June 5, 1951 W. C. TRAUTMAN ET AL 2,555,426

HYDRAULICALLY ACTUATED PUMPING SYSTEM FOR WELLS

Filed Sept. 24, 1945 2 Sheets-Sheet 1

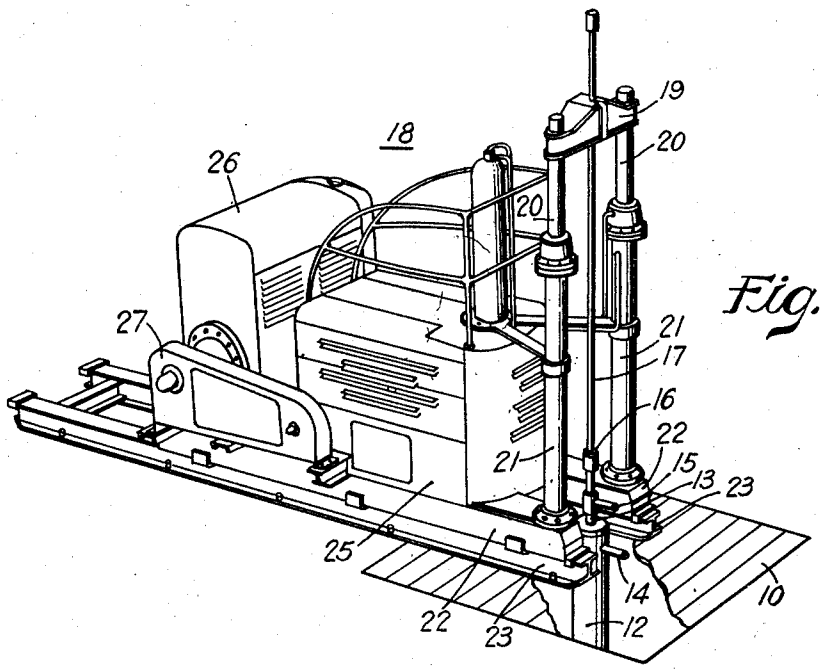
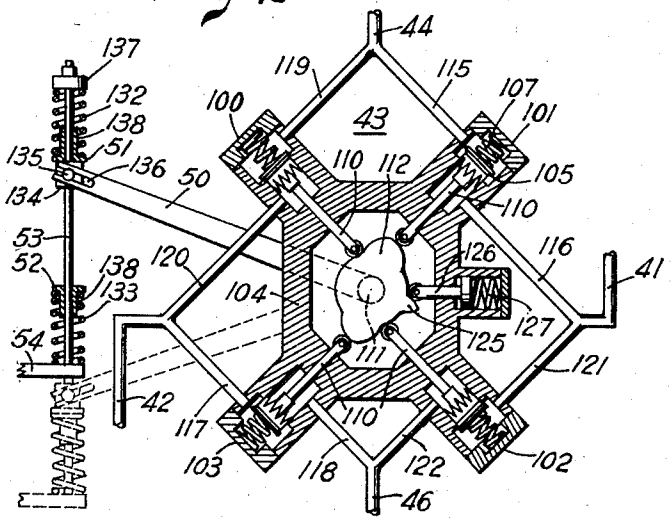


