April 9, 1940. W. E. SAXE 2,196,816

METHOD AND APPARATUS FOR AUTOMATICALLY COUNTERBALANCING PUMPING APPARATUS ON OIL WELLS

Filed Sept. 6, 1938 3 Sheets-Sheet 1

Fig. 1.

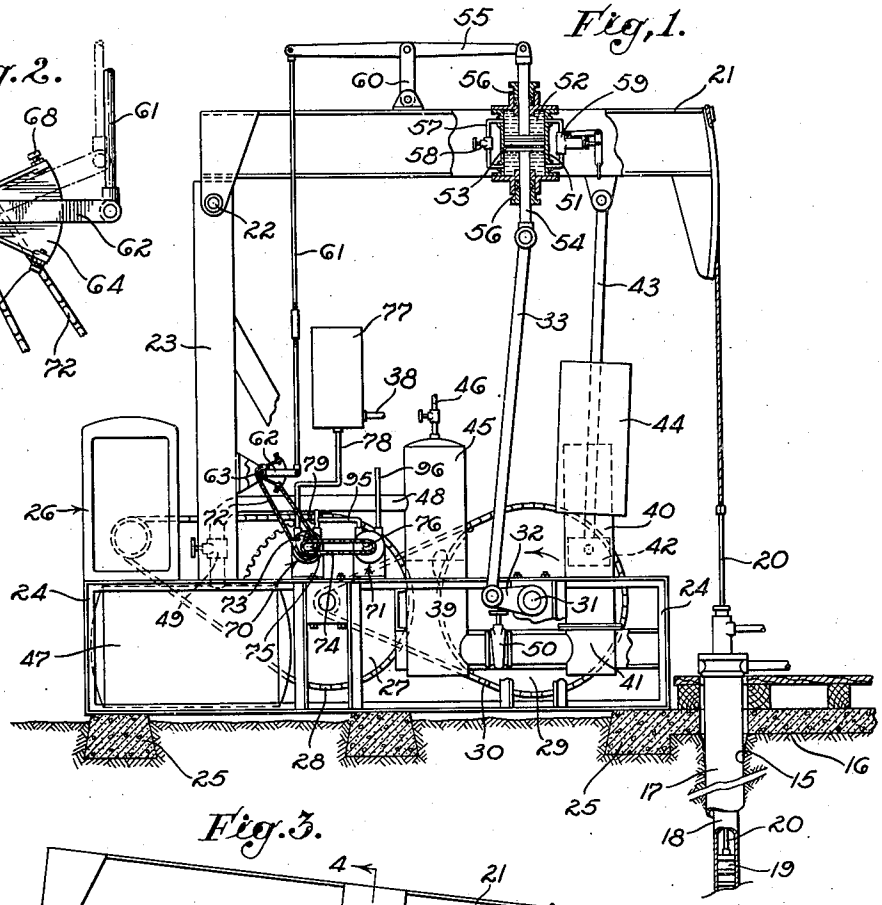


Fig. 2.

Fig. 3.

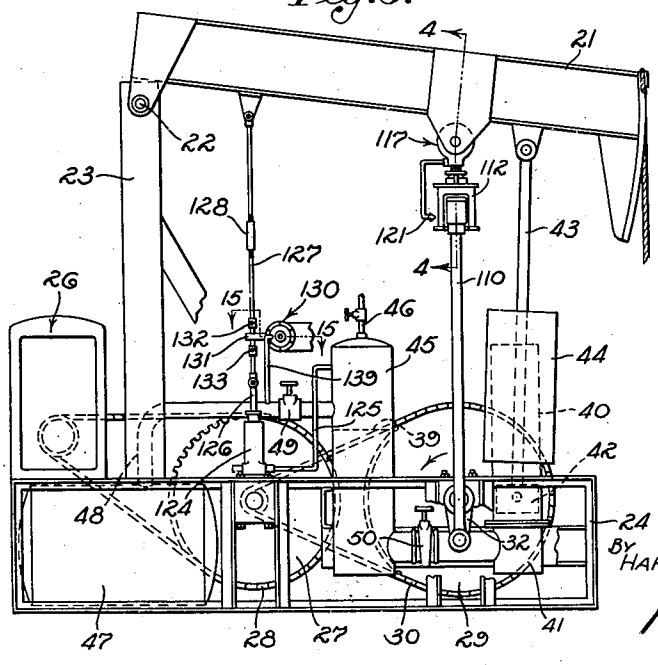
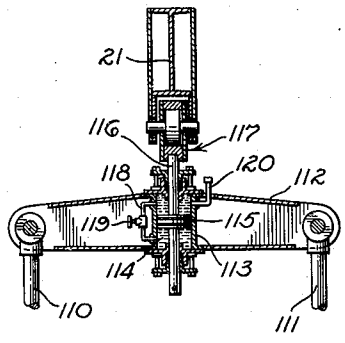


Fig. 4.



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Fig. 6.

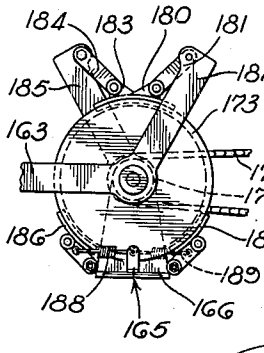


Fig. 5.

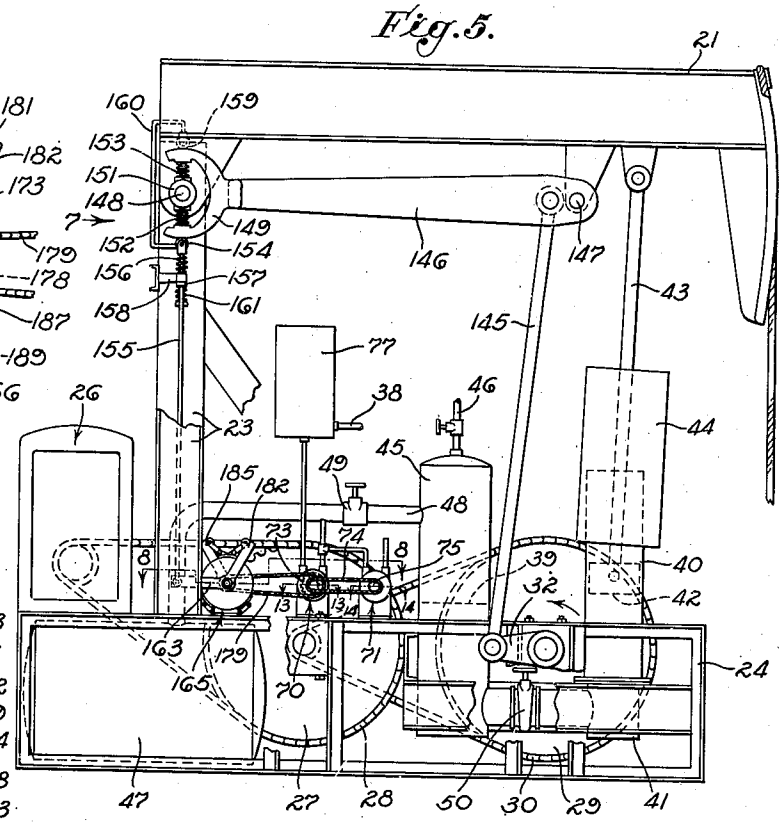


Fig. 7.

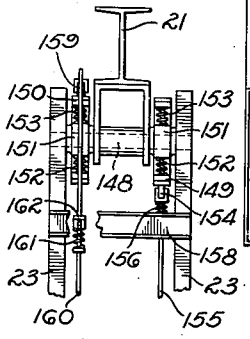
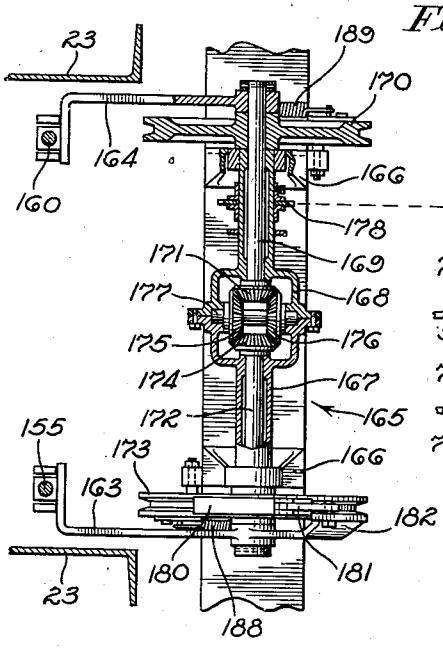


Fig. 8.



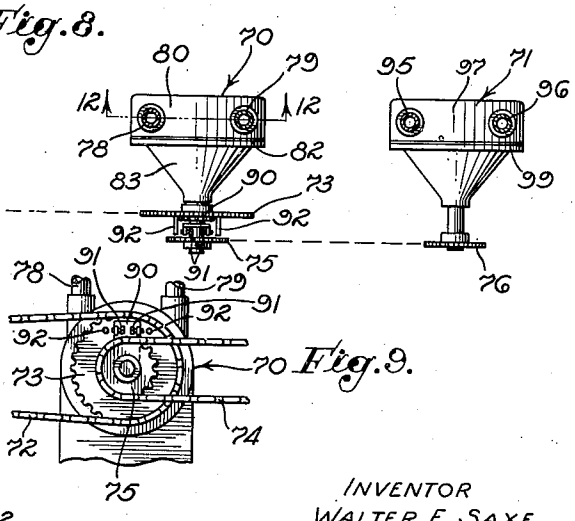


Fig. 9.

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Fig. 11.

