

[54] **HYDRAULICALLY POWERED POWER UNIT**

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[51] Int. Cl.**F15b 11/00, F15b 13/00, F04b 17/00, F04b 35/00**
[58] Field of Search.....**417/246, 346, 318, 382, 900; 91/411 R, 411 D, 411 B**

References Cited

UNITED STATES PATENTS
3,426,650 2/1969 Jenney**91/411 R**
3,505,929 4/1970 Coppola et al.**91/411 R X**

Primary Examiner—Robert M. Walker
Attorney—Burns, Doane, Swecker & Mathis

[57] **ABSTRACT**

An hydraulically powered multiplex pump having at least three pumping units, each operable in a cycle including suction, precompression and discharge phases, with the cycles being out of phase with one another, whereby simultaneous performance of these functions results in a substantially constant pressure and flow of both the pumped fluid and the power fluid. Separate power and cycle control circuits, which may employ different fluids, are provided. Control valve assemblies, each including two sleeve valves communicating with a common chamber, are operated by the control circuit fluid to condition power circuit flow for the various phases of the pumping cycle. The power end of the pumping units includes power cylinders which may be fluid interconnected at their rod ends so that operations in each power cylinder affect functions in the other chambers, and provision is made for automatic correction of errors in stroke length.

18 Claims, 18 Drawing Figures

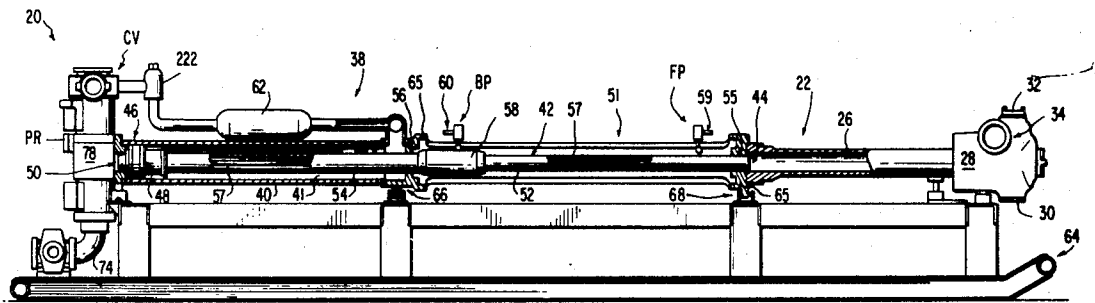


FIG. 1

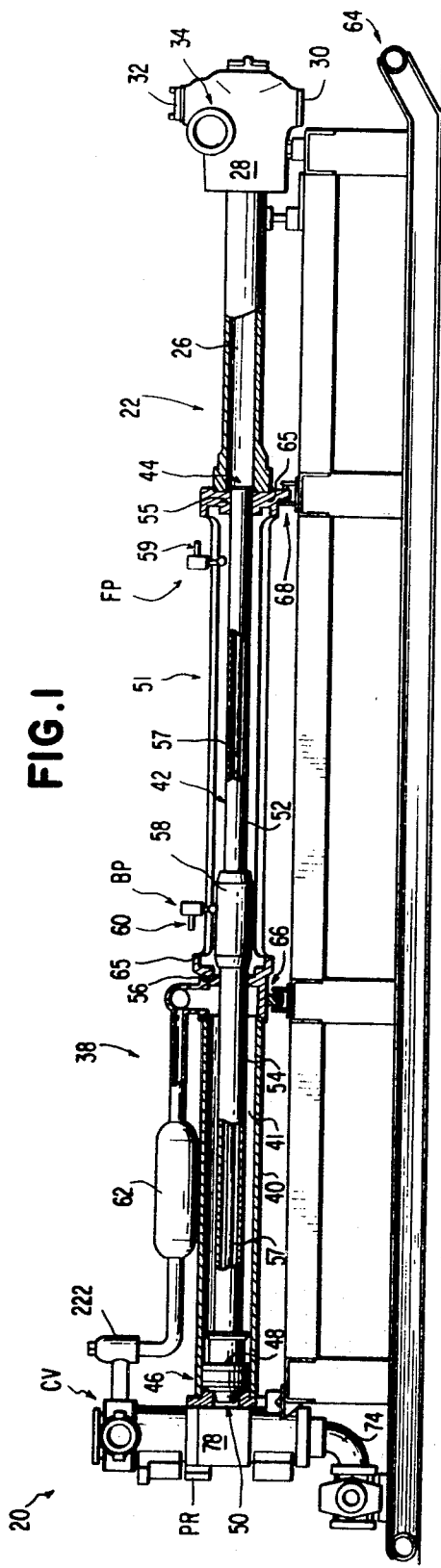
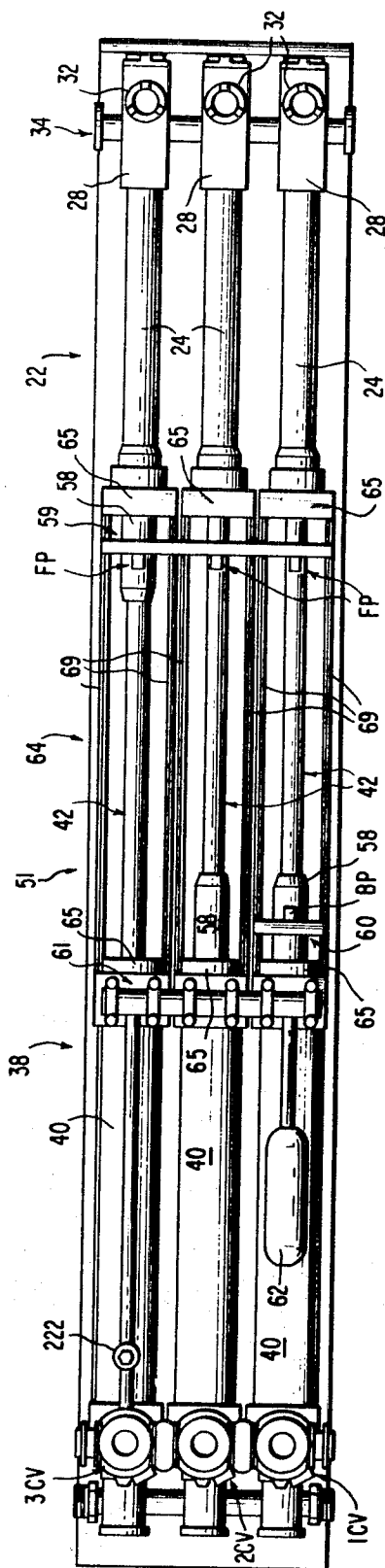


