Feb. 16, 1943. C. J. COBERLY 2,311,157

FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

Filed March 29, 1941 6 Sheets-Sheet 1

Fig. 1.

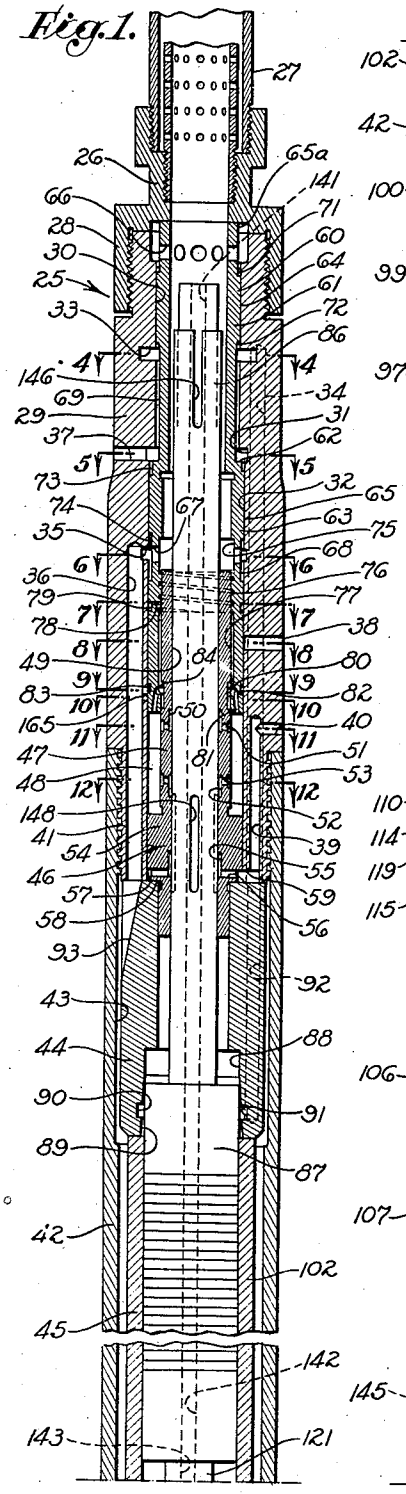


Fig. 2.

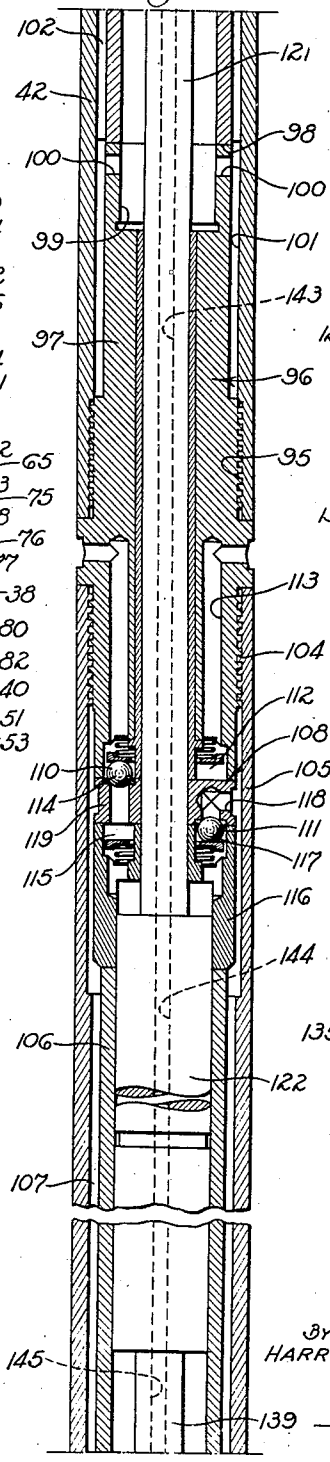
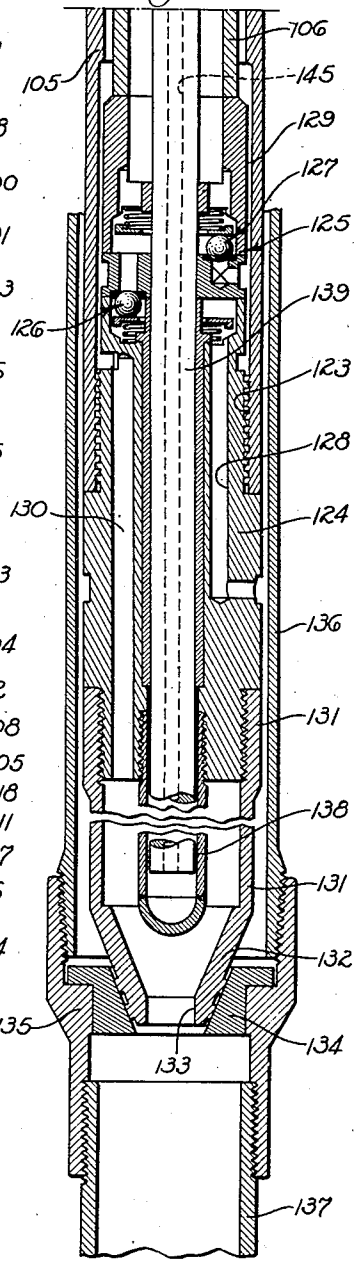


Fig. 3.



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FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

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Fig. 4.

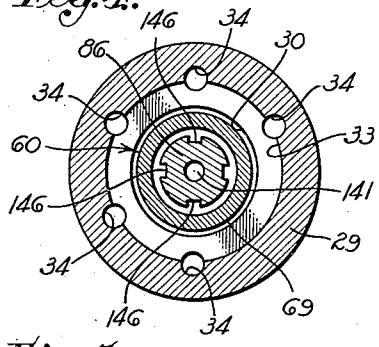


Fig. 8.

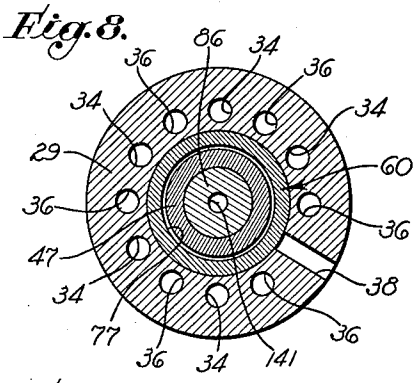


Fig. 5.

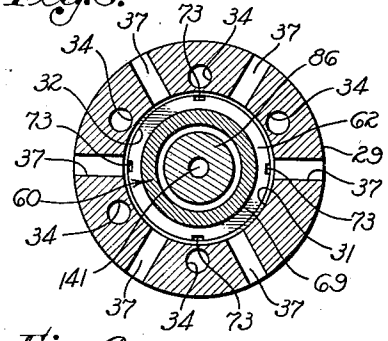


Fig. 9.

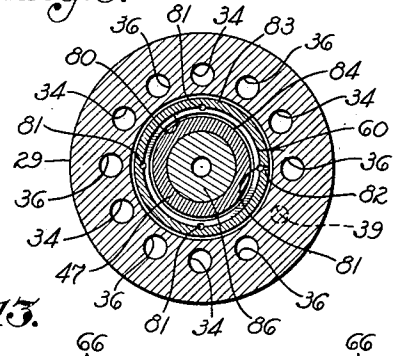


Fig. 6.

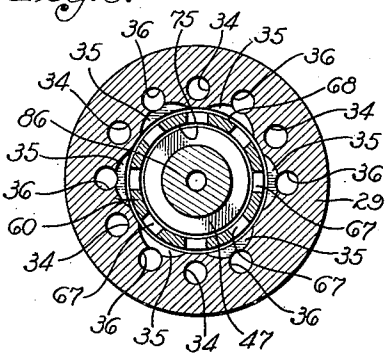


Fig. 13.

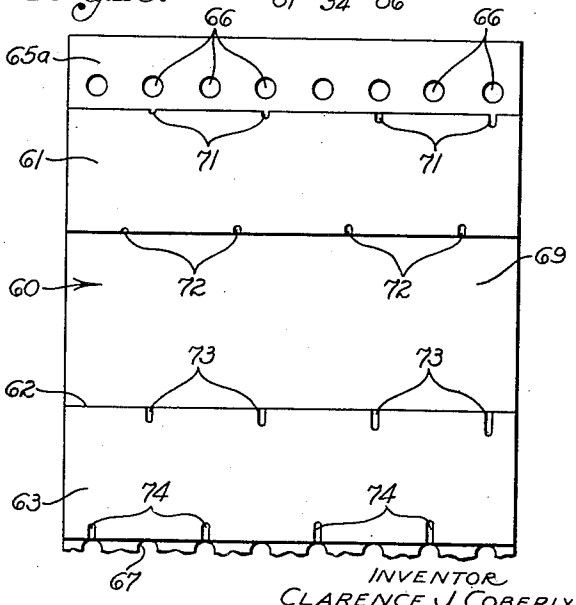
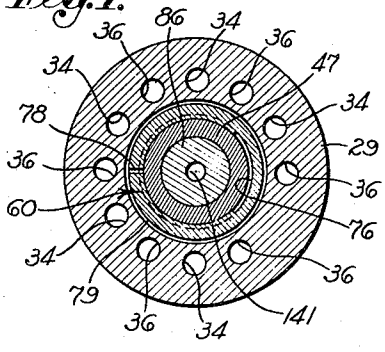


Fig. 7.



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FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

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Fig. 19.

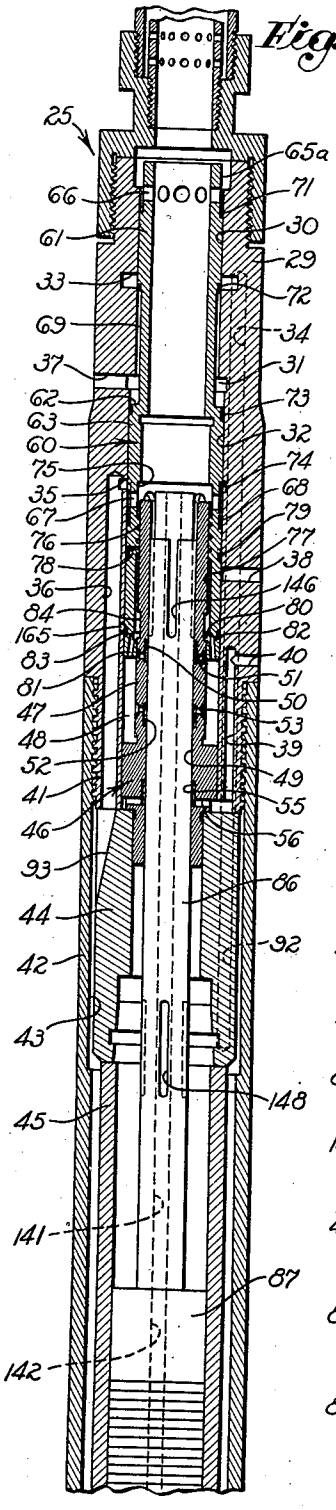


Fig. 20.

