Dec. 8, 1953 W. FERRIS 2,661,695

REDUCTION OF NOISE AND SHOCK IN POWER PUMPS

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FIG. 1

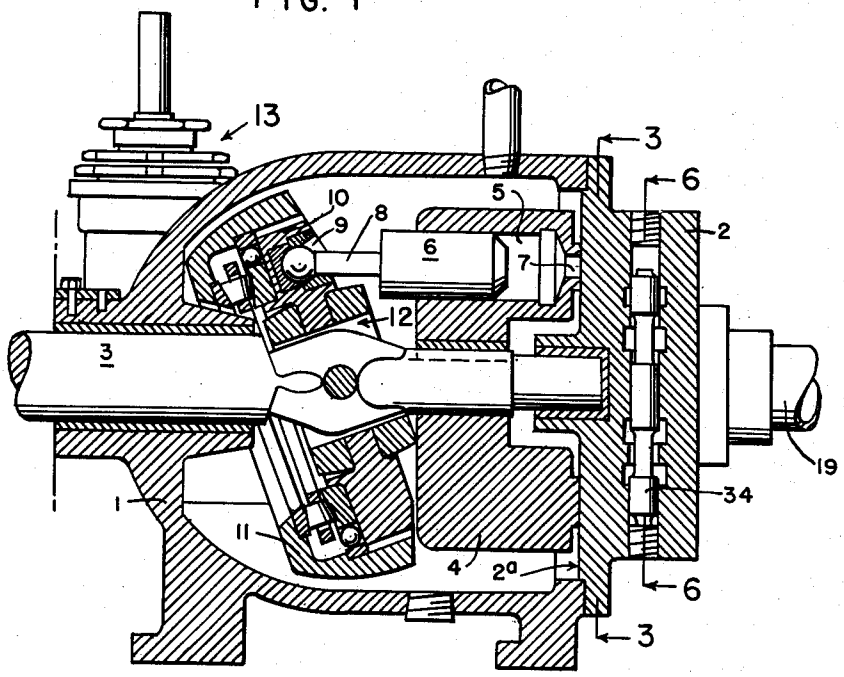
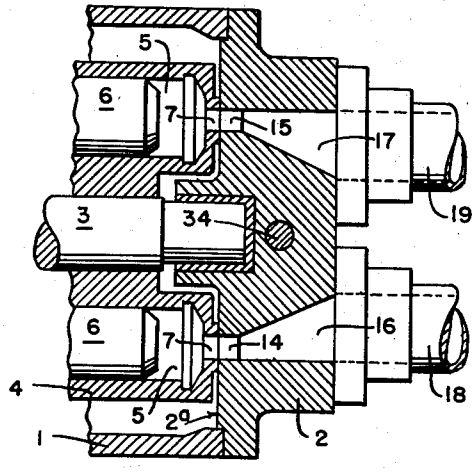


FIG. 2



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REDUCTION OF NOISE AND SHOCK IN POWER PUMPS

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FIG. 4

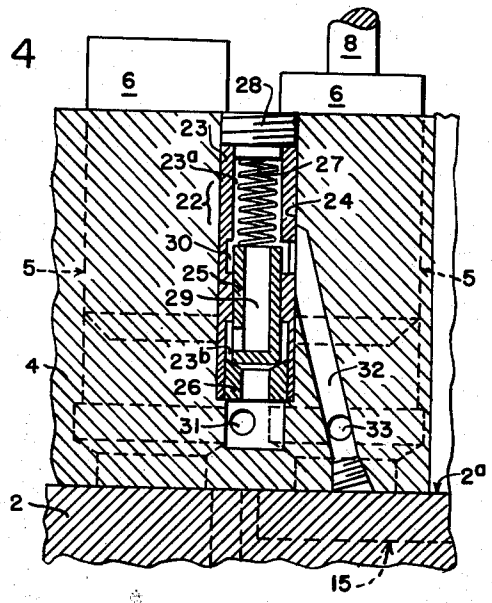
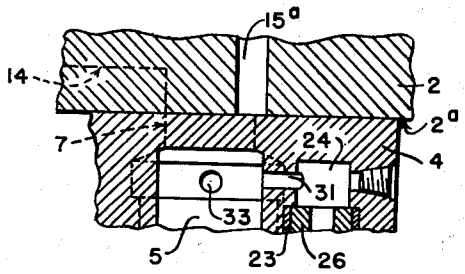