FIG. 2



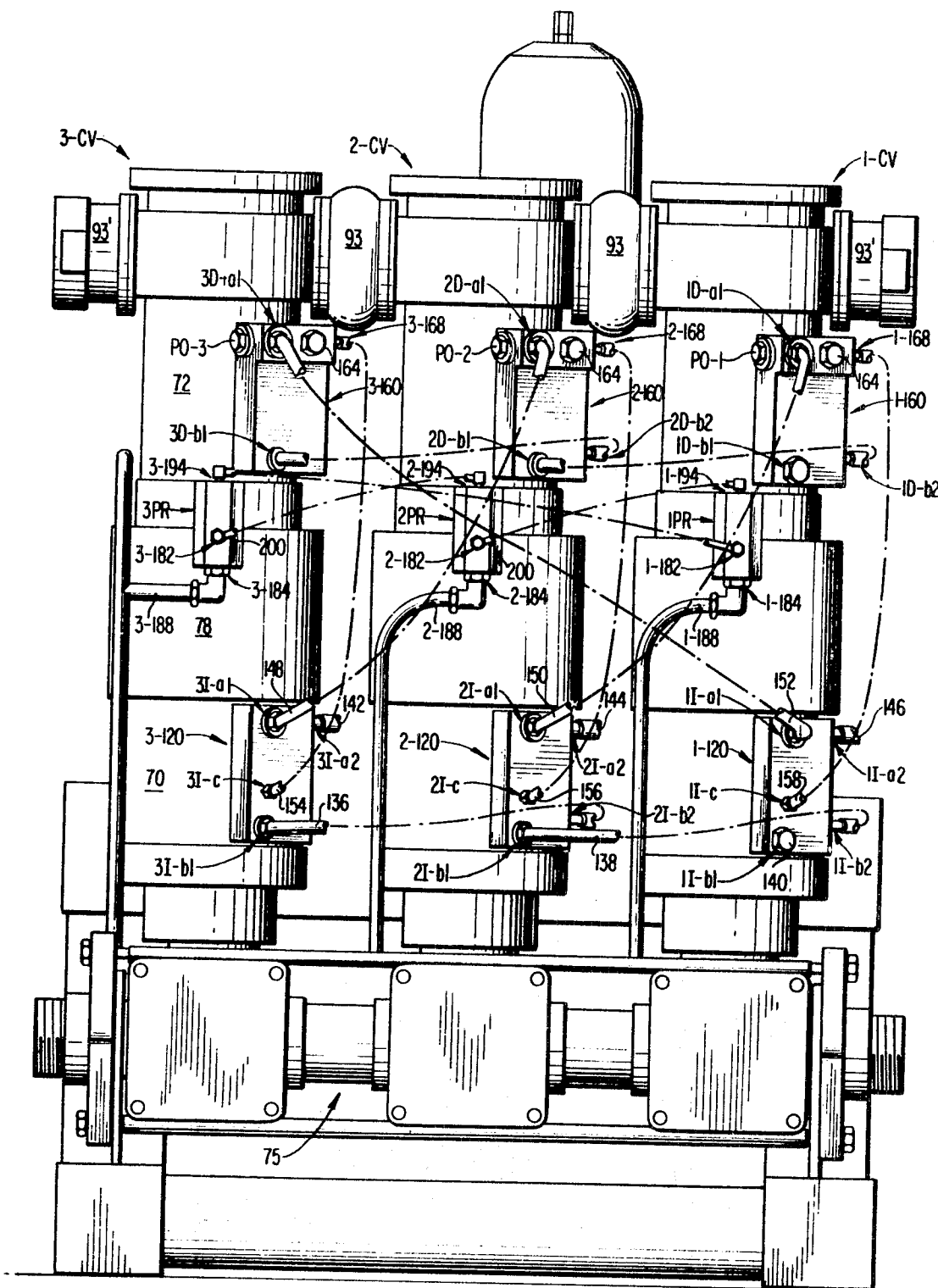


FIG. 3

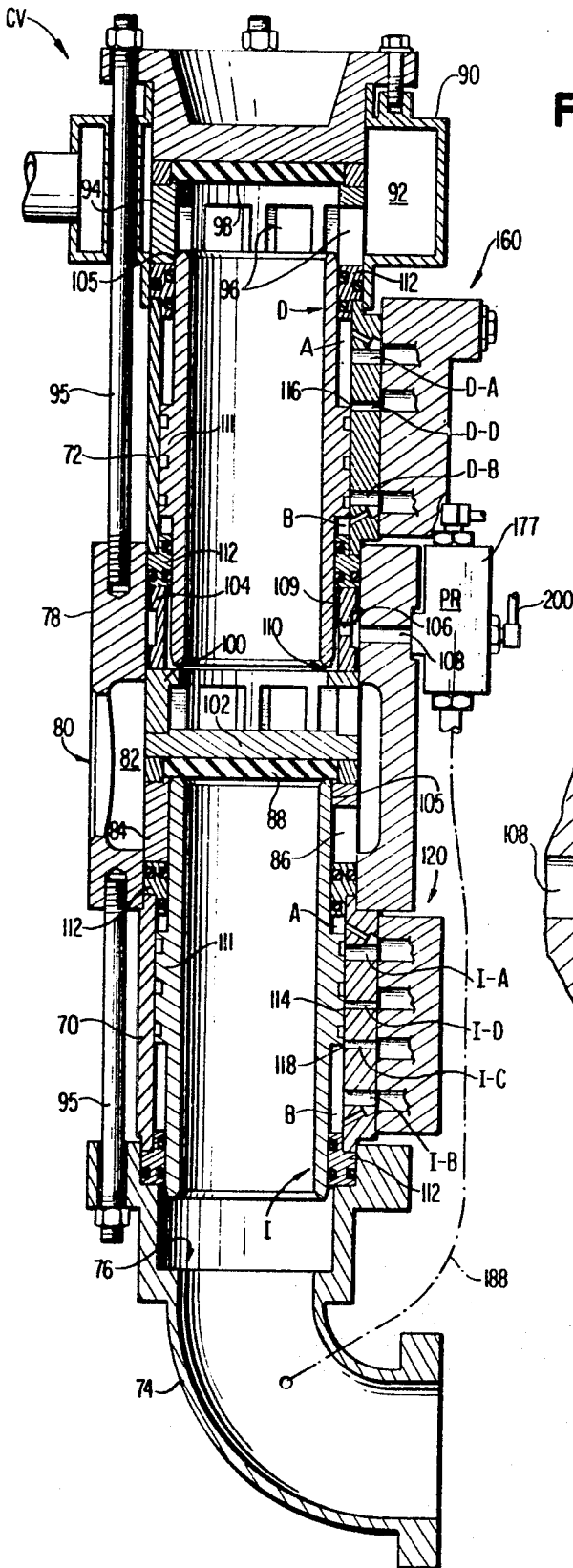


FIG. 4

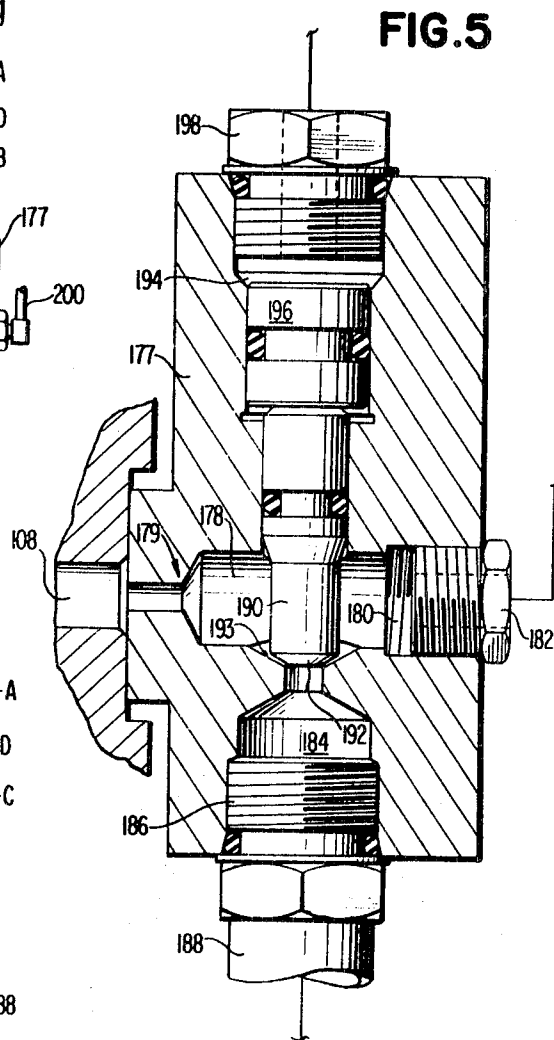
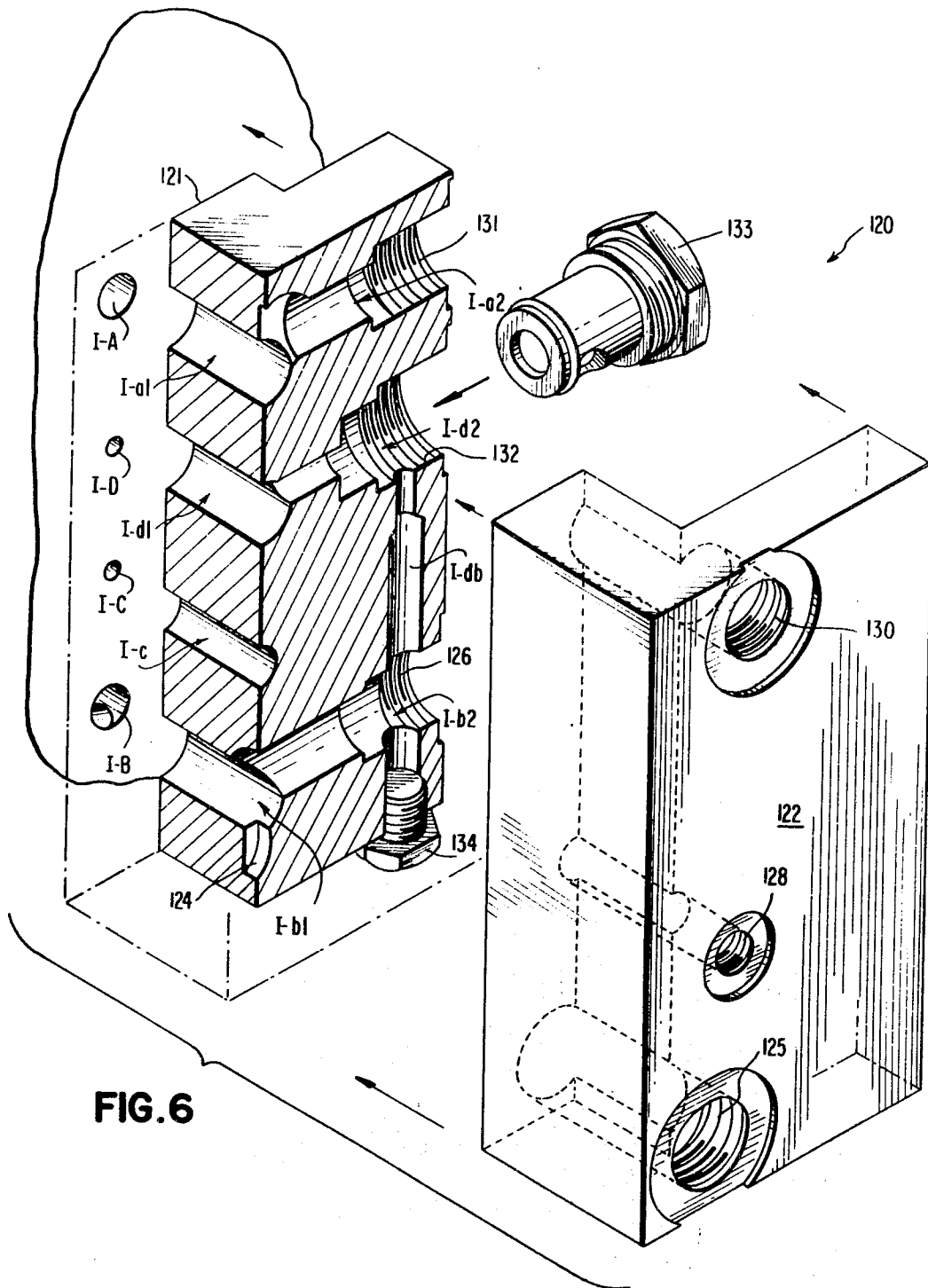
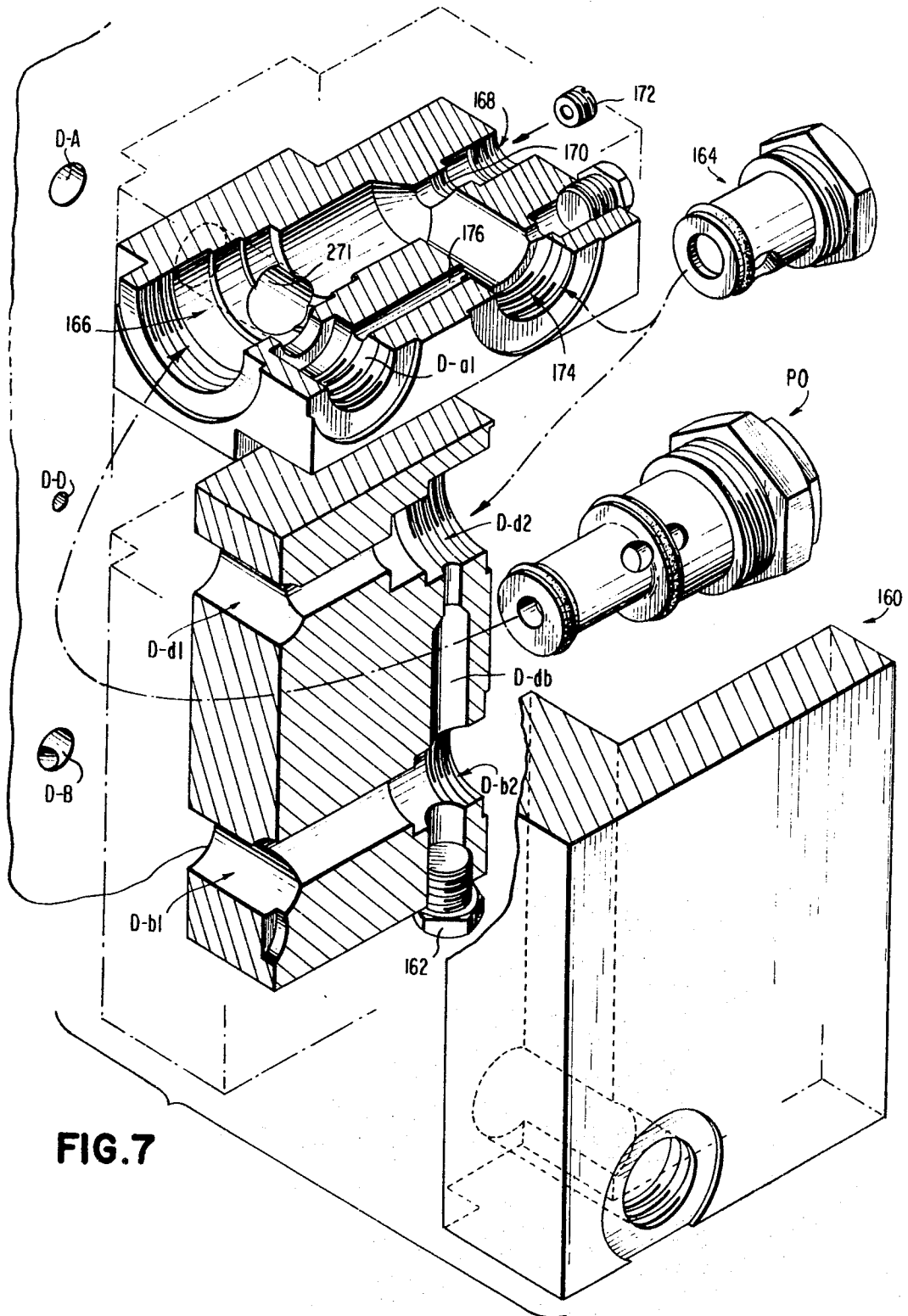


