposes of draining the fluid system. Pressure switches 64 are provided to function in the nature of safety devices arranged to stop the prime mover when a predetermined pressure, considered to be unsafe, is attained in lines 18 or 19.

In operation, fluid passes alternately between cylinders 21 and 16 through conduits 18 and 19 with valves 61 open and bypass valves 70 closed, the fluid in the system serving to transmit energy from the pulsator cylinder 21 to the ram cylinder 16 and vice versa. The bypass conduits 62 and 63 and bypass valves 70 are provided only for purposes of initial adjustment of the fluid system and whatever subsequent adjustment or servicing may be required.

Curve A in Figure 6 shows the relationship between percent of pump piston stroke and degrees of crank rotation. It represents simple harmonic motion produced by the Scotch crosshead fixed to the lower end of the pulsator piston rod 26. Simple harmonic motion is defined as a rectilinear motion in which the acceleration is always directed toward a fixed point in the path of motion and in which the magnitude of the acceleration is proportional to the distance between the moving point and the fixed point, the moving point in this case being the piston and the fixed point being the top or bottom of the stroke. This curve indicates clearly that at

90 degrees and 270 degrees of crank rotation, the velocity or rate of motion is at its maximum and that the increments of acceleration and deceleration between zero and 180 degrees of crank rotation are duplicated in reverse order but in the same magnitude from 180 degrees to 360 degrees of crank rotation. The pulsator piston is therefore moving in what is known as simple harmonic motion. This motion can be placed in an harmonic phase with the natural vibration period of the sucker rod system. The sucker rod system may be likened to a huge spring. Now it is commonly known that normal or natural vibration of a spring occurs as simple harmonic motion. Any other motion imparted to a spring or, in this case, to the sucker rod system, will be out of harmonic phase and therefore undesirable. In deep well pumping, the sucker rods are stressed close to their ultimate strength and any irregular motion will add additional stresses and lead to the failure of the rods. Harmonic motion avoids undesired stresses and is therefore most desirable.

The theoretical optimum rate of reciprocation of a sucker rod system is calculated by well known methods, attention being given to the length of the rod, its diameter, the area of the well pump piston and its stroke and the gravity of the fluid pumped. The prime mover and its associated transmission device are adjusted to provide this optimum reciprocation. By measuring the rod stretch and by taking an expansion and contraction diagram from the top of the sucker rod, by well known means and methods, one can determine if the number of reciprocations per minute is that most advantageously employed, i. e., is the rod being moved at a rate consistent with its own period of vibration. If it is not, the prime mover can be speeded up or the drive ratio between it and the pump shaft can be changed.

Curve B in Figure 6 shows the relationship between per cent of pump stroke and degrees of crank rotation for a piston driven by an ordinary connecting rod. It clearly indicates that the relative motion between the pulsator piston and crank during the first half of the stroke, that is from F to G, is different from that of the second half, from G to H. This difference in motion, while not of apparent great magnitude on the diagram, is most undesirable since it is out of harmony with any natural period of vibration of the sucker rod system; furthermore, the acceleration and deceleration never take place in a state of simple harmonic motion during the entire stroke cycle. This state of motion does not readily lend itself to being put in harmonic phase with the natural vibration period of the sucker rod system. The remainder of the stroke cycle from H to I and I to J is similarly affected.

Curve C in Figure 7 is a curve of one cycle of pump piston travel plotted against degrees of crank rotation for a representative pulsator. It is a curve of simple harmonic motion similar to curve A. Curve D is a curve of sucker rod piston travel for the same equipment and shows how the harmonic motion is transferred to and is amplified in the sucker rod piston. The amplified stroke of the sucker rod piston is brought about by having the sucker rod piston net area less than the pulsator piston net area.