FIG. 5



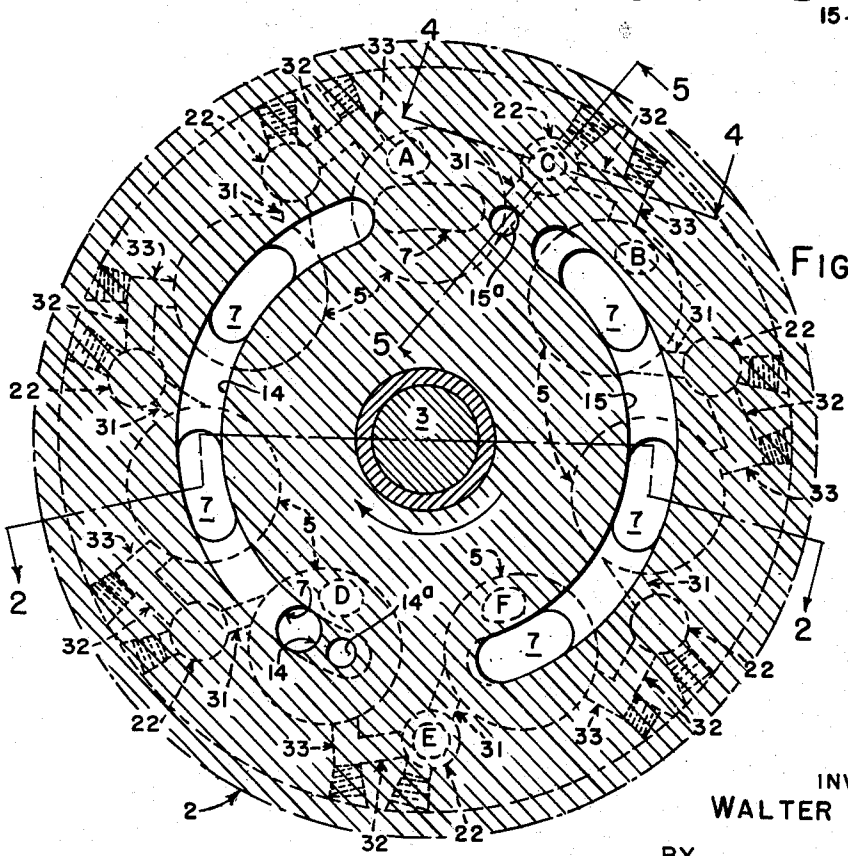


FIG. 3

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REDUCTION OF NOISE AND SHOCK IN POWER PUMPS

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FIG. 9

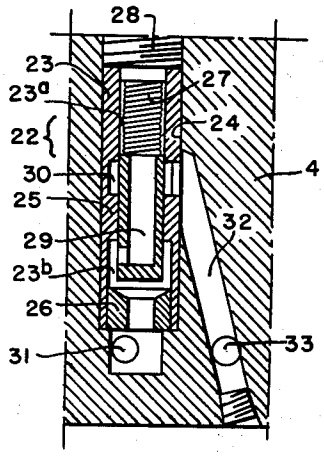


FIG. 7

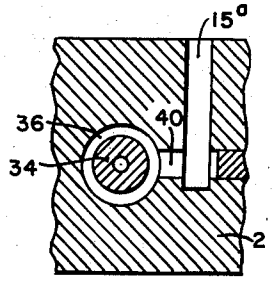


FIG. 8

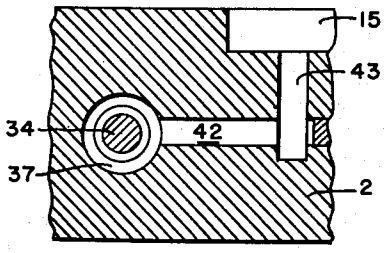
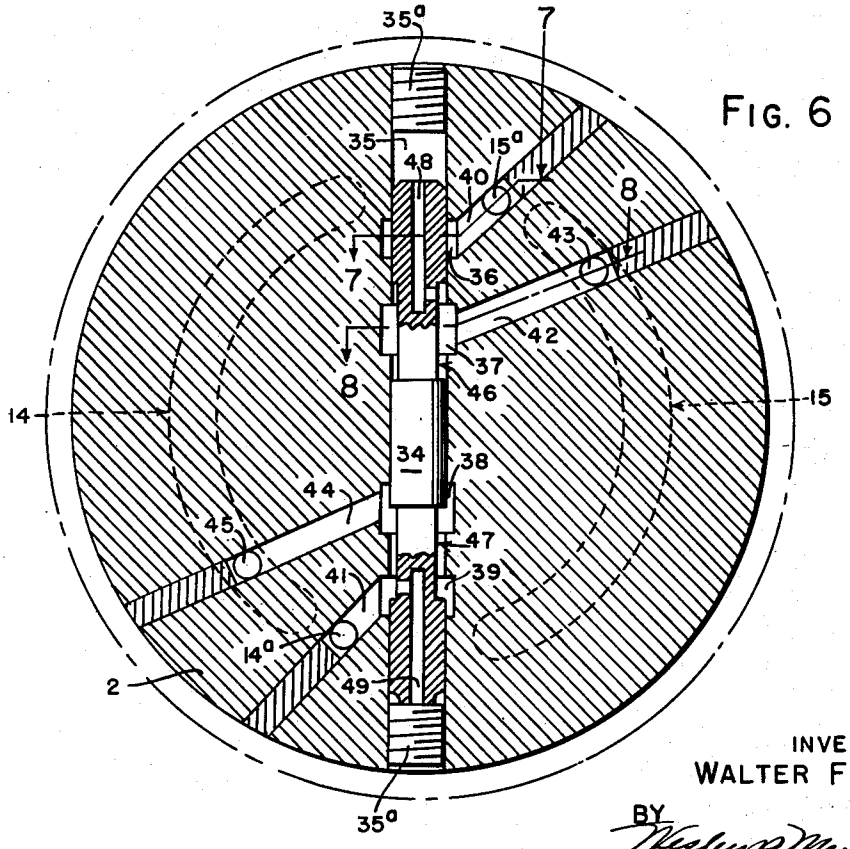


FIG. 6



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2,661,695

UNITED STATES PATENT OFFICE

2,661,695

REDUCTION OF NOISE AND SHOCK IN POWER PUMPS

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Application July 21, 1950, Serial No. 175,190

4 Claims. (Cl. 103—3)

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This invention relates to pumps of the expansible chamber type which are employed to pump liquid at pressures high enough to enable the liquid to perform useful work, such as energizing hydraulic motors or charging accumulators.

A pump of this type includes at least one intake port for connection to a supply of liquid, at least one discharge port which is spaced from the intake port and is adapted to be connected to an external circuit, a plurality of pump chambers, means to cause each pump chamber to register with the intake port and the discharge port alternately and means to increase the capacity of each chamber while it is in registry with the intake port and decrease the capacity of each chamber while it is in registry with the discharge port to thereby cause liquid to flow from the intake port into each chamber in registry therewith and liquid to be expelled into the discharge port from each chamber in registry therewith.

When the liquid discharged by the pump is required to do useful work such as energizing a motor, the liquid expelled from the chambers into the discharge port causes pressure to rise therein but the liquid in the chambers which are not in registry with the discharge port is under a low or negative pressure and very often it contains entrained gas. Consequently, when a chamber opens to the discharge port, the pressure in the discharge port causes liquid to rush therefrom into that chamber and compress the liquid and entrained gas therein until the pressure in that chamber is the same as the pressure in the discharge port. This sudden back flow of liquid from the discharge port into the chamber causes a shock and a resultant noise and, if the pump is creating a high pressure, the shock and noise are of considerable magnitude.