FIG. 5





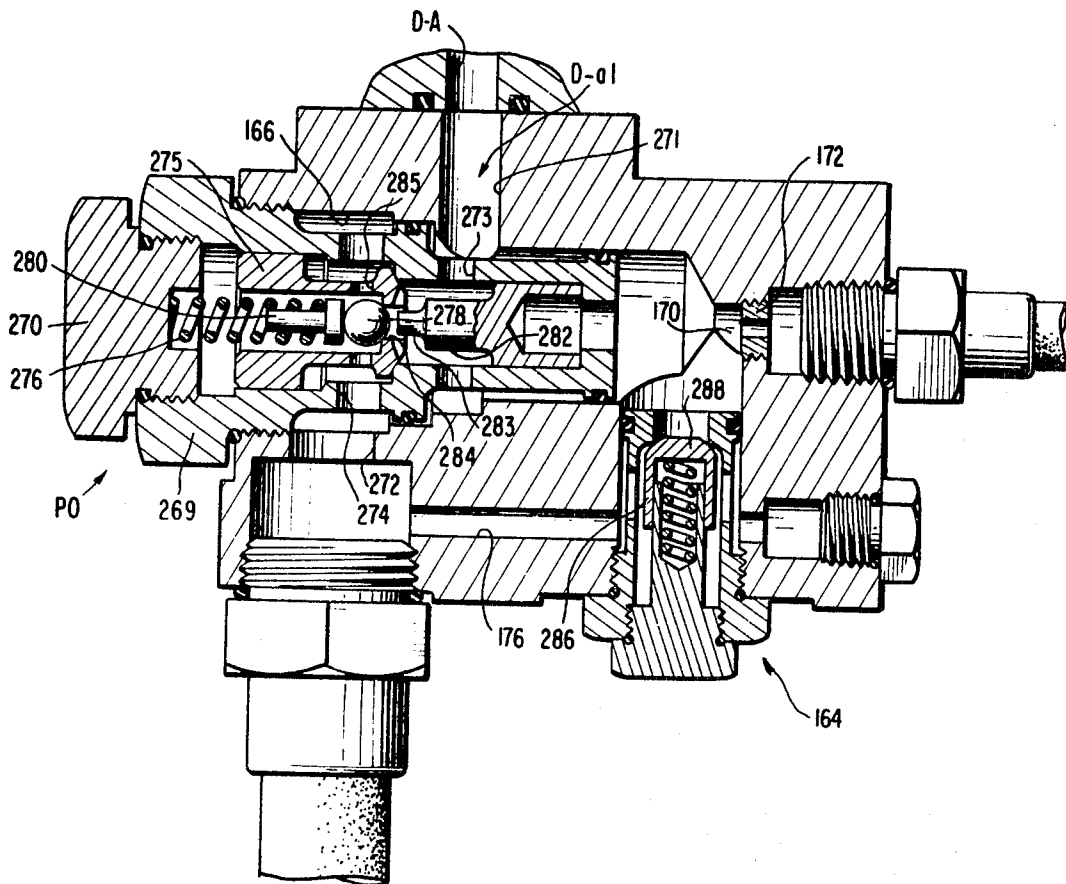
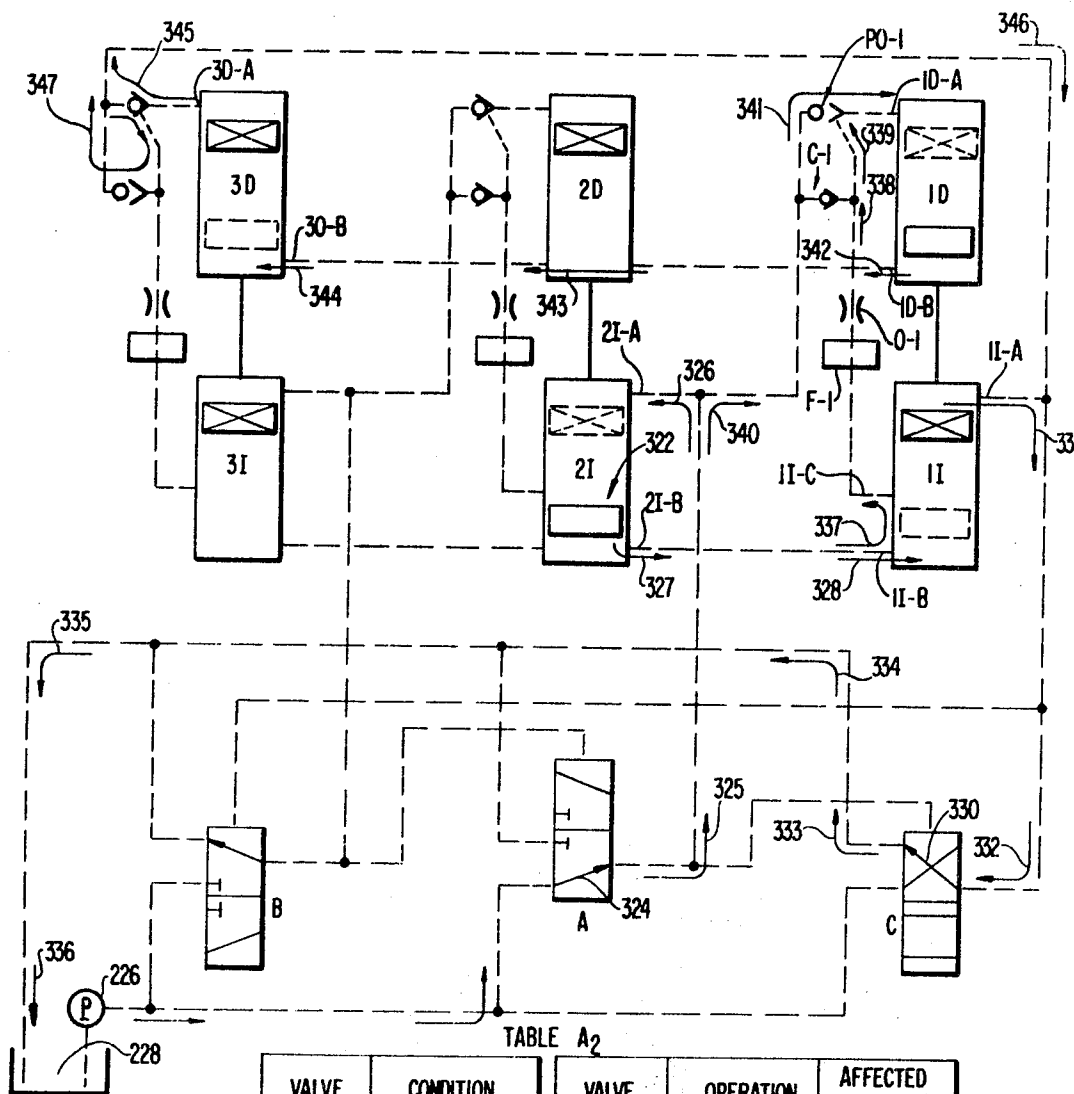


FIG. 7A

FIG. 9A2



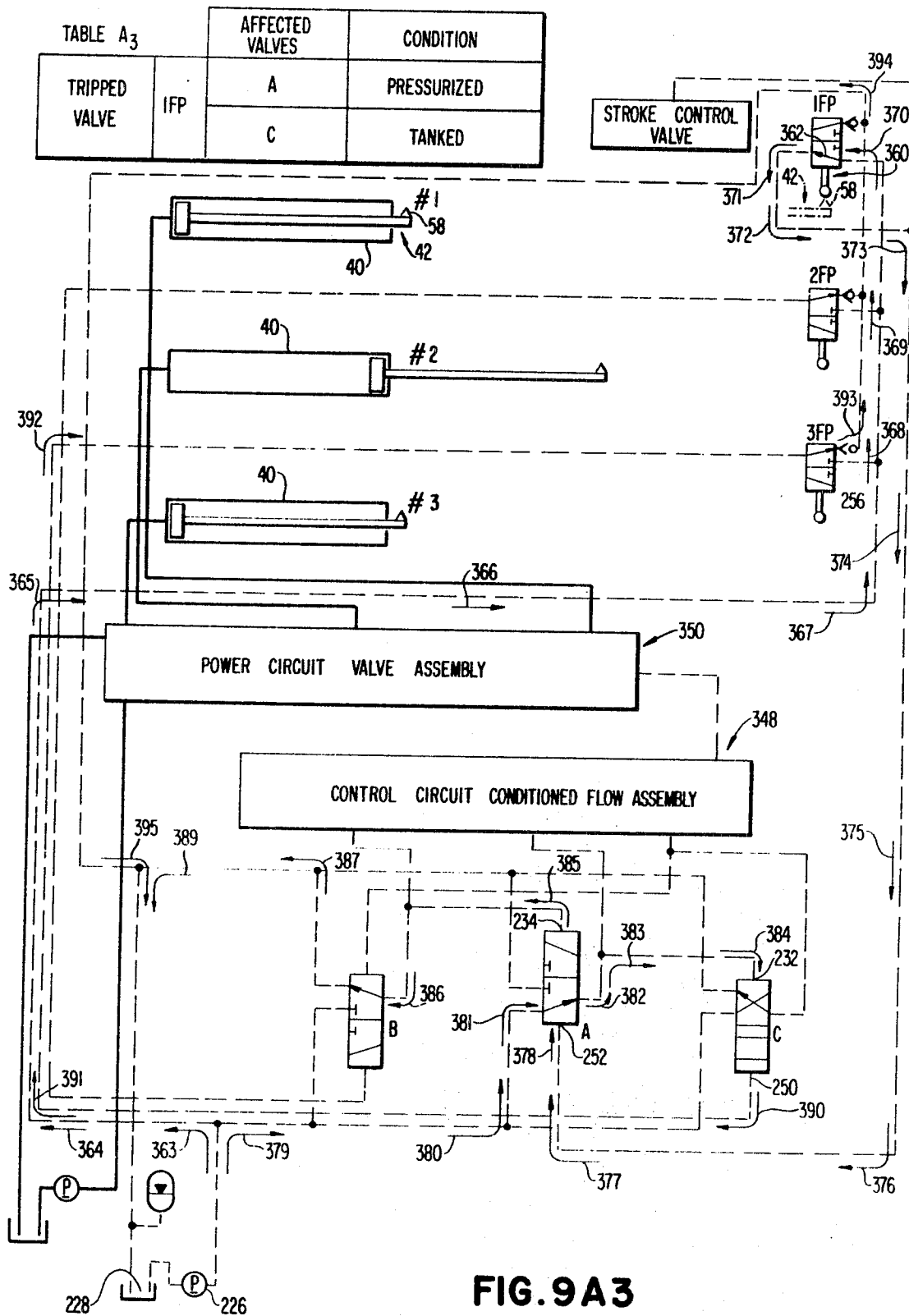


FIG. 9A3

TABLE B1

VALVE	CONDI- TION	CYL- INDER	FUNC- TION
1I	C	# 1	PRE- COMPRESSION
1D	C		
1PR	O		
2I	C	# 2	SUCTION
2D	O		
2PR	C		
3I	O	# 3	DISCHARGE
3D	C		
3PR	C		