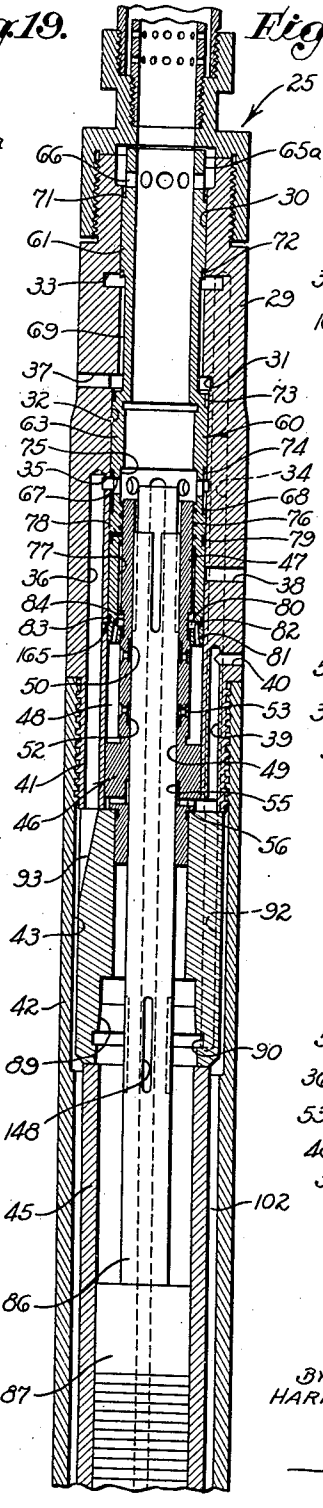


Fig. 10.

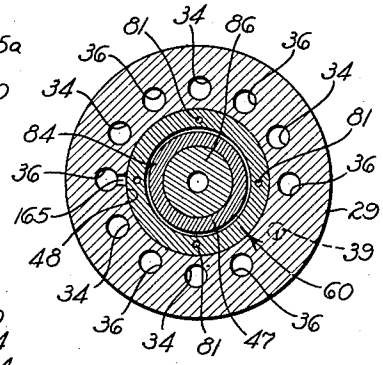


Fig. 11.

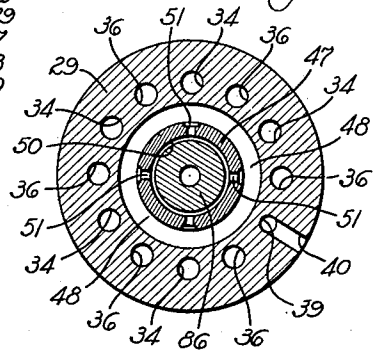
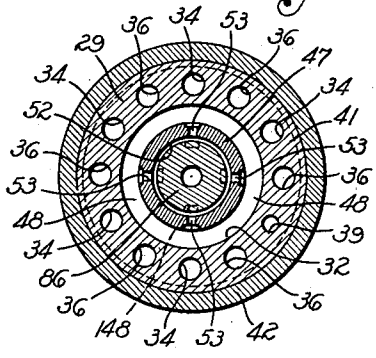


Fig. 12.



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FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

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Fig. 14.

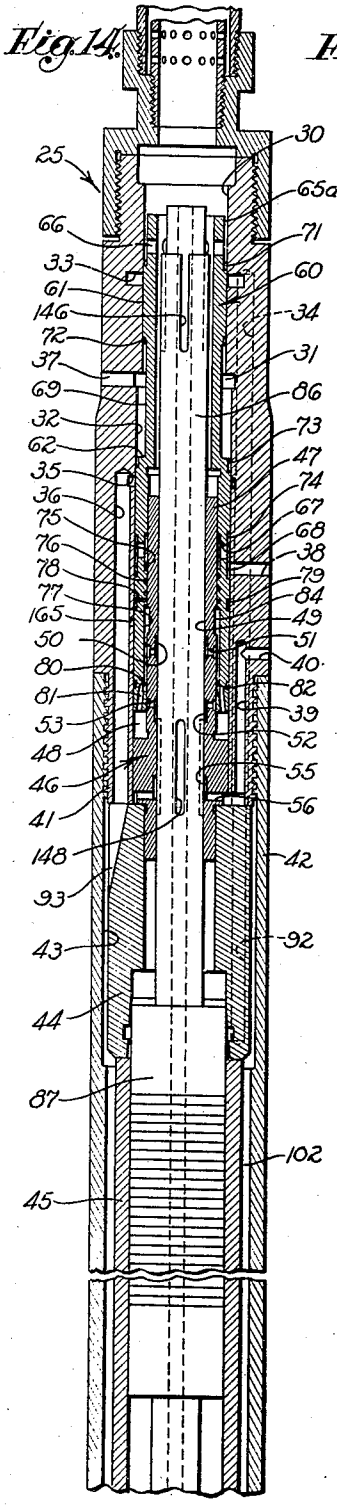


Fig. 15.

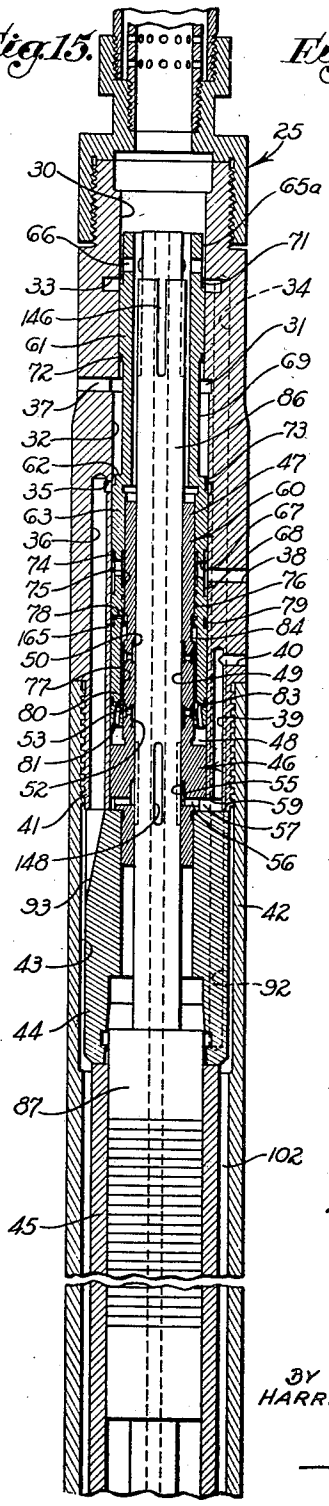
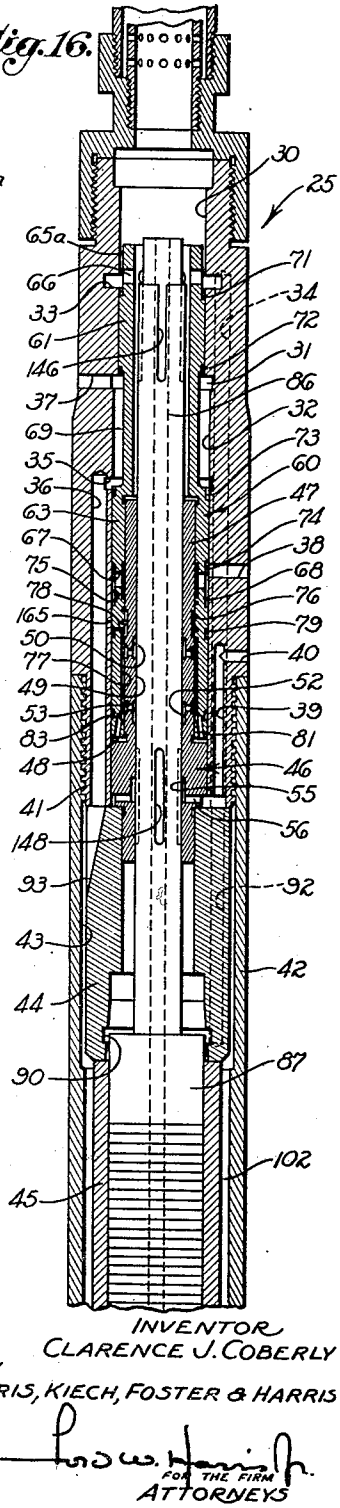


Fig. 16.



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FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

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Fig. 17.

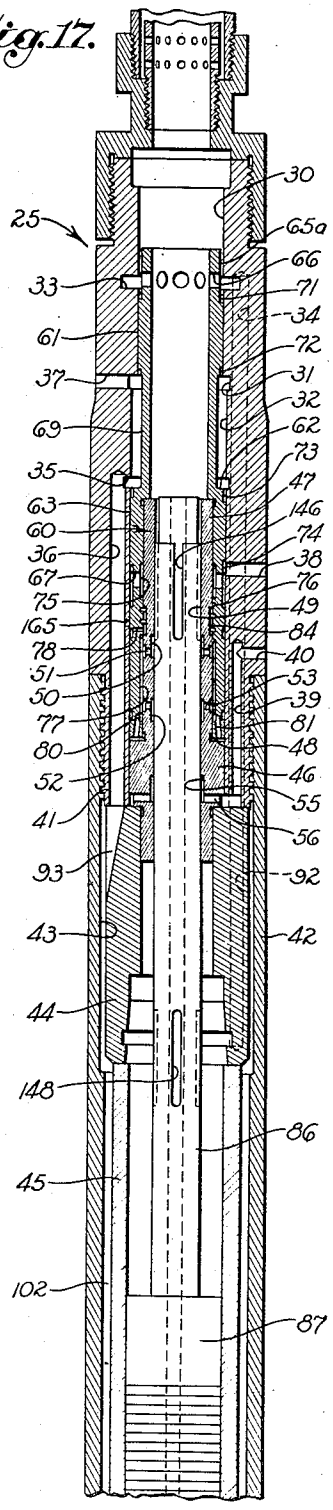
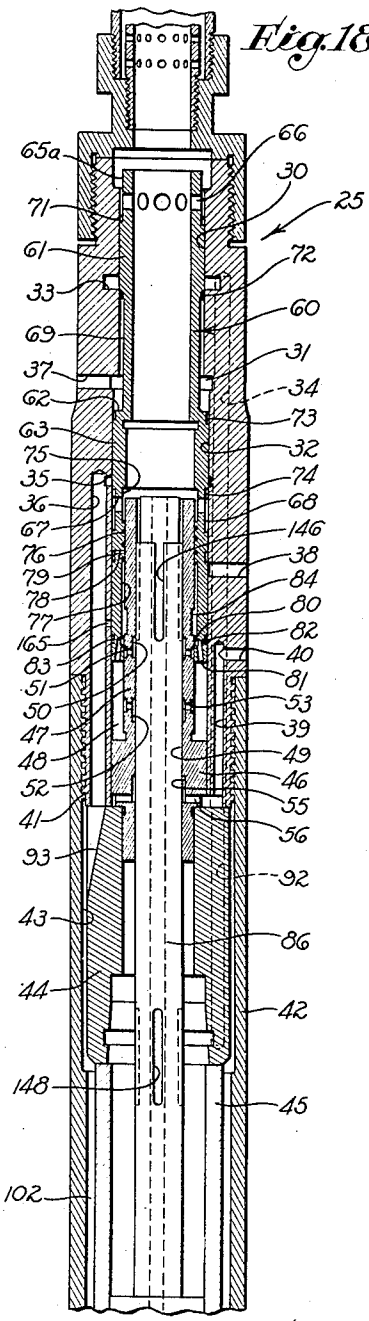


Fig. 18.