The present invention has as an object to reduce the shocks and noise inherent in pumps of this type.

Another object is to prevent any shock or noise due to back flow of liquid from the discharge port into the pumping chambers.

A pump embodying the invention has the advantage that it will operate more quietly than a prior pump of the same type and with increased efficiency.

Other objects and advantages will appear from the description hereinafter given of pumps to which the invention has been applied.

According to the invention in its principal aspect, the fluid in each pumping chamber is compressed to a pressure somewhat greater than the pressure in the discharge port before that chamber opens to the discharge port.

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For the purpose of illustration, the invention will be explained as applied to an axial type piston pump but the invention is also applicable to other types of pumps.

The invention is exemplified by the pump illustrated in the accompanying drawings in which the views are as follows:

Fig. 1 is a longitudinal vertical section through an axial pump in which the invention is embodied.

Fig. 2 is an approximately horizontal section through the rear part of the pump shown in Fig. 1, the plane of the view being indicated by the irregular line 2—2 of Fig. 3.

Fig. 3 is a transverse section taken on the line 3—3 of Fig. 1 but drawn to a considerably larger scale.

Figs. 4 and 5 are fragmentary sectional views taken, respectively, on the lines 4—4 and 5—5 of Fig. 3.

Fig. 6 is a transverse section taken on the line 6—6 of Fig. 1 but drawn to a considerably larger scale.

Figs. 7 and 8 are fragmentary sectional views taken, respectively, on the irregular lines 7—7 and 8—8 of Fig. 6.

Fig. 9 is a view similar to a part of Fig. 4 but showing the check valve in a different position.