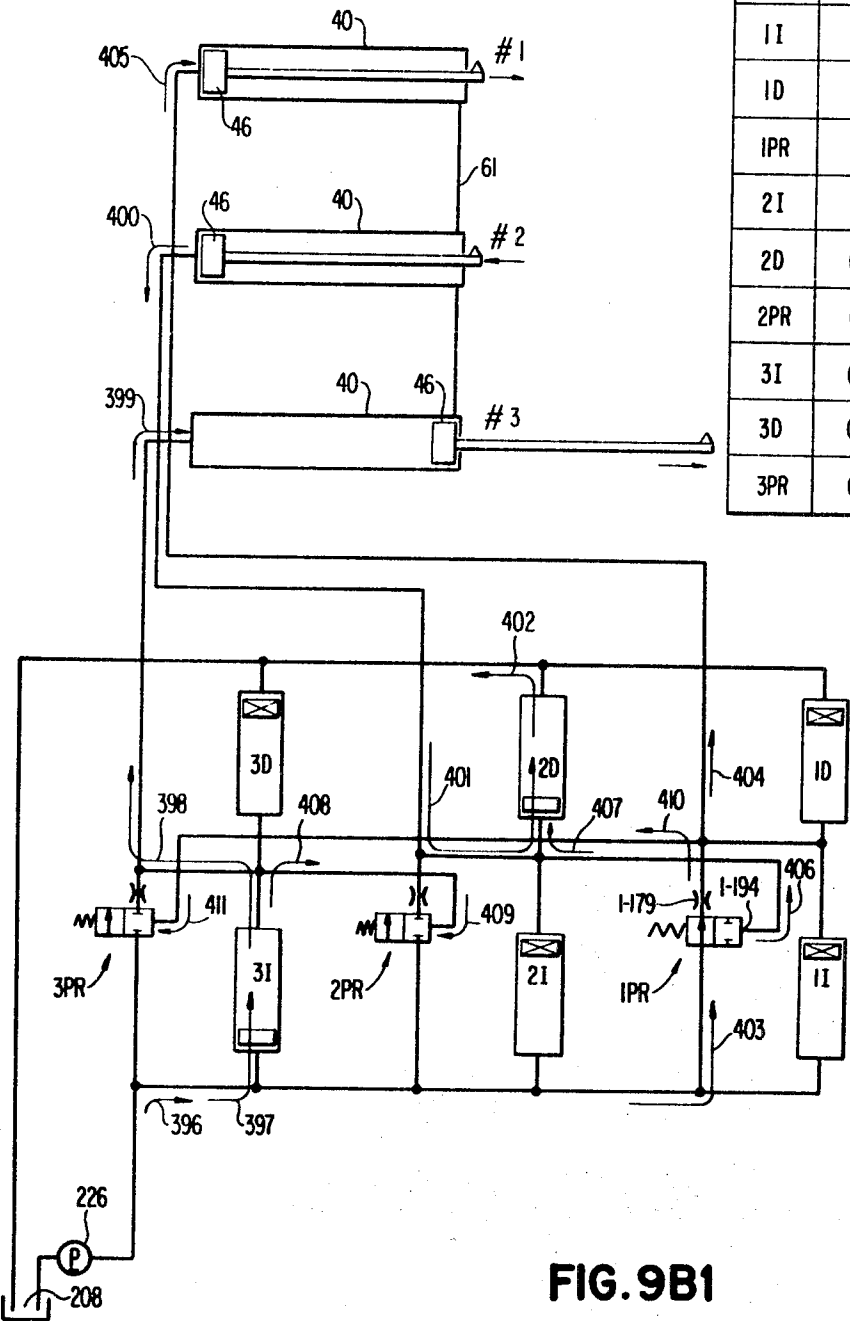


FIG. 9 B2

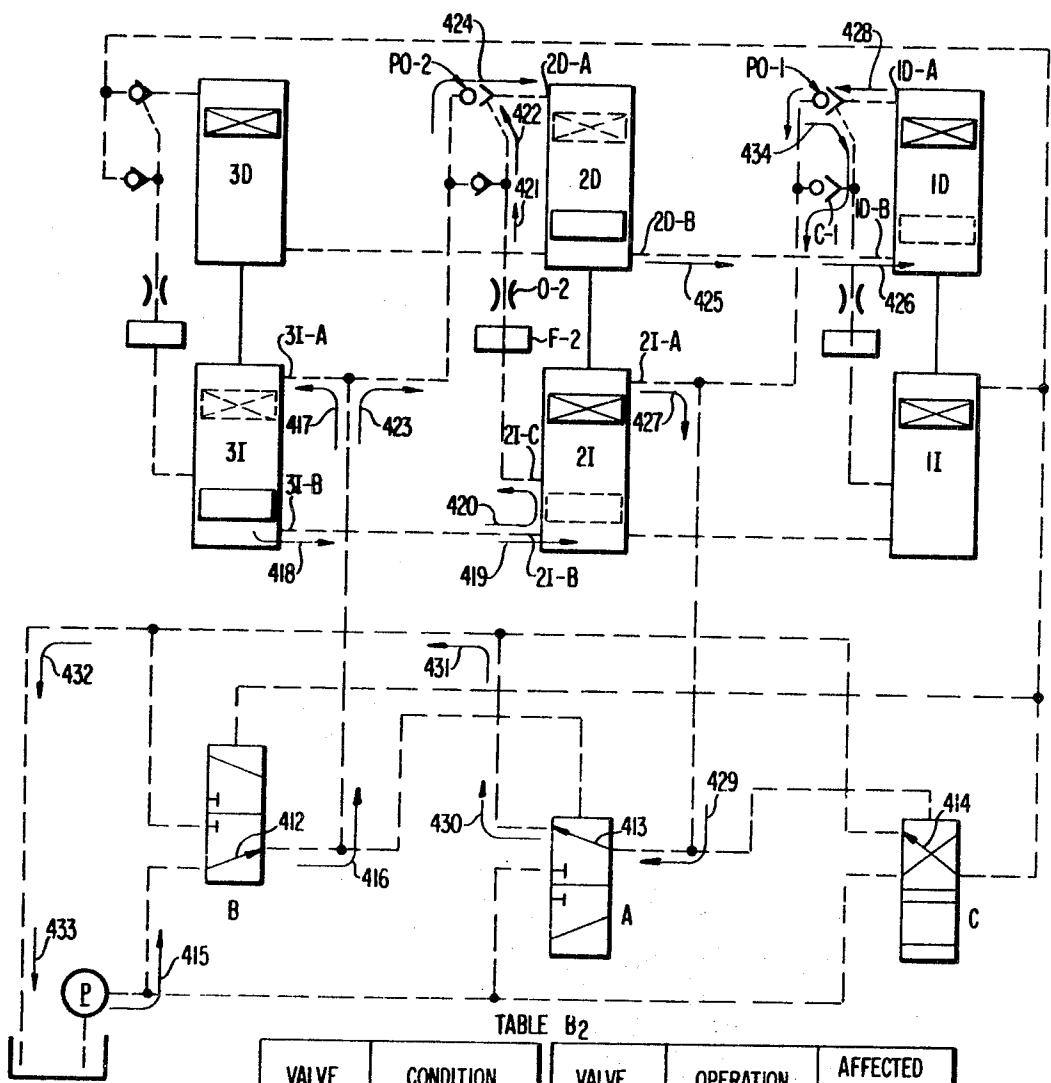


TABLE B2

VALVE	CONDITION	VALVE	OPERATION	AFFECTED VALVES
B	PRESSURIZED	3I	OPENED	2I
A	TANKED	2I	CLOSED	2D
C	TANKED	2D	OPENED	ID & IPR
		ID	CLOSED	NONE

TABLE B ₃		AFFECTED VALVES	CONDITION
TRIPPED VALVE	2FP	B	PRESSURIZED
		A	TANKED

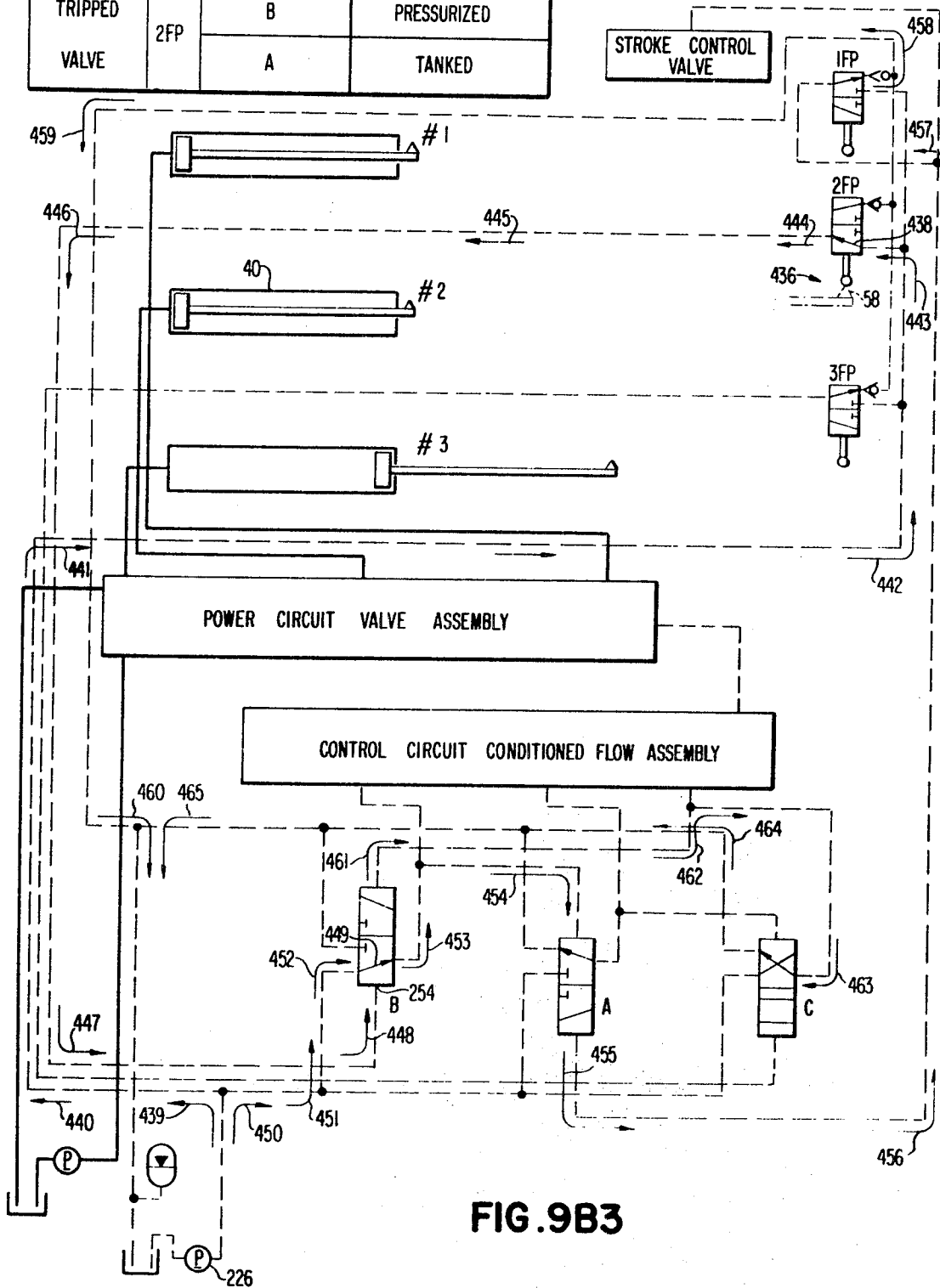


FIG. 9B3

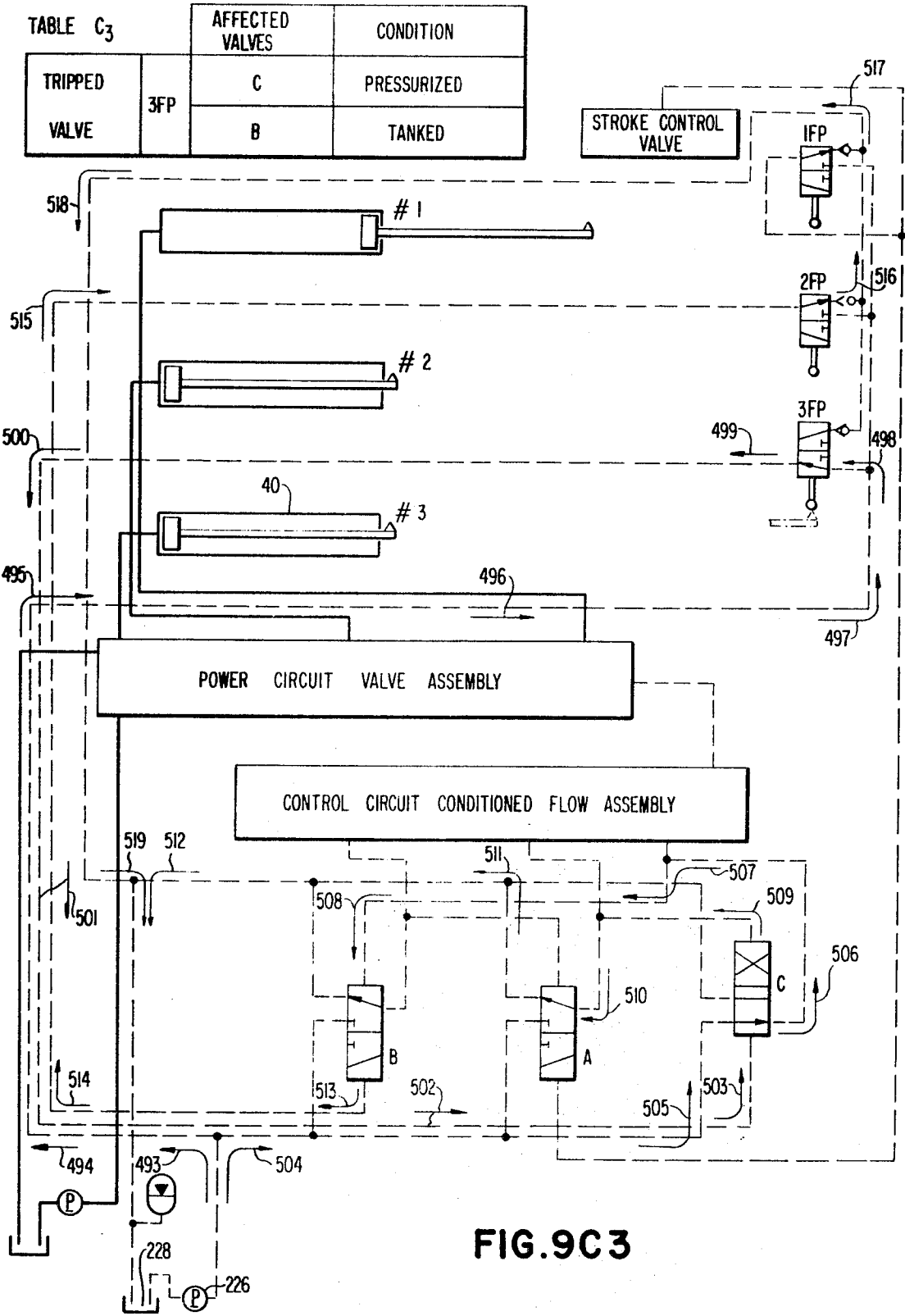


FIG.9C3

HYDRAULICALLY POWERED POWER UNIT

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RELATED APPLICATION

This application is a Division of U.S. Pat. application Ser. No. 886,687 filed Dec. 19, 1969 by Clinton W. Cole for "Hydraulically Powered Pump Having a Precompression Function."