Fig. 1

Fig. 2



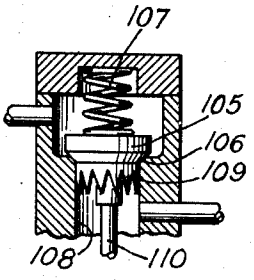


Fig. 3

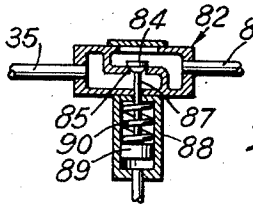


Fig. 4

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HYDRAULICALLY ACTUATED PUMPING SYSTEM FOR WELLS

Filed Sept. 24, 1945 2 Sheets-Sheet 2

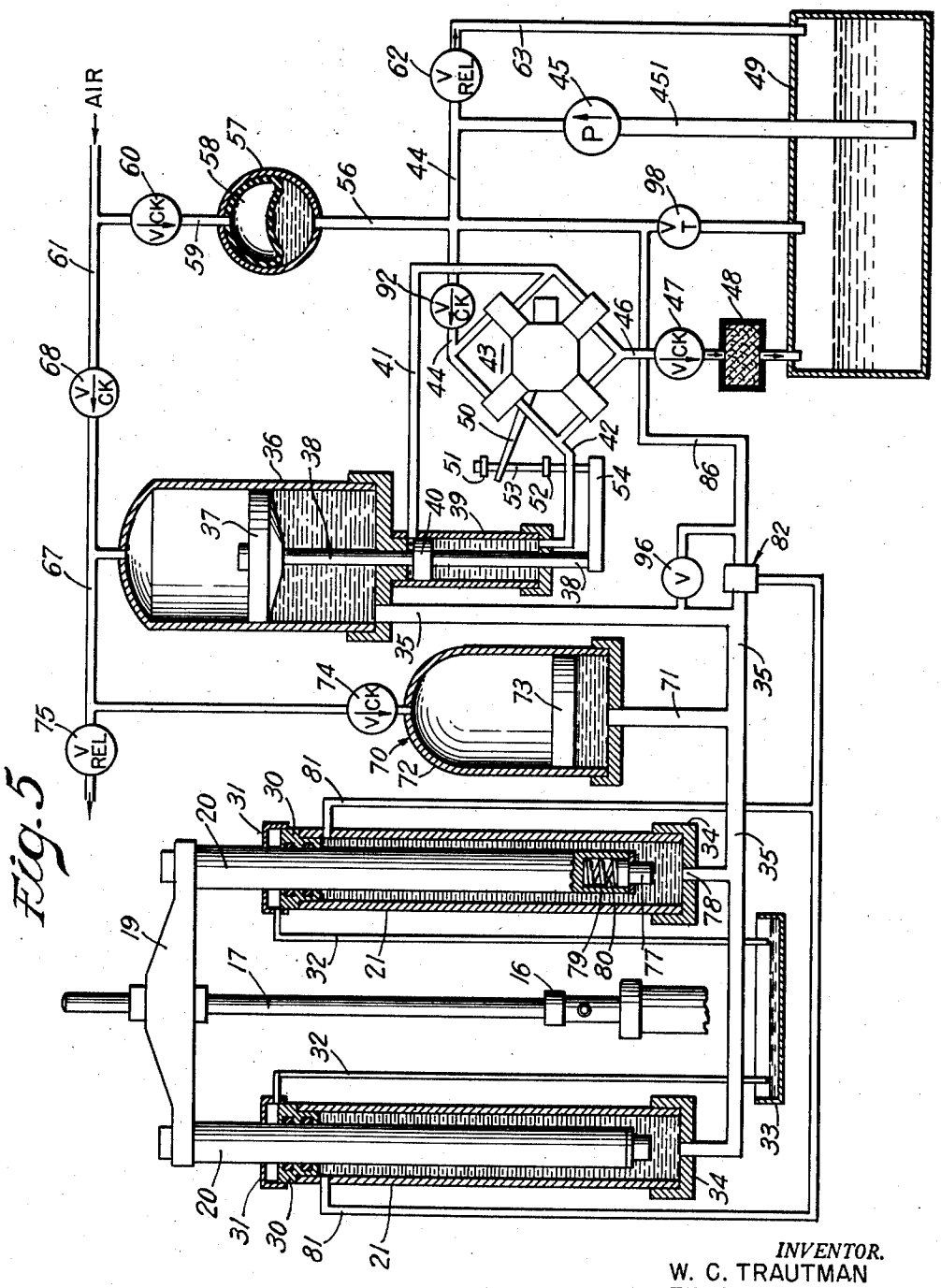


Fig. 5

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Patented June 5, 1951

2,555,426

UNITED STATES PATENT OFFICE

2,555,426

HYDRAULICALLY ACTUATED PUMPING SYSTEM FOR WELLS

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Application September 24, 1945, Serial No. 618,184

6 Claims. (Cl. 60—52)

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This invention relates to hydraulic actuation of in-the-well pumps and is particularly useful for the actuation of pumps in relatively deep wells, such as many oil wells, in which a pump at a substantial depth in the well is reciprocated from the surface through a sucker rod which may have substantial stretch because of its length.

A broad object of the invention is to increase the efficiency of an in-the-well pump actuated through a long sucker rod, by applying substantially constant force to the sucker rod throughout its stroke irrespective of variations in the velocity of the upper end of the sucker rod at different positions within its stroke.

Another object is to provide a power unit for reciprocating the sucker rod of an in-the-well pump, which unit is compact and self-contained and can be readily moved between an operative position in which it is connected to the sucker rod and an inactive position in which it is clear of the well, to permit various operations, such as pulling the pump out of the well and cleaning the well, etc.

Another object is to provide a hydraulic actuating mechanism for an in-the-well pump, in which the sucker rod of the pump is directly actuated by fluid at a relatively low, safe pressure supplied by a large volume, low pressure, pump which, in turn, is directly actuated by a relatively compact hydraulic motor supplied by a relatively low volume, high pressure pump.

Another object is to provide a practicable and reliable system for applying substantially uniform force to the upper end of the sucker rod of an in-the-well pump throughout the pumping stroke of the sucker rod.

Another object is to provide a practicable valve mechanism for controlling flow of high pressure actuating liquid to a reciprocating hydraulic motor in such a way as to effect smooth reversal of the motor at opposite ends of its stroke.

Another object is to provide a hydraulic pumping mechanism for reciprocating the sucker rod of an in-the-well pump which is substantially fully automatic and self-adjusting to compensate for unavoidable fluid leakage in the system.

Other more specific objects and features of the invention will appear from the detailed description to follow of one specific embodiment of the invention.

It has been common practice for many years to reciprocate the plunger or piston of an in-the-well pump through a sucker rod extending from the pump to the surface and connected at the surface to a rotating crank through a connecting

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rod or the equivalent, so that, in response to rotation of the crank, the upper end of the rod was reciprocated with a motion that was substantially simple harmonic, the upper end of the rod accelerating uniformly from zero speed at the lower end of its stroke to a maximum speed at the middle of its stroke and then decelerating gradually from the middle of the stroke to the upper end of the stroke. The maximum rate at which the sucker rod could be reciprocated by these old methods was determined by the maximum stress applied to the rod at some particular point in the stroke, which stress was usually much greater than the average stress throughout the stroke. In order to obtain utmost efficiency, the upper end of the sucker rod should be moved at such a rate throughout its stroke that the stress is substantially constant and of substantially the same magnitude as the maximum stress which it is safe to apply to the rod. Unfortunately, it is impossible to obtain this result with mechanisms which reciprocate the upper end of the sucker rod in accordance with some predetermined rate of movement, because of factors such as the inertia and stretch, which are unavoidable and the effects of which are difficult to compute in a long sucker rod. It is essential, therefore, in order to attain a high pumping efficiency to employ a mechanism that will apply substantially constant force to the sucker rod and let the acceleration and deceleration of the rod be determined by the resistance it offers to movement, which resistance varies unpredictably over wide limits because of the stretch and inertia of the rod.