The invention has been shown applied to an ordinary swash plate type pump which is substantially the same as the pump shown in Patent No. 1,020,285. Consequently, only so much of the pump has been illustrated as is necessary to an explanation of the invention.

The pump has its mechanism arranged within and carried by a casing 1 having its rear end closed by a removable end head 2 the front portion of which constitutes a valve for controlling the flow of liquid to and from the pumping cylinders as will presently be explained. A drive shaft 3 journaled in the front wall of casing 1 and in end head 2 has fixed for rotation therewith a cylinder barrel 4 having seven equally spaced cylinders 5 formed therein parallel to the axis of shaft 3. Each cylinder 5 has a piston 6 fitted therein and it communicates at its inner end with a cylinder port 7 which extends through the rear end of cylinder barrel 4 and preferably is elongated in the direction of rotation as shown in Fig. 3.

Each piston 6 is connected by a ball and socket joint (not shown) to one end of a connecting rod

8 having the other end thereof connected by a ball and socket joint 9 to a thrust member 10 which is rotatably supported within a tilting box 11 and is fixed for rotation with shaft 3 by a universal joint 12 so that thrust member 10 and cylinder barrel 4 will rotate in unison.

Cylinder barrel 4 is adapted to be rotated only in a clockwise direction in respect to Fig. 3 as indicated by the arrow on that figure, and in order that the pump may be capable of discharging liquid in either of two opposite directions and at selected rates in each direction, box 11 is supported at opposite sides thereof upon two trunnions (not shown) which are fixed in opposite sides of casing 1, and it is adapted to be tilted upon those trunnions by a stroke changing mechanism 13.

The arrangement is such that, when thrust member 10 is vertical, the pump will be at zero stroke so that no liquid will be discharged thereby and, when thrust member 10 is tilted in one direction or the other, the pump will discharge liquid in a direction and at a rate determined by the direction and the degree that thrust member 10 is tilted from its vertical position.

The rear end of cylinder barrel 4 engages the front or valve face 2a on end head 2 and the contacting surfaces thereof are made flat and smooth. Two arcuate valve ports 14 and 15 (Figs. 2 and 3) are formed in the valve face 2a of end head 2 and communicate, respectively, through two passages 16 and 17 (Fig. 2) with two pipes 18 and 19 which form parts of the two sides of a hydraulic circuit. Ports 14 and 15 are formed upon the same radius as cylinder ports 7 so that the cylinder ports will register successively with a valve port and each cylinder port will register with the two valve ports alternately during rotation of cylinder barrel 4. The front portion of end head 2 containing ports 14 and 15 thus constitutes a valve for controlling the flow of liquid to and from cylinders 5.

When thrust member 10 is inclined in the direction shown in Fig. 1 and cylinder barrel 4 is rotated in the direction of the arrow shown in Fig. 3, thrust member 10 will pull the upward moving pistons outward and will force the downward moving pistons inward. The upward and outward moving pistons will draw liquid into their cylinders from port 14 until they reach the dead center position on the vertical centerline of the pump and the downward and inward moving pistons will eject liquid from their cylinders into port 15 until they reach the dead center position on the vertical centerline of the pump. If thrust member 10 is then inclined in the opposite direction, the downward moving pistons will draw liquid into their cylinders from port 15 and the upward moving pistons will eject liquid from their cylinders into port 14. Each of ports 14 and 15 may thus function either as an inlet port or a discharge port.

The pump as thus far described is substantially the same as the pump shown in Patent No. 1,020,285 but in the patented pump the valve ports are spaced apart a distance equal to or only slightly greater than the length of a cylinder port while in a pump embodying the invention, the valve ports are spaced farther apart.

When a pump is performing useful work, it creates a high pressure in the discharge port and in the cylinders in communication therewith but the cylinders in communication with the inlet ports contain liquid under a low or negative pressure and each cylinder as it moves out of communication with the inlet port may not be completely filled with liquid. If the valve ports are spaced apart a distance equal to or only slightly greater than the length of a cylinder port so that a cylinder port opens to the discharge port as soon as it moves out of communication with the inlet port as is the case in conventional pumps, the high pressure in the discharge port will cause liquid to rush therefrom into the cylinder to fill any void and to compress the liquid and gas therein to the pressure prevailing in the discharge port, thereby causing a sudden shock and a resultant noise.