BACKGROUND OF THE INVENTION

This invention relates to pumps of the multiplex type. More particularly, this invention relates to a multiplex pump of the type in which the pumped fluid is precompressed prior to discharge.

In the oil industry it has been common in the past to utilize multiplex pumps designed to deliver pumped fluid at high pressures on the order of 15,000 p.s.i. or greater. It has been found that even the slight compressibility of this relatively incompressible pumped medium may result in a pulsating discharge pressure condition since a portion of the power intended to accomplish the discharge phase of each pumping cycle is inherently utilized to first compress the medium before it is brought to discharge pressure.

This discharge pattern is particularly undesirable where both high pumping pressure levels and very high delivery volumes are involved. The resulting pulsations could, under such conditions, subject the discharge conduits to severe vibrational forces. Thus, the pumping unit would be subject to stress conditions that might cause failure.

It would, therefore, be extremely desirable to provide a pump that is capable of delivery of a high volume of fluid at high pressure levels without being subject to pulsation problems.

To this end the present invention involves the provision of a precompression function in the pump that continuously serves to bring pumped fluid to a pressure approaching discharge pressure prior to actual discharge. Thus, a relatively smooth constant pressure output of the pumped fluid may be obtained.

It has been previously proposed to provide a fluid operated duplex pump (operable on a highly compressible fluid) with a precompression function in order to induce smoother discharge characteristics. This previously proposed pump is fluid operated in such a manner that one pumping unit is conditioned to undergo a discharge function while the other pumping unit undergoes both a suction and precompression function during the same time interval.

Although such a system may be satisfactory for some purposes, it may prove undesirable for a number of reasons.

For example, since all three functions associated with a pumping cycle (i.e. suction, precompression and discharge) are not simultaneously performed, there is an absence of constant pressure flow into the fluid end common to both pumping chambers. Therefore, the suction line or suction header common to the two pumping units is subject to pulsating flow that may have undesirable consequences similar to those in-

tended to be eliminated in connection with the discharge function.

Moreover, the lack of simultaneous performance of all three functions also prevents constant pressure flow of power fluid into and out of pressure and reservoir headers common to the power cylinders constituting the power end of the pumping unit. Thus, pulsation problems may also be created at the power end of the pump.

It would, therefore, be highly desirable to provide a multiplex pump which provides non-pulsating suction flow as well as discharge flow. It would also be desirable to operate such a pump with power fluid that flows into and out of the power end of the pump without pulsation.

Another disadvantage of the previously proposed pump stems from the direct utilization of pressurized power fluid to produce the stroking of the power plungers in each direction and in each cycle phase. Thus, the cycle in each pumping unit is not inherently functionally dependant upon the cycle in the other unit. As a result, a phasing error in one stroke, e.g. overtravel or undertravel of the power plunger during precompression, cannot be corrected without intervention by an operator so that the error may be self perpetuating.

Furthermore, the previously proposed pumping unit does not utilize the power fluid in the rod end of the power cylinder to a most efficient advantage. During discharge and precompression this fluid in the rod end may be exhausted to a power fluid reservoir where the potential power of this fluid, which is pressurized by the rod displacement, is lost.

It would, therefore, be desirable to provide a multiplex pump with a precompression function and a self-regulating stroke control, as well as with efficient utilization of power fluid in the rod end of the power cylinder.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore, a general object of the invention to provide a multiplex pump which obviates or minimizes disadvantages of the sort previously noted.

It is a particular object of the invention to provide an improved multiplex pump having a precompression function.

It is a further object of the invention to provide a multiplex pump which provides non-pulsating suction flow as well as discharge flow.

It is another object of the invention to provide such a multiplex pump which may be fluid operated with constant pressure flow of power fluid into and out of the power end of the pump.

It is a related object of the invention to provide a control valve assembly for such a multiplex pump which establishes constant pressure and flow of power fluid into and out of the power end of the pump.

It is still another object of the invention to provide a multiplex pump having a precompression function and means for automatically regulating the pumping strokes.

It is a related object of the invention to provide a multiplex pump having a precompression function and in which the stroking in each pumping unit is responsive to the stroking in the other units.

It is yet another object of the invention to provide an improved multiplex pump which may be fluid operated by the use of separate power and control circuits.

A preferred embodiment of the invention intended to accomplish at least some of the foregoing objects comprises a multiplex pump having at least three pumping units each operable in a cycle including suction, precompression, and discharge phases, with the cycles of each unit being out of phase with one another. The fluid end of the pump terminates in a common discharge line which is in fluid communication with the discharge end of each pumping unit. Likewise, the suction ends of each of the pumping units are in communication with a common suction line.

Operation of the pump according to the described cycle insures simultaneous performance of all functions associated with a given cycle to the end that constant pressure and flow

of the pumped fluid occurs in the common suction line and in the common discharge line.

Each pumping unit is fluid operated by power fluid acting on a piston rod assembly extending between the fluid end and a power cylinder assembly at the power end of that unit. Each power cylinder assembly is connected through a control valve assembly to a common flow line communication with a source of pressurized power fluid and a second common flow line communicating with a power fluid reservoir. By simultaneous performance of the suction, precompression and discharge phases of the cycle, a substantially constant pressure flow of the power fluid to and from these common flow lines is provided.

The control valve assemblies each include two sleeve valves communicating with a common chamber, which in turn communicates with a power cylinder. When one sleeve valve of a given control valve assembly is in an open position and the other is closed, pressurized power fluid enters the associated power cylinder assembly to provide a discharge function in the fluid end of the associated fluid end cylinder assembly. When the sleeve valves are in a reversed position, a suction function is permitted resulting in discharge of the power fluid in the power cylinder assembly to the power fluid reservoir. During a phase of the cycle when both of these sleeve valves are in closed position, a precompression valve is opened, and power fluid is directed to the power cylinder through this precompression valve.

A separate control circuit is utilized to move the sleeve valves to their desired positions.

The rod ends of the power cylinders are fluid interconnected so that the functions in each pumping unit are performed in response to those performed in the other units. Also, a portion of the power circuit is interrelated with the control circuit to provide for self-correction of the stroke lengths in the power cylinder assemblies.

THE DRAWINGS

Other objects and advantages of the present invention will become apparent from the subsequent detailed description thereof in connection with the accompanying drawings in which:

FIG. 1 is a side elevational view partially broken away of a triplex pump according to the present invention;

FIG. 2 is a top plan view of the pump illustrated in FIG. 1;

FIG. 3 is a front elevational view of the pump shown in FIG. 1, illustrating the control valve assemblies associated with the power end of the pump and the interconnection of the control fluid manifold blocks;

FIG. 4 is a partial cross-sectional view of one control valve assembly;

FIG. 5 is a cross-sectional view of a precompression valve employed in the control valve assembly of FIG. 4;

FIG. 6 is an exploded perspective view of the lower control fluid manifold associated with the control valve assembly of FIG. 4;

FIG. 7 is an exploded perspective view of the upper control fluid manifold associated with the control valve assembly of FIG. 4;

FIG. 7A is a cross-sectional view of the upper portion of the control fluid manifold in FIG. 7 and the check valves assembled therein;

FIG. 8 is a schematic illustration of a power circuit and a control circuit of the present invention;

FIGS. 9A1, 9B1 and 9C1 are respectively schematic illustrations depicting the control valve conditions, the power circuit flow, and the power cylinder assembly functions respectively associated with the first, second and third phases of the pumping cycle;

TABLES A1, B1 and C1 respectively provide an index of the valve conditions and cylinder functions depicted in FIGS. 9A1, 9B1 and 9C1;

FIGS. 9A2, 9B2 and 9C2 schematically illustrate the positions of the control circuit conditioning valves, the resulting movement of the control valves, and the control circuit fluid

flow that accomplishes this control valve movement in the phases of the pumping cycle respectively associated with FIGS. 9A1, 9B1 and 9C1;

TABLES A2, B2 and C2 provide an index of the condition of the control circuit conditioning valves and an index of the control valve movement associated with these conditions as reflected in FIGS. 9A2, 9B2 and 9C2, respectively;

FIGS. 9A3, 9B3 and 9C3 schematically illustrate the tripping of the cycling valves and the resulting control circuit fluid flow that causes the positioning of the control circuit conditioning valves illustrated respectively in FIGS. 9A2, 9B2 and 9C2; and,

TABLES A3, B3 and C3 provide an index of the tripped valve and its affect on the control circuit conditioning valves as respectively illustrated in connection with FIGS. 9A3, 9B3 and 9C3.

DETAILED DESCRIPTION

20 General Summary

Referring now to FIGS. 1 and 2, an overall view of a triplex pump 20 according to the present invention is there shown.

The pump 20 includes a fluid end assembly 22 comprising three substantially identical cylinders 24. The fluid end assembly is of the type utilized in the HT-400 pump series referred to on page 6 of the "1968 Sales and Service Catalogue" of Halliburton Services, Duncan, Oklahoma.

The internal passages 26 of each of the fluid end cylinders 24 are each in communication with a valved pump cylinder head 28 of the type more particularly described in U.S. Pat. No. 3,259,075, assigned to the assignee of the present invention. The disclosure of this patent is hereby incorporated by reference. Each of the cylinder heads 28 is provided with a conventional suction valve assembly 30 and a conventional discharge valve assembly 32. The discharge valve assemblies 32 communicate with a common discharge manifold 34, and the suction valve assembly similarly communicates with a common and conventional suction header (not shown).

Extending from the fluid end assembly 22 in a direction away from the chambers 28 is a power end assembly 38. The power end assembly 38 includes three substantially identical power cylinders 40 having internal passages 41. Each of these power cylinders 40 is in generally longitudinal alignment with one of the fluid end cylinders 24. A piston rod assembly 42 extends longitudinally into each power end cylinder 40 and the aligned fluid end cylinder 24. The ends of the piston rod assemblies 42 which extend into the chambers 26 of the fluid end cylinders 24 are provided by capped plunger ends, which function as pumping pistons 44 that are operable to bring about suction and discharge action in a conventional manner, and precompression action in a manner hereinafter more fully described.

The opposite ends, or power pistons, 46 of the piston rod assemblies 42 are in sliding and sealed engagement with the walls of the internal passages 41 of the power cylinders 40. In a manner hereinafter more fully described, power fluid acts on opposite faces 48 and 50 of the power pistons 46 to reciprocate the piston rod assemblies 42.