In accordance with the present invention we are able to apply a substantially constant force to the upper end of a sucker rod by directly connecting the sucker rod to a hydraulic jack of relatively large effective diameter, which is actuated to lift the sucker rod by admitting pressure fluid to the jack and to lower the sucker rod by releasing pressure fluid from the jack. The pressure fluid is supplied by a reciprocating pump which is directly connected to the jack, and the pump in turn is reciprocated by a reciprocating hydraulic motor directly connected thereto and energized with high pressure fluid from a suitable pump.

The high pressure pump is adapted to supply fluid at substantially constant pressure which is applied without restriction to the reciprocal motor during the main portions of the strokes of the latter, but is throttled near the end of each stroke to rapidly but smoothly decelerate

the motor. Hence, during the major portion of the stroke a substantially constant force is applied to the reciprocating pump, which delivers pressure liquid to the jack. To enable the jack to move at varying velocity in different parts of each stroke, according to the resistance afforded to its movement by the sucker rod, a relatively large hydraulic accumulator is connected in parallel with the jack to supply additional pressure fluid to the jack when it tends to move rapidly, and to absorb excess fluid delivered by the reciprocating pump when the resistance of the sucker rod reduces its velocity below normal.

The accumulator must be of substantial size to have the desired fluid capacity without excessive variation in pressure and it is dangerous to have a system containing a compressed gas such as air at extremely high pressure. On the other hand, it is usually more economical in a hydraulic power transmission system to employ fluid at relatively high pressure because it greatly reduces the dimension of the pumps, motors and connecting conduits necessary to handle a given amount of power. In accordance with the present invention the hydraulic jack and the reciprocating pump, which directly supplies fluid to actuate the jack, are of relatively large diameter and are positioned close together, so that they can be economically interconnected by large diameter conduits, thereby enabling the use of fluid at relatively low operating pressures in that part of the system in which compressed gas is used (in the accumulator) to equalize the pressure. On the other hand, the hydraulic motor which drives the reciprocating pump and the hydraulic pump, which supplies it, can be made of relatively small capacity but adapted to operate at a substantially higher pressure than that used in the jacks.

It is desirable in an in-the-well pump system to counter-balance the weight of the sucker rod in some way. A particular advantage of the present invention is that it permits ready compensation for the weight of the sucker rod by applying compressed air to the rear side of the piston of the reciprocating pump, which supplies pressure fluid to the jack. By suitably choosing the air pressure applied to this piston, a force can be readily developed that is sufficient to counter-balance the weight of the sucker rod, without increasing the inertia of the system.

The jack, the reciprocating pump, and the accumulator are connected together in a normally closed hydraulic system from which some leakage will inevitably occur and if such leakage is not compensated for, the supply of fluid will decrease at intervals to the point where it is insufficient to lift the jack through the desired stroke. A feature of the present invention is an automatic system responsive to downward movement of the jack below its normal limit to admit additional fluid into the closed system to restore the normal amount of fluid.

For a full understanding of the invention, together with other minor objects and features thereof, reference is made to the detailed description and the drawing in which:

Fig. 1 is a perspective view of a complete pump driving unit in accordance with the invention, shown in operative position with respect to a well;

Fig. 2 is a sectional view of a four-way valve employed in the apparatus;

Fig. 3 is an enlarged longitudinal sectional view of one of the poppet valve assemblies in four-way valve of Fig. 2;

Fig. 4 is a detailed sectional view illustrating a pressure actuated valve that is employed in the apparatus; and

Fig. 5 is a schematic diagram illustrating the complete system and its mode of operation.

Referring first to Fig. 1, there is disclosed a conventional oil well head structure comprising a floor 10 above the well within which there extends the usual well casing 12, the upper end of which is sealed about an oil tube 13, and is provided with a pipe connection 14. The oil tube 13 is provided with a connection 15, through which the pumped oil is delivered, and is closed at its upper end by a stuffing box 16 through which a conventional polish rod 17 extends. The lower end of the polish rod 17 is connected within the oil tube 13 to the upper end of a sucker rod, which extends down through the well to a conventional pump located at a substantial depth, which may be many thousand feet. The pump contains a barrel or cylinder, which is anchored in the well, and a reciprocal plunger or piston, which is connected to the lower end of the sucker rod and is reciprocated by the sucker rod in response to reciprocation of the polish rod 17. The apparatus so far described is conventional and constitutes no part of the present invention.

The present invention consists of a driving unit 18 for reciprocating the polish rod 17. As shown, it comprises a cross member 19 which is clamped to the polish rod 17 and is supported at its outer ends on the plungers 20 of a pair of identical hydraulic jack cylinders or barrels 21, which are positioned parallel to and on opposite sides of the polish rod 17, and are supported at their lower ends on a pair of frame members 22 which are slidably supported on a pair of track members 23.

In addition to the parts described, the driving unit 18 contains various hydraulic elements positioned within a housing 25, and including a pump which may be driven by any suitable source of power. As shown in Fig. 1, the unit includes a motor housing 26 containing an internal combustion motor, the shaft of which is coupled by driving belts positioned within a casing 27 to the shaft of a pump positioned within the casing 25.