In a pump embodying the present invention, a cylinder does not open to the discharge port until the piston in that cylinder has compressed the liquid and gas therein to a pressure which is approximately the same as the pressure in the discharge port. If the pressure in a cylinder as it moves out of communication with the inlet port were always the same, if the pump stroke were constant and if the cylinder were always completely filled with liquid, the valve ports could be spaced apart such a distance that at the time the cylinder opened to the discharge port the pistons in that cylinder would have compressed the liquid therein to a pressure approximately the same as the pressure in the discharge port. However, the pressure and the volume of fluid in a cylinder at the instant that it moves out of communication with the inlet port both vary widely under different operating conditions and the amount of air or gas therein is variable and unknown. Therefore, in order to compensate for such varying conditions, each cylinder which has just moved out of communication with the inlet port is connected to the discharge port through a check valve which opens only after the pressure in the cylinder has been raised by the instroke of the piston until it is approximately the same as the pressure in the discharge port.

As shown, the upper end of port 14 and the lower end of port 15 are each spaced from the adjacent dead center position a distance equal to or only slightly greater than one-half of the length of a cylinder port 7 the same as in the prior pumps but the upper end of port 15 and the lower end of port 14 are spaced at such a distance from the adjacent dead center position that, when a cylinder moves from a dead center position toward the adjacent port, the piston in that cylinder will be forced inward far enough to compress the fluid in that cylinder to a pressure at least as high as the pressure in that port before the cylinder opens to that port, and each cylinder is connected through a check valve 22 to the cylinder immediately preceding it so that, when the pressure in a cylinder passing from the inlet port to the discharge port becomes high enough, liquid will flow through the check valve 22 and through the preceding cylinder into the discharge port. A check valve 22 is arranged in cylinder barrel 4 between each two adjacent cylinders 5 and the several check valves are arranged in a circle which is larger than the cylinder circle.

If check valves 22 were of an ordinary type, liquid could flow through a check valve from the discharge port into the inlet port during each time that one cylinder was open to the inlet port and the following cylinder was open to the discharge port as will presently be more fully explained. While two adjacent cylinders communicate simultaneously with the two valve ports for

only a very brief interval (such as one four-hundredths of a second) so that only a very limited volume of liquid could flow through a check valve from the discharge port to the inlet port, it is desirable to prevent any such flow. Therefore, limited capacity check valves are employed. That is, each check valve 22 will open in response to liquid attempting to flow therethrough at a limited rate but will close in response to liquid attempting to flow therethrough at a higher rate.

Check valve 22 is not per se a part of the present invention but is one of the check valves described and claimed in application Serial No. 182,623 filed September 1, 1950, now Patent No. 2,633,447.

As shown in Fig. 4, each check valve 22 includes a sleeve 23 which is closely fitted in a bore 24 which extends inward from the front end of cylinder barrel 4 and has the inner end portion thereof reduced in diameter. Sleeve 23 has a valve plunger 25 slidably fitted in the bore 23a thereof and normally having the inner end thereof in engagement with an annular valve seat 26 which is arranged in a counterbore 23b at the inner end of sleeve 23. Plunger 25 is urged toward seat 26 by a relatively weak spring 27 arranged between its outer end and a plug 28 which is threaded into the outer end of bore 24 and holds sleeve 23 and valve seat 26 against the shoulder formed by the reduced portion of bore 24.

When the check valves are arranged with the axes thereof parallel to the rotor axis as shown, the valve element of each check valve must be urged toward its seat by a spring which preferably has only enough strength to positively move the valve element against its seat. In some types of pumps however, the springs may be dispensed with and the check valves be arranged radially so that the valve elements thereof are urged toward the valve seats by centrifugal force.

Plunger 25 has an internal passage 29 which extends axially inward from the outer end thereof and then extends radially through the side wall of the plunger at a point spaced from the inner end thereof. When the check valve is opened, passage 29 provides communication between the reduced inner end of bore 24 and an annular groove or port 30 which is formed in the inner wall of sleeve 23 and so located that it will be closed by plunger 25 if plunger 25 lifts a predetermined distance from seat 26.

The arrangement is such that, when the pressure in the inner end of bore 24 exceeds the pressure in port 30 by an amount determined by the resistance of spring 27, plunger 25 will lift a short distance from its seat and permit liquid to flow from the inner end of bore 24 through valve seat 26, sleeve 23 and passage 29 into port 30 at any rate within the capacity of the valve but, if the liquid tries to flow through the valve at a rate in excess of the capacity thereof, plunger 25 will be lifted farther from its seat 26 and will close port 30, as shown in Fig. 9, and thereby prevent flow of liquid through the valve.