The power end assembly 38 and the fluid end assembly 22 are separated by a spacer frame assembly 51 which permits the fluid end piston rods, or plungers, 52 and the power end piston rods 54 to be separate members thereby facilitating maintenance operations. These rods 52 and 54 are each hollow, cylindrical members sealably received in the fluid end cylinder passages 26 and the power end cylinder passages 41, as indicated at 55 and 56. If desired, a floating annular rod seal may be employed so as to allow the rods to operate slightly eccentric to the power cylinder bores, thereby eliminating the necessity of extremely accurate alignment between the power cylinders and the fluid end cylinders.

Extending longitudinally of and internally of each of these members are tie rods 57 which are joined at one end to the pistons 44 and 46 and at the opposite end with a cam actuator 58 to form, together with the rods 52 and 54 and their associated piston means 44 and 46, the integral piston rod as-

sembly 42. The permissible stroke length of each piston rod assembly 42 is such that each cam actuator 58 is movable between a back position adjacent the power end cylinders 40 and a forward position adjacent the fluid end cylinders 24.

In a manner hereinafter more fully described, the cam actuators 58 are operable, in connection with cycling valves FP, to provide a signal that the piston rod assembly has reached its forward position. These cycling valves FP are mounted on the spacer frame 51 at that forward position by suitable mounting means, indicated at 59. The location of this mounting means is such that the lengths of the cam actuator 58 cooperate with the valves FP for a time sufficient to permit the necessary circuit functions to take place.

In a similar manner, at least one cam actuator 58 is operable, in connection with a stroke control valve BP, to provide a signal that its associated piston rod assembly 42 has reached its back position. This stroke control valve BP is also mounted on the spacer frame 51 at that back position by suitable mounting means 60.

At the end of the power cylinders 40 remote from the fluid end assembly 22, each power cylinder is in continuous communication with one of three identical control valve assemblies CV. To facilitate description of a pump of the present invention, the three control valves are hereinafter referred to as 1-CV, 2-CV and 3-CV, respectively. Similarly, the hereinafter described identical portions of the CV valve assemblies are differentiated by the prefixes 1-, 2- and 3-, as are the associated power cylinder assemblies 40.

The function of the control valves CV is to direct power fluid to and from the power cylinders 40 in a manner such that the power cylinders each operate on a suction, precompression, discharge cycle, each out of phase with one another.

In the discharge phase of the cycle in a given power cylinder 40, power fluid acts on the outer face 50 of a power piston 46 to transmit force through the piston rod 42 so as to cause the fluid end piston 44 to move to its forwardmost stroke position whereby fluid in the cylinder head 28 is expelled to the common discharge manifold 34. Prior to the discharge phase of the cycle, this fluid has been precompressed by power fluid acting on the power piston face 50 after passing through a precompression valve PR mounted on the control valve assembly CV. This precompression flow of power fluid causes the power piston 46, through the piston rod assembly 42, to move forward by an increment sufficient to compress the fluid to be pumped and thereby raise the pressure of the fluid to approach the discharge pressure.

Suction movement of each power piston 46 is caused by power fluid acting on the inner face 48 of the power piston 46. The internal passages 41 of the power cylinders 40 are fluid interconnected in a normally closed circuit by a suitable common conduit 61. Thus fluid in two rod ends of the passages 41, which fluid is displaced during precompression and discharge movement of the associated power pistons 46, is caused to flow through this common conduit 61 into the third passage 41 to act on the inner face 48 of the power piston 46 in that third passage 41.

In this manner, the suction, precompression and discharge functions are simultaneously and responsively performed, one function being performed in each fluid end cylinder 24. Therefore, constant pressure flow continually exists between the fluid end of the pump and the common suction header and common discharge manifold 34.

For purposes of accomplishing automatic stroke correction, as hereinafter more fully described, the common conduit 61 connecting the rod ends of the power cylinders 40 is in fluid circuit with a conventional accumulator 62 and with a source of power fluid through a normally closed filling valve (not shown in FIG. 1) hereinafter described. Also, a rod end relief valve 222 provides selective communication between the rod ends and a power fluid reservoir.

Also, as hereinafter described, the control valve assemblies CV which direct the power fluid, preferably water, are, in the illustrated embodiment, monitored by a separate control fluid circuit, preferably utilizing a different fluid such as oil, air or a combination thereof. It will, however, be apparent that con-

trols other than a control fluid circuit (e.g., an electrical sensing arrangement) may be utilized to monitor the power circuit.

It will be appreciated that the elements of the control circuit, the control valve assemblies CV, the power end assembly 38, and the fluid end assembly 22, may all be mounted on a suitable common frame such as a skid 64. Preferably the mounting on the skid is designed to permit the fluid end cylinders 24 and the power end cylinders 24 to move longitudinally for a limited distance, during reciprocation of the piston rod assemblies 42, so as to relieve stresses on those members. Provision for such movement may be made by supporting the members 65 providing the connection between the spacer frame 51 and the cylinders 40 and 24 for limited sliding movement within suitable brackets as indicated at 66 and 68. These connecting members 65 may, in turn, be joined by tie bars 69.

Detailed Structure:

The Control Valve Assembly

Referring now particularly to FIGS. 3 and 4, the previously identified identical control valve assemblies 1-CV, 2-CV and 3-CV will be described.

From the partial cross sectional view of one assembly shown in FIG. 4, it may be seen that each assembly includes two pilot operated sleeve valves, I and D, which respectively provide for the inlet of power fluid to an associated power cylinder 40 and the discharge of power fluid from that cylinder. The sleeve valves I and D are generally vertically aligned and are slidably received in vertically aligned cylinders 70 and 72.

The bottom of the lower cylinder 70 communicates with a power fluid inlet elbow 74. Internally each elbow 74 is provided with a stepped bore indicated at 76, which continuously communicates with a source of pressurized power fluid. Referring to FIG. 3, it will be seen that the inlet elbows 74 of the control valve 1-CV, 2-CV and 3-CV communicate with a common passageway 75 which in turn provides the continuous fluid communication with pressurized power fluid.

The smaller internal diameter of the inlet elbow 74 at the step 76 is less than the external diameter of the lower end of the lower sleeve I so that downward movement of this sleeve beyond the step is prevented.

The upper end of the lower cylinder 70 and the lower end of the upper cylinder 72 are spaced from one another and are joined to a common, generally cylindrical, housing 78. This housing 78 is provided with a laterally facing opening 80 communicating with the piston end of a power cylinder 40 (see FIG. 1) and with a central chamber 82 within the housing. Within the chamber 82 is a slotted spacer 84 which is generally cylindrical and has an internal bore generally aligned with the lower cylinder 70.

This spacer 84 is provided, adjacent its lower end, with lateral slots 86 communicating with the central chamber 82. On top of the spacer and blocking its central bore from vertical communication with the central chamber 82 is a soft seat 88. The relationship of the outer diameter of the upper portion of the lower sleeve I and the inner diameter of the spacer 84 is such that when the lower sleeve I is in its uppermost position abutting the soft seat 88, fluid communication between the chamber 82 and the inlet elbow 74 is totally blocked. However, when the lower sleeve I is in its lowermost position adjacent the elbow shelf 76, fluid communication between the elbow inlet 74 and the chamber 82 is established by means of the lateral slots 86 and the sleeve valve I.

The upper end of the control valve assembly is surrounded by a cylindrical discharge housing 90 defining a discharge chamber 92. The discharge chambers 92 of the control valve assemblies are in communication with one another and in continuous communication with a power fluid reservoir by means of connecting conduits 93 (FIG. 3) and 93', the former of which may be flexible to permit relative movement of the control valve assemblies during operation of the pump.

As seen in FIG. 4, the discharge housing 90, the central housing 78 and the elbow inlet 74 are suitably joined together by bolts 95.

The discharge chambers 92 are also in potential fluid communication with the central chamber 82 of the central housing 78. This fluid communication is either established or blocked through a slotted spacer 94 located above the upper cylinder 72 in a manner similar to the positioning of the slotted spacer 84 above the lower cylinder 70. This spacer 94 is provided with lateral slots 96 and a soft seat 98 cooperating with the upper end of the upper sleeve valve D, in like manner to the cooperation between the lower sleeve valve I and the slotted spacer 84 in the central chamber 82.

A small clearance 105 exists between the outer diameters of the sleeve I and D and the inner diameters of the slotted spacers 84 and 94. This clearance at the D sleeve aids in limiting the rate of decompression of the power cylinders by limiting flow through the slots 96 from the sleeve D at the initial downward movement of the sleeve. Thus, shock forces are minimized during suction strokes causing decompression of the power cylinders 40. The clearance 105 at the I valve limits flow through the slots 86 as the I valve nears its seat 88 while the D valve begins to open.

The lower end of the upper sleeve valve D communicates with the open top of a third slotted spacer 100 mounted within the central chamber 82 and abutting a backing plate 102 for the soft seat 88 located within that chamber 82. The upper end of the third slotted spacer 100 abuts an annular spacer ring 104. This ring 104 is provided with a laterally facing bore 106 aligned with a laterally facing bore 108 in the central housing 78.

In a manner to be subsequently described, power fluid may enter the bores 108 and 106 through a precompression valve, PR, for purposes of initiating a precompression function in one of the power cylinders 40. Power fluid so flowing through these bores 108 and 106 may enter the central chamber 82 by means of the central passage 109 and the open top of the third slotted spacer 100.

It will thus be appreciated that the internal diameter of the spacer ring 104 is greater than the external diameter of the lower end of the upper sleeve D to provide the passage 109 for facilitating this flow of fluid. As will be hereinafter described this flow of fluid occurs when the D valve is in its upper position.

The upper sleeve D, when in its lower position, is maintained in a position spaced from the upper end of the spacer ring 100 (by control fluid in the hereinafter described actuator chamber B) as indicated by the clearance 110 thus provided. As an alternative to the clearance 110, the lower end of the sleeve D may be apertured. The function of the clearance 110 is to provide communication between the chamber 82 and the PR valve when pilot pressure is to be released from a PR valve of another CV valve as hereinafter described.

The open upper end of the spacer 100 has an internal diameter less than the external diameter of the lower end of the upper sleeve D so that downward movement of the sleeve D beyond this spacer end is prevented.

For purposes of facilitating further discussion of the control valve assemblies, the sleeve valves I and D will be described as being closed when they are located in position abutting their associated soft seats 88 and 98. In these upper positions the sleeves respectively block communication between the common central chamber 82 and the central passage of inlet elbow 74 or the chamber 92 in discharge housing 90.

Movement of the sleeves I and D to these upper positions, and to open or lower positions permitting the required fluid communication, is accomplished through the use of a control fluid. This control fluid causes such sleeve movement by entering into the cylinders 70 and 72 through control ports extending laterally therethrough. These control ports are labeled I-B, I-A, D-B and D-A respectively and are defined by (unnumbered) communicating passages of different diameters.

Approximately midway thereof, each of the sleeves I and D is provided with an external annular flange 111 which engages the internal wall of one of the cylinders 70 and 72. These flanges 111 function as pistons and define, together with the outer periphery of the sleeve valves above and below the

flanges and suitable annular seal and bearing assemblies 112 located at opposite ends of each of the cylinders 70 and 72, upper and lower control fluid chambers A and B.

It will be appreciated that the internal diameters of the sealing assemblies 112 are equal to the external diameter of the sleeve valves I and D adjacent the ends thereof; and it will be further appreciated that the length of each of the sleeve valves I and D is greater than the distance between the upper and lower seal and bearing assemblies 112. Thus, regardless of the position of the sleeve valves, the control fluid chambers A and B are continually isolated from power fluid which may exist in the elbow 74, the common central chamber 82, or the discharge chamber 92.

Moreover, the distance between the seal and bearing assemblies 112 on the upper ends of a given cylinder 70 or 72 and the soft seat 88 or 98 thereabove is such that the sleeve flanges or pistons 111 are spaced from the upper seal and bearing assemblies 112 in all positions of the sleeve valves I and D.