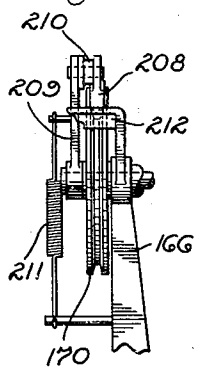


Fig. 10.

Fig. 12.

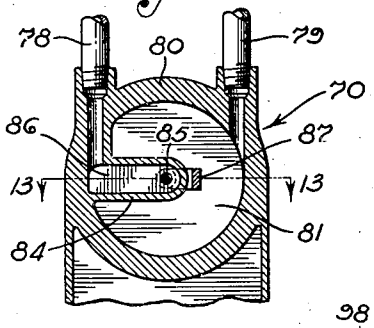


Fig. 15.

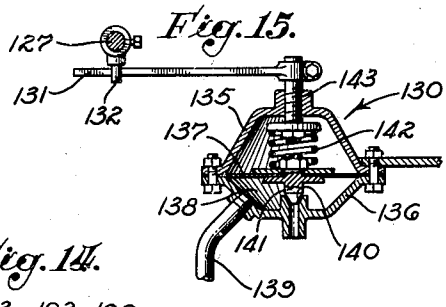


Fig. 14.

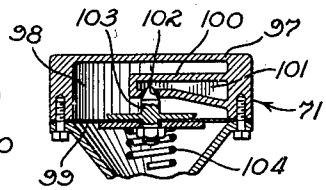
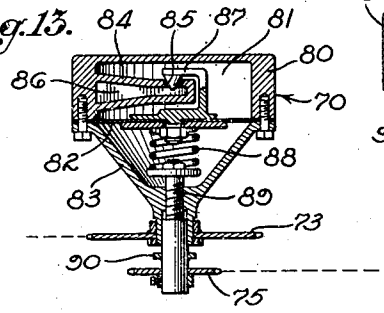


Fig. 13.



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UNITED STATES PATENT OFFICE

2,196,816

METHOD AND APPARATUS FOR AUTOMATICALLY COUNTERBALANCING PUMPING APPARATUS ON OIL WELLS

Walter E. Saxe, Alhambra, Calif.

Application September 6, 1938, Serial No. 228,536

22 Claims. (Cl. 74—589)

My invention relates to a method and apparatus for securing automatic counterbalancing, and particularly to a method and apparatus for automatically providing correct counterbalance for a reciprocating member which is driven by a rotating shaft and, which if not counterbalanced, subjects the rotating shaft to unequal loads during the two oppositely directed strokes.

My invention finds particular utility in the automatic counterbalancing of pumping apparatus for oil wells, and an embodiment of the apparatus of my invention and apparatus capable of performing the method of my invention will be described in connection with such use, it being understood, however, that my invention is not limited to such use.

In oil well pumping apparatus it is customary to employ a prime mover for rotating a shaft and to translate the rotary movement of such shaft to the reciprocating movement of a pump plunger through a crank arm, a pitman, and a walking beam. When the crank arm, in its rotation, is nearly vertical, the component of its movement parallel to the direction of travel of the walking beam and the pump plunger is relatively small, and therefore the load on the prime mover when the crank is in this position is also relatively small. On the other hand, when the crank arm is near either of its horizontal positions, it has a relatively large component of its movement parallel to the direction of travel of the walking beam and the pump plunger, and the load on the prime mover is then most influenced by the load on the walking beam. If no counterbalance is employed, it is evident that on the upstroke of the string of sucker rods, when the crank arm is horizontal, the prime mover is subjected to its greatest load, being required at that time to lift with greatest velocity the walking beam, the string of sucker rods, and all of the liquid being elevated in the well tubing; while on the downstroke, the walking beam and string of sucker rods fall by gravity, subjecting the prime mover to little or no load.

In my Patent No. 2,122,871, I disclose a method and apparatus for counterbalancing such an oil well pumping apparatus wherein air is compressed on the downward stroke of the walking beam and energy is thus stored to assist the prime mover on the upward stroke. By proper adjustment of that apparatus, I am able to make the maximum load on the prime mover during the downward stroke equal to the maximum load on the prime mover during the upward stroke, whereby increased efficiency and longer life of the pumping apparatus result, or bringing into consideration the time element, I may adjust that apparatus to make the work done by the prime mover during the downward stroke equal to the work done by the prime mover during the upward stroke for the same purpose of increasing efficiency.

I have found, however, that in the case of many wells, the load during the upstroke of the sucker rod does not remain constant but may vary gradually and, over a period of hours, may be considerably altered. This change may come about through operation of various factors. The fraction of water contained in the oil may change, resulting in a heavier column of liquid to be raised; or the fraction of gas contained in the oil may change, resulting in a lighter column of liquid. Moreover, in those wells situated adjacent the ocean, the well pressure and the load on the sucker rod are found to change with the tide. In the case of installations of this kind, it is desirable to vary the counterbalancing force as the load on the sucker rod varies, to make the loads on the prime mover equal during the upward and downward strokes of the sucker rod. To do this ordinarily requires close attendance to the apparatus, which is desirable to avoid.

It is an object of this invention, therefore, to provide a method and apparatus for automatically providing a counterbalancing force which shall result either in the maximum prime mover load existing during the downward or return stroke of the sucker rod being substantially equal to the maximum prime mover load existing during the upward or pumping stroke of the sucker rod or in the work performed by the prime mover during the downward or return stroke of the sucker rod being substantially equal to the work performed by the prime mover during the upward or pumping stroke of the sucker rod.

It is also an object of the invention to provide a method and apparatus for automatically making the loads upon the prime mover substantially equal when the crank arm is moving upwardly through a horizontal position and when it is moving downwardly through a horizontal position.

Another object of my invention is to provide a method and apparatus whereby the prime mover is required to compress a gas during that stroke of the pump plunger in which the prime mover is normally subjected to its lesser load, and the gas is expanded during that stroke of the pump plunger in which the prime mover is normally subjected to its greater load, and whereby the pressure to which the gas is com-

pressed is automatically regulated to equalize either the maximum loads upon the prime mover or the work done by the prime mover during the two oppositely directed strokes of the pump plunger.

More specifically, it is an object of the invention to provide in a counterbalancing apparatus for oil wells, wherein gas is compressed on the downward stroke of the sucker rod to effect counterbalancing, means for automatically regulating the pressure of the gas in response to the load to be counterbalanced in such manner as to equalize either the maximum loads upon the prime mover or the work done by the prime mover during the two oppositely directed strokes of the pump plunger.

Another object is to provide in oil well pumping and counterbalancing apparatus of the character above described, a connection between the crank arm and walking beam which is of variable length dependent upon the load transmitted by this connection, and means for regulating the counterbalancing force in response to the change in length of the connection.

A further object in one practice of my invention is to provide apparatus which weighs or measures the maximum loads to which the prime mover is subjected on both the upward and downward strokes of the pump plunger and adjusts the counterbalancing force in response to the relative loads on the two oppositely directed strokes; and in another practice of my invention it is my object to provide apparatus which measures the work done by the prime mover on the upward and downward strokes respectively of the pump plunger and adjusts the counterbalancing force in response to the relative amount of work done on the two oppositely directed strokes.

Another object is to provide apparatus which measures the torque demanded of the source of motive power and adjusts the counterbalancing force to equalize the maximum torque demanded during the two oppositely directed strokes of the pump plunger.

Still another object of the invention is to provide automatic counterbalancing apparatus which shall require a minimum of attention, shall be efficient in operation, and shall be of long life.

These and other apparent objects I attain in a manner which will be clear from a consideration of the following description taken in connection with the accompanying drawings, of which:

Fig. 1 is an elevational view of one form of my automatic counterbalancing apparatus, shown partly in section, as applied to pumping apparatus for a well.

Fig. 2 is a side view of a part of the regulating means of the apparatus of Fig. 1.

Fig. 3 is an elevational view of an alternative form of my automatic counterbalancing apparatus.

Fig. 4 is a sectional view of a part of the apparatus of Fig. 3 taken along the line 4—4, as indicated.

Fig. 5 is an elevational view of an alternative form of my automatic counterbalancing apparatus.

Fig. 6 is a side view of a part of the regulating means of the apparatus of Fig. 5.

Fig. 7 is an end view of a portion of the apparatus of Fig. 5, as indicated by the arrow 7.

Fig. 8 is a partial sectional view of the apparatus of Fig. 5, taken along the line 8—8 of Fig. 5.

Fig. 9 is a side view of one of the pressure regulating valves shown in Fig. 8.

Fig. 10 is an elevational view of an alternative form of my automatic counterbalancing apparatus.

Fig. 11 is an end view of a portion of the apparatus of Fig. 10.

Fig. 12 is a sectional view of one of the pressure regulating valves of Fig. 8, taken along the line 12—12, as indicated.

Fig. 13 is a sectional view of the pressure regulating valve shown in Fig. 12, taken along the line 13—13.

Fig. 14 is a sectional view of one of the pressure regulating valves of the apparatus of Fig. 5, taken along the line 14—14.

Fig. 15 is a sectional view of part of the pressure regulating means of the apparatus of Fig. 3, taken along the line 15—15, as shown.