The unitary construction depicted in Fig. 1 has the advantage that it can be readily transported to and from a well and can be readily removed for repairs or adjustments. Furthermore, the unit can be easily shifted away from the well by sliding the frame members 22 along the tracks 23 when service work is to be performed on the well. All that it is necessary to do prior to shifting the unit 18 away from the well along the tracks 23 is to disconnect cross member 19 of pumping jacks from the polish rod 17.

Referring now to the schematic diagram of Fig. 5, it will be observed that the plungers 20 extend into the upper ends of the jack cylinders 21 through sealing upper end caps 30 of conventional construction. Some seepage of the hydraulic liquid, hereinafter referred to as oil, occurs past the seals 30, and caps 31 may be provided above the seals to trap this oil and conduct it through tube 32 to a drain pan 33.

Oil to actuate the jacks is supplied to the lower ends 34 of the jack cylinders through a conduit 35 of relatively large diameter from the lower end of a pump cylinder 36 containing a piston 37. The diameter of the cylinder 36 and the piston 37, and the stroke of the piston are such as to

displace a volume of oil equal to the volume of oil displaced by the jack plungers 20 during a full working stroke of the polish rod 17, and the jack plungers 20 reciprocate in unison with the piston 37 of the pump.

The piston 37 is reciprocated by a piston rod 38 which extends through the lower end of the pump cylinder 36 and through a motor cylinder 39 positioned immediately therebelow, and a motor piston 40 is secured to the rod 38 within the cylinder 39. The motor piston 40 is reciprocated by application of high pressure oil to the motor cylinder 39. Thus, the upper end of the motor cylinder is connected by a conduit 41 and the lower end of the motor cylinder is connected by a conduit 42 to a four-way valve 43, which valve is connected by a conduit 44 to the output of a high pressure pump 45, and through a conduit 46 containing a check valve 47, and a filter 48, to an oil reservoir 49. The pump 45 is supplied with oil through a conduit 451 from the reservoir 49. The four-way valve 43 has an actuating lever 50, which is actuated by a pair of stops 51 and 52 on a rod 53, which is connected by a cross member 54 to the lower end of the piston rod 38, for actuation thereby. The construction and operation of the four-way valve 43 will be described in detail later with reference to Fig. 2. It will suffice at this time to state that when the motor piston 40 reaches the lower limit of its stroke, the stop 51 carries the lever 50 past its center position, whereupon it snaps into a lower position, in which the valve 43 connects the pressure line 44 to the conduit 42 leading to the lower end of the motor cylinder 39 and connects the conduit 41 leading from the upper end of the motor cylinder 39 to the exhaust line 46, so that the piston 40 is moved upwardly. Likewise, when the piston 40 reaches the upper end of its stroke, the stop 52 carries the lever 50 upwardly to its center position, whereupon it snaps into its upper position, in which the valve 43 connects the conduit 41 to the pressure line 44, and connects the conduit 42 to the exhaust line 46, so that the piston 40 is then moved downwardly.

The flow of pressure fluid through the pressure line 44 from the pump 45 to the four-way valve 43 is momentarily interrupted or reduced each time the valve is reversed, and to reduce pressure fluctuations in the line 44 it is connected by a branch line 56 to an accumulator 57 which is shown as of the type containing a flexible bladder 58, containing air under pressure, the air pressure being maintained through a connection 59 containing a check valve 60 to an air line 61, which is supplied from any suitable source of compressed air, which is not shown in Fig. 5.

A relief valve 62 is also connected to the pressure line 44 for releasing excess pressure oil back to the reservoir 49 through a conduit 63 and prevent the pressure exceeding a predetermined limit. It will be observed that the weight of the sucker rod is at all times applied through the polish rod 17 and the cross member 19 to the jack plungers 20, and is therefore applied to the oil in the jack cylinders to maintain a corresponding pressure therein, which pressure is transmitted through the conduit 35 to the oil in the pump cylinder 36, where it is applied to the under-side of the piston 37. In accordance with the present invention this approximately constant upward force on the piston 37 is counterbalanced by maintaining compressed air in the upper end of the cylinder 36. For this purpose,

the upper end of cylinder 36 is connected to a conduit 67, which in turn is connected to the air supply line 61 through a check valve 68, so that the pressure in the conduit 67 and the upper end of cylinder 36 is never less than the pressure in the air supply line 61. The latter pressure is so chosen as to exert a downward force on the piston 37 approximately equal to the force developed against the under-side of the piston by the weight of the sucker rod plus half the weight of the fluid column being lifted. Of course, as the piston 37 is moved upwardly in response to downward movement of the sucker rod and the jack plungers 20, the air is compressed in the upper end of the cylinder 36 so that the force exerted by the air against the upper side of the piston increases. However, this increase can be kept within desirable limits by making the cylinder 36 relatively long, so as to provide a large total volume in the upper part of the cylinder as compared to the displacement volume of the piston 37. It is to be understood that the cylinder 36 may be much longer in proportion to its diameter than is shown in the schematic drawing of Fig. 5.