With this arrangement, pressurization of the upper control ports I-A and D-A, in a manner subsequently described, always causes control fluid to enter the upper control chambers A. The associated sleeve valves are thus caused to move to their lower or open positions, as illustrated by the position of the sleeve D in FIG. 4. Conversely, pressurization of the lower control ports I-B and D-B moves the sleeves to their upper or closed positions, as indicated by the sleeve I in FIG. 4, by action of control fluid on the lower chamber B upon the sleeve pistons 111.

The I and D valves are hydraulically cushioned or decelerated near the end of either an upward or downward stroke by the restriction offered by the smaller of the two passages comprising the control ports A and B. When a given sleeve nears completion of a shift in either direction the larger passage is covered by the piston 111 causing the fluid exhausting the actuator chamber to pass through the smaller passage.

With continued reference to FIG. 4, it will be seen that the cylinders 70 and 72 are provided with further control ports labeled I-D and D-D. The function of these ports is to supply makeup control fluid to the lower control ports I-B and D-B as will be described subsequently. At this point, it need only be noted that the positioning of the D ports between the A and B ports is such that the D ports are blocked by the piston 111 of the sleeve I or D in all positions of the sleeve except the lowermost positions thereof, as indicated respectively at 114 and 116 in FIG. 4.

In connection with the lower sleeve valves I and their associated cylinders 70, it may be seen that a further control port, I-C, is provided between the D and B ports. In a manner to be described hereinafter, this port I-C functions to supply a signal that the I valve of the associated control valve assembly is in its closed position. As indicated at 118 (FIG. 4) when the I valve is in this closed position, the I-C port communicates with the lower control fluid chamber B. In all other positions of the sleeve valve, the I-C port is blocked by the sleeve piston 111.

The Control Valve Manifolds

Referring now to FIGS. 3, 4, 6 and 7, the means by which control fluid is directed to and from the control ports in the cylinders 70 and 72 of the I and D valves will be described.

FIG. 6 illustrates a broken away perspective view of an integral, lower control block manifold 120 which is attached to each of the lower cylinders 70 (as shown in FIG. 3) in any suitable manner, adjacent the control ports I-A, I-D, I-C and I-B.

The lowermost control port I-B is in communication with a first manifold flowpath comprising a first passageway I-b1 which extends generally horizontally through the control block 120 from the face 121 adjacent the control port I-B to the outermost face 122 thereof. This passageway I-b1 may comprise a stepped bore as indicated at 124.

Extending transversely through the manifold 120 so as to intersect the first passageway I-b1 is a second passageway, or

bore, I-b2. The first and second passageways I-b1 and I-b2 together form the first manifold flow path, hereinafter referred to as I-b.

The ends of the bores I-b1 and I-b2 on the outer faces of the block 120 are threaded as indicated at 125 and 126. As will be subsequently described, these threaded ends may be blanked off by a threaded closure or may be connected to suitable fittings for fluid communication with the *b* passageways of the lower control block manifolds 120 of another control valve assembly CV.

Extending through the manifold 120 and generally parallel to the first passageway I-b1 is a third passageway or bore I-c which likewise terminates with a threaded portion 128. This third passageway functions as a second manifold flow path communicating with the I-C port.

A third manifold flow path hereinafter designated I-a communicates with the I-A port of the control valve CV. This flow path comprises a fourth passageway, or bore, I-a1 extending through the manifold generally parallel to the first and third bores I-b1 and I-c. This bore I-a1 also terminates at the outer manifold face 122 in a threaded end 130. Extending transversely into the manifold, generally parallel to the second passageway I-b2 and intersecting the fourth passageway I-a1 is a fifth passageway or bore, I-a2, which completes the I-a flow path. This bore I-a2 also terminates in threaded end 131.

A fourth manifold flow path, hereinafter referred to as I-d, communicates with the I-D port of the lower sleeve valve I, and comprises sixth and seventh intersecting passageways I-d1 and I-d2, respectively parallel to the fourth and fifth passageways I-a1 and I-a2. It will be appreciated that the seventh passageway I-d2 terminates in a threaded end 132 at the manifold face wherein the threaded end 131 of the I-a2 bore terminates, but the sixth passageway I-d1 does not extend through the manifold to the outer face 122.

Internally of the control block 120 is a connecting passageway I-db which provides fluid communication between the bores I-d2 and I-b2. This communication is normally blocked by a check valve 133 (hereinafter more fully described) threaded into the I-d2 bore. The end of the I-db bore that terminates on the outer portion of the control valve manifold block 120 is blanked off by a threaded closure 134.

Referring now to FIG. 3, it will be seen that the *b* flow paths of the three lower control block manifolds 120 are in continuous fluid communication with one another. The 2I-b2 passageway is connected by a suitable conduit means, schematically shown at 136, to the 3I-b1 passageway, while the 2I-b1 passageway is connected by a suitable conduit means 138 to the 1I-b2 port. The remaining ports, 1I-b1 and 3I-b2 of the *b* flow path are blanked off by suitable threaded closures 140.

It will thus be appreciated that the opening of one of the lower sleeve valves I by pressurizing its A control chamber (which causes the lower control port chamber B to contract thereby pressurizing the I-B port of that valve) will tend to close any of the other I valves which are open by means of the described interconnected *b* flow paths. If there is insufficient fluid in these flow path systems *b* to affect closure of such an open I valve, additional fluid is supplied from the A control chamber through the check valve 133 in the *d* flow path of the control block 120 associated with the opening I valve.

From FIG. 3 it will be seen that the I-a2 ports of the lower control block manifold 120 are each connected to a conduit means 142, 144 and 146. These conduit means are each selectively connected, through valve means hereinafter described, to a source of pressurized control fluid which may be supplied to the *a* flow path system to effect opening of the I sleeve valves. The conduit means 142, 144 and 146 are also selectively connected to a control fluid reservoir to which control fluid is exhausted from the A control chamber during closing of the I sleeve valves.

For the purposes of interrelating the movements of the I valves of one control valve assembly CV with the movements of the D valves of other assemblies, the I-a1 ports of the *a* flow path are each attached to a suitable conduit means 148, 150 and 152. This interrelated movement is subsequently detailed.

With continued reference to FIG. 3, it may be seen that the I-c bores of each control valve assembly CV are connected, by suitable conduit means 154, 156 and 158, to an upper control block manifold 160 associated with the D valves of that same assembly.

In FIG. 7, a broken away view of one of these upper control block manifolds 160 is illustrated. Each manifold 160 includes a lower bore D-b1 and a transversely intersecting bore D-b2 providing a *b* flow path. This *b* flow path provides communication with the B chamber of the D sleeve valve in a manner identical to that previously described in connection with the B chamber of the I valve, and the *b* flow paths are similarly interconnected by conduit means. Also in a similar manner to that described in connection with the I valves, the control block 160 provides communication between the D port and the B port of the upper cylinder 72 by means of a *d* flow path. This path includes bores D-d1 and D-d2, as well as a connecting bore D-db, closed at one end by a threaded closure 162, and a check valve 164 (all of which are identical to the corresponding structure in the lower control block manifold 120).

The upper end of the upper control block manifold 160 is also provided with an *a* flow path communicating with the D-A port of the D sleeve valve. This *a* flow path includes a D-a1 bore corresponding to the I-a1 bore in the lower control block manifold 120. As shown in FIG. 3, the 3D-a1, 2D-a1 and 1D-a1 bores communicate respectively with the 1I-a1, 3I-a1 and 2I-a1 bores through the previously described conduit means 152, 150 and 148. Thus, when pressurized control fluid is supplied to the *a* path of any I sleeve valve (through one of the aforementioned conduit means 142, 144 and 146) to open that valve, this fluid is also supplied to the *a* path of the connected D sleeve valve to open that valve.

However, flow into the D-a1 ports is normally maintained blocked by a pilot operated check valve assembly PO (hereinafter more fully described) which lies in a bore 166 in the upper control block 160. This bore 166 extends transversely through the block 160 and intersects the bore D-a1. Although the flow of pressurized control fluid through the bore D-a1 is normally prevented by the blocking position of the pilot operated check valve assembly PO in the intersecting bore 166, the assembly PO will assure a non-blocking position when pilot pressure is provided.

Such pilot pressure is produced by control fluid entering a pilot bore 168 in the control block 160 longitudinally aligned with the valve bore 166. As seen in FIG. 3, the sources of pilot fluid entering the pilot bores 1-168, 2-168 and 3-168 are the previously identified conduit means 158, 156 and 154 leading respectively from the 1-Ic, 2-Ic and 3-Ic bores of the lower control block manifolds 120. This fluid in the connecting conduit means 158, 156 and 154 is provided from the pressure in the B control chambers of the I valves when these chambers are pressurized to close those valves, thereby permitting the aforementioned communication between the B chamber and I-C port of the lower cylinder 70 (see FIG. 4).

It will be appreciated that the pilot ports 168 each have threaded ends 170 in which a plug, or cap, 127 providing an orifice O is threadably received. This orifice O controls the opening of the PO valve in the bore 166, which in turn controls the opening of the D valve by fluid entering the bore D-a1.

For the purpose of connecting the D-A control chambers with the control fluid reservoir to allow closure of the D sleeve valves (as hereinafter described) a further bore 174 intersects the valve bore 166 and the pilot bore 168 adjacent their intersection. This further bore 174 is generally parallel to the D-a1 bore and threadably receives a check valve 164 as does the D-d2 bore. A connecting bore 176 provides valved communication between the D-a1 port and the valved bore 174.

The Precompression Valve

As will be pointed out in the subsequent discussion of the pumping cycle, when both the I valve and the D valve of a given control valve assembly are maintained in their upper or

closed positions by proper control fluid flow through, and pressure in, the previously described control block manifolds 120 and 160, the precompression assembly PR associated with that control valve assembly is conditioned to permit precompression flow of power fluid into the common chamber 82.

Referring now particularly to FIGS. 3, 4 and 5, the operation and structure of the precompression valves will become apparent. Each PR valve assembly comprises a block 177 having a generally horizontal bore 178 extending therethrough. The bore 178 terminates in an orifice 179 which may optionally be of the fixed or pressure compensated type. When the valve assembly is suitably mounted on the control valve assembly CV, this orifice 179 communicates with the previously identified lateral port 108 in the central housing 78. The bore 178, at a position remote from the housing 78, terminates in a threaded outlet end 180 with which a threaded and apertured fitting 182 is threadedly engaged.

Intersecting the horizontal bore 178 and extending downwardly therefrom is an inlet bore 184 serving as an inlet for power fluid. A threaded fitting 186 is received in this bore and provides through a suitable conduit means 188, fluid communication between the inlet bore 184 and a source of pressurized power fluid existing in the elbow 74 of the control valve assembly. This pressurized power fluid is normally prevented from entering the common central chamber 82 of the control valve assembly through the horizontal bore 178 by a movable valve member 190.

The valve member 190 has a tapered poppet seating surface which functions as a piston-like end 192 seated at a tapered body face 193 located at the intersection of the horizontal bore 178 and the inlet 184. The valve member 190 also extends upwardly into a pilot bore 194 longitudinally aligned with the inlet bore 184.

The pilot bore 194 receives an enlarged end 196 of the valve member 190. This end 196 defines a second piston-like member having a diameter substantially greater than the outside diameter of the tapered seating surface 192. Thus, when pilot pressure is maintained in the pilot bore 194 at a level equal to the power circuit pressure in the inlet port 184, the difference in areas between the pistons 192 and 196 causes the valve member 190 to remain seated (as shown in FIG. 5) and thus prevents communication between pressurized power fluid and the common chamber 82 through the horizontal bore 178.

Such pilot pressure is normally maintained in the pilot bore 194 through communication of an apertured fitting 198, threaded therein, with the apertured fitting 182 in the output bore 180 of another PR valve through suitable conduit means 200 (see also FIG. 3). The provision of pressurized fluid existing in the output bore 180 of the connected PR valve and the conduit means 200 may be accomplished in one of two ways.