My invention is illustrated as applied to the pumping apparatus for an oil well 15 extending downwardly into the earth 16. The well 15 has a casing 17 and a pump tubing 18 in the lower end of which a pump plunger 19 is reciprocated by a string of sucker rods 20. The sucker rods 20 extend upwardly through the pump tubing to above the surface of the earth and are attached by suitable means such as a cable to the working end of a walking beam 21, the other end of the walking beam preferably being mounted upon a pivot 22 carried by a fulcrum frame 23. This assembly is arranged in such a manner that rocking of the walking beam results in reciprocation of the pump plunger 19 throughout a pumping cycle comprising an upwardly directed pumping stroke and a downwardly directed return stroke. The fulcrum frame 23 and the remainder of the pumping and counterbalancing apparatus are preferably mounted on an underframe 24 carried on a foundation 25. In the form of pumping apparatus illustrated in the drawings, a source of motive power, or prime mover 26, drives a relatively large sprocket 27 through a chain 28, which in turn drives a sprocket wheel 29 through a chain 30. Connected with the wheel 29 for rotation about a fixed axis 31 is a crank arm 32. Attached to the crank arm 32 and in operative connection with the walking beam 21 is a pitman 33, the whole apparatus being adapted to raise and lower the walking beam once for every revolution of the crank arm 32.

Assume that the crank arm 32 rotates in the direction indicated by the arrow in Fig. 1. As previously explained, the prime mover 26 will encounter the greatest load when the crank is in the horizontal position on the upstroke if no counterbalance is employed. At this time the walking beam 21, the string of sucker rods 20, the pump plunger 19, and the column of fluid in the tubing 18 are all being elevated. As in my issued patent, above-mentioned, I preferably counterbalance the pumping apparatus by providing an apparatus which includes a cylinder 40 secured at its lower end to a housing 41 with which it freely communicates. Reciprocable within the cylinder 40 is a piston 42 having a connecting rod 43 pivotally connected thereto. The connecting rod 43 is pivoted at its upper end to the walking beam 21 at a point which is preferably near the point of connection of the pitman 33. The rod 43 preferably carries a hood 44 which moves therewith and serves as a protective cover for the cylinder 40. The housing 41 normally

communicates with a compression and expansion chamber 45 provided with a valved supply pipe 46 for the introduction of liquid to the chamber 45, the housing 41, and cylinder 40. The chamber 45 is preferably normally in communication with a relatively large additional chamber 47 through a pipe 48 and valve 49. The valve 49 and a valve 50 between the cylinder 40 and the chamber 45 are ordinarily not closed unless the walking beam is to be disconnected from the sucker rod, or the various units of the apparatus are to be isolated for some other reason.

Normally a liquid 39, preferably oil, fills the housing 41, is in contact with the piston 42, and has a surface within the chamber 45 in contact with a gas, preferably air, under pressure, which fills the remaining space in the chamber 45 and the chamber 47. The chambers 45 and 47, housing 41, and cylinder 40 thus constitute a gas-containing chamber closed by the movable piston 42.

In normal operation, as the walking beam is brought down, the piston 42 forces liquid out of the chamber 40 and into the chamber 45, compressing the gas in the chambers 45 and 47 and requiring the prime mover to exert a torque on the downward stroke of the walking beam which is determined by the dimensions of the gas space, the stroke of the piston, and the initial pressure of the gas in the compression space. The use of a relatively large chamber 47, providing a large compression space, results in a relatively small change in gas volume due to movement of the piston 42, and therefore in a relatively small change in gas pressure throughout the cycle of movement of the piston 42. Under these conditions it will be evident that the greatest torque required of the prime mover in compressing the gas will be encountered when the crank arm 32 is in nearly a horizontal position on the downward stroke, as previously explained. On the upward stroke the gas in the chambers 45 and 47 acts upon the piston 42 to help raise the walking beam, at the same time expanding to its original volume. I preferably automatically control the gas pressure in the chambers 45 and 47 to result in equal maximum torques required of the prime mover during the upward and downward strokes of the walking beam; or in equal torques at certain stages in the upward and downward strokes, as when the crank arm 32 is in horizontal position on the upward stroke and in horizontal position on the downward stroke. The maximum torques required of the prime mover on the upward and downward strokes of the walking beam will be equal when the force exerted on the piston 42 is such that the moment of this force about the pivot axis 22 is approximately equal to the moment of the forces of gravity on the walking beam 21, the string of sucker rods, the pump plunger, and one-half of the liquid being elevated in the tubing 18. The apparatus of my invention is adapted to automatically regulate the pressure of gas in the chambers 45 and 47 to automatically bring about and maintain equality of the maximum torque required to raise the walking beam on its upward stroke and that required to lower it on its downward stroke.

In the embodiment disclosed in Fig. 1, the effective length of the pitman, or the distance between the walking beam 21 and the crank arm 32, is variable in response to the force at the connection of the pitman and walking beam required to move the walking beam, and the variation of this effective length is employed to regulate the pressure of gas in the chambers 45 and 47. Mounted on the walking beam 21 is a cylinder 51 filled with liquid 52, in which cylinder is a movable piston 53 on a piston rod 54 which projects from both ends of the cylinder 51. The bottom of the piston rod 54 is pivotally connected to the pitman 33, and the top of the rod 54 is pivotally connected to a lever 55. Suitable packing means 56 is provided at the ends of the cylinder 51 to prevent leakage around the rod 54. A by-passing conduit 57 connects the liquid at opposite ends of the cylinder through an adjustable valve 58. A hand pump 59 is also connected between the liquid compartments on opposite sides of the piston 53 and serves to raise the walking beam relative to the piston 53 by pumping liquid out of the lower compartment and into the upper one. The lever 55 is pivotally supported on an arm 60 which in turn is pivotally supported on the walking beam 21. The end of the lever 55 opposite to that which connects with the piston rod 54 is pivotally connected to a rod 61 of adjustable length which connects with the regulating means.

In the apparatus, as best illustrated in Fig. 2, the lower end of the rod 61 is pivotally connected to an arm 62 which pivots about an axis 63. Another member 64 is also mounted to pivot about the axis 63 and carries a sprocket wheel 65 and two flange portions angularly spaced apart and positioned in the path of the arm 62 as it is rocked by movement of the walking beam. Suitable adjustment means are provided which may take the form of screws 68 and 69 which are normally so adjusted that the angular spacing between them less the angular width of the lever 62 is approximately equal to the angle through which the arm 62 is moved during a stroke of the walking beam 21 if the piston 53 remains stationary relative to the walking beam. By this means the arm 62 is permitted to move through an angle characteristic of normal torque and correct counterbalance conditions without engaging the member 64 at either end of its stroke.

Rotation of the member 64 is adapted to change the adjustment of pressure regulating valves 70 and 71 by reason of the connection of a chain 72 with the sprocket wheel 65 and a sprocket wheel 73 of the valve 70, and the connection of a chain 74 with sprocket wheels 75 and 76 of the valves 70 and 71, respectively. The valve 70 is preferably connected with a high pressure gas reservoir 77 through a conduit 78, and through a conduit 79 with the conduit 48 connecting with the chambers 45 and 47, the valve 70 being adapted to permit gas to flow from the reservoir 77 into the chambers 45 and 47 to raise the pressure therein until it reaches an equilibrium value determined by the adjustment of the valve 70. The pressure of gas in the reservoir 77 may be maintained at a suitably high value above that in the chambers 45 and 47 by any suitable means, such as an air compressor, connected to the reservoir 77 through the conduit 38.

The valve 70 may be constructed as shown in Figs. 8, 9, 12, and 13. In this construction a housing 80, providing an interior chamber 81, has one side closed by a flexible diaphragm 82 which is clamped between the housing 80 and a member 83. A hollow portion 84 extends inwardly from the housing 80 into the chamber 81 and is formed with a valve passage 85 connecting a passage 86 with the chamber 81. The passage 86 is in communication with the conduit 78, and the chamber 81 is in communication with the conduit 79. Carried on the diaphragm 82 is a valve 87 which is adapted to close the valve

passage 85 by action upon the diaphragm 82 of air pressure within the chamber 81. A spring 88 acts upon the diaphragm 82 tending to lift the valve 87 from its seat, and is compressed between the diaphragm and the end of a screw 89 which is in threaded engagement with the member 83 and its attached to the sprocket 75. The screw 89 has threads of relatively great pitch so that it is advanced a relatively great distance toward or away from the diaphragm upon rotation through a small angle. The threads on the screw 89 are cut in a direction such as to advance the screw toward the diaphragm upon clockwise rotation of the screw as viewed from the sprocket side of the valve. In the form of my apparatus illustrated in Fig. 1, the screw 89 may be connected for rotation with the sprocket 73 without any backlash, but since in another form of my invention, hereinafter described, it is desirable to have backlash between these parts, I have illustrated the valve 70 in a form which permits adjustment to provide or eliminate backlash as desired. In this form an arm 90 is attached for rotation with the screw 89 and carries flanges at either side through which are threaded adjusting screws 91, which are adapted to be engaged by pins 92 attached to the sprocket 73 for rotating the arm 90 and screw 89 when the sprocket 73 is rotated so as to contact one or the other of the screws 91. In the apparatus of Fig. 1, the adjusting screws 91 are both adjusted to contact the respective pins 92 so as to connect the sprocket 73 for rotation with the screw 89 without backlash.

In the operation of the valve 70, it will be apparent that the valve will remain open, permitting gas to flow from the high pressure reservoir 77 into the chambers 45 and 47 until the pressure in the chamber 81, which is equal to that in the chambers 45 and 47, becomes great enough to force the diaphragm 82 sufficiently far against the spring 88 to close the valve 87. The farther the screw 89 is advanced toward the diaphragm 82, the greater must be the pressure in the chamber 81 before the valve is closed. Thus, the pressure in the chambers 45 and 47 is raised by rotation of the sprocket 73 in a clockwise direction as viewed from the sprocket end of the valve 70, and the equilibrium pressure, below which the valve 70 will not permit the pressure in the chambers 45 and 47 to fall, is reduced by rotation of the sprocket 73 in a counterclockwise direction.