Fairly constant pressure is maintained on the pressure side of the motor piston 40 during the major part of its stroke, so that the velocity of this piston, the velocity of the piston 37, and the velocity of the jack plungers 20 can vary according to the resistance to movement of the polish rod 17, which resistance is in large measure determined not only by the resistance of the pump in the well, but also by the inertia and stretch of the sucker rod. However, it is highly desirable in a system of this type that the jack plungers 20 apply as constant a force as possible to the polish rod 17 and this may necessitate relatively rapid changes in the velocity of the jack plungers 20, at different points in their stroke, and to increase the ability of the system to maintain relatively constant pressure in the jack cylinders 21 we provide an accumulator 70 of relatively large capacity, directly connected to the conduit 35 by a short, large diameter branch conduit 71.

This accumulator 70 is shown as consisting of a cylinder 72 connected at its lower end to the branch conduit 71 and containing a floating piston 73. The lower portion of the cylinder 72, below the piston 73, is filled with oil and the upper portion, above the piston 73, is filled with compressed air, at a pressure equal to the maximum pressure existent in the upper end of the pump cylinder 36. This is accomplished by connecting the upper end of cylinder 72 through a check valve 74 to the conduit 67. A relief valve 75 may be connected to the conduit 67 to prevent the pressure from rising to a dangerous value, but it will remain closed during normal operation of the system.

The accumulator 70 is of relatively large capacity so as to permit relatively great variations in the velocity of the jack plungers 20, as compared to the velocity of the pump piston 37, without materially changing the pressure in the jack cylinders 21, conduit 35, and the lower end of the pump cylinder 36. This not only facilitates rapid changes in the velocity of the jack plungers 20 in response to changes in the load applied to the jack plungers by the sucker rod, but makes the demands on the high pressure pump 45 relatively uniform, thereby reducing the size of the pump 45 and the motive means that drives it.

During the operation of the system, a certain

amount of oil is lost by leakage, such as leakage between the jack plungers 20 and the seals 30, and provision is made for automatically replenishing the supply of oil before it drops to a value where it would interfere with the proper operation of the system. Loss of fluid from that portion of the system including the jack cylinders 21, the conduit 35, the conduit 71, the accumulator 70, and the pump cylinder 36, results in lowering of the jack plungers 20 below their normal mean position, and movement of the polish rod 17 through only a fraction of its normal stroke. Hence, we provide means responsive to movement of the jack plungers 20 below predetermined lower limits for admitting additional fluid to the conduit 35. This means includes a pair of spring valves 77 in the lower ends of the jack plungers 20, which seal against the oil passages 78 in the lower ends of the jack cylinders whenever the plungers drop below their normal lower limits of movement. These valves 77 are mounted in recesses 79 in the lower ends of the jack plungers 20, and each valve is urged outwardly by a helical compression spring 80 so that after spring valves 77 seat against their associated passages 78, the plungers can continue to move a limited distance. Normally, whenever the plungers 20 are moving downwardly, the oil they displace in the jack cylinders 21 escapes through the opening 78 into the conduit 35. However, after the passages 78 have been closed by the spring valves 77, normal escape of the oil from the jack cylinders is prevented, and the pressure rapidly rises and is applied through conduits 81 to a pressure actuated valve 82, which connects the conduit 35 to a conduit 86 extending to the conduits 44.

A suitable construction of the pressure responsive valve 82 is shown in Fig. 4. It will be observed that it comprises a poppet valve 84, normally seated against a seat 85 to interrupt communication between the conduit 35 and the conduit 86 extending to the high pressure oil line 44. The stem 87 of the poppet extends into a separate cylinder 88 and is secured to a piston 89 therein. A helical compression spring 90 normally maintains the piston 89 in its lowermost position, in which the poppet 84 is seated. The poppet is also urged into closed position by the high pressure applied to it. Normally the pressure in the conduit 81 is never sufficient to overcome the force of the spring 90 and the force exerted on the poppet 84 by the pressure oil in the conduit 86, but when the jack plungers 20 drop below their normal lower limits of movement as a result of loss of oil from the system and the spring valve 77 closes the passages 78 the pressure in the jack cylinders 21 is suddenly increased to a very high value and this pressure is transmitted through the conduit 81 to the under side of the piston 89 in valve 82 opening the poppet 84 to permit high pressure oil from the conduit 86 to flow into the conduit 35. The poppet 84 is relatively small so as to permit only a limited flow of oil and it remains open only for the short period of time during which the jack plungers 20 are at the bottom of their stroke. However, if the poppet 84 did not remain open long enough to admit sufficient makeup oil on the first stroke, the valves 77 on the jack plungers will again close the passages 78 on succeeding strokes and again actuate the valve 82 until the lost oil has been fully replaced.

A check valve 92 is preferably provided in the high pressure oil line 44 leading to the four-way valve 43 to prevent return flow from the motor cylinder 39 when the pump 45 is shut down, and thereby lock the motor piston 40 against reverse movement.

When starting up the system it is sometimes necessary to replenish the supply of oil in the closed circuit including the jack cylinder 21, conduit 35, accumulator 70, and pump cylinder 36, and this can be done by opening a valve 96 which connects the conduit 35 with the conduit 86 leading to the pressure conduit 44.

A valve 98 is provided to by-pass oil from the pressure conduit 44 back to the reservoir and thereby reduce the pressure in conduit 44 when it is desired to move the motor piston 40 slowly into a desired position, as when adjusting the position of the cross head 19 with respect to the polish rod 17. The pumping speed can also be controlled by adjusting the valve 98, although it is preferable to do this by varying the speed of the pump 45.