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FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

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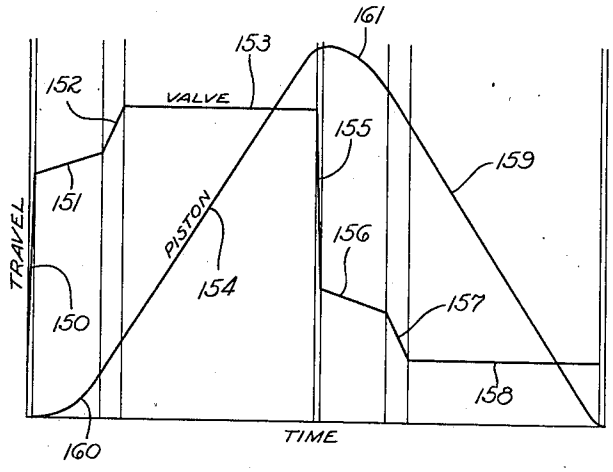


Fig. 21.

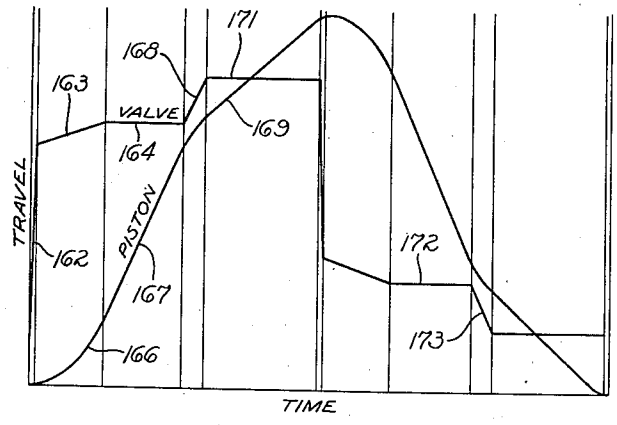


Fig. 22.

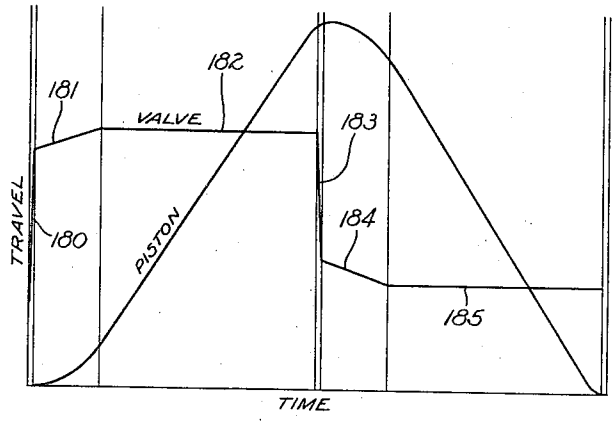


Fig. 23.

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Patented Feb. 16, 1943 2,311,157

UNITED STATES PATENT OFFICE

2,311,157

FLUID OPERATED PUMP WITH BUILT-IN GOVERNOR

Clarence J. Coberly, Los Angeles, Calif., assignor to Roko Corporation, Reno, Nev., a corporation of Nevada

Application March 29, 1941, Serial No. 385,874

24 Claims. (Cl. 121—157)

My invention relates to a fluid operated motor and, more particularly, to such a device having a reciprocating motor piston in which the rate of reciprocation of the motor piston is automatically maintained below a predetermined maximum regardless of changes in the working load on such piston.

In certain respects my invention is an improvement on the device disclosed in my earlier Patent No. 2,134,174, issued October 25, 1938, to which reference is hereby made.

Alhough my invention is of particular utility in the oil industry in combination with a pump for pumping oil from a well, and for the purpose of illustration is described in connection with such use, it will be apparent to those skilled in the art that it is susceptible of other and different uses, and, consequently, I do not intend to be limited to the particular use described.

In the oil industry it is common practice to use a fluid operated pump in pumping oil from a well, such a pump generally comprising a coupled motor and pump combination set in the well at the level from which it is desired to pump the oil. In such a pumping device, the motor is normally actuated by admitting operating fluid, such as oil, under relatively high pressure alternately to opposite ends of a motor piston to reciprocate the same, the reciprocation of the motor piston being suitably communicated to a pump piston in the pump end of the device so as to pump oil from the well. In order to conduct operating fluid alternately to opposite ends of the motor piston, a main valve mechanism is ordinarily employed, such as is shown in my said Patent No. 2,134,174. It is a primary object of my present invention to provide such a main valve mechanism in an improved form as described hereinafter.

In pumping oil from a well, the well oil frequently contains mixed therewith or in solution therein varying quantities of natural gas produced from the well together with the oil, the quantity of such gas depending upon local conditions for particular wells. Furthermore, it is common experience in the oil industry that the quantity of gas in the oil of a particular well frequently varies within wide limits at different times during production from the well. Since displacement type pumps are most commonly used to pump oil, considerable difficulty has been experienced, particularly in pumps of the fluid operated type as described above, with gas pockets forming in the pump cylinder, thus reducing materially the pumping load until the pump piston compresses the gas in the pocket and strikes solid well fluid in the pump cylinder. Such fluid operated pumps are ordinarily operated at relatively great depths in oil wells, and, accordingly, a large volume of operating fluid under high pressure is confined in the supply tubing between the well pumping mechanism and the operating pump on the surface of the ground which supplies the operating fluid. Due to the compressibility of this large volume of operating fluid, and due to the expansion of the supply tubing under the high pressure of the operating fluid exerted thereon, a large amount of energy is stored in the system under these operating conditions. If for any reason the pumping load on the fluid operated pump decreases, due to the presence of gas in the well liquid, failure of the pump valve to seat properly, or due to any other cause, the operating fluid in the supply tubing expands as a result of the release of the energy of compression stored therein, and the supply tubing contracts due to the release of the energy of expansion stored therein, causing an increased rate of flow of operating fluid to the fluid operated pump. This condition occurs even when a positive displacement surface pump is used on the ground surface to convey operating fluid downwardly through the supply tubing, and such surface pump is operated at a constant speed. As will be appreciated, an increase in the rate of flow of operating fluid delivered through the supply tubing will cause the fluid operated pump to run at increased speed, which becomes excessive if the rate of flow of operating fluid is substantially increased, as is true under the conditions described. Thus, when the pump load decreases, the fluid operated pump will run at excessive speed until the pump load is raised by removing the gas from the pump or otherwise rectifying the condition. The pump may thus race for a portion of a stroke or for a number of successive strokes, and in any event the pump will operate at excessive speed until all of the energy of compression stored in the operating fluid and energy of expansion stored in the supply tubing are released, or until the pump load is again applied to the fluid operated pump.

When a fluid operated pump runs at excessive speed, it may be very harmful to certain parts of the pumping equipment. This is particularly true when the pump cylinder is only partially filled with well fluid, in which case the pump piston will move at extremely high speed during the first part of its stroke while it is compressing the gas therein and will then strike the

liquid therein while moving at high velocity. This introduces a hydraulic shock load which results in abnormal stresses on the parts of the pump and may cause considerable damage in the form of excessive wear, scoring, seizing, or breakage of the parts. To prevent uneven operation of the pumping equipment, and to prevent such racing, various expedients have been used, one of which is to provide a flow governor in the operating fluid supply line which will reduce the flow of operating fluid to the fluid operated motor in response to a reduction in pump load, such a device being shown in my Patent No. 2,119,736, issued on June 7, 1938, to which reference is hereby made for the purpose of illustration. Such flow governors are separate articles of equipment and must necessarily be attached in the operating fluid supply line at a point above the pumping equipment, thus increasing the cost of the pumping installation and, because the governor must perforce be located at a point relatively remote from the motor cylinder, increasing the hazards of the pump racing due to the normal time lag in the operation of the flow governor.

It is therefore another important object of my invention to provide a fluid operated pump which has mechanism therein for controlling the flow of operating fluid to the motor cylinder and maintaining the rate of such flow below a predetermined maximum. I prefer to accomplish this by building such a flow governing device directly into my main valve mechanism, so as to obviate the provision of a separate flow governor, which is another object of the invention.

A further object of my invention is to provide a fluid flow governor mechanism in a well and immediately adjacent the motor cylinder of a fluid operated pump for controlling the flow of operating fluid to the motor cylinder, so as to reduce the time lag normally incident to the use of a fluid flow governor with such pumping mechanism.

It is a further object of my invention to provide a main valve mechanism for a fluid operated pump, adapted to convey operating fluid alternately to opposite ends of the motor piston of the pump, and which is adapted to maintain the flow of operating fluid to the motor cylinder below a predetermined maximum rate when the pumping load on the pump drops below a predetermined value so as to prevent racing of the pistons thereof.

Another object of my invention is to provide a main valve mechanism for a fluid operated pump, adapted to convey operating fluid alternately to opposite ends of the motor piston, and to control the discharge of spent operating fluid from the motor piston, and which is adapted to maintain such discharge of spent operating fluid below a predetermined maximum when the pumping load on the pump drops below a predetermined value so as to prevent racing of the pistons of the device.

Another object of my invention is to provide a novel type of movable main valve for a fluid operated pump, the movement of which has novel characteristics providing smoother and more efficient operation of the valve.

As my invention may be used in connection with hydraulic equipment other than pumps such as are described hereinabove, still another object of my invention is to provide in a valve device for directing a fluid flow a mechanism responsive to changes in the rate of fluid flow for regulating the rate of such fluid flow.

Other objects and advantages will be evident from the following specification and the drawings, which are for the purpose of illustration only and in which:

Fig. 1 is a vertical sectional view of the motor and main valve of my invention.

Fig. 2 is a vertical sectional view of my invention, carried downwardly from the lower end of Fig. 1.

Fig. 3 is a vertical sectional view of my invention, carried downwardly from the lower end of Fig. 2.

Fig. 4 is a cross-sectional view taken on the line 4—4 of Fig. 1.

Fig. 5 is a cross-sectional view taken on the line 5—5 of Fig. 1.

Fig. 6 is a cross-sectional view taken on the line 6—6 of Fig. 1.

Fig. 7 is a cross-sectional view taken on the line 7—7 of Fig. 1.

Fig. 8 is a cross-sectional view taken on the line 8—8 of Fig. 1.

Fig. 9 is a cross-sectional view taken on the line 9—9 of Fig. 1.

Fig. 10 is a cross-sectional view taken on the line 10—10 of Fig. 1.

Fig. 11 is a cross-sectional view taken on the line 11—11 of Fig. 1.

Fig. 12 is a cross-sectional view taken on the line 12—12 of Fig. 1.

Fig. 13 is a view showing the outer surface of the main valve of my invention projected onto a vertical plane.

Fig. 14 is a vertical sectional view of my invention, showing the main valve in one position of operation.

Fig. 15 is a vertical sectional view of my invention, showing the main valve in another position of operation.

Fig. 16 is a vertical sectional view of my invention, showing the main valve in another position of operation.

Fig. 17 is a vertical sectional view of my invention, showing the main valve in another position of operation.

Fig. 18 is a vertical sectional view of my invention, showing the main valve in another position of operation.

Fig. 19 is a vertical sectional view of my invention, showing the main valve in another position of operation.

Fig. 20 is a vertical sectional view of my invention, showing the main valve in another position of operation.

Fig. 21 is a graph showing the operation of my invention under normal operating conditions.

Fig. 22 is a graph showing the operation of my invention when the pump cylinder contains only about 30% solid fluid.