I claim:

1. In combination, a relatively long rod positioned vertically, a first piston on said rod, a first cylinder cooperatively positioned with respect to

said first piston and in which said first piston is movable to raise and lower said rod, a pulsator cylinder, a piston movable in said pulsator cylinder on a piston rod, a counter-balance cylinder, a counter-balance piston on said piston rod and movable in said counter-balance cylinder, means for controlling fluid pressure in said counter-balance cylinder to counter-balance at least a substantial portion of the dead-weight load of the rod and the piston thereon, the area of said pulsator piston being relatively large as compared to the area of said first piston, the stroke of said first piston being relatively large as compared to said pulsator piston stroke, a first conduit connecting one end of said pulsator cylinder to one end of said first cylinder, a second conduit connecting the other end of said pulsator cylinder to the other end of said first cylinder, and means for moving said pulsator piston back and forth in said pulsator cylinder at a rate substantially corresponding to a rate designated as harmonic motion.

2. In combination, a relatively long rod positioned vertically, a first rod, a first cylinder cooperatively positioned with respect to said first piston and in which said first piston is movable to raise and lower said rod, a pulsator cylinder, a pulsator piston movable in said pulsator cylinder on a piston rod, a counter-balance cylinder, a counter-balance piston on said piston rod and movable in said cylinder, means for controlling fluid pressure in said counter-balance cylinder to counter-balance at least a substantial portion of the dead-weight load of the vertical rod and the first piston, the area of said pulsator piston being relatively large as compared to the area of said first piston, the stroke of said first piston being relatively large as compared to said pulsator piston stroke, a first conduit connecting one end of said pulsator cylinder to one end of said first cylinder, a second conduit connecting the other end of said pulsator cylinder to the other end of said first cylinder, a liquid filling said cylinders and said conduits, and means for moving said pulsator piston back and forth in said pulsator cylinder to deliver fluid to said first cylinder and move the first piston therein at a rate substantially corresponding to a rate designated as harmonic motion, the liquid volume displaced from said pulsator cylinder upon movement of the pulsator piston therein from one extreme of travel to the other extreme being equal to the liquid volume displaced from the first cylinder upon movement of the first piston from one extreme to the other.

3. In combination, a relatively long vertical rod, a first piston on said vertical rod, a first cylinder cooperatively positioned with respect to said first piston and in which said first piston is movable to raise and lower said vertical rod, a pulsator cylinder, a pulsator piston movable in said pulsator cylinder on a piston rod, a counter-balance cylinder, a counter-balance piston on said piston rod and movable in said cylinder, means for controlling fluid pressure in said counter-balance cylinder to counter-balance at least a substantial portion of the dead-weight load of the vertical rod and the first piston, a first conduit connecting one end of said pulsator cylinder to one end of said first cylinder, a second conduit connecting the other end of said pulsator cylinder to the other end of said first cylinder, and means for moving said pulsator piston back and forth in said pulsator cylinder at a rate substantially corresponding to a rate designated as harmonic motion.

4. In combination, a long vertical rod, a first piston on said vertical rod, a first cylinder cooperatively positioned with respect to said first piston and in which said first piston is movable to raise and lower said vertical rod, a pulsator cylinder, a pulsator piston movable in said pulsator cylinder on a piston rod, a counter-balance cylinder, a counter-balance piston on said piston rod and movable in said counter-balance cylinder, means for controlling fluid pressure in said counter-balance cylinder to counter-balance at least a substantial portion of the dead weight load of the vertical rod and the first piston, the area of said pulsator piston being relatively large as compared to the area of said first piston, the stroke of said first piston being relatively large as compared to said pulsator piston stroke, a first conduit connecting one end of said pulsator cylinder to one end of said first cylinder, a second conduit connecting the other end of said pulsator cylinder to the other end of said first cylinder, and means for moving said pulsator piston back and forth in said pulsator cylinder at a rate substantially corresponding to a rate designated as harmonic motion and including a rotatable shaft, and a Scotch yoke interposed between said shaft and said pulsator piston.

5. In a hydraulic pulsator, a pulsator transmitter cylinder, a pulsator piston movable in said cylinder on a piston rod, a counter-balance cylinder, a counter-balance piston on said piston rod and movable in said counter-balance cylinder, means for controlling fluid pressure in the said counter-balance cylinder to counter-balance a substantial portion of an unbalanced load driven by said pulsator, and means for driving said pistons in said respective cylinders.

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