Referring now to Fig. 2, the four-way valve 43 comprises four separate poppet valve assemblies 100, 101, 102, and 103, all mounted on a common frame 104 and adapted to be actuated by the control lever 50, which as previously pointed out, is tripped by stops 51 and 52 on the rod 53 connected to the piston of the hydraulic motor which is controlled by the valve 43.

Each of the valve assemblies 100 to 103 inclusive comprises a poppet 105 (Fig. 3) which seats against a seat 106 and is urged against its seat by a helical compression spring 107. The seat 106 is defined by the orifice of a bore 108, and the poppet 105 is provided with a downwardly depending skirt 109, which may be slotted or contoured to provide a gradually increasing opening for the flow of liquid as the poppet is lifted off its seat. The poppet 105 is also provided with an actuating stem 110, which is guided in a suitable aperture in the frame 104 (Fig. 2). The lever 50 is connected to a shaft 111 which is rotatably supported and carries a cam 112 which is adapted to bear against the stems 110 of the poppets. It will be observed that when the lever 50 is in one end position as shown in Fig. 2, the cam 112 opens the poppets in the valve assemblies 101 and 103. When the lever 50 is in its other extreme position, as shown in dotted lines, the cam 112 closes the poppets in the valves 101 and 103 and opens the poppets in the valves 100 and 102. When the lever is in the position shown in Fig. 2, pressure oil flows from the conduit 44 through a branch conduit 115 through the open valve 101, and through a branch conduit 116 to the conduit 41 leading to the top of the motor cylinder 39. At the same time, the conduit 42 leading from the lower end of the motor cylinder 39 is connected, through a branch conduit 117 and the open valve 103 and a branch conduit 118, to the conduit 46 which returns to the reservoir. When the lever 50 is in the opposite (dotted line) position, valves 101 and 103 are closed, valve 100 is open, to admit pressure oil from conduit 44 through a branch conduit 119 and a branch conduit 120, to the conduit 42 leading to the lower end of motor cylinder 39, and oil is exhausted from the upper end of the cylinder, through the conduit 41, a branch conduit 121, valve 102 and a branch conduit 122, to the conduit 46 leading back to the reservoir.

As has been previously mentioned, valve 43 is so constructed that following movement of the lever 50 to its center position by one of the stops 51 or 52, the lever snaps into its other extreme

position. The mechanism for accomplishing this, as shown in Fig. 2, comprises a cam 125 on the shaft 111, which moves past a detent 126 which is urged to the left into the path of the cam 125 by the helical compression spring 127. As the lever 50 moves from either end position to its center position, the cam 125 depresses the detent 126, thereby loading the spring 127, and as soon as the lever is moved past center position, the reaction of the detent 126 on the cam 125, snaps the lever into the other end position.

In order to obtain high pumping efficiency in a system of the general type described, the jack plungers 20 should have substantially constant force applied to them throughout the major portion of their stroke, their speed being determined solely by the resistance to movement afforded by the sucker rod. However, it is desirable to stop the plungers smoothly but rapidly at the ends of their stroke. The rate at which the jack plungers are reversed is in part dependent upon the rate at which the pump piston 37 is reversed, which in turn is dependent upon the flow of fluid to the motor cylinder 39, which, of course, is controlled by the four-way valve 43.

It is desirable to decelerate the motor piston 40 rapidly but uniformly at the end of its stroke, and then accelerate it as rapidly as possible at the beginning of the next stroke in the opposite direction. This is accomplished by closing one pair of poppet valves gradually as the piston 40 approaches the end of its stroke and opening the other pair of poppet valves suddenly as the piston reaches the end of its stroke. This desired valve action is obtained by means of springs 132 (Fig. 2) and 133 associated with the stops 51 and 52, which stops are slidable on the rod 53 and contact a trunnion collar 134, which is slidable on the rod 53 and has trunnions 135 engaging slots 136 in a bi-furcate end portion of the lever 50. The helical compression spring 132 is compressed between the slidable stop 51 and a fixed stop 137 secured to the rod 53. The helical compression spring 133 is positioned between the slidable stop 52 and the cross member 54 which actuates the rod 53. It will be observed that each of the slidable stops 51 and 52 has a stem 138 adapted to limit compression of the associated spring 132 or 133 by contact with the fixed stop 137 or the cross member 54.

As shown in Fig. 2, the rod 53 is in its upper end position corresponding to upper end position of the motor piston 40 (Fig. 5) and the poppet valves 101 and 103 are wide open to deliver pressure fluid from the pump conduit 44 to the top end of cylinder 39 through the cylinder conduit 41, and exhaust fluid from the lower end of cylinder 39 through the cylinder conduit 42, and the valve 103 to the conduit 46 leading back to the reservoir. The motor piston will therefore move downwardly at accelerating speed in response to full pump pressure applied thereabove, its rate of acceleration being limited only by the resistance presented by the pump piston 37 until the motor piston closely approaches the lower end of its stroke. During this major portion of the downward movement of the motor piston and the rod 53, the valve lever 50 is maintained in its upper position by the detent 126, and the spring 132 compresses without moving the slidable stop 51. However, slightly before the rod 53 reaches the lower limit of its stroke, the stop 37 contacts the upper end of the stem 138 on