Fig. 23 is a graph showing the operation of my invention when the pump cylinder contains no solid fluid but 100% gas.

Referring to the drawings, Figs. 1, 2, and 3 show a fluid operated pump 25 having an upper fitting 26 by which the fluid operated pump is secured to the lower end of a fluid supply tubing 27 by which operating fluid under relatively high pressure is delivered to the motor section of the fluid operated pump. The fitting 26 has an internally threaded portion 28 adapted to receive the upper threaded end of a valve body 29. The valve body 29 has an axial minor bore 30 formed in the upper part thereof, which is separated by

a circular channel 31 from a major bore 32 axially formed in the lower portion of the valve body 29.

Substantially intermediate between the ends of the minor bore 30 is an upper circular channel 33 which intersects the upper ends of primary fluid passages 34, as best shown in Fig. 4, such fluid passages extending within the wall of the valve body 29 to the lower end thereof. Spaced below the channel 31 in the major bore 32 is a fluted annular channel 35 the flutes of which intersect with the upper ends of secondary fluid passages 36, as best shown in Fig. 6, each of which extends longitudinally to the lower end of the valve body 29, the secondary fluid passages 36 being spaced between the primary fluid passages 34.

Connecting the circular channel 31 with the exterior of the valve body 29 is a motor discharge port 37, and an upper valve discharge port 38 is provided in the wall of the valve body 29 to connect between the exterior thereof and the interior of the major bore 32. Extending upwardly from the bottom of the valve body 29 is a valve exhaust passages 39, best shown in Figs. 1, 11 and 12, the exhaust passage being disposed between two of the secondary fluid passages 36. Connecting the upper end of the valve exhaust passage 39 with the exterior of the valve body 29 is a lower valve exhaust port 40.

The lower end of the valve body 29 is provided with a threaded portion 41 to which is threaded the upper end of a motor cylinder 42. The motor cylinder 42 is provided at its upper end with a counterbored axial chamber 43 in which is disposed a plug body 44 held in fluid-tight engagement with the lower end of the valve body 29 and in fluid-tight engagement with the upper end of a motor cylinder liner 45 when the parts are assembled as shown in Fig. 1. Mounted in the upper part of the plug body 44 is a valve liner 46 having an upper sleeve portion 47 extending upwardly within the major bore 32 of the valve body 29 to a point a short distance below the fluted annular channel 35, there being an annular space 48 formed within the major bore 32 around the upper sleeve portion 47 of the valve liner 46. The valve liner 46 is provided with an axial bore 49 therethrough, in which is formed an annular channel 50 communicating through a plurality of upper liner ports 51 with the annular space 48 with the parts in the position shown in Fig. 1. Below the channel 50 in the bore 49 of the valve liner 47 is an annular channel 52 which communicates through a plurality of intermediate liner ports 53 with the annular space 48. A shoulder or collar 54 is formed on the valve liner 46 in a position to rest upon the upper end of the plug body 44, the outer periphery of the collar 54 making a fluid-tight fit with the lower end of the major bore 32. In the bore 49 of the valve liner 46, below the annular channel 52, is formed a lower annular channel 55 which communicates through a plurality of lower liner ports 56 in the wall of the valve liner 46 with an annular space 57 surrounding a lower reduced portion 58 of the collar 54, the space 57 communicating through an opening 59 in the lower end of the valve body 29 with the valve exhaust passage 39.

Slidable within the valve body 29 is a main valve member 60 which is of tubular form and which has an upper minor portion 61 which is separated by an annular shoulder 62 from a lower major portion 63. The minor portion 61 of the valve member 60 is of a smaller diameter than the major portion 63 thereof and has an external surface 64 which forms a substantially fluid-tight sliding fit in the minor bore 30 of the valve body 29. The major portion 63 of the valve member 60 has an external surface 65 which forms a substantially fluid-tight sliding fit with the major bore 32 of the valve body 29, the major portion of the valve member extending downwardly into the annular space 48 between the major bore and the external surface of the valve sleeve 47. The uppermost part of the minor portion 61 of the valve member 60 is reduced in diameter to provide an annular channel 65*a* therearound in which are upper inlet ports 66, and in the major portion 63 are lower inlet ports 67 which communicate with an annular channel 68 formed on the exterior of the valve member. Formed on the external surface of the minor portion 61 of the valve member 60 is an annular channel 69 which, when the valve member is in the position shown in Fig. 1, communicates between the circular channel 33 and the motor discharge port 37. As best shown in Fig. 13, connecting with the annular channel 65*a* and consequently with each of the upper inlet ports 66 is a short vertical channel 71 formed in the outer surface of the minor portion 61 of the valve member 60, the channels 71 being of varying lengths. Similarly formed in the outer surface of the minor portion 61 are a set of vertical channels 72 communicating with the annular channel 69, and formed in the external surface of the major portion 63 of the valve member 60 are vertical channels 73 also communicating with the annular channel 69. Likewise, vertical channels 74 are formed in the major portion 63 of the valve member 60 and communicate with the lower inlet ports 67. The channels comprising each of the sets of vertical channels 71, 72, 73, and 74 are of varying lengths, as illustrated in Fig. 13, for a purpose to be described hereinafter.

Formed in the bore of the major portion 63 of the valve member 60 is an annular channel 75 communicating with the lower inlet ports 67. Also formed in the major portion 63 is a helical passage 76 of relatively small cross-sectional area which communicates between the annular channel 75 and a wide annular channel 77 therebelow. In between the threads of the lower end of the helical passage 76 is an upper governing port 78 which communicates with a circular channel 79 formed on the exterior surface of the major portion 63 of the valve member 60. At the lower end of the wide annular channel 77 is a circular channel 80 which communicates with the annular space 48 below the valve member 60 through valve passages 81, and which also communicates through a lower governing port 82 with a circular channel 83 formed in the outer surface of the major portion 63 of the valve member. Formed in the outer surface of the upper sleeve portion 47 of the valve liner 46, above the upper liner port 51, is an annular channel 84, and communicating between one of the secondary passages 36 and the interior of the major bore 32 of the valve body 29 is an outer governing port 165.

Slidable within the bore of the valve liner 46 in fluid-tight relation therewith, and movable within the bore of the valve member 60 in spaced relation thereto, is a pilot rod 86, the lower end of which is connected to the upper end of a motor piston 87 adapted to be reciprocated within the motor cylinder liner 45 of the motor cyl-

inder 42. A cavity 88 formed in the lower end of the plug body 44 constitutes a continuation of the bore of the cylinder liner 45, and is provided with an inwardly tapered wall portion 89 having an annular channel 90 formed therein which intersects the lower ends of a plurality of vertical passages 92 formed in the plug body 44, each of the vertical passages 92 being axially aligned with the primary passages 34, the upper end of each of the vertical passages 92 registering with the lower end of one of the primary passages 34. The cavity 88 above the annular channel 90 forms a dashpot chamber for holding a body of fluid to stop the upward movement of the power piston 87 with a cushioning effect, as is well known in the art. As will be noted, the secondary fluid passages 36, which lead downwardly from the fluted annular channel 35, connect with fluid passages 93 having the form of grooves in the external face of the plug body 44, the lower end thereof communicating with the axial chamber 43.

The lower end of the motor cylinder 42 is connected by threads 95 to an intermediate plug 96 which has an upwardly extending tubular projection 97, the upper end of which engages the lower end 98 of the cylinder liner 45 in fluid-tight engagement. In the upper end of the tubular projection 97 is a dashpot cavity 99 for a purpose similar to that of the cavity 88, the upper end of the dashpot cavity 99 communicating through lower motor cylinder ports 100 with an annular space 101 around the tubular projection 97 and within the motor cylinder 42, the upper end of which communicates through longitudinal passages 102 formed between the motor cylinder 42 and the cylinder liner 45 with the lower end of the axial chamber 43.

The lower portion of the intermediate plug 96 is provided with external threads 104, to which is threaded the upper end of a pump cylinder 105 having a cylinder liner 106 therein, similarly to the motor cylinder 42 with its liner 45 therein, vertical longitudinal passages 107 being provided between the pump cylinder and the cylinder liner. Disposed between the lower end of the intermediate plug 96 and the upper end of the cylinder liner 106 of the pump cylinder 105 is an upper pump valve device 108 which includes an upper discharge valve 110 and an upper inlet valve 111. The upper discharge valve 110 is housed in a chamber 112 formed in the lower end of the intermediate plug 96, which communicates through upper discharge passages 113 with the exterio of the intermediate plug 96, the upper discharge valve including spring-held ball members 114 adapted to open upwardly to permit a flow of fluid from the upper end of the cylinder liner 106 therethrough and through the upper discharge passages 113, but preventing a reverse flow. The upper inlet valve 111 is disposed in a chamber 115 provided in a valve cage 116, and includes spring-held ball members 117 adapted to open downwardly to permit a flow of fluid into the upper end of the cylinder liner 106 through an upper inlet passage 118 formed in a valve ring 119 disposed between the lower end of the intermediate plug 96 and the upper end of the valve cage 116.

An intermediate piston rod 121 extends downwardly from the lower end of the motor piston 87 through the intermediate plug 96 and the upper pump valve device 108, and has its lower end connected to a pump piston 122, the pump piston being reciprocable in the cylinder liner 106.

The lower end of the pump cylinder 105 is provided with internal threads 123 by which the same is connected to a lower plug 124. Between the upper end of the lower plug 124 and the lower end of the cylinder liner 106 is disposed a lower pump valve device 125 which includes a lower discharge valve 126 and a lower inlet valve 127, the lower discharge and inlet valves 126 and 127, respectively, being similar in construction to the upper discharge and inlet valves 110 and 111, respectively. The lower discharge valve 126 communicates with the lower end of the cylinder liner 106 and with a lower discharge passage 128 formed in the lower plug 124, which in turn communicates with the exterior of the plug. The lower inlet valve 127 communicates between the interior of the lower end of the cylinder liner 106 and with a space 129 between the exterior of the lower pump valve device 125 and the pump cylinder 105, the space in turn communicating with vertical inlet passages 130 formed in the lower plug 124.

The lower end of the lower plug 124 is connected by external threads to a lower inlet fitting 131 provided with a lower conical end 132 in which an inlet opening 133 is formed. The conical end 132 of the inlet fitting 131 is adapted to seat in an inlet seat 134 carried by a bottom hole fitting 135 suitably threaded to the lower end of a production tubing 136 which extends upwardly through the well to the surface of the ground and is adapted to convey pumped fluid therethrough. I prefer to connect to the lower end of the fitting 135 a liner 147 having a lower open end and which may extend as far as desired below the fitting into the well, although it will be understood that this liner may be omitted if desired.

Threaded into the lower end of the lower plug 124 is a tubular closure member 138 having its lower end closed. A lower piston rod 139 is suitably connected to the lower end of the pump piston 122 and extends downwardly through the lower pump valve device 125 and the lower plug 124 into the interior of the tubular closure member 138. As will be noted, the pilot rod 86, the motor piston 87, the intermediate piston rod 121, the pump piston 122, and the lower piston rod 139 are provided with axially aligned and communicating longitudinal passages 141, 142, 143, 144, and 145, respectively, so as to provide fluid communication therethrough with the interior of the tubular closure member 138 so as to balance the fluid pressure on the upper and lower ends of the rods.