Each check valve 22 has its inlet connected to the discharge end of a cylinder 5 and its outlet connected to a passage which communicates with a valve port when that cylinder 5 moves out of communication with the other valve port. As shown, the discharge end of each cylinder 5 is connected through a passage 31 (Figs. 3–5) with the inner end of the bore 24 containing the check

valve 22 which immediately precedes that cylinder 5 in respect to the direction of rotation of cylinder barrel 4, and the port 30 of that check valve 22 is connected through a passage 32 and a passage 33 to the discharge end of the cylinder 5 which immediately precedes that check valve 22 in respect to the direction of rotation of cylinder barrel 4. Each cylinder 5 is thus connected to the two adjacent check valves 22 and each check valve 22 is connected to the two adjacent cylinders 5.

When cylinder barrel 4 is rotated in the direction of the arrow on Fig. 3 and the pump is discharging liquid under pressure through valve port 15, the cylinder 5 at the upper dead center position (which has been designated as cylinder A in Fig. 3) will contain liquid at a low or negative pressure and the next preceding cylinder (which has been designated as cylinder B in Fig. 3) will contain liquid at a high pressure. The pressure in cylinder B will extend therefrom through passages 33 and 32 and port 30 into the upper part of the sleeve 23 of the adjacent check valve 22 (which has been designated as valve C) and will assist spring 27 in holding the plunger 25 of valve C against its seat 26.

As cylinder A moves in the direction of the arrow, the piston 6 in cylinder A will be forced inward by thrust member 10 and will compress the liquid in cylinder A until it creates therein a pressure which exceeds the pressure in discharge port 15 by an amount slightly in excess of the force exerted by light spring 27 and which extends through passage 31 and valve seat 26 and acts upon the inner end of plunger 25 of valve C. Then the pressure acting upon plunger 25 will raise it from seat 26 and the inward moving piston will expel liquid from cylinder A through passage 31, check valve C and passages 32 and 33 and cylinder B into discharge port 15 until cylinder A opens to port 15. Since the pressure in cylinder A is approximately the same as the pressure in discharge port 15, there is no sudden compression of the liquid in cylinder A and, consequently, no resultant shock and noise such as occurs in conventional pumps. As soon as cylinder A opens to port 15, the piston in cylinder A can eject liquid therefrom through its port 7 directly into port 15 and the pressure at the inlet of check valve C becomes the same as the pressure at the outlet thereof, thereby permitting valve C to be closed by its spring 27. Each of check valves 22 will function in the above described manner as the cylinder 5 associated therewith passes from the inlet port to the discharge port.

After each cylinder 5 has passed a short distance beyond lower dead center position as indicated by the cylinder which has been designated as cylinder D in Fig. 3, its port 7 opens to inlet port 14 and thereby reduces the pressure at the outlet of the following check valve 22 which has been designated in Fig. 3 as valve E. At that time, the following cylinder 5, which has been designated in Fig. 3 as cylinder F, is still open to discharge port 15 so that the inlet of valve E is subjected to the discharge pressure.

Dropping the pressure in cylinder D permits the high pressure in cylinder F to raise the plunger 25 of check valve E from its seat. If the check valve were of the ordinary type which opens and remains open in response to a predetermined drop in pressure thereacross, liquid could flow therethrough from discharge port 15 into inlet port 14 until the port 7 of cylinder F moved out of registry with port 15 and this would occur each time a

cylinder passed across lower dead center. Each check valve 22 has ample capacity to pass the relatively small volume of liquid which is ejected from a cylinder 5 as the cylinder passes from its upper end center position to the position in which its port 7 opens to discharge port 15 but it is obvious that all of the liquid discharged by the pump into port 15 at any given instant could not flow through a check valve 22. Consequently, when the port 7 of cylinder D opens to inlet port 14, the pressure therein is suddenly reduced to a low or negative value and the large volume of high pressure liquid in discharge port 15 tries to flow through check valve E but, since it cannot do so, it raises the plunger 25 of valve E high enough to cause it to block port 30, as shown in Fig. 9, thereby preventing flow of liquid from port 15 to port 14. As soon as cylinder F opens to port 14, the pressure at opposite ends of check valve E are equalized and valve E is closed by its spring 27. All of the check valves 22 function in the same manner as the cylinders associated therewith pass across lower dead center.

When the pump is operating normally, the portion of bore 23a containing spring 27 will be filled with liquid which will stop further movement of plunger 25 immediately after it has closed port 30. Under certain temporary conditions however, the spring portion of bore 23a may contain some air or gas which might permit plunger 25 to be moved too far from seat 26, whereupon spring 27 might not be able to return it against seat 26 before the cylinder associated with the check valve reached upper dead center. Therefore, the movement of plunger 25 away from valve seat 26 is limited by a suitable stop. For example, spring 27 may be so designed that it goes solid and prevents further movement of plunger 25, as shown in Fig. 9, as soon as the upper end of plunger 25 passes the upper edge of port 30.