the slidable stop 51 and begins to move it, together with the collar 134 and the lever 50, to gradually close the valves 101 and 103, and increasingly throttle fluid flow to and from the motor cylinder 39. The adjustment is such that the lever 50 is carried into its mid or neutral position, in which all the valves 100 to 103 inclusive are closed, just as the rod 53 reaches the lower limit of its stroke. In this position the compressed spring 132 is able to overcome the resistance of the detent 126, and it carries the lever 50 past neutral position, whereupon the detent spring 127, instead of opposing the spring 132, as it did during the first half of the movement of lever 50 aids the spring 132, and the combined forces of the two springs suddenly snap the lever 50 into full lower position. This suddenly opens the valves 100 and 102 to apply pressure fluid from the pump to the under side of the motor piston 40, and exhaust fluid from the upper side of the piston back to the reservoir. The rod 53 thereupon begins its return movement (with the motor piston 40) and the spring 133 is compressed by the cross member 54 until the rod 53 approaches its upper stroke limit and the cross member 54 contacts the stem 138 on the slidable stop 52, whereupon the lever 50 is moved back to neutral position in unison with the rod 53, to gradually close valves 100 and 102 and throttle the fluid flow to and from the motor cylinder 39, to decelerate the piston 40. When the lever reaches its mid position, the spring 133 carries it past mid position, and the spring 127 becomes effective to aid the spring 133 and snap the lever 50 into full upper position, thereby completing a cycle of operation.

It will be noted from the foregoing description of operation, with reference to Fig. 2 that the lever 50 is moved positively, with the rod 53 and with the motor piston 40, out of end position. The initial movement of the lever begins to close the valves that are controlling flow of fluid to and from the cylinder so that the piston begins to decelerate, and movement of the lever 50 decelerates with the motor piston to decelerate the movement of the valves as they approach closed position. The supply of pressure fluid to and the exhausting of fluid from the motor cylinder is thereby automatically increasingly throttled to produce a desired smooth deceleration. The rate of deceleration can be further controlled by the shape of the skirts 109 of the poppet valves, and/or the shape of the cam 112, to obtain the most desirable rate of deceleration of the motor piston.

The rate of movement of the motor piston 40 and the pump piston 37 at the end of each stroke is largely determined by the characteristics of the four-way valve 43 and the mechanism coupling it to the motor piston 40. However, the jack plungers 20 are not directly connected to the motor piston 40, and their movement will differ from the movement of the motor piston. Thus, as the pump piston 37 moves down rapidly in response to full application of high pressure oil to the upper end of the motor cylinder 39 from the pump 45, the jack plungers 20 will lag behind the pump piston 37, because of the inertia of the sucker rod, and fluid will flow from the conduit 35 into the accumulator 70 to prevent the pressure in the jack cylinders 21 from rising above the maximum value the sucker rod is designed to withstand. However, the oil stored in the accumulator 70 during that portion

of the cycle when peak pressure is produced, will return to the conduit 35 and maintain the pressure therein during the last portion of the upward stroke of the jack plungers, when the pump piston 37 is decelerating. This enables the maintenance of substantially constant oil pressure in the jack cylinders 21 throughout the major portion of the upward stroke of the jack plungers.

Downward movement of the jack plungers 20 is produced solely by the weight of the sucker rod and the oil column, but the rate of movement is limited by the rate at which oil can escape from the jack cylinders 21 into the pump cylinder 36 during upward movement of the pump piston 37. Initially at the beginning of each upward stroke, the pump piston 37 will move more rapidly than the jack plungers 20, and oil will escape from the accumulator 70 into the conduit 35. However, as the pump piston 37 is rapidly decelerated at the upper end of its stroke, the jack plungers 20 will continue to move at a relatively rapid rate because of the inertia of the sucker rod and oil column, and excess oil from the jack cylinders will be forced into the accumulator 70 and limit the increase in pressure. However, there will be some increase in pressure in the conduit 35 at the time the pump piston 37 reverses and starts its downward movement, so that maximum pressure is available to start the jack plungers 20 on their next upward stroke.

The stroke of the jack plungers 20 will vary with different wells and with variations in the fluid level and gas pressure in a given well. In the present system the stroke can be readily adjusted to any desired value by adjusting the position, on the rod 53, of the collar 137, which controls the position in the upward travel of the jack plungers 20 at which the valve 43 is reversed.

Various departures from the particular construction disclosed and described can be made without departing from the invention, which is to be limited only to the extent set forth in the appended claims.

We claim:

1. Apparatus for reciprocating the sucker rod of an in-the-well pump comprising: hydraulic jack means adapted to be mechanically connected to the sucker rod for directly reciprocating it in response to supply to and release from the jack means of pressure liquid; a liquid conduit connected to said jack means through which said liquid is supplied and released; reciprocating pump means connected to said conduit for successively supplying liquid thereto and withdrawing liquid therefrom during successive strokes of said pump means, and comprising a cylinder containing a reciprocal piston, one end of said cylinder being in direct liquid connection with said conduit and filled with pressure liquid and the other end of the cylinder being filled with a gas under pressure, and means for reciprocating said pump piston; an accumulator comprising a container directly connected to said conduit and containing a gas under pressure; a gas supply line containing a check valve connected to said other end of said pump cylinder for supplying gas thereto while preventing return flow; and means including a check valve connecting said accumulator with said other end of said pump cylinder for permitting gas flow from said pump cylinder to said accumulator while preventing reverse flow, whereby gas flows from the other end of said pump cylinder in the said accumulator whenever the gas pressure in said accumulator is less than the gas pressure in said other end of said pump cylinder, said accumulator container containing a movable wall separating the gas and liquid therein and preventing escape of gas into said conduit.

2. Apparatus as described in claim 1 including a source of gas under predetermined pressure and check valve means connecting it to said other end of said pump cylinder.