As shown in Figs. 1 and 4, the upper end of the pilot rod 86 is provided with a plurality of circumferentially spaced upper vertical channels 146, and also formed therebelow in the external surface of the pilot rod is a set of lower vertical channels 148, as best shown in Figs. 1 and 12, for a purpose to be described hereinafter.

During operation, operating fluid, such as, for example, oil, under relatively high pressure is conveyed through the fluid supply tubing 27 and the upper fitting 26 to the interior of the valve body 29, from whence it is conveyed through the main valve member 60, as will be described hereinafter, alternately to opposite ends of the motor piston 87, causing the same to reciprocate in the cylinder liner 45. Reciprocation of the motor piston 87 is communicated through the intermediate piston rod 121 to the pump piston 122,

causing the same to reciprocate similarly in the cylinder liner 106. In the position shown in Fig. 2, the motor piston 87 is substantially at the upper end of its stroke, and as it moves downwardly to the position shown in Fig. 17, in which it is substantially at the lower end of its stroke, it carries with it the pump piston 122, and well fluid flows upwardly through the liner 137, the inlet opening 133, the lower inlet fitting 131, the vertical inlet passages 130, the space 129, the longitudinal passages 107, and the upper inlet passages 118, through the upper inlet valve 111, and into the upper end of the cylinder liner 106 above the pump piston 122 as the same moves downwardly. During such downward movement of the pump piston 122, fluid in the cylinder liner 106 therebelow is expelled therefrom through the lower discharge valve 126 and the lower discharge passage 128 directly into the production tubing 136, from whence it flows upwardly therethrough to the surface of the ground. During downward movement of the pump piston 122, obviously, the upper discharge valve 110 and the lower inlet valve 127 will both remain closed. When the motor piston 87 starts its upward stroke from the position shown in Fig. 17 to that shown in Fig. 2, it carries with it the pump piston 122, and well fluid from the space 129 will be drawn inwardly through the lower inlet valve 127 into the lower end of the cylinder liner 106 below the pump piston 122, and at the same time fluid in the cylinder liner 106 above the pump piston 122 will be expelled therefrom through the upper discharge valve 110 and the upper discharge passages 113 into the production tubing 136, from whence it flows upwardly to the surface of the ground. Thus, it will be understood that a substantially continuous flow of pumped fluid is created in the production tubing 136 during reciprocation of the pump piston 122.

The operation of the main valve member 60 will now be described, but as it operates differently under different well conditions its normal operation under normal well conditions will first be described. By "normal well conditions" I mean the normal situation when the pump cylinder liner 106 is filled with substantially solid fluid, i. e., when there is little or no gas mixed with the liquid entering the cylinder liner 106 from the well.

With the parts in the position shown in Fig. 1, the main valve member 60 is in substantially its uppermost position, and the motor and pump pistons 87 and 122, respectively, and the pilot rod 86 have reached substantially the upper end of their upward strokes. The lower inlet ports 67 are aligned with the fluted annular channel 35 and fully open, and there is an unrestricted flow of operating fluid from the interior of the valve body 29 through the lower inlet ports 67, the fluted annular channel 35, the secondary fluid passages 36, the fluid passages 93, the axial chamber 43, the longitudinal passages 102, and the lower motor cylinder ports 100 into the cylinder liner 45 below the motor piston 87, tending to cause the same to move upwardly. The upper end of the motor piston 87 is open to the relatively low fluid pressure in the production tubing 136, the same being called "discharge pressure" hereinafter, through the annular channel 90, the vertical passages 92, the primary fluid passages 34, the circular channel 33, the annular channel 69, and the motor discharge port 37, and during upward movement of the motor piston spent operating fluid thereabove may thus exhaust into the production tubing.

As the pilot rod 86 has substantially reached the upper end of its upward stroke, as shown in Fig. 1, the lower vertical channels 148 therein span the lower annular channel 55 and the annular channel 52 to open the annular space 48 beneath the main valve member 60 to discharge pressure through the intermediate liner ports 53, the annular channel 52, the lower vertical channels 148, the lower annular channel 55, the lower liner ports 56, the annular space 57, the opening 59, the exhaust passage 39, and the lower valve exhaust port 40. Since the pressure exerted by the operating fluid on the upper end of the minor portion 62 of the valve member 60 is substantially greater than the pressure exerted on the lower end of the major portion 63 of the valve member by the discharge pressure in the production tubing 136, the valve member, as shown in Fig. 1, is about to move downwardly. The valve member 60 then moves downwardly at a relatively high rate of speed to the position shown in Fig. 14, at which time the downward speed thereof is materially reduced, the initial phase of the downward movement of the valve member being graphically represented by the portion 150 of the chart illustrated in Fig. 21.

As the valve member 60 moves downwardly from the position shown in Fig. 1 to the position shown in Fig. 14, the lower inlet ports 67 therein pass out of registry with the fluted annular channel 35, thus shutting off the flow of operating fluid to the lower end of the power piston 87. Similarly, the annular channel 69 formed on the exterior of the valve member 60 passes out of registry with the circular channel 33, thus shutting off the exhaust flow of spent operating fluid from the upper end of the motor piston 87.

When the valve member 60 reaches the position shown in Fig. 14, the lower end thereof has just closed the intermediate liner ports 53 so as to shut off the open exhaust of fluid therethrough from the lower end of the annular space 48. However, just prior thereto downward movement of the valve member 60 has caused the annular channel 68 to register with the upper valve discharge port 38, so as to maintain the annular space 48 below the valve member in communication with the discharge pressure through the valve passages 81, the circular channel 80, the wide annular channel 77, the helical passage 76, the annular channel 75, the lower inlet ports 67, the annular channel 68, and the upper valve discharge port 38. Since the helical passage 76 is relatively long and is of restricted cross-sectional area, fluid from the space 48 below the valve member 60 exhausts slowly, and, consequently, the valve member 60 moves slowly until it reaches the position shown in Fig. 15, this slow phase of its movement being graphically illustrated by the portion 151 of the chart shown in Fig. 21.

During the relatively slow downward movement of the valve member 60 between the positions shown in Figs. 14 and 15, the flow of operating fluid to the upper end of the motor piston 87 is started and increased gradually to prevent fluid shock which would otherwise occur if the full volume of operating fluid were suddenly delivered to the motor piston. This gradual increase in the volume of operating fluid delivered to the upper end of the motor piston 87 is controlled by the varying-length vertical channels 71, best shown in Fig. 13, which, as downward

movement of the valve member 60 progresses, successively open restricted fluid communication between the operating fluid and the circular channel 33, and, consequently, the upper end of the motor piston. Consequently, the motor piston 87 accelerates gradually in its initial downward movement, as graphically indicated by the portion 160 of the chart of Fig. 21. Similarly, during this same portion of movement of the valve member 60, the lower side of the motor piston 87 is gradually opened to exhaust pressure by the varying-length vertical channels 73 successively registering with the fluted annular channel 35. It will thus be understood that during the first portion of this slow phase of the downward movement of the valve member 60 the flow of operating fluid to the upper end of the motor piston 87 is metered by the vertical channels 71, and the discharge from below the motor piston is simultaneously metered by the vertical channels 73.

As soon as the vertical channels 71 start to register with the upper circular channel 33 and operating fluid flows therethrough to the upper end of the motor piston 87 to start the downstroke thereof, the pilot rod 86 also moves downwardly to take the lower vertical channels 148 therein out of registry with the annular channel 52, as shown in Fig. 15, thus shutting off all communication between the annular channel 52 and the lower annular channel 55 during the remainder of the downstroke of the valve member 60. However, upon the valve member 60 reaching the position shown in Fig. 15, the circular channel 79 registers with the outer governing port 165, and the lower end of the valve member 60 is thus additionally opened to discharge pressure through the upper governing port 78, the outer governing port 165, the secondary passage 36, the fluted annular channel 35, the vertical varying-length channels 73, the shallow annular channel 69, and the motor discharge port 37. Since the cross-sectional area of this fluid path is large relative to that of the path through the helical passage 76, the valve member 60 increases its downward rate of movement until it reaches the position shown in Fig. 16, this phase of downward travel of the valve member being graphically represented by the portion 152 of the chart shown in Fig. 21. As will be noted from Fig. 21, however, the downward speed of the valve member 60 during the portion 152 is not as great as the speed of its initial travel represented by the portion 150, which is due to the difference in lengths and cross-sectional areas of the passages and ports through which the fluid exhausts from the annular space 48 in the two portions of travel of the valve member, respectively.

It is to be noted that on the downstroke of the valve member 60, although the vertical channels 71 initially register with the circular channel 33 simultaneously with the initial registry of the vertical channels 73 with the fluted annular channel 35 so as to simultaneously throttle the initial flow of operating fluid to the upper end of the motor piston 87 and the initial discharge of spent operating fluid from below the motor piston, the annular channel 65*a* on the upper end of the valve member 60 opens to the circular channel 33 before the annular channel 69 opens to the fluted annular channel 35, due to the fact that the vertical channels 71 are shorter than the vertical channels 73, as best shown in Fig. 13.

As soon as the annular channel 65*a* registers with the circular channel 33, a substantially uninterrupted flow of operating fluid can flow to the upper end of the motor piston 87, and thus the vertical channels 73 continue to throttle the flow of spent operating fluid from beneath the motor piston after a free flow of operating fluid is permitted to flow to the upper end of the motor piston. This continued throttling of the spent operating fluid through the vertical channels 73 only continues, of course, until the valve member 60 has moved downwardly sufficiently to permit the annular channel 69 to register directly with the fluted annular channel 35, at which time, as shown in Fig. 16, the circular channel 33 is fully open to operating fluid through the annular channel 65*a* and the upper inlet ports 66, and the fluted annular channel 35 is fully open to discharge pressure through the annular channel 69 and the motor discharge port 37.

When the valve member 60 reaches the position shown in Fig. 16, it will be noted that the circular channel 79 has passed downwardly out of registry with the outer governing port 165, and, consequently, fluid from the annular space 48 must again exhaust through the helical passage 76 and the upper valve discharge port 38, which, due to the relatively small cross-sectional area of this path of flow, produces a small amount of end movement of the valve member at the same rate as represented by the portion 151 of the graph of Fig. 21. This slow end action of the valve member is designed to protect it against undesirable hammering, and for the purpose of simplification has been omitted from the graphs of Figs. 21 and 22, although it will be understood that it will be present under all conditions of operation where the valve member completes its stroke. So far as a general understanding of the action of the valve member 60 is concerned, however, the valve member may be regarded as remaining substantially in the position shown in Fig. 16 until it starts its upstroke, this stationary phase of the valve member's action being shown by the portion 153 of the chart of Fig. 21. As will be noted, when the valve member 60 reaches the position shown in Fig. 16, operating fluid unrestrictedly flows to the upper end of the motor piston 87 from the upper fitting 26 through the annular channel 65*a* and the upper inlet ports 66, through the circular channel 33, the primary fluid passages 34, the passages 92, and through the annular channel 90 into the upper end of the cylinder liner 46. In this position, also, the lower end of the motor piston 87 is unrestrictedly opened to exhaust pressure through the lower motor cylinder ports 100, the longitudinal passages 102, the axial chamber 43, the fluid passages 93, the secondary fluid passages 36, the fluted annular channel 35, the annular channel 69, and the motor discharge port 37. The motor piston 87 then completes its downward stroke, graphically represented by the portion 154 of the chart of Fig. 21, reaching the piston shown in Fig. 17.