When thrust member 10 is tilted in a direction opposite to that shown in Fig. 1, the pump will discharge liquid in opposite direction, port 14 will be the discharge port and port 15 will be the inlet port but check valves 22 will function in the above described manner. That is, the check valves will permit liquid to flow therethrough from the cylinders into the discharge port as the cylinders pass from the inlet port to the discharge port and they will prevent flow of liquid from the discharge port into the inlet port as the cylinders pass from the discharge port to the inlet port.

In a prior pump of this type, each cylinder is open to the inlet port during nearly a full half-revolution of the cylinder barrel. If a pump embodying the invention is unidirectional, the lower end of inlet port 14 is spaced from the vertical centerline of the pump a distance equal to or only slightly greater than one-half of the length of a cylinder port 7 so that each cylinder is open to the inlet port during nearly a full half-revolution of the cylinder barrel the same as in the prior pumps but, if the pump is reversible as shown, the lower end of port 14 is spaced from the vertical centerline of the pump the same distance that the upper end of port 15 is spaced from the vertical centerline in order that the pump may be reversed as explained above. Therefore, the time during which a cylinder is open to the inlet port is considerably less than in the prior pumps and, if the pistons must draw liquid into their cylinders from a reservoir arranged below the cylinder barrel, each piston might not be able to completely fill its cylinder with liquid during the time its cylinder was open to the inlet port.

If the pump is reversible as shown, it is provided with two auxiliary ports 14a and 15a (Figs. 3 and 6) which extend through valve face 2a and are adapted to be connected, respectively, to ports 14 and 15 under the control of an automatic valve 34 (Figs. 1 and 6). Ports 14a and 15a are arranged upon the same radius as ports 14 and 15 and each is so located that the distance between the vertical centerline of the pump and the adjacent edge of the auxiliary port is equal to or only slightly greater than one-half the length of a cylinder port so that a cylinder port will open to an auxiliary port immediately after it moves out of registry with the preceding port 14 or 15.

As best shown in Fig. 6, valve 34 is fitted in a bore 35 which extends through end head 2 and has its ends closed by two plugs 35a. Bore 35 has four annular grooves or ports 36, 37, 38 and 39 formed in the wall thereof. Port 36 is connected to auxiliary port 15a by a channel 40, as shown in Figs. 6 and 7, and port 39 is similarly connected to auxiliary port 14a by a channel 41. Port 37 is connected through a channel 42 to a channel 43 which opens into main port 15, as shown in Figs. 6 and 8, and port 38 is similarly connected through two channels 44 and 45 to main port 14. Valve 34 has two cannelures 46 and 47 formed in the peripheral surface thereof to provide communication between ports 36 and 37 or between ports 38 and 39. Cannelure 46 communicates with a passage 48 which extends radially therefrom into valve 34 and then extends axially outward through the adjacent end of the valve. Cannelure 47 communicates with a passage 49 which extends radially therefrom into valve 34 and then extends axially outward through the adjacent end of the valve.

The arrangement is such that, when the pump is discharging into port 15, pressure therefrom extends through passages 43 and 42, port 37, cannelure 46 and passage 48 to the upper end of bore 35 and, if valve 34 is in its upper position, the pressure moves it downward to the position shown in which position it blocks port 36 so that no liquid can escape through auxiliary port 15a. Then as soon as the port 7 of a cylinder 5 opens to auxiliary port 14a, the piston in that cylinder can draw liquid into the cylinder through auxiliary port 14a, passage 41, port 39, cannelure 47 and passages 44 and 45 from main port 14.

When thrust member 10 is tilted in the opposite direction and causes the pump to discharge into port 14, pressure from port 14 will extend through passages 45 and 44, port 38, cannelure 47 and passage 49 to the lower end of bore 35 and move valve 34 to its upper position in which position it blocks port 39 so that no liquid can escape through auxiliary port 14a. Then as soon as the port 7 of a cylinder 5 opens to auxiliary port 15a, the piston in that cylinder can draw liquid into the cylinder through auxiliary port 15a, passage 40, port 36, cannelure 46 and passages 42 and 43 from main port 15. Thus in either direction of pump delivery the angular distance through which liquid can be drawn into a cylinder is just as great as in the prior pumps.