It will be observed that the valve 70 is not adapted to reduce the pressure in the chambers 45 and 47, but this function is performed by the valve 71 which is connected through a conduit 95 with the gas under compression in the chambers 45 and 47, and with the atmosphere through a conduit 96. The valve 71 has a housing 97 providing a chamber 98 within and has one side closed by a diaphragm 99. A hollow portion 100 provides a space 101 within, which is in connection with the conduit 96, and has a valve passage 102 connecting with the chamber 98. A valve member 103, which is adapted to close the valve passage 102, is carried on the diaphragm 99 and is urged into closed position by action of a spring 104 pressing on the diaphragm. As in the case of the valve 70, the end of the spring 104 is forced to or from the diaphragm by rotation of the sprocket wheel, which, in the case of the valve 71, is designated by the numeral 76. The construction of the valve 71 is such that when the chain 74 is connected between the valves 70 and 71 as shown, rotation of the sprockets 75 and 76 in a clockwise direction, as viewed from the sprocket end of the valves, results in increasing the compression of the spring 104, and, conversely, rotation in a counterclockwise direction decreases the compression of the spring 104.

In the operation of the valve 71, the valve passage 102 will be open if the air pressure in the chamber 98 acting upon the diaphragm 99 is sufficient to overcome the compression of the spring 104, and under these circumstances air in the chambers 45 and 47 may pass out through the valve passage 102 to the atmosphere until the pressure has been reduced to a value at which the spring 104 will cause the valve member 103 to seat. It will be clear that in this manner the valve 71 will automatically limit the pressure in the chambers 45 and 47 to a pressure equal to or below that for which the valve will open, and that by rotation of the sprocket 76 the equilibrium pressure of the valve may be raised or lowered.

The valves 70 and 71 are preferably so adjusted relative to one another, as by the relative orientation of the sprockets 75 and 76, as to cause the valve 71 to open at a pressure somewhat higher than the pressure at which the valve 70 is adapted to close, the difference in these two pressures preferably being about the same as, or a little more than, the difference in air pressure within the chambers 45 and 47 which is to be expected from the movement of the piston 42.

The operation of the apparatus of Fig. 1 can now advantageously be explained. At the start of the pumping operation, if the piston 53 is not located about in the middle of the cylinder 51, it is preferably brought to this location by opening the valve 58 and moving the piston relative to the walking beam. If desired, the hand pump 59 may be employed for this purpose. When the piston 53 is centrally positioned in the cylinder 51, the valve 58 is partially closed to provide only a small by-pass opening for flow of liquid through the conduit 57, and the pumping apparatus may be started. As the walking beam 21 is forced up and down by the pitman 33 acting through the piston 53 and the liquid 52 contained in the cylinder 51, the piston 53 will reciprocate slightly within the cylinder 51. On the upward stroke the piston 53 will force a small amount of liquid out of the upper compartment through the conduit 57 and valve 58 into the lower compartment, the amount of liquid thus transferred depending upon the adjustment of the valve 58 and the average force with which the piston 53 presses upwardly upon the liquid 52 during the time period of the upward stroke. On the downward stroke, the piston 53 forces a small amount of liquid out of the lower compartment into the upper compartment through the conduit 57 and valve 58. Thus, the piston and cylinder connection between the pitman and walking beam measures the work done by the pitman during its two oppositely directed strokes. If the displacement of the liquid on the upward or pumping stroke is equal to the liquid displacement on the downward or return stroke, the piston will after each downward stroke be located in the same position relative to the cylinder 51 and walking beam 21; but, if the liquid displacement on the upward stroke is greater than that on the downward stroke, the piston will on each upward stroke rise in the cylinder 51 more than it will fall on the downward stroke and will therefore gradually assume a higher position in the cylinder 51. If, however, the liquid displacement by the pis-

ton on the downward stroke is greater than that exerted on the upward stroke, the piston will gradually shift to a lower position in the cylinder 51.

The upward movement of the piston 53 relative to the walking beam causes the rod 61 to be moved downwardly relative to the walking beam, resulting in a clockwise rotation of the arm 62 (as seen in Figs. 1 and 2). Since the walking beam carrying the rod 61 is normally moved with each revolution of the crank 32 up and down through a fixed angle, the arm 62 also has a certain normal oscillation due to the movement of the walking beam. Preferably, the screws 68 and 69 of the member 64 are so adjusted that in the normal oscillation of the arm 62 due to movement of the walking beam, with the piston 53 and lever 55 stationary relative to the walking beam, the arm 62 will come nearly to but not move the screws 68 and 69 at the respective ends of its stroke. When the rod 61 is depressed relative to the walking beam, it is evident that the arm will contact the screw 69 at the lower end of its stroke, causing clockwise rotation of the member 64 and sprocket 65, and as the rod 61 is further depressed by reason of the piston 53 rising still higher in the cylinder 51, the sprocket 65 will be further rotated in proportion to the movement of the piston 53. As the sprocket 65 is rotated clockwise, the sprockets 73 and 76 of the valves 70 and 71, respectively, will also be rotated clockwise. As previously explained, this readjustment of the valves 70 and 71 will result in higher equilibrium pressures for the two valves. Consequently, the valve 70 will open to permit air from the high pressure reservoir 77 to flow into the chambers 45 and 47 until the pressure therein rises to the new equilibrium value. This causes the force exerted by the liquid 39 on the piston 42 to be greater on the upward stroke, which reduces the load on the pitman 33, and on the downward stroke the pitman 33 is required to pull harder in order to compress the air under the higher pressure. Thus, the excess of force of the piston 53 on the liquid 52 on the upward stroke over that on the downward stroke is reduced by the increase in pressure of air in the chamber 45 and 47 which has taken place. Eventually the pressure of air in the chambers 45 and 47 will rise to a value at which the work performed by the piston 53 on the liquid in the cylinder 51 is the same on the upward stroke as on the downward stroke, and the mean position of the piston 53 relative to the walking beam 21 will remain the same from one cycle to the next. Under these conditions, the work demanded by the pump will be correctly counterbalanced.

It will be apparent that when the work demanded by the pump is reduced, the piston 53 will gradually fall relative to the walking beam, causing the rod 61 to be elevated, and resulting in the arm 62 contacting the screw 68 at the upper end of its stroke, thereby rotating the member 64 and sprocket 65 in a counterclockwise direction. The sprockets 73 and 76 will be rotated in counterclockwise direction, and the equilibrium pressures of the valves 70 and 71 will be lowered. The valve 71 will therefore open and permit air to pass out to the atmosphere until the pressure in the chambers 45 and 47 has fallen to a value at which the valve 71 will close. In this manner the force exerted upon the piston 42 by the liquid 39 will be reduced until the force required to be exerted by the piston 53 on the liquid 52 is substantially the same during the upward and downward strokes, and the pump load is again correctly counterbalanced. It will be observed that, regardless of how the pump load changes, my apparatus automatically brings about a condition of correct counterbalance for the new load.

In the form of my apparatus illustrated in Figs. 3 and 4, I preferably provide another crank arm similar to the crank arm 32 and positioned on the other side of the drive sprocket 29. Each of two substantially parallel pitmans 110 and 111 is connected to the crank arms and extends upwardly to connect with the walking beam 21 through a liquid cylinder and piston connection similar in principle to that illustrated in the apparatus of Fig. 1. The pitmans 110 and 111 are at their upper ends connected to opposite ends of a beam 112 extending transverse to the walking beam 21. In the middle of the beam 112 and fixed thereto is a cylinder 113 filled with liquid 114. Within the cylinder 113 is a movable piston 115 fixed on a piston rod 116 which passes through suitable packing and projects through both ends of the cylinder. The upper end of the rod 116 is pivotally connected with the walking beam 21 through suitable bearing means 117. A by-pass conduit 118 is provided connecting the liquid on opposite sides of the piston 115, and an adjustable valve 119 is placed in the conduit 118. A pipe 120 is provided for filling the cylinder with liquid. An indicating finger 121 is carried by the piston rod 116 and serves to indicate the position of the piston 115 within the cylinder.

For regulating the pressure in the chambers 45 and 47, I provide an air compressor 124, provided with suitable intake and discharge valves and adapted to take in air from the atmosphere and compress it into the chambers 45 and 47 through a conduit 125. The compressor 124 preferably has a vertical cylinder mounted stationary with respect to the frame 24 of the pumping apparatus, has a piston movable in the cylinder, and has a piston rod 126 connected to the piston. The piston rod 126 is pivotally connected to a connecting rod 127, having means 128 for adjusting its length, the connecting rod 127 being pivotally connected to the walking beam 21. The piston of the compressor 124 will thus be reciprocated as the walking beam is moved up and down. The stroke of the piston will remain substantially constant regardless of the position of the cylinder 113 relative to the walking beam 21, but the depth to which the piston moves in the compressor 124, and therefore the clearance of the compressor, will depend upon the relative position of the cylinder 113 and the walking beam. The discharge pressure of a compressor beyond which it will not compress is dependent upon the clearance of the compressor, the smaller the clearance being, the higher being the pressure to which it will compress. Thus, the maximum pressure attainable in the chambers 45 and 47 is determined by the minimum clearance allowed in the compressor 124. The normal clearance of the compressor 124 is preferably adjusted by varying the length of the rod 127 to permit a discharge pressure which, acting through the liquid 39 on the piston 42, will provide substantially the correct degree of counterbalancing of the pump load normally encountered when the piston 115 is positioned in the middle of the cylinder 113.