When the motor piston 87 and pilot rod 86 approach their lower position, shown in Fig. 17, the upper longitudinal channels 146 in the pilot rod register with the annular channel 50 in the upper sleeve portion 47 of the valve liner 46, so as to open fluid communication between the operating fluid in the supply pipe 27 and the lower end of the space 48 through the annular channel 50, the upper liner ports 51, the wide annular channel 77, the circular channel 80, and the

valve passages 81. Since the cross-sectional area of the lower end of the valve member 60 is greater than that of its upper end, and since the valve member 60 is so designed that when in this position the total upward force exerted by the operating fluid thereon exceeds the total downward force exerted thereon by the operating fluid and the discharge pressure, the admission of operating fluid beneath the valve member 60 causes the same to move upwardly at a relatively high rate of speed to the position shown in Fig. 18, this first phase of the upward movement of the valve member being graphically illustrated by the portion 155 of the chart shown in Fig. 21. It will be understood that the area ratio between the pressure ends of the valve member 60 which includes the areas open to exhaust can be altered to vary the action of the valve member as desired.

Upon its arrival at the position shown in Fig. 18, the lower end of the valve member 60 has just closed the upper liner ports 51, but considerably previous thereto the annular channel 75 has opened fluid communication between the operating fluid and the annular space 48 through the helical passage 76, the wide annular channel 77, the circular channel 80, and the valve passages 81. Thus, closure of the upper liner ports 51 does not stop the upward movement of the valve member 60, but due to the restricted cross-sectional area of the helical passage 76 the flow of operating fluid to the under side of the valve member is retarded, and, consequently, the valve member moves relatively slowly to the position shown in Fig. 19, this second phase of the upward movement of the valve member being graphically illustrated by the portion 156 of the chart of Fig. 21. It is to be noted that the distance the valve member 60 must travel on its upstroke during which the lower inlet ports 67 are out of communication with the upper valve discharge port 38 and with the operating fluid above the valve liner 46 is very small. This is an important feature, as occasionally the pilot rod 86 may move upwardly slightly so as to move the upper longitudinal channels 146 therein out of registry with the annular channel 50, which stops the flow of operating fluid to the lower end of the annular space 48 through the upper liner ports 51, and if the annular channel 75 has not then been raised to communicate with the operating fluid above the valve liner 46 and the channel 68 has been cut off from the upper valve discharge port 38, the valve member 60 may stop on dead center. This tendency is reduced in my device by providing only a small travel of the valve member 60 during which the lower inlet ports 67 are out of fluid communication with either the upper valve discharge port 38 or the operating fluid above the valve liner 46. If the pilot rod 86 moves upwardly slightly so as to move the upper longitudinal channels 146 out of registry with the annular channel 50 while the lower inlet ports 67 are still in fluid communication with the upper valve discharge 38 through the annular channel 68, since fluid communication still exists between the lower end of the space 48 and the discharge pressure through the helical passage 76, the fluid from below the valve member will slowly exhaust therethrough, permitting the valve member to move downwardly to the lower end of its stroke, following which it will again start its upstroke, and since by the time the valve member reaches the lower end of its stroke operating fluid will again have moved the motor piston to the lower end of its stroke, a normal upstroke of the valve member can be performed. Similarly, if the pilot rod moves upwardly slightly so as to move the upper longitudinal channels 146 out of registery with the annular channel 50 after the upper end of the annular channel 75 has moved above the upper end of the valve liner 46, operating fluid is then in direct communication with the lower end of the valve member through the helical passage 76, and it can complete its upstroke at the rate indicated by the portion 151 of the graph of Fig. 21. The same feature to reduce the tendency of the valve member 60 to stop on dead center is provided in the downstroke of the valve member 60 when the lower inlet ports 67 move downwardly out of communication above the valve liner 46 with the operating fluid and before the annular channel 68 registers with the upper valve discharge port 38, the tendency of the valve member to stop on dead center being thus reduced to a minimum.

During the relatively slow upward movement of the valve member 60 between the positions shown in Figs. 18 and 19, the flow of operating fluid to the lower end of the motor piston 87 is started and increased gradually to prevent fluid shock which would otherwise occur if the full volume of operating fluid were suddenly delivered to the motor piston. This gradual increase in the volume of operating fluid delivered to the lower end of the motor piston 87 is controlled by the varying-length vertical channels 74, best shown in Fig. 13, which progressively register with the fluted annular channel 35, to meter the flow therethrough as described above in connection with the vertical channels 71 upon the downstroke of the valve member. Consequently, the motor piston 87 accelerates gradually in its initial upward movement, as graphically represented by the portion 161 of the chart shown in Fig. 21. Simultaneously with the initial registry of the vertical channels 74 with the fluted annular channel 35, the vertical channels 72 register with the circular channel 33 to gradually open the upper end of the motor piston 87 to discharge pressure simultaneously with the initial admission of operating fluid to the lower end of the motor piston. Since the vertical channels 74 are shorter than the vertical channels 72, on the upstroke of the valve member 60 the annular channel 69 fully registers with the circular channel 33 to permit uninterrupted discharge from the upper end of the motor piston 87 while the vertical channels 74 are still throttling the flow of operating fluid therethrough to the fluted annular channel 35 and to the lower end of the motor piston.

When the valve member 60 reaches the position shown in Fig. 19, the circular channel 83 and the lower governing port 82 register with the outer governing port 165, and the lower end of the valve member 60 is thus additionally opened to operating fluid through the lower inlet ports 67, the fluted annular channel 35, the secondary passage 36, the outer governing port 165, the lower governing port 82, and the valve passage 81, and thereupon the valve member continues its upward movement at an increased rate of speed until it reaches the position shown in Fig. 20. This phase of upward movement of the valve member 60 is graphically illustrated by the portion 157 of the chart shown in Fig. 21.

When the valve member 60 reaches the position shown in Fig. 20, the upper end of the motor

piston 87 is unrestrictedly opened to discharge pressure from the primary fluid passages 34, the circular channel 33, the annular channel 69, the circular channel 31, and the motor discharge port 37. Also, the lower end of the motor piston 87 is unrestrictedly opened to operating fluid through the lower motor cylinder ports 100, the longitudinal passages 102, the axial chamber 43, the fluid passages 93, the secondary fluid passages 36, the fluted annular channel 35, and the lower inlet ports 67. Consequently, from the position shown in Fig. 20 the motor piston 87 moves upwardly to the position shown in Fig. 1. When the valve member 60 has moved upwardly to the position shown in Fig. 20, it will be noted that the upper end of the valve member has not yet engaged the fitting 26 and that the annular channel 83 has just moved out of registry with the outer governing port 165. Consequently, in this position operating fluid can still flow to the lower end of the valve member 60 through the helical passage 76, which causes a slight further end movement of the valve member at a reduced rate of speed which is the same as that indicated by the portion 156 of Fig. 21, and which provides a small amount of upward end movement of the valve member similar to the lower end movement thereof described hereinabove. So far as a general understanding of the operation of the valve member 60 is concerned, the valve member may be regarded as remaining substantially stationary in the position shown in Fig. 20, as graphically indicated by the portion 158 of the chart of Fig. 21, the remaining upward movement of the motor piston being represented by the portion 159 of the chart. When the parts reach the positions shown in Fig. 1, a complete cycle of operation has been completed, and a new cycle starts, as described hereinabove.

In the operation of a fluid operated pump, such as described herein, it is desirable to maintain the flow of operating fluid to the motor piston at a substantially uniform rate. If, however, the pump load is suddenly decreased, the rate of flow of operating fluid normally would increase, as pointed out hereinabove, with an attendant excessive increase in the speed of the motor and pump. To prevent this condition occurring, my invention includes governing means adapted to operate in response to a decrease in pump load to maintain the flow of operating fluid to the motor piston 87 below a predetermined maximum rate, so as to prevent undesired acceleration of the moving parts, and the operation of such governing means is now described.

The governing means of my invention includes the upper and lower governing ports 78 and 82, respectively, and the outer governing port 165 communicating between one of the secondary fluid passages 36 and the annular space 48, as shown in Fig. 10.

When the pump cylinder liner 106 ahead of the pump piston 122 contains only about 30% well liquid and the balance gas, the governing action of my device is as follows: The valve member 60 moves downwardly from the position shown in Fig. 1 to the position shown in Fig. 14 at a rapid rate, this portion of its movement being illustrated graphically by the portion 162 of the chart of Fig. 22, which action is exactly the same as the action thereof shown by the portion 150 of Fig. 21. The valve member 60 then continues its downward movement at a slow rate, this portion of its travel being illustrated by the portion 163 of the chart of Fig. 22, which action is exactly the same as the action thereof shown by the portion 151 of Fig. 21. At the beginning of the slow downward movement of the valve member 60, in which it is in the position shown in Fig. 15, the vertical channels 71 begin to register with the circular channel 33 to permit an initial restricted flow of operating fluid from the supply pipe 27 to the upper end of the motor piston 87, and simultaneously during this portion of the movement of the valve member 60 the vertical channels 73 successively register with the fluted annular channel 35 to permit a restricted flow of spent operating fluid to exhaust from below the motor piston 87. After the vertical channels 73 begin to register with the fluted annular channel 35 and the annular channel 65a is fully open to the circular channel 33, the circular channel 79 registers with the outer governing port 165. Since the pump cylinder liner 106 below the pump piston 122 is filled largely with compressible gas, the force needed to move the pump piston downwardly to compress this gas is relatively small compared with the force required to move the pump piston when it is engaging solid liquid, and, consequently, even a restricted flow of operating fluid to the upper end of the motor piston 87 is sufficient to start the downward movement of the motor and pump pistons at a greater rate of speed than would be the case if the pump piston were engaging solid liquid. The increased rate of speed of this initial downward movement of the motor piston 87 is graphically illustrated by the portion 166 of the chart shown in Fig. 22, which can readily be compared with the initial downward movement of the motor piston under normal conditions by referring to the portion 160 of Fig. 21. Due to this increased initial velocity of the pump piston 122, and due to the fact that the discharge from below the pump piston is throttled by the restricted cross-sectional areas of some of the vertical channels 73 communicating with the fluted annular channel 35, fluid pressure quickly builds up in the secondary passages 36, and this rise in fluid pressure is communicated to the lower end of the valve member 60 through the outer governing port 165 and the upper governing port 78, which prevents further downward movement of the valve member until the fluid pressure therebelow is reduced, as the valve member is so designed that a predetermined rise in pressure therebelow will stop its continued downward movement, due to the difference in areas of its upper and lower ends, and due to the fact that fluid under such increased pressure is supplied from the secondary passage 36 through the outer governing port to the bottom of the annular space 48 faster than it can exhaust through the helical passage 76. It is also to be noted that the proper relation must be maintained in design between the cross-sectional area of the outer governing port 165, the helical passage 76, the annular channel 79, the port 78, the wide annular channel 77, the annular channel 80, and the parts 81, as the outer governing port 165 must admit fluid to the lower end of the valve member 60 faster than the helical passage 76 will permit it to exhaust through the upper valve discharge port 38.