3. Apparatus for reciprocating the sucker rod of an in-the-well pump comprising: hydraulic jack means adapted to be mechanically connected to the sucker rod for elevating it in response to supply of pressure liquid to the jack means and lowering it in response to release of liquid from the jack means; a liquid conduit connected to said jack means through which liquid is supplied to and exhausted from said jack means; reciprocating pump means connected to said conduit for successively supplying liquid to and withdrawing liquid from said jack means during successive strokes of the pump means, for reciprocating said jack means; said hydraulic jack means including a cylinder and means therein reciprocal with said sucker rod for displacing liquid from said cylinder during downward movement of said sucker rod, said cylinder having a passage in one end through which liquid displaced from said cylinder normally escapes; valve means for closing said passage and preventing escape of displaced liquid when the sucker rod exceeds its normal downward movement; a source of pressure liquid of higher pressure than the maximum pressure in said liquid conduit; and pressure-actuated valve means for admitting liquid from said source to said conduit in response to pressure created in said cylinder by downward movement of the sucker rod following closure of said passage in said cylinder.

4. Apparatus for reciprocating the sucker rod of an in-the-well pump comprising: hydraulic jack means adapted to be mechanically connected to the sucker rod for directly reciprocating it in response to supply to and release from the jack means of pressure liquid; a liquid conduit connected to said jack means through which said liquid is supplied and released; reciprocating pump means connected to said conduit for successively supplying liquid thereto and withdrawing liquid therefrom during successive strokes of said pump means, and comprising a cylinder containing a reciprocal piston, one end of said cylinder being in direct liquid connection with said conduit and filled with pressure liquid, and the other end of the cylinder being filled with a gas under pressure, and means for reciprocating said pump piston; an accumulator comprising a container directly connected to said conduit and containing a gas under pressure; said means for reciprocating said pump piston comprising: a hydraulic motor having a cylinder, and a piston therein directly connected to said pump piston; a source of pressure liquid; and valve means for successively admitting pressure liquid from said source to opposite ends of said motor cylinder while exhausting liquid from the other end, in which said valve means comprises four poppet valves, one pair of which are connected between one end of said motor cylinder and exhaust, and between the other end of said motor cylinder and said pressure source, respectively, and the other

pair of which are connected between said one end of said motor cylinder and said pressure source and between the other end of said motor cylinder and exhaust, respectively, and a mechanism responsive to movement of said motor piston for slowly closing one pair of said poppets as said motor piston approaches one end of its stroke, and suddenly opening said other pair of poppets as said piston reaches said end of its stroke.

5. Apparatus for reciprocating the sucker rod of an in-the-well pump comprising: hydraulic jack means adapted to be mechanically connected to the sucker rod for directly reciprocating it in response to supply to and release from the jack means of pressure liquid; a liquid conduit connected to said jack means through which said liquid is supplied and released; reciprocating pump means connected to said conduit for successively supplying liquid thereto and withdrawing liquid therefrom during successive strokes of said pump means, and comprising a cylinder containing a reciprocal piston, one end of said cylinder being in direct liquid connection with said conduit and filled with pressure liquid, and the other end of the cylinder being filled with a gas under pressure, and means for reciprocating said pump piston; an accumulator comprising a container directly connected to said conduit and containing a gas under pressure; said means for reciprocating said pump piston comprising: a hydraulic motor having a cylinder, and a piston therein directly connected to said pump piston; a source of pressure liquid; and valve means for successively admitting pressure liquid from said source to opposite ends of said motor cylinder while exhausting liquid from the other end, in which said valve means comprises four poppet valves, a first pair of which are connected between one end of said motor cylinder and exhaust, and between the other of said motor cylinder and said pressure source, respectively, and the other pair of which are connected between said one end of said motor cylinder and said source and between the other end of said motor cylinder and exhaust, respectively, and a mechanism responsive to movement of said motor piston for slowly closing one pair of said poppets as said motor piston approaches one end of its stroke, and opening said other pair of poppets as said piston reaches the end of its stroke; the two poppet valves connected to said liquid pressure source, each comprising a seat and a poppet reciprocal toward and away from the seat, the poppet having an inwardly extending skirt slidable within the seat, and the skirt having such contour as to increasingly throttle fluid flow through the seat as the poppet approaches the seat.

6. Apparatus for reciprocating the sucker rod of an in-the-well pump comprising: hydraulic jack means adapted to be mechanically connected to the sucker rod for directly reciprocating it in response to supply to and release from the jack means of pressure liquid; a liquid conduit connected to said jack means through which said liquid is supplied and released; means connected to said conduit for successively supplying liquid thereto and withdrawing liquid therefrom for reciprocating said jack and comprising a counterbalancing chamber partially filled with liquid and partially filled with gas under pressure, said chamber being so connected to said jack that the pressure therein opposes downward movement of the sucker rod; an accumulator comprising a container having a movable wall therein separating the interior of the container into a gas compartment and a liquid compartment; means connecting said liquid compartment directly to said conduit; a gas supply line containing a check valve connected to said counterbalancing chamber for supplying gas thereto while preventing return flow; and means including a check valve connecting the gas compartment of said accumulator with the gas-containing part of said counterbalancing chamber for permitting gas flow from said counterbalancing chamber to said accumulator while preventing reverse flow, whereby gas flows from said counterbalancing chamber into said accumulator whenever the pressure in said counterbalancing chamber exceeds that in said accumulator.

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