The variation of clearance of the compressor 124 from its normal amount may be employed to

increase the air pressure in the chambers 45 and 47, but to decrease the air pressure I employ a valve 130 which is stationarily mounted on a member of the frame and has an operating arm 131 projecting therefrom in the path of an upper pin 132 and a lower pin 133 adjustably mounted on the rod 127. The pins 132 and 133 are preferably spaced apart along the rod 127 at such a distance that in the normal movement of the rod 127 due to oscillation of the walking beam 21 the pins at opposite ends of the stroke almost, but not quite, contact the arm 131. The valve 130 may be constructed as illustrated in Fig. 15. Two dished members 135 and 136 are clamped together with a diaphragm 137 between providing a chamber 138 between the diaphragm and the member 136. Connecting with the chamber 138 is a conduit 139 which leads to the gas under compression in the chambers 45 and 47. A valved passage 140 leads from the chamber 138 to the atmosphere, and is adapted to be closed by a valve member 141 which is carried on the diaphragm 137 and urged by a spring 142 into a closed position. The compression of the spring 142 is adapted to be increased by counterclockwise rotation of the arm 131, as seen in Fig. 3, and to be decreased by clockwise rotation thereof, this adjustment being effected through action of a screw 143 attached to the arm 131. When the pressure of air in the chambers 45 and 47, and therefore in the chamber 138, is great enough to overcome the compression of the spring 142, the valve member 141 is unseated, permitting air to flow out of the chambers 45 and 47 until the pressure drops to a value at which the spring is able to close the valve. By movement of the arm 131 up or down, then the maximum pressure permitted in the chambers 45 and 47 may be lowered or raised.

In the operation of the apparatus illustrated in Figs. 3 and 4, preferably the piston 115 is first located about in the middle of the cylinder 113. This may be accomplished by opening the valve 119 and moving the walking beam 21 relative to the cylinder 113 until the piston is in the desired position as indicated by the indicator 121. The valve 119 is then preferably closed to a point where the piston 115 moves only a slight distance within the cylinder 113 during a stroke of the walking beam. If the pressure of air in the chambers 45 and 47 is such that the pump load is correctly counterbalanced, the piston 115 will move down in the cylinder 113 a short distance on the upward stroke of the pump plunger and up an equal distance on the downward stroke. The clearance of the compressor 124 will remain constant at an amount which limits the discharge pressure of the compressor to that existing in the chambers 45 and 47, and the arm 131 will be unmoved by the reciprocation of the rod 127. If, however, the counterbalancing effect of the pressure in the chamber 45 is not sufficient, the piston 115 will fall in the cylinder 113 on the upward stroke more than it will rise on the downward stroke, and the piston 115 will gradually assume a lower and lower position in the cylinder 113. This, in effect, shortens the pitmans and decreases the clearance in the compressor 124. The compressor therefore compresses air into the chambers 45 and 47 to a higher pressure until a pressure is reached at which the piston 115 no longer falls in the cylinder 113 and the counterbalance is again correct for the load. Should the pump load decrease so as to result in the counterbalancing force being too great, the piston 115 will rise more in the cylinder 113 on the downward stroke than it will fall on the upward stroke, and the piston will gradually rise in the cylinder 113. This, in effect, lengthens the pitmans and results in the pin 133 engaging the arm 131 at the end of the upward stroke of the rod 127, causing readjustment of the valve 130 to a lower equilibrium pressure. Air thereupon escapes from the chambers 45 and 47 through the valve 130 to the atmosphere until the pressure on the piston 42 is such as to result in a balance of the work performed through the pitmans 110 and 111 on their two oppositely directed strokes. When this condition of balance occurs, the valve 130 will not be disturbed from its condition of equilibrium by reciprocation of the rod 127, and the apparatus continues to function with correct counterbalance.

In the form of my counterbalancing apparatus illustrated in Figs. 5, 6, 7, and 8, the pitman 145 is at its lower end pivotally connected to the crank arm 32, and at its upper end to a weighing arm 146 preferably near a pivot 147 through which the weighing arm 146 is pivotally connected to the walking beam 21. The walking beam is pivotally supported on a pivot 148 mounted in the fulcrum frame members 23. The end of the weighing arm 146 is bifurcated to provide two semi-circular branches 149 and 150 disposed in parallel planes. Located between the lower halves of the branches 149 and 150 of the weighing arm and spring abutments 151, which are mounted on the pivot 148, are springs 152, and between the upper halves of the branches 149 and 150 and the spring abutments 151 are springs 153 preferably identical to the springs 152. Riding on the under side of the branch 149 of the weighing arm is a roller 154 rotatably mounted on the end of a rod 155 and urged into contact with the branch 149 by a spring 156. A stop 157 on the rod 155 limits the upward travel of the rod 155, by engagement with a stationary bracket 158, to a position wherein the roller 154 is in engagement with the branch 149 when the semi-circular branches 149 and 150 of the weighing arm 146 are concentric with the pivot 148. Riding on the upper side of the branch 150 of the weighing arm is a roller 159 rotatably mounted on the end of a rod 160 and urged into contact with the branch 150 by a spring 161. A stop 162 on the rod 160 limits the downward travel of the rod 160, by engagement with the bracket 158, to a position wherein the roller 159 is in engagement with the branch 150 when the semi-circular branches 149 and 150 of the weighing arm 146 are concentric with the pivot 148. The lower ends of the rods 155 and 160 are pivotally connected to levers 163 and 164, respectively, of a differential motion device 165 which is adapted to translate the varying reciprocation of the rods 155 and 160 into changes in adjustment of the pressure regulating valves 70 and 71.

The differential motion device 165 may comprise a frame providing two spaced bearing brackets 166 having suitable bearing means in which is rotatably supported a tubular shaft 167 having an enlarged gear housing portion 168. Mounted rotatably within the tubular shaft 167 at one side of the housing portion 168 is a shaft 169 to which is attached for rotation therewith a grooved wheel 170. Within the housing 168 and attached to the shaft 169 is a beveled gear 171. Mounted rotatably within the tubular shaft 167 on the other side of the housing portion 168 is a shaft 172 to which is attached for rotation

therewith a grooved wheel 173. Within the housing 168 and attached to the shaft 172 is a beveled gear 174. Within the housing 168 and meshing with both gears 171 and 174 are beveled gears 175 and 176 mounted rotatably on a shaft 177 which is supported in the housing portion 168 of the tubular shaft 167. A sprocket 178 is adjustably mounted on the tubular shaft 167 for rotation therewith and is in driving relation with the sprocket 73 of the valve 70 through a chain 179. A shoe 180 engages the peripheral groove of the wheel 173 and is connected by a link 181 to an arm 182 of the lever 163 which is mounted to pivot about the axis of the wheel 173. The arrangement of the arm 182, link 181, and shoe 180 is such that rotation of the arm 182 in a counterclockwise direction results in urging the shoe 180 into closer contact with the wheel 173, whereby continued rotation of the arm 180 rotates the wheel 173 in the same direction. In engagement with the peripheral groove of the wheel 170 is a shoe 183 connected by a link 184 with the arm 185 of the lever 164. The arrangement of the arm 185, link 184, and shoe 183 is such that clockwise rotation of the arm 185, as viewed in Figs. 5 and 6, results in urging the shoe 183 into closer contact with the wheel 170, whereby continued rotation of the arm 185 rotates the wheel 170 in the same direction. Brake shoes 186 and 187 are hingedly supported from the frame and are held in tight engagement with the wheels 173 and 170, respectively, by springs 188 and 189, respectively, in order to prevent rotation of the wheels except when acted upon by the appropriate shoes in driving contact.

By reason of the above-described driving connections of the levers 163 and 164 with the wheels 170 and 173, and the above-described gear connections within the device 165, it will be evident that if the lever 163 is moved downwardly, the sprocket 178 is rotated counterclockwise as viewed in Fig. 5, and if the lever 164 is lifted, the sprocket 178 is rotated in a clockwise direction, the differential gearing enabling each of the wheels 170 and 173 to be moved independently of the others. The connection of the chain 179 to the sprockets 178 and 73 causes the sprocket 73 to be moved in a direction to adjust the valve 70 to a higher equilibrium pressure in the chambers 45 and 47 when the lever 164 is lifted. Since in normal operation the levers 163 and 164 are moved upwardly and downwardly through small angles as the walking beam is moved upwardly and downwardly, resulting in oscillation of the sprocket 73 through a small angle, it is desirable to move the screws 91 on the valve 70 away from contact with the pins 92 so as to allow an angular movement of the sprocket 73 equal to that produced during normal correct counterbalance conditions without resulting in movement of the arm 90 and change in adjustment of the valve 70. When the angular movement of the sprocket 73 is greater than normal in either direction, however, the arm 90 is engaged and moved to adjust the valve 70 and, through the sprockets 75 and 76 and chain 74, to adjust the valve 71, as previously described. It will be understood that instead of providing the valve 70 with backlash through use of the screws 91 and pins 90, I may provide a suitable amount of backlash between the sprocket 178 and the shaft 167.