The invention herein set forth is susceptible of various modifications and is adaptable to various other types of pumps without departing from the scope of the invention which is hereby claimed as follows:

1. In a pump having a rotor provided with a plurality of pistons and cylinders and a cylinder port leading from each cylinder, means for rotating said rotor, and piston reciprocating means

for causing the pistons on one side of a central longitudinal plane of said pump to move progressively inward and the pistons on the other side of said plane to move progressively outward during rotation of said rotor, the combination of a main valve cooperating with said cylinder ports to control the flow of liquid to and from said cylinders and having formed therein upon opposite sides of said plane an arcuate inlet port and an arcuate discharge port with which each cylinder port communicates alternately during rotation of said rotor, the leading end of said discharge port in respect to the direction of rotation of said rotor being spaced from said central plane a distance greater than one half the angular length of a cylinder port so that the port of a cylinder after it passes beyond said central plane toward the discharge port will not open to the discharge port until after the piston in that cylinder has moved inward far enough to eject a limited volume of liquid from that cylinder, and a plurality of limited capacity check valves arranged in said rotor, each of said check valves having an inlet connected to one cylinder and an outlet connected to the cylinder next preceding said one cylinder in the direction of rotation of said rotor and a plunger having one end thereof normally closing said inlet and the other end thereof adapted to close said outlet only after said plunger has been moved a substantial distance from its normal position so that as said one cylinder passes beyond said central plane toward the discharge port the limited volume of liquid ejected from said one cylinder by the inward moving piston therein will move said plunger far enough from its normal position to permit said limited volume of liquid to flow through said check valve into said preceding cylinder and when said preceding cylinder opens to the inlet port the resultant sudden rush of liquid into said inlet will cause said plunger to move far enough to close said outlet and prevent flow of liquid through the check valve from the discharge port into the inlet port.

2. In a pump having a rotor provided with a plurality of pistons and cylinders and a cylinder port leading from each cylinder, means for rotating said rotor, piston reciprocating means for causing the pistons on one side of a central longitudinal plane of said pump to move progressively inward and the pistons on the other side of said plane to move progressively outward during rotation of said rotor, and means for adjusting said piston reciprocating means to reverse the movements of said pistons and thereby reverse the direction of pump delivery, the combination of a main valve cooperating with said cylinder ports to control the flow of liquid to and from said cylinders and having formed therein upon opposite sides of said plane two arcuate main ports with which each cylinder port communicates alternately during rotation of said rotor and either of which may function either as an inlet port or as a discharge port depending upon the adjustment of said piston reciprocating means, the leading end of each of said main ports in respect to the direction of rotation of said rotor being spaced from said central plane a distance greater than one half the length of a cylinder port so that the port of a cylinder

after it passes beyond said central plane toward the discharge port will not open to the discharge port until after the piston in that cylinder has moved inward far enough to eject a limited volume of liquid from that cylinder, a plurality of limited capacity check valves arranged in said rotor, each of said check valves having an inlet connected to one cylinder and an outlet connected to the cylinder next preceding said one cylinder in the direction of rotation of said rotor and a plunger having one end thereof normally closing said inlet and the other end thereof adapted to close said outlet only after said plunger has been moved a substantial distance from its normal position so that as said one cylinder passes beyond said central plane toward the discharge port the limited volume of liquid ejected from said one cylinder by the inward moving piston therein will move said plunger far enough from its normal position to permit said limited volume of liquid to flow through said check valve into said preceding cylinder and when said preceding cylinder opens to the inlet port the resultant sudden rush of liquid into said inlet will cause said plunger to move far enough to close said outlet and prevent flow of liquid through the check valve from the discharge port into the inlet port, and means for supplying liquid to each cylinder port after it moves out of communication with the discharge port and before it opens to the inlet port.

3. The combination set forth in claim 2 in which the last mentioned means includes an auxiliary port formed in said main valve between the leading end of each of said main ports and said central plane, channel means for connecting each auxiliary port to the adjacent main port, and means arranged in said channel means for blocking communication between the discharge port and the adjacent auxiliary port.

4. The combination set forth in claim 2 in which the last mentioned means includes an auxiliary port formed in said main valve between the leading end of each of said main ports and said central plane, a valve bore, separate channels connecting said valve bore to each of said main ports and to each of said auxiliary ports, and a shuttle valve arranged in said bore to control communication between said channels and having a passage extending into it from each of its ends and communicating with the adjacent channel leading to a main port so that pressure in one main port can extend through the channel leading therefrom and through the passage in the adjacent end of said shuttle valve and shift said valve to a position in which it blocks communication between the main port containing pressure and the adjacent auxiliary port.

WALTER FERRIS.

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