Thus, the valve member 60, under such operating conditions, will remain stationary, as graphically illustrated by the portion 164 of the chart of Fig. 22, and the motor piston 87 will move at slightly increased but controlled velocity, as indicated by the portion 167 of Fig. 22, until

the pump piston strikes solid liquid. When this occurs, the downward rate of movement of the pump piston 122, and the motor piston connected thereto, is materially reduced, and consequently the fluid discharge pressure in the secondary passages 36 drops due to the reduction in speed of the pistons, thus allowing the fluid beneath the valve member 60 in the annular space 48 to exhaust into the secondary passages 36 through the outer governing port 165 to permit the valve member to resume its downward movement from the position shown in Fig. 15 to that shown in Fig. 16, which movement is represented by the portion 168 of the graph of Fig. 22, and which is exactly the same as the corresponding valve movement under normal conditions as represented by the portion 152 of the graph of Fig. 21. During the movement of the valve member 60 from the position shown in Fig. 15 to that shown in Fig. 16, the annular channel 69 registers with the fluted annular channel 35 to open fully the discharge from the lower end of the pump piston 122. Prior to the governing or metering action through the vertical channels 73, the annular channel 65a has registered with the circular channel 33 to open the upper end of the power piston 87 to operating fluid, as described hereinabove in connection with the operations shown in Fig. 21. As soon as the pump piston 122 hits solid liquid in the pump, the balance of the stroke of the motor piston 87 is at a velocity reduced below normal, as indicated by the portion 169 of the graph of Fig. 22, the change in speed of the piston from high velocity to low velocity being gradual as the valve member is in the throttling or controlling position shown in Fig. 15 when the pump piston strikes solid liquid and the valve has to open before the piston can assume normal speed under load, which, plus the compression of the gas below the pump piston, tends to round off the curve shown in Fig. 22 and make a gradual transition from governed high speed to low speed of the piston. As soon as the valve member 60 reaches the position shown in Fig. 16, it remains substantially stationary until the motor piston 87 completes its downward stroke, this portion of the action of the valve member being represented by the portion 171 of the graph of Fig. 22.

The same type of governing action takes place upon the upward movement of the valve member 60, as is shown by Fig. 22, but is accomplished in a slightly different manner. When the pump cylinder liner 106 above the pump piston 122 is similarly filled with a mixture of gas and fluid, the upward movement of the valve member 60 is the same as the upward movement thereof under normal conditions of operation as shown in Fig. 21 until the valve member reaches the position shown in Fig. 19. When the valve member 60 reaches the position shown in Fig. 19, the upper end of the motor piston 87 is fully open to exhaust pressure by registry of the annular channel 69 with the circular channel 33, but operating fluid is still metered through the vertical channels 74 which have just started to register with the fluted annular channel 35, thus throttling the flow of operating fluid to the lower end of the motor piston 87, as described hereinabove. and the circular channel 83 of the lower governing port 82 has just registered with the outer governing port 166. As will also be noted from Fig. 19, the motor piston 87 has started its upward movement, and the vertical channels 146 are out of registry with the annular channel 50. Due to gas in the pump cylinder above the pump piston 122, the fluid pressure of the operating fluid in the secondary passages 36 remains relatively low as the flow is throttled through the vertical channels 74 until the pump piston strikes solid liquid, and while the pressure in the secondary passages is thus relatively low, operating fluid which would be normally supplied to the lower end of the valve member 60 through the helical passage 76 is permitted to discharge from the wide annular channel 77 through the lower governing port 82, the circular channel 83, and the outer governing port 165 into the secondary passages 36, thus keeping the full pressure of the operating fluid off the lower end of the valve member 60 which causes it to remain stationary, as illustrated by the portion 172 of the chart of Fig. 22. As the valve member 60 thus hangs up until the pump piston 122 again strikes solid liquid, the flow of operating fluid to the lower end of the motor piston 87 is metered through the vertical channels 74 while the valve member remains stationary. As soon as the pump piston strikes solid liquid, the fluid pressure in the secondary passages 36 rises due to a decrease in the throttling action of the vertical channels 74 because of the resulting lower pump piston speed, and, consequently, the discharge of operating fluid from the lower governing port 82 stops, and operating fluid then flows to the lower end of the valve member 60 from the secondary passages 36, causing the valve member 60 to resume its upward movement represented by the portion 173 of the graph shown in Fig. 22. The upstroke of the motor piston 87 is the same as the downstroke, as shown in Fig. 22, when the proportion of gas and liquid on both ends of the pump piston 122 is the same.

Fig. 23 graphically illustrates the operation of the motor piston 87 and the valve member 60 in the special case when the pump is operating at zero efficiency, i. e., when the pump is not pumping any fluid from the well. This curve assumes that the fluid operated pump has been operating at zero efficiency for a sufficient length of time so that the stored energy of compression of the operating fluid and the stored energy of expansion of the supply tubing have been entirely released, and, therefore, the pistons will operate at the normal number of strokes per minute as determined by the rate of flow of operating fluid delivered through the supply tubing to the fluid operated pump by the surface pump. This condition of zero efficiency may be caused by the upper and lower inlet valves 111 and 127, respectively, becoming clogged with foreign material so that they will not unseat, or may be caused by other operating conditions. Under these conditions of operation, the valve member 60 performs its first two functions, illustrated by the portions 180 and 181 of the graph of Fig. 23, normally, as will be seen by a comparison with the chart of Fig. 21, but hangs up and remains in the throttling position shown in Fig. 15 and graphically indicated by the portion 182 of Fig. 23 for the remainder of the downstroke of the motor piston 87. The valve member 60 hangs up due to the normal pressure drop in the passages due to fluid friction therein, which pressure drop is sufficient to cause the valve member to hang up so long as no fluid is being pumped by the pump piston 122. If any fluid, even gas, is being discharged by the pump piston 122, then the valve action will generally resemble the action there-

of illustrated in Fig. 22. At the end of the downstroke of the motor piston 87, the valve member 60 then resumes substantially normal operation for its first two functions, as graphically indicated by the portions 183 and 184 of Fig. 23, on the start of the upstroke of the motor piston, but hangs up in the throttling position shown in Fig. 19 and graphically shown by the portion 185 of Fig. 23 for the balance of the upstroke of the motor piston. It will therefore be appreciated that under such conditions of operation the piston motion is almost exactly normal and the energy of the operating fluid, which would normally be used to operate the fluid operated pump to lift well liquid, is all consumed in the throttling action of the valve member 60.

It will be appreciated that the conditions of operation graphically illustrated by Figs. 21, 22, and 23 are not mutually exclusive or typical, but are merely examples of the operation of my invention under selected different operating conditions. The movement of the valve member 60 under other operating conditions may vary substantially, but in every case will be such as to meter the flow to the motor piston 87 on the upstroke of the valve member and to meter the flow from the motor piston on the downstroke of the valve member, to prevent racing of the pistons. Those skilled in the art will readily understand that the flow governing action of my valve construction occurs whenever the pump piston 122 strikes gas instead of solid liquid, and that the upward or downward movement of the valve member 60 stops until the pump piston strikes solid liquid, thus providing an automatic throttling action to maintain the flow of operating fluid to the motor piston 87 below a predetermined maximum rate, thus preventing racing of the pump with the attendant danger of damage to the moving parts. It will thus be apparent that the number of strokes per minute of my pump will be maintained below a predetermined maximum, regardless of the presence of gas in the pump liner 106 and regardless of the amount of such gas, in spite of the normal tendency of the pistons to speed up under such circumstances. It will also be appreciated that any sudden increase in the speed of the prime mover in the surface pump supplying the operating fluid will likewise fail to cause the piston 87 to race, as any momentary increase in the rate of flow from whatever cause will be governed in the same manner as described hereinabove.

Although I have described my invention as applied to a fluid operated pump, in which it may be used to particular advantage, it is to be understood that my device may be used in other capacities without departing from the spirit of my invention. Consequently, I do not intend to be limited to the particular construction described, but desire to be afforded the full scope of the following claims.

I claim as my invention:

1. A valve mechanism for a fluid motor of the character described having a motor piston operable in a motor cylinder and having a passage for supplying operating fluid to one end of said cylinder, including: a valve member movable between primary and secondary positions to open said passage; means for moving said valve member at a relatively high rate of speed from said primary position to a first point at which said valve member is about to open said passage; means for moving said valve member at a materially reduced uniform rate of speed from said first point to a second point at which said valve has fully opened said passage; and means for moving said valve member from said second point to said secondary position at a materially increased rate of speed.

2. A valve mechanism for opening a passage adapted to carry a flow of fluid, including: a valve member movable between primary and secondary positions to open said passage at a point intermediate said primary and secondary positions; throttling means associated with said valve member for gradually opening said passage as said valve member approaches said point so as to meter the flow of fluid through said throttling means; means for moving said valve member between said point and said secondary position; and means for maintaining said valve member in said metering position when the rate of flow of fluid through said throttling means tends to rise above a predetermined maximum.

3. A valve mechanism for opening a passage adapted to carry a flow of fluid, including: a valve member movable between primary and secondary positions to open said passage at a point intermediate said primary and secondary positions; throttling means associated with said valve member for gradually opening said passage as said valve member approaches said point so as to meter the flow of fluid through said throttling means; means for moving said valve member between said point and said secondary position; and means for stopping said valve member in said metering position when the pressure of said fluid in said passage drops below a predetermined minimum and retaining said valve member in said metering position until the pressure of said fluid in said passage rises above a predetermined maximum.

4. A valve mechanism for a fluid motor of the character described having a motor piston operable in a motor cylinder and having a passage for exhausting spent operating fluid from one end of said cylinder, including: a valve member movable between primary and secondary positions to open said passage at a point intermediate said primary and secondary positions; throttling means associated with said valve member for gradually opening said passage as said valve member approaches said point so as to meter the exhaust flow of spent operating fluid through said throttling means; means for moving said valve member between said second point and said secondary position; and means for stopping said valve member in said metering position when the pressure of said exhausting operating fluid rises above a predetermined maximum and retaining said valve member in said metering position until the pressure of said exhausting operating fluid drops below a predetermined minimum.

5. A valve mechanism for a fluid motor of the character described having a motor piston operable in a motor cylinder and having a passage for supplying operating fluid to one end of said cylinder, including: a valve member movable between primary and secondary positions to open said passage at an intermediate point between said positions; means for moving said valve member at a relatively high rate of speed from said primary position to a first point at which said valve member is about to open said passage; means for moving said valve member at a materially reduced rate of speed from said first point to said intermediate point; throttling means associated with said valve member for gradually opening

said passage as said valve member moves from said first point to said intermediate point so as to meter the flow of operating fluid through said passage; means for moving said valve member from said intermediate point to said secondary position at a materially increased rate of speed; and means for maintaining said valve member in said metering position between said first point and said intermediate point when the rate of flow of operating fluid through said throttling means tends to rise above a predetermined maximum.

6. In a fluid operated motor device, the combination of: a motor cylinder having a motor piston therein; a fluid passage communicating with one end of said motor cylinder; a valve member in the line of said fluid passage and movable between primary and secondary positions to open fluid communication through said fluid passage; means for moving said valve member between said primary and secondary positions; and means for controlling said movement of said valve member in response to variations in fluid pressure in said fluid passage between said valve member and said motor cylinder.

7. In a fluid operated motor device, the combination of: a motor cylinder having a motor piston therein; a fluid passage communicating with one end of said motor cylinder; a source of operating fluid under pressure; a valve member movable between primary and secondary positions to alternately connect said fluid passage with said operating fluid under relatively high pressure or with a point of discharge at relatively low pressure, said valve member being of the differential area type having a small face continuously subjected to the pressure of said operating fluid and having a large face alternately subjected to the pressure of said operating fluid; throttling means for metering the flow of fluid through said passage as said valve means approaches said primary and secondary positions; and port means for connecting said fluid passage with said large end of said valve member in both of said metering positions.