The operation of the apparatus of Figs. 5, 6, 7, and 8 is as follows. On the upward stroke, the pitman 145 acts through the weighing arm 146 to lift the walking beam and in so doing lifts the bifurcated end of the weighing arm against the springs 152. The roller 159 and rod 160 are raised, lifting the member 164. The oscillation of the walking beam does not disturb the position of the rod 160 because the surface of the branch 150 of the bifurcated weighing arm is concentric with the pivot of the walking beam. As the weighing arm 146 rises relative to the pivot 148, the rod 155 also rises until the weighing arm passes the position in which its bifurcated end is concentric with the pivot 148. At this point the rod 155 is stopped by engagement of the stop 157 with the bracket 158 and is not moved again until the weighing arm 146 is again lowered below its concentric position. On the downward stroke the pitman 145 acts through the weighing arm 146 to lower the walking beam and in so doing depresses the bifurcated end of the weighing arm against the springs 153, lowering the lever 163. The rod 160 follows the weighing arm down until it passes the position of concentricity with the pivot 148, at which point the rod 160 is stopped by engagement of the stop 162 with the bracket 158 and is not moved again until lifted by engagement with the weighing arm on its upward stroke. It is apparent, then, that during each upward stroke of the pump plunger the rod 160 and lever 164 will be lifted, and the wheel 170 will be rotated clockwise (in Fig. 5) by an amount proportional to the distance the bifurcated end of the weighing arm 146 is raised above the position of concentricity with the pivot 148; and that on each downward stroke the rod 155 and lever 163 are lowered, and the wheel 173 is rotated counterclockwise, by an amount proportional to the distance the bifurcated end of the weighing arm is lowered below the position of concentricity with the pivot 148. Since the wheel 170 is moved only when the lever 164 is raised, and the wheel 173 is moved only when the lever 163 is lowered, and since the resultant rotation of the sprocket 178 is proportional to the difference in motion of the wheels 170 and 173, it will be evident that during each complete cycle of movement of the walking beam up and down, the sprocket 178 will be advanced or retracted through an angle determined by the difference in distances above and below the position of concentricity to which the weighing arm 146 is moved on the upward and downward strokes. The resultant movement of the sprocket 178 is therefore responsive to the difference in force exerted by the pitman during its two oppositely directed strokes. If on each upward stroke the weighing arm 146 is raised farther from the concentric position than it is lowered below that position on the downward stroke, the wheel 170 will be rotated clockwise on the upward stroke more than the wheel 173 will be rotated counterclockwise on the downward stroke, and there will be a resultant rotation of the sprocket 178 in a clockwise direction. If on the downward stroke the weighing arm 146 is lowered from its central position more than it is raised beyond this position on the upward stroke, there will be a resultant rotation of the sprocket 178 in a counterclockwise direction.

When the conditions are such that correct counterbalance exists, the force exerted by the pitman 145 on the weighing arm 146 is the same on the upward stroke as on the downward stroke, and the same compression of the springs 152 and 153 therefore results. Under these conditions, therefore, the rod 160 will be lifted on the upward stroke through the same distance that the

rod 155 will be lowered on the downward stroke, and there will be no resultant rotation of the sprocket 178. The sprockets 178 and 73 will oscillate back and forth at each stroke, but the arm 90 will not be engaged at either end of the oscillation, and the adjustment of the valves 70 and 71 will not be disturbed. If, however, the load changes so that the counterbalancing force is insufficient, the weighing arm 146 will be raised more from the central position on the upward stroke than it is lowered below that position on the downward stroke, and the sprockets 178 and 73 will be rotated more in the clockwise direction than in the counterclockwise direction. The arm 90 of the valve 70 will then be rotated slightly in the clockwise direction during each cycle, resulting in a gradual readjustment of the valves 70 and 71 toward a higher equilibrium pressure in the chambers 45 and 47, as previously described in connection with the apparatus of Fig. 1. This process of readjustment will be continued until the pressure in the chamber 45 becomes great enough to exert sufficient force on the piston 42 to result in a condition of correct counterbalance in which the springs 152 and 153 are compressed equally on the upward and downward strokes, respectively, whereupon no further resultant rotation of the sprockets 178 and 73 results, and the valves 70 and 71 are not further changed. When the pump load decreases so as to require less counterbalancing force, it will be evident that the rod 155 will be lowered more on each downward stroke than the rod 160 will be raised on each upward stroke, and there will be a resultant rotation of the sprockets 178 and 73 in a counterclockwise direction which will gradually effect a readjustment of the valves 70 and 71 to decrease the pressure in the chambers 45 and 47 until a condition is reached in which the bifurcated end of the weighing arm 146 is raised on the upward stroke above the pivot 148 as much as it is lowered below the pivot on the downward stroke. When this condition of correct counterbalance is reached, no further adjustment of the valves 70 and 71 takes place until the pump load further changes.

In the form of my apparatus illustrated in Figs. 10 and 11, I preferably, although not necessarily, employ as a prime mover an electric motor 200 the frame of which is pivotally mounted in bearings 201 and resisted in its rotation by a spring 202 located between a stationary spring abutment 203 and an arm 204 attached to the motor frame. The motor 200 drives the pumping apparatus through the chain 28, sprocket 27, chain 30, and sprocket 29, as in the other forms of my apparatus. A pitman 205 is pivotally attached at one end to the crank arm 32 and at the other end is pivotally attached directly to the walking beam 21. Supported on a pedestal 206 on the under frame 24 is a differential motion device 207 similar to that illustrated in Fig. 8 except for the following differences which relate to the means for moving the wheels 170 and 173. A shoe 208 is in contact with the top of the wheel 170 and is connected to an arm 209 through a link 210. The arm 209 is pivoted about the axis of the wheel 170 and is drawn down by a spring 211 against a stationary stop 212. The arrangement of the shoe 208, link 210, and arm 209 is such that rotation of the arm 209 in a clockwise direction, as viewed in Fig. 10, results in urging the shoe 208 into closer contact with the wheel 170 and rotation of the wheel 170 in a clockwise direction. In contact with the wheel 173 is a shoe 213 connected by a link 214 to an arm 215 which is pivoted about the axis of the wheel 173 and drawn up by a spring 216 against a stationary stop 217. The arrangement of the shoe 213, link 214, and arm 215 is such that counterclockwise rotation of the arm 215 results in urging the shoe 213 into closer contact with the wheel 173 and rotation of the wheel 173 in a counterclockwise direction. The sprocket 178 of the differential device, which is moved in response to the differential motion of the wheels 170 and 173, is connected to the sprocket 73 of the valve 70 by the chain 179, and the valves 70 and 71 are, as in the previously described apparatus, connected by the chain 74.

An arm 220 is pivotally attached preferably to the top of the frame of the motor 200 and projects toward the differential motion device 207. The end 221 of the arm 220 extends transversely a sufficient distance to engage either the arm 209 or the arm 215 if it is located at a suitable vertical elevation and is moved toward the right in Fig. 10. The end 221 is preferably rounded at its top and bottom edges to permit it to readily move into positions opposite the arms 209 and 215 when these arms lie against their respective stops. A cable 222 is connected to the pitman 205, passes over a pulley 223 which is attached to the fulcrum frame 23, and connects to the end 221 of the arm 220 in such manner that when the crank arm 32 is rotating in the counterclockwise direction as seen in Fig. 10, and as indicated by the arrow, and when the crank arm 32 is in the horizontal position on its upward stroke, the arm 220 is positioned opposite the arm 209, and when the crank arm 32 is in the horizontal position on its downward stroke, the arm 220 is positioned opposite the arm 215.

In the operation of the apparatus of Fig. 10, the torque of the motor 200 will be found to vary continually being greatest at the times when the crank arm 32 is in an approximately horizontal position. Since the motor armature is rotating in a counterclockwise direction in order to turn the crank arm 32 in a counterclockwise direction, the frame of the motor 200 will tend to turn in a clockwise direction and will be resisted by the spring 202 bearing on the arm 204. As the torque of the motor 200 varies, the frame of the motor will therefore assume various angular positions determined by the torque and by the resistance of the spring 202. As the frame of the motor 200 turns clockwise in response to increasing torque, the arm 220 will be moved toward the differential motion device 207. Since the torque is greatest when the arm 220 is opposite either the arm 209 or the arm 215, it is evident that at these times the arm 220 will be forced farthest to the right. The arrangement and dimensions are such that the arm 220 in its uppermost position engages the arm 209 and in its lowermost position engages the arm 215 under any condition of torque greater than the lowest torque to be expected at these positions. During the pumping operation, then, the arm 220, on the downward stroke of the walking beam, engages the arm 215, moves it to the right, turning the wheel 173 counterclockwise, and withdraws as it proceeds upwardly, and, on the upward stroke of the walking beam, engages the arm 209, forcing it to the right, turning the wheel 170 in a clockwise direction, and again withdraws as it moves downwardly. After each engagement by the arm 220, the arms 209 and 215 are returned by the

springs 211 and 216, respectively, against the stops 212 and 217, respectively, where they are in position to again be engaged by the arm 220. It will be apparent, then, that the sprockets 178 and 73 will be rotated in a counterclockwise direction at the midpoint of each downward stroke of the walking beam and will be rotated back in a clockwise direction at the midpoint of each upward stroke of the walking beam, and that the angles through which the sprockets move will be proportional to the maximum torque of the motor during the two strokes. The screws 91 on the arm 90 of the valve 70 are preferably set away from the pins 92 so that with a normal torque and a condition of correct counterbalance the pins 92 do not engage the screws 91 and the sprocket 73 oscillates back and forth at each stroke without moving the arm 90 controlling the valve 70.

When a condition of correct counterbalance exists, the maximum torque exerted by the motor 200 is the same on the upward stroke as on the downward stroke, and the arm 209 will be moved through the same angle in a clockwise direction as the arm 215 is moved in a counterclockwise direction. The controlling arm 90 of the valve 70 will therefore remain unmoved, and the pressure in the chamber 45 will remain unchanged. If, however, the pump load increases so as to make the counterbalancing force insufficient, the torque exerted on each upward stroke will be greater than that exerted on each downward stroke, and the sprocket 73 will be turned clockwise during each pumping cycle more than it will be turned counterclockwise, with the result that the arm 90 of the valve 70 will at each upward stroke be advanced through a small angle in the clockwise direction, causing readjustment of the valves 70 and 71 to a higher equilibrium pressure. This gradual readjustment of the valves 70 and 71 will continue until the pressure in the chamber 45 is increased sufficiently to equalize the maximum torque exerted by the motor 200 on the two oppositely directed strokes of the pump plunger. Should the pump load decrease so as to make the counterbalancing force too great, it will be clear that the sprocket 73 will be rotated farther during each downward stroke than during each upward stroke, and the valves 70 and 71 will gradually undergo readjustment to a lower equilibrium pressure until the pressure in the chamber 45 has dropped to a value at which the maximum torque of the motor 200 is the same on the upward and downward strokes of the walking beam and correct counterbalance again exists.

In summary, it may be noted that in the form of my invention shown in Figs. 1 and 2 and again in the form of the invention shown in Figs. 3 and 4 the amount of liquid displaced and the means for counterbalancing pressure varies with both the force and the time interval during which the force is effective on one of the strokes of the apparatus. The fluid displacement on a stroke, then, varies with the work performed by the prime mover on a stroke. On the other hand, in the form of my invention illustrated in Figs. 5 to 8 and again in the form illustrated in Figs. 10 and 11, the maximum force exerted by the prime mover on the respective strokes of the apparatus is measured mechanically without regard to the time duration of the force, and the automatic arrangement tends to establish a condition in which the maximum force exerted by the prime mover on the one stroke of the apparatus is equal to the maximum force exerted by the prime mover on the other stroke of the apparatus.

At the heart of my invention is the concept of selecting or providing some means in the apparatus responsive to the loads imposed on the prime mover, measuring the response of that means to the loads imposed on the prime mover on the working strokes of the apparatus, measuring the response of that means to the loads imposed on the prime mover on the return strokes of the apparatus, and then readjusting the counterbalancing means as required in proportion to the difference in said response during the two opposite strokes of the apparatus to make said responses substantially equal. In the first two forms of my invention illustrated in Figs. 1 to 4 the means that responds to the loads imposed on the prime mover is a hydraulic arrangement. In the other two forms of my invention the means that responds to variations in the loads imposed on the prime mover is of mechanical character. It is to be noted that the responsive means may be located in various parts of the apparatus and may be functionally associated with various elements of the apparatus. Thus, the responsive means may be incorporated somewhere in the chain of operative connections between the prime mover and the pump in the well, or, as in the form of the invention shown in Figs. 10 and 11, the responsive means may be associated with the prime mover alone apart from any operative connections or means for transmitting power from the prime mover.

It is understood that the apparatus and method herein disclosed are only illustrative of the invention and that various changes and modifications therein may be made by those skilled in the art without departing from the spirit and scope of the appended claims.

I claim as my invention:

1. In an apparatus for reciprocating a member through a power stroke and a return stroke, and including a driving element, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, whereby the loads on said driving element during the power and return strokes of said member are substantially equalized; and means responsive to the difference in loads during the oppositely directed strokes of said member adapted upon relative increase in load during the power stroke to increase said counterbalancing force, and adapted upon relative decrease in load during the power stroke to decrease said counterbalancing force.

2. In an apparatus for reciprocating a pump plunger, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof; means for increasing said counterbalancing force; means for decreasing said counterbalancing force; and means responsive to the difference in loads on a moving part of said apparatus during the pumping and return strokes of said plunger adapted upon relative increase in load during the pumping stroke to bring into operation said means for increasing said counterbalancing force, and adapted upon relative decrease in load during the pumping stroke to bring into operation said means for decreasing said counterbalancing force.

3. In apparatus for reciprocating a pump plunger throughout a pumping cycle compris-

ing a pumping stroke and a return stroke, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof; and means responsive to the difference in loads on a moving part of said apparatus during the pumping and return strokes of said plunger and acting during a portion of each pumping cycle, said last mentioned means being adapted upon relative increase in load during the pumping stroke to increase said counterbalancing force, and adapted upon relative decrease in load during the pumping stroke to decrease said counterbalancing force.

4. In apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke, said apparatus including a motive power source, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof; and means responsive to the difference in torque exerted by said motive power source during the pumping and return strokes of said plunger and acting during a portion of each pumping cycle, said last mentioned means being adapted upon relative increase in load during the pumping stroke to increase said counterbalancing force, and acting upon relative decrease in load during the pumping stroke to decrease said counterbalancing force.

5. In an apparatus for reciprocating a pump plunger including a rotating crank, a walking beam, and connecting means extending from said walking beam to said pump plunger whereby the rocking of said walking beam moves said pump plunger, the combination of: a pitman connected to said crank; means for applying a counterbalancing force to said walking beam for counterbalancing the reciprocating parts of said apparatus; adjustable means for controlling the amount of said counterbalancing force; and means interposed between said pitman and said walking beam responsive to the difference in force exerted by said pitman during the pumping and return strokes of said pump plunger adapted upon relative increase of the force exerted by said pitman during the pumping stroke of said pump plunger to adjust said controlling means to effect a greater counterbalancing force, and adapted upon relative decrease of the force exerted by said pitman during the pumping stroke of said pump plunger to adjust said controlling means to effect a smaller counterbalancing force.

6. In an apparatus for reciprocating a pump plunger including a rotating crank, a walking beam, and connecting means extending from said walking beam and to said pump plunger whereby the rocking of said walking beam moves said pump plunger through a pumping cycle comprising pumping and return strokes, the combination of: a pitman connected to said crank; means for applying a counterbalancing force to said walking beam for counterbalancing the reciprocating parts of said apparatus; means for increasing said counterbalancing force; means for decreasing said counterbalancing force; and means interposed between said pitman and said walking beam responsive to the difference in force exerted by said pitman during the pumping and return strokes of said plunger and acting during a portion of each pumping cycle, adapted upon relative increase in force exerted by said pitman during the pumping stroke of said plunger to bring into operation said means for increasing said counterbalancing force, and adapted upon relative decrease in force exerted by said pitman during the return stroke to bring into operation said means for decreasing said counterbalancing force, whereby the amount of said counterbalancing force is automatically adjusted to such a value that the force exerted by said pitman is substantially equal during the pumping and return strokes of said plunger.

7. In an apparatus for reciprocating a pump plunger, the combination of; means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, said means including a fluid-tight chamber containing gas under pressure, and a piston closing said chamber and connected to a moving part of said apparatus in such manner that said gas is expanded and energy delivered to said piston during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; and means responsive to the difference in loads on a moving part of said apparatus during the pumping and return strokes of said plunger adapted upon relative increase in load during the pumping stroke to increase the pressure of said gas, and adapted upon relative decrease in load during the pumping stroke to decrease the pressure of said gas.

8. In apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, said means including a fluid-tight chamber containing gas under pressure, and a piston closing said chamber and connected to a moving part of said apparatus in such manner that said gas is expanded and energy is delivered to said piston during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; means for increasing the pressure of said gas; means for decreasing the pressure of said gas; and means responsive to the difference in loads on a moving part of said apparatus during the pumping and return strokes of said plunger and acting during a portion of each pumping cycle, said last mentioned means being adapted upon relative increase in load during the pumping stroke to bring into operation said means for increasing the pressure of said gas, and adapted upon relative decrease in load during the pumping stroke to bring into operation said means for decreasing the pressure of said gas.

9. In apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke, including a member operatively connected with said plunger, a prime mover, and a second member driven by said prime mover, the combination of: means connecting said members for reciprocation of said plunger, said means comprising a cylinder connected to one of said members and containing fluid, a piston in said cylinder connected to the other of said members and dividing said cylinder into two fluid compartments, and a restricted fluid connection between said two compartments, whereby said piston reciprocates in said cylinder coincidentally with the reciprocation of said plunger; means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof; and means acting during a portion of each

pumping cycle to increase said counterbalancing force when the length of stroke of said piston occurring during the pumping stroke of said plunger is greater than the oppositely directed stroke of said piston occurring during the return stroke of said plunger, and acting to decrease said counterbalancing force when the first mentioned stroke of said piston is less than the last mentioned stroke of said piston.

10. In an apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke, including a rotating crank, a walking beam, a pitman connected to said crank, and means extending from said walking beam to said pump plunger whereby rocking of said walking beam causes reciprocation of said pump plunger, the combination of: means of variable length connecting said pitman with said walking beam for rocking said walking beam and comprising a cylinder containing fluid, a piston in said cylinder dividing said cylinder into two fluid compartments, and a restricted fluid connection between said two compartments, whereby the length of said connecting means is varied coincidentally with reciprocation of said pump plunger; a chamber containing gas under pressure; a piston closing said chamber and connected to said walking beam in such manner that said gas is expanded and energy is delivered to said walking beam during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; a reservoir containing gas under pressure higher than the pressure of gas in said chamber; a valve adapted to admit gas from said reservoir into said chamber when the pressure in said chamber is below an equilibrium pressure; a valve adapted to exhaust gas from said chamber when the pressure in said chamber is above an equilibrium pressure; and means acting to increase the equilibrium pressures of said valves when the change in length of said connecting means occurring during the pumping stroke of said plunger is greater than that occurring during the return stroke of said plunger, and acting to decrease the equilibrium pressures of said valves when the change in length of said connecting means occurring during the pumping stroke of said plunger is less than that occurring during the return stroke of said plunger.

11. In an apparatus for reciprocating a pump plunger in a well including a rotating crank, a pitman connected to said crank, a walking beam, and means extending from said walking beam to said pump plunger whereby rocking of said walking beam causes reciprocation of said pump plunger, the combination of: a cylinder connected to said walking beam and containing fluid; a piston in said cylinder dividing said cylinder into two fluid compartments; a fluid connection between said two compartments; adjustable flow restricting means in said fluid connection; a chamber containing gas under pressure; a piston closing said chamber and connected to said walking beam in such manner that said gas is expanded and energy is delivered to said walking beam during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; a reservoir containing gas under pressure higher than the pressure of gas in said chamber; a valve adapted to admit gas from said reservoir into said chamber when the pressure in said chamber is below an equilibrium pressure; a valve adapted to exhaust gas from said chamber when the pressure in said chamber is above an equilibrium pressure; and means responsive to a shift in position of said piston in said cylinder acting to adjust said valves to higher equilibrium pressures when said piston shifts upward in said cylinder, and acting to adjust said valves to lower equilibrium pressures when said piston shifts downward in said cylinder.