8. In a fluid operated motor device, the combination of: a motor cylinder having a motor piston therein; a first fluid passage communicating with one end of said motor cylinder; a second fluid passage communicating with the other end of said motor cylinder; a source of operating fluid under pressure; a valve member movable between primary and secondary positions and constructed and arranged so that when in said primary position it connects said first fluid passage with said operating fluid under relatively high pressure and said second fluid passage with a point of discharge at relatively low pressure, and when in said secondary position it connects said first fluid passage with said point of discharge and connects said second fluid passage with said operating fluid, said valve member being of the differential area type having a small face continuously subjected to the pressure of said operating fluid and having a large face alternately subjected to the pressure of said operating fluid; throttling means for metering the flow of fluid through said passages as said valve means approaches said primary and secondary positions; and port means for connecting one of said fluid passages with said large end of said valve member in both of said metering positions.

9. In a fluid operated motor device, the combination of: a motor cylinder having a motor piston therein; a fluid passage communicating with one end of said motor cylinder; a source of operating fluid under pressure; a valve member movable between primary and secondary positions to alternately connect said fluid passage with said operating fluid under relatively high pressure or with a point of discharge at relatively low pressure, said valve member being of the differential area type having a small face continuously subjected to the pressure of said operating fluid and having a large face alternately communicating with said operating fluid and said low pressure discharge point through a restricted fluid flow passage; throttling means for metering the flow of fluid through said passage as said valve means approaches said primary and secondary positions; and port means for connecting said fluid passage with said restricted flow passage in both of said metering positions.

10. In a fluid operated motor device, the combination of: a motor cylinder having a motor piston therein; a first fluid passage communicating with one end of said motor cylinder; a second fluid passage communicating with the other end of said motor cylinder; a source of operating fluid under pressure; a valve member movable between primary and secondary positions and constructed and arranged so that when in said primary position it connects said first fluid passage with said operating fluid under relatively high pressure and said second fluid passage with a point of discharge at relatively low pressure, and when in said secondary position it connects said first fluid passage with said point of discharge and connects said second fluid passage with said operating fluid, said valve member being of the differential area type having a small face continuously subjected to the pressure of said operating fluid and having a large face alternately communicating with said operating fluid and said low pressure discharge point through a restricted fluid flow passage; throttling means for metering the flow of fluid through said passages as said valve means approaches said primary and secondary positions; and port means for connecting one of said fluid passages with said restricted flow passage in both of said metering positions.

11. In a valve device, the combination of: a housing having an inlet and a discharge port; a first passage in said housing; a second passage in said housing; valve means in said housing adapted to move between primary and secondary positions so as to alternatively connect said first passage with said inlet and said second passage with said discharge port or to connect said first passage with aid discharge port and said second passage with said inlet; and means for connecting said first passage with said inlet before said second passage is connected with said discharge port.

12. In a valve device, the combination of: a housing having an inlet and a discharge port; a first passage in said housing; a second passage in said housing; valve means in said housing adapted to move between primary and secondary positions so as to alternatively connect said first passage with said inlet and said second passage with said discharge port or to connect said first passage with said discharge port and said second passage with said inlet; means for connecting said first passage with said inlet before said second passage is connected with said discharge port; and means for connecting said first passage with said discharge port before said second passage is connected to said inlet.

13. In a valve device, the combination of: a

housing having an inlet and a discharge port; a first fluid passage in said housing; a second fluid passage in said housing; a valve member movable between a primary position in which said valve member connects said first passage with said inlet and connects said second passage with said discharge port and a secondary position in which said valve member connects said first passage with said discharge port and connects said second passage with said inlet; throttling means for metering a flow of fluid through said second passage at is opens to communication with said discharge port through said valve member; and means for causing said valve member to open communication between said first passage and said inlet before it opens communication between said second passage and said discharge port, so that when said valve member is in said metering position communication will be fully open between said inlet and said first passage.

14. In a valve device, the combination of: a housing having an inlet and a discharge port; a first fluid passage in said housing; a second fluid passage in said housing; a valve member movable between a primary position in which said valve member connects said first passage with said inlet and connects said second passage with said discharge port and a secondary position in which said valve member connects said first passage with said discharge port and connects said second passage with said inlet; throttling means for metering a flow of fluid through said second passage as it opens to communication with said inlet through said valve member; and means for causing said valve member to open communication between said first passage and said discharge port before it opens communication between said second passage and said inlet, so that when said valve member is in said metering position communication will be fully open between said discharge port and said first passage.

15. A valve mechanism for a fluid motor of the character described having a motor piston operable in a motor cylinder and having a first passage for supplying operating fluid to one end of said cylinder and a second passage for supplying operating fluid to the other end of said cylinder, including: a valve movable from a primary position to a secondary position to open said first passage, and movable from said secondary position to said primary position to open said second passage; means for moving said valve member at a relatively high rate of speed from said primary position to a first point at which said valve member is about to open said first passage; means for moving said valve member at a materially reduced rate of speed from said first point to a second point at which said valve member has fully opened said first passage; means for moving said valve member from said second point to said secondary position at a materially increased rate of speed; means for moving said valve member at a relatively high rate of speed from said secondary position to a third point at which said valve member is about to open said second passage; means for moving said valve member at a materially reduced rate of speed from said third point to a fourth point at which said valve member has fully opened said second passage; and means for moving said valve member from said fourth point to said primary position at a materially increased rate of speed, to complete a cycle of operation of said valve member.

16. A valve mechanism for opening a passage adapted to carry a flow of fluid, including: a valve member alternately movable in either of two directions between primary and secondary positions to open said passage at a zone intermediate said primary and secondary positions; thottling means associated with said valve member for gradually opening said passage as said valve member approaches said zone in either of said directions so as to meter the flow of fluid through said throttling means; and means for maintaining said valve member in said metering position so long as the rate of flow of fluid through said throttling means tends to rise above a predetermined maximum.

17. A valve mechanism for opening a passage adapted to carry a flow of fluid, including: a valve member movable between primary and secondary positions, said valve member opening said passage at an intermediate zone of movement between said positions; throttling means associated with said valve member for gradually opening said passage as said valve member passes through said zone to meter the flow of fluid through said throttling means; and means for maintaining said valve member in said metering position so long as the pressure of fluid in said passage varies from a prescribed value.

18. A valve mechanism for opening a passage adapted to carry a flow of fluid, including: a valve member movable between primary and secondary positions, said valve member opening said passage at an intermediate zone of movement between said positions; throttling means associated with said valve member for gradually opening said passage as said valve member passes through said zone to meter the flow of fluid through said throttling means; means for maintaining said valve member in said metering position so long as the pressure of fluid in said passage varies from a prescribed value; and means for completing the movement of said valve member between said positions when the pressure of fluid in said passage returns to said prescribed value.

19. In a fluid operated motor device, the combination of: a motor cylinder having a motor piston therein; a first fluid passage communicating with one end of said motor cylinder; a second fluid passage communicating with the other end of said motor cylinder; a valve member movable between primary and secondary positions, said valve member when in said primary position opening said first passage to a source of operating fluid under pressure and said second passage to a low pressure discharge, said valve member when in said secondary position opening said first passage to said discharge and said second passage to said source; means for moving said valve member between said primary and secondary positions; and means for controlling said movement of said valve member in response to variations in fluid pressure in one of said fluid passages between said valve member and said motor cylinder.

20. In a valve mechanism for opening a passage adapted to carry a flow of fluid, including: a source of operating fluid under pressure; a point of discharge at relatively low pressure; a valve member movable between first and second operating positions to alternately connect said fluid passage with said operating fluid under relatively high pressure or with said point of discharge, said valve member being of the differential area type having a small face continuously subjected to the pressure of said operating fluid and having a large face alternately subjected to

the pressure of said operating fluid; and means for controlling said movement of said valve member in response to variations in fluid pressure in said fluid passage.

21. In a valve mechanism for opening a passage adapted to carry a flow of fluid, including: a source of operating fluid under pressure; a point of discharge at relatively low pressure; a valve member movable between first and second operating positions to alternately connect said fluid passage with said operating fluid under relatively high pressure or with said point of discharge, said valve member being of the differential area type having a small face continuously subjected to the pressure of said operating fluid and having a large face alternately subjected to the pressure of said operating fluid; and port means for connecting said fluid passage with said large face of said valve member as said valve member approaches each of said positions.

22. In a valve device, the combination of: a housing having an inlet port and a discharge port; a first passage in said housing; a second passage in said housing; valve means in said housing adapted to move between primary and secondary positions so as to alternately connect said first passage with said inlet port and said second passage with said discharge port or to connect said first passage with said discharge port and said second passage with said inlet port, said valve means being so constructed and arranged that it connects said first passage with said inlet port before said second passage is connected with said discharge port; throttling means for alternately gradually opening said second passage to said inlet port or said discharge port to meter a flow of fluid through said second passage; and means for controlling the operation of said valve member in response to variations in fluid pressure in said second passage.

23. In a valve device, the combination of: a valve housing having an inlet adapted to be connected to a source of operating fluid under relatively high pressure, and having first and second exhaust ports adapted to be connected to a point at relatively low pressure; a valve member in said housing and of the differential area type having a small end adapted to be subjected to the fluid pressure in said inlet and a large end adapted to be opened to said low pressure to move said valve member from a primary position to a secondary position; movable auxiliary valve means adapted to open fluid communication between said large end and said first exhaust port to permit a first zone of movement of said valve member from said primary position toward said secondary position; means adapted to open fluid communication between said large end and said second exhaust port to permit a completion of said movement of said valve member from said primary position to said secondary position; and means for returning said valve member to said primary position in the event that said auxiliary valve means closes fluid communication between said large end and said first exhaust port during said first zone of movement of said valve member.

24. In a valve device, the combination of: a valve housing having an inlet adapted to be connected to a source of operating fluid under relatively high pressure; a valve member in said housing and of the differential area type having a small end adapted to be subjected to said inlet pressure and a large end adapted to be alternately subjected to said inlet pressure to move said valve member from a primary position to a secondary position; first port means communicating with said large end and adapted to be opened to fluid communication with said inlet to admit operating fluid to said large end to cause a first zone of movement of said valve member from said primary position toward said secondary position; second port means adapted to be subsequently opened to fluid communication with said inlet to admit operating fluid to said large end to complete said movement of said valve member to said secondary position; movable auxiliary valve means adapted to open said communication between said first port means and said inlet; and means for returning said valve member to said primary position in the event that said auxiliary valve means closes fluid communication between said first port means and said inlet during said first zone of movement of said valve member.

CLARENCE J. COBERLY.

CERTIFICATE OF CORRECTION.

Patent No. 2,311,157. February 16, 1943.

CLARENCE J. COBERLY.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, second column, line 36, for "liner 147" read --liner 137--; page 6, second column, line 65, for "piston" read --position--; page 7, second column, line 26, for "flnid" read --fluid--; page 11, second column, line 55, claim 11, for "aid" read --said--; page 12, first column, line 12, claim 13, for "at is" read --as it--; and second column, line 6, claim 16, for "thottling" read --throttling--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 20th day of April, A. D. 1943.

Henry Van Arsdale,

(Seal) Acting Commissioner of Patents.