12. In apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke including a member operatively connected with said plunger, a prime mover, and a second member driven by said prime mover, the combination of: means connecting said members for reciprocation of said plunger, said means comprising a cylinder connected to one of said members and containing fluid, a piston in said cylinder dividing said cylinder into two fluid compartments, and a restricted fluid connection between said compartments; a chamber containing gas under pressure; a piston closing said chamber and connected to a moving part of said apparatus in such manner that said gas is expanded and energy is delivered to said piston during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; a variable-clearance compressor adapted to discharge gas into said chamber; a valve adapted to exhaust gas from said chamber when the pressure in said chamber is greater than an equilibrium pressure; and means acting to decrease the clearance of said compressor and to increase the equilibrium pressure of said valve when the length of stroke of said piston occurring during the pumping stroke of said plunger is greater than the oppositely directed stroke of said piston occurring during the return stroke of said plunger, and acting to increase the clearance of said compressor and to decrease the equilibrium pressure of said valve when the first mentioned stroke of said piston is less than the last mentioned stroke of said piston.

13. In apparatus for reciprocating a pump plunger in a well including a rotating crank, a pitman connected to said crank, a walking beam, and means extending from said walking beam to said pump plunger whereby rocking of said walking beam causes reciprocation of said pump plunger, the combination of: means of variable length connecting said pitman with said walking beam for rocking said walking beam and comprising a cylinder containing fluid, a piston in said cylinder dividing said cylinder into two compartments, and a restricted fluid connection between said two compartments, whereby the length of said connecting means is varied coincidentally with reciprocation of said pump plunger; a chamber containing gas under pressure; a piston closing said chamber and connected to said walking beam in such a manner that said gas is expanded and energy is delivered to said walking beam during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; a compressor adapted to discharge gas into said chamber, said compressor having a piston connected to said walking beam whereby rocking of said walking beam causes reciprocation of said compressor piston and compression of the gas within said compressor to a pressure determined by the length of said connecting means, the discharge pressure of said compressor increasing with shortening length of said connecting means;

a valve adapted to exhaust gas from said chamber when the pressure in said chamber is above an equilibrium pressure; and means acting upon decrease in length of said connecting means to increase the equilibrium pressure of said valve, and acting upon increase in length of said connecting means to decrease the equilibrium pressure of said valve.

14. In apparatus for reciprocating a pump plunger in a well including a rotating crank, a pitman connected to said crank, a walking beam, and means extending from said walking beam to said pump plunger whereby rocking of said walking beam causes reciprocation of said pump plunger, the combination of: an arm pivoted at spaced points to said pitman and to said walking beam; spring means resisting movement of said arm in either direction from a central position; a chamber containing gas under pressure; a piston closing said chamber and connected to said walking beam in such manner that said gas is expanded and energy is delivered to said walking beam during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; a reservoir containing gas under pressure higher than that in said chamber; a valve adapted to admit gas from said reservoir into said chamber when the pressure in said chamber is less than an equilibrium pressure; a valve adapted to exhaust gas from said chamber when the pressure in said chamber is greater than an equilibrium pressure; a movable member; a second movable member; means engageable with said arm adapted to move said first movable member when said arm moves upward beyond said central position; means engageable with said arm adapted to move said second movable member when said arm moves downward beyond said central position; and means responsive to the differential movement of said first and second movable members acting to readjust the equilibrium pressures of said valves in such manner that the equilibrium pressures are increased when the force exerted by said pitman is greater during its upward stroke than during its downward stroke and said equilibrium pressures are decreased when the force exerted by said pitman is less during its upward stroke than during its downward stroke.

15. In apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke including a motive power source adapted to drive said pump plunger, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, said means including a chamber containing gas under pressure, and a piston closing said chamber and connected to a moving part of said apparatus in such manner that said gas is expanded and energy is delivered to said piston during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; means for increasing the pressure of said gas; means for decreasing the pressure of said gas; a movable member; a second member movable independently of said first member; means responsive to the maximum torque of said motive power source during the pumping stroke of said plunger acting to move said first movable member, and responsive to the maximum torque of said motive power source during the return stroke of said plunger acting to move said second movable member; and means responsive to the differential movement of said movable members acting to bring into operation said means for increasing the pressure of said gas when the movement of said first member is greater than the movement of said second member, and acting to bring into operation said means for decreasing the pressure of said gas when the movement of said first member is less than the movement of said second member.

16. In apparatus for reciprocating a pump plunger throughout a pumping cycle comprising a pumping stroke and a return stroke including a motive power source adapted to drive said plunger, the combination of: means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, said means including a chamber containing gas under pressure, and a piston closing said chamber and connected to a moving part of said apparatus in such manner that said gas is expanded and energy is delivered to said piston during the pumping stroke of said plunger and the gas is compressed by said piston during the return stroke of said plunger; a reservoir containing gas under pressure higher than that in said chamber; a valve adapted to admit gas from said reservoir into said chamber when the pressure in said chamber is less than an equilibrium pressure; a valve adapted to exhaust gas from said chamber when the pressure in said chamber is greater than an equilibrium pressure; a first movable member; a second member movable independently of said first movable member; means responsive to the differential movement of said movable members acting to readjust the equilibrium pressures of said valves in such manner that the equilibrium pressures are increased when the movement of said first movable member is greater than that of said second movable member, and the equilibrium pressures are decreased when the movement of said first movable member is less than that of said second movable member; means in engagement with said first movable member for moving it in one direction; means in engagement with said second movable member for moving it in a direction opposite to said first mentioned direction; means for pivotally supporting the frame of said motive power source; resilient means resisting rotation of said frame of the motive power source; means connected to said frame of the motive power source, said means being adapted at the time of maximum torque of said motive power source during the pumping stroke of said plunger to engage said means in engagement with said first movable member, whereby said first movable member is moved by an amount corresponding to said torque then existing, and being adapted at the time of maximum torque of said motive power source during the return stroke of said plunger to engage said means in engagement with said second movable member, whereby said second movable member is moved by an amount corresponding to said torque then existing; and means returning said means in engagement with said first and second movable members to definite positions in the path of said means connected to said frame.

17. The method of automatically counterbalancing the reciprocating parts of a pumping apparatus in which a pump plunger is reciprocated throughout a pumping cycle consisting of a pumping stroke and a return stroke, comprising: applying a counterbalancing force to a moving

part of said apparatus; measuring the force required to be exerted by a moving part of said apparatus during the pumping stroke of said plunger; measuring the force required to be exerted by said last mentioned moving part during the return stroke of said plunger; and readjusting said counterbalancing force in proportion to the difference in said forces exerted during the two oppositely directed strokes of said plunger to make said forces equal.

18. The method of automatically counterbalancing the reciprocating parts of a pumping apparatus in which a pump plunger is reciprocated throughout a pumping cycle consisting of a pumping stroke and a return stroke, comprising: applying a counterbalancing force to a moving part of said apparatus; measuring the force required to be exerted by a moving part of said apparatus during each pumping stroke of said plunger; measuring the force required to be exerted by said last mentioned moving part during each return stroke of said plunger; and, during a portion of each pumping cycle, readjusting said counterbalancing force in proportion to the difference in said forces exerted during the two oppositely directed strokes of said plunger in such a direction as to make said forces more nearly equal.

19. The method of automatically counterbalancing the reciprocating parts of a pumping apparatus in which a pitman rocks a walking beam which is operatively connected to a pump plunger for reciprocation thereof, comprising: compressing a gas on the downward stroke of said plunger and expanding said gas on the upward stroke of said plunger, whereby a counterbalancing force is applied to a moving part of said apparatus; measuring the force exerted by said pitman on said walking beam during each upward stroke of said plunger; measuring the force exerted by said pitman during each downward stroke of said plunger; and readjusting the pressure of said gas in proportion to the difference in said forces exerted during said oppositely directed strokes in such a direction as to make said forces more nearly equal.

20. In an apparatus for reciprocating a member through a power stroke and a return stroke, and including a driving element, the combination of: adjustable means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, whereby the loads on said driving element during the power and return strokes of said member are substantially equalized; means movable in response to preponderance of the load on said driving element during one of said strokes over the load on the driving element during the other of said strokes; and means operatively connecting said responsive means with said counterbalancing means to adjust said counterbalancing means for reduction of said preponderance, whereby substantial equalization of the loads on said two strokes is maintained with changing magnitude of the load on the power stroke.

21. In an apparatus for reciprocating a member through a power stroke and a return stroke, and including a driving element, the combination of: adjustable means for applying a counterbalancing force to a moving part of said apparatus for counterbalancing the reciprocating parts thereof, whereby the loads on said driving element during the power and return strokes of said member are substantially equalized; and means to indicate adjustment of said counterbalancing means required to maintain said substantial equalization of loads, said indicating means being adapted to move from a normal neutral position in response to preponderance of the load on said driving element during one of said strokes over the load on the driving element during the other of said strokes.

22. The method of automatically counterbalancing the reciprocating parts of an apparatus in which a prime mover reciprocates a working member throughout a cycle consisting of a working stroke and a return stroke, and in which some means responds to the load imposed on the prime mover, said method including the steps of: applying a counterbalancing force to a moving part of said apparatus; measuring the response of said means to the loads imposed on the prime mover on the working strokes of the apparatus; measuring the response of said means to the loads imposed on the prime mover on the return strokes of the apparatus; and readjusting said counterbalancing means in proportion to the difference in said responses on the two opposite strokes of the apparatus to make said responses substantially equal.

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