A first source of this fluid lies in the supply of pressurized power fluid entering the common central chamber 82 of the control valve assembly through an open I valve. This fluid communicates with the central bore 178 of the PR valve by means of the previously mentioned clearance 110 providing communication between the central housing bore 108 and the common chamber 82. An alternative source of pilot pressure is established by pressurized fluid entering the central bore 178 and the output port 180 of the connected PR valve when its valve member plunger 190 is moved upwardly because of the absence of pilot pressure in its pilot port 194.

The precompression valve assemblies thus function as two-way, spring-offset, single-piloted valves being normally closed by pilot pressure, with fluid pressure in the inlet port 184 substituting for a mechanical spring. It will be appreciated that the pilot pressure is removed when the output port 180 of a connected PR valve communicates with the power circuit reservoir. This communication is established at any time in which the I valve of the connected control valve assembly CV is in its upper closed position and the D valve is in its lower open position, as shown in FIG. 4.

Absent pilot pressure, the lower piston 192 of the valve member unseats by moving upward a limited amount, thereby

providing fluid communication between the inlet bore 184 and the central bore 178. This communication permits a small flow of pressurized power fluid into the common chamber 82 to initiate a precompression function. This small flow of fluid is restricted by the orifice 179. Restoration of the pilot pressure recloses the precompression valve.

In FIG. 3, the interconnection between the output bores 188 of each PR valve with a pilot bore 194 of one other valve is shown. Also illustrated is the communication between the inlet bores 184 and elbow inlets 74 of the control valve assembly. By means of the illustrated connections, only one precompression valve is permitted to be in open position during any one phase of the pumping cycle.

The Power Fluid and Control Fluid Circuits

The basic structure of a triplex pump according to the present invention having been described, reference may now be had to FIG. 8 which schematically depicts, in dashed lines, the overall control circuit and, in solid lines, the overall power circuit utilized in operating the pump.

The three power cylinders 1-40, 2-40 and 3-40 and their associated pistons 46 and piston rod assemblies 42 are illustrated in a neutral position. Subsequently, they will be illustrated as displaced from these positions in connection with the description of the pumping cycle. Connecting flow paths 202, 204 and 206 respectively indicate the fluid communication between the power cylinders 40 and the common control chambers 1-82, 2-82 and 3-82 of the control valve assemblies through which power fluid is displaced during displacement of the power pistons 46.

During a suction function this fluid is displaced through the upper sleeve valves 1-D, 2-D and 3-D of the control valve assemblies to a power circuit reservoir 208. To initiate a precompression or discharge function, pressurized power fluid is supplied to the power cylinder 40 from a power circuit pump 210 through either the lower sleeve valves 1-I, 2-I and 3-I or the precompression valves 1-PR, 2-PR and 3-PR.

As illustrated, the inlet ends of the I valves are in continuous fluid communication with one another and with the power circuit pump 210 while the outlet ends of the D valves are in continuous fluid communication with one another and with the power circuit reservoir. The precompression valves PR are shown as being closed by pilot pressure at the pilot ports 194 acting against spring 212 representative of the fluid pressure continually acting against the valve piston 192 as previously described.

Interconnection of the rod ends by the conduit means 61 results in responsive operation of the power cylinder assemblies 40 since this interconnection is established by a normally closed circuit. In normal operation, the total fluid in the rod ends displaced during precompression and discharge of two pumping units is equal to the amount of fluid needed to accomplish a complete suction stroke in the other unit by entry into its rod end through the connection 61.

In a manner to be subsequently described, should an error in stroke length occur (for example, due to undertravel or overtravel of the piston rod assembly 42 during precompression) an excess of fluid over that necessary to accomplish a complete suction stroke in one cylinder will always be created. This excess flows into the previously identified accumulator through a conventional check valve schematically indicated at 214. The amount of fluid removed from the closed system is automatically replenished to correct the cycle error, as described hereafter, from either the accumulator 62 or the power circuit pump. Replenishing occurs through normally closed valves schematically shown at 216 and 218. These valves 216 and 218, when opened, communicate with the rod end of the No. 1 power cylinder as indicated at 220. For convenience the valves 214, 216 and 218 have not been shown in FIG. 1.

The power circuit is also provided with a rod end relief valve 222, of conventional type and may be provided with a main power circuit relief valve 224, also of conventional type. These valves 222 and 224 serve to prevent excessive pressure

conditions in the rod ends of the cylinders 40 and the main power circuit, respectively. It will be appreciated that the pressure setting of the rod end relief valve 222 is greater than that of the check valve 214 leading to the accumulator.

The control circuit comprises a pump 226 providing a source of pressurized control fluid which is utilized to effect opening and closing of the sleeve valves I and D of the control valve assembly.

Opening actuator control fluid for moving the 1-I and 3-D valves to their open positions is directed to the previously described, interconnected A ports of these valves through control circuit conditioning valve C, hereinafter described. This valve C also provides fluid communication between the A ports of the 1-I and 3-D sleeve valves and a control fluid reservoir 228 to which control fluid is exhausted upon closing of these sleeve valves. In a similar manner two other control circuit conditioning valves A and B respectively associated with the interconnected 2I-A and 1D-A ports and the interconnected 3I-A and 2D-A ports.

Each control circuit conditioning valve is prevented from drifting by means of a conventional double cylinder lock valve schematically shown at DCL-A, DCL-B and DCL-C. Each of these lock valves also serve to interconnect a shifting port of each of the control circuit conditioning valves, as indicated at 232, 234 and 236, with pressurized power fluid that may pass through another one of the control circuit conditioning valves. The purpose of this interconnection, more fully described hereinafter, is to insure automatic conditioning of the A, B and C valves upon sensing of a completed stroke of the piston rod assemblies 42.

The previously identified FP valves cooperate with the cam actuators 58 to sense the completed stroke. Each of these FP valves is illustrated as being normally closed by a spring 238. Upon completion of a discharge stroke the cam actuator 58 trips a follower 240 so as to permit pressurized control circuit fluid to pass from the pump 226 and through the FP valve. The interconnection of the FP valves with one another and with the control circuit pump 226 is indicated by the flow line 242.

Pressurized control fluid passing through an FP valve travels along one of the flow paths indicated at 244, 246 and 248 to one of the shifting ports 250, 252 and 254 of the control circuit conditioning valves A, B and C. This causes that valve to assume a condition to pass pressurized power fluid to the A ports of associated sleeve valves and to one of the closing, shifting ports 232, 234 and 236 of another conditioning valve. The latter valve is thereby placed in communication with the control circuit reservoir, hereinafter referred to as a tanked position.

As this closing occurs, fluid displaced out of the opposite shifting ports 250, 252 or 254 of the tanked valve is displaced to the reservoir 228 through conventional check valves 256 communicating with the FP valves. It has been found in practice that the cracking or opening pressure of the valves DCL-A, DCL-B and DCL-C should be greater than that of the check valves 256 or that these valves 256 should be eliminated.

The previously identified BP valve is substantially identical to the FP valves and cooperates with the cam actuator 58 of the 1-42 piston rod assembly to sense whether this assembly has undergone a completed suction stroke. In the event this has not occurred, power fluid is subsequently placed into the rod end system through valves 216 and 218. Details of this operation, subsequently described, include the removal of pilot pressure on the valves 216 and 218 through the stroke control valve.

Other details of the control and power circuits will be described in connection with the description of the pumping cycle. At this point, the brief description of these circuits may be completed with reference to the conventional pressure relief valve 260 and the conventional accumulators 262 and 264 in the control circuit. These elements monitor the pressure in

that control circuit.

Miscellaneous Valve Structures

Prior to a detailed discussion of the pumping cycle, details of the commercial availability of some of the preferred valve structures, heretofore only functionally described, will be indicated.

The BP and FP valves preferably comprise cam operated "c" spring offset only valves, available from Racine Hydraulics and Machinery, Inc., Sarasota, Florida, as part of their "Directional Control Series." These valves, more fully described in connection with FIG. 11 of Racine Bulletin MS 2. 403 dated October, 1966, include a spool biased by the springs 238 to first position to permit flow through one flow path of the valve. The cam followers 240 each comprise a roll pin and stem combination which may be displaced, to move the spool, against the spring to a position permitting flow through the valve through a second flow path.

The double cylinder lock valves DCL-A, DCL-B and DCL-C are preferably of the ¼ inch type available also from Racine Hydraulics and Machinery, Inc. and are disclosed in Bulletin ED6, 75, dated February, 1968. Each valve includes cylinder ports 266 and valve ports 268 (see DCL-A in FIG. 8). These ports are interconnected through a chamber housing a main piston (not shown) having an equal area on all surfaces exposed to pressure, and through spherical decompression poppet valves.

With directional control valve in neutral position, flow from both ends of a cylinder is blocked by the double cylinder lock valve. When the fourway valve is activated to direct flow to one side of the cylinder, pressure opens the poppet and simultaneously moves the piston over to the opposite poppet, opening this poppet and allowing free flow to the directional control valve.

Use of the DCL valves militates against drifting of the control circuit conditioning valves A, B and C after they are shifted by pilot signals from the FP valves. This is particularly desirable in instances wherein the pump of the present invention must be stopped and restarted frequently.

The control circuit conditioning valves A, B and C and the valve 258 which normally maintains the stroke correction circuit valves 216 and 218 closed, are preferably pilot operated, ¼ inch stackable valves available also from Racine Hydraulics and Machinery, Inc. and disclosed in Bulletin ME3. 98, dated March, 1968. The C valve is a four-way valve, while the other stackable valves are three-way valves, one port being blocked. The stackable valves A, B and C not only furnish pressure signals to the control valve I-A ports, but also maintain this pressure in the A ports after shifting of the I sleeve valves until they are to shift again.

The circuit relief valves 222, 224 and 260 may be of the same general type as the 55-RO type available from Texstream Corporation, Houston, Texas. It will, however, be appreciated that these valves may be any fluid handling relief valve adequate for the pressure and flow capability.

The valves 216 and 218 which serve to add power fluid to the rod end of the power cylinders 40 when needed, function identically to the poppet-type PR valves previously described in connection with FIG. 5. The valves are also similar in construction to the PR valves except that the area ratios between the ends of the slidable valve members are altered as required by the pressure ratio between the control circuit pressure and power circuit or rod end pressure.

Referring now to FIG. 7A, the pilot operated check valve PO and the check valve 164 associated therewith are shown. The PO valves each comprise a hollow body 269 closed by a plug 270 and receivable in the bore 266, which intersects the D-a1 passage of the upper control block manifold 160. The bore D-a1 is offset to include a valve port 271 and a cylinder port 272, and the hollow body is provided with lateral bores 273 and 274, respectively, aligned therewith. A poppet 275 normally provides a one way check against the passage of fluid through the passage D-a1 into the D-A chamber by blocking the bore 274, which is aligned with the cylinder port 272. A

spring 276 loading a ball 278 by means of a spring end 280 biases the poppet 275 to blocking position. It will be apparent that flowout of the D-A chamber through the D-a1 passage is not restricted since the bore 273 aligned with the valve port 274 is not blocked.

Entry of pilot pressure through the pilot bore 168 acts on a piston 282 which causes the PO valve to open in two stages. The first stage involves displacement of the ball 278 by a piston finger 283 which enters a larger diameter aperture 284 in the end of the poppet 275. This permits passage of fluid from the bore 274 to the bore 273 through a lateral port 285 in the poppet 275. During the second stage, the piston 282 completely displaces the poppet 275 against the action of the spring 276 so as to permit the bore 274 to be completely uncovered.

The two stage opening of the PO valve thus causes two stage opening of the connected D valve so as to prevent its connected power cylinder from decompressing at too great a rate.

The PO valves are commercially available from Racine Hydraulics and Machinery, Inc. as $\frac{3}{4}$ inch pilot operated check valve cartridges. These cartridges are illustrated in Bulletin MS6, 81, dated March, 1968.

The check valve 164 is a modified version of the PO valve. As may be seen in FIG. 7A, the poppet 286 of this valve has a closed end 288 and no ball assembly. Moreover, no pilot piston assembly (such as that shown at 282 in the PO valve) is included, the valve being opened by fluid action directly on the poppet.

All the remaining check valves received in the control block manifolds 120 and 160 are similarly constructed.

The disclosures of the above-identified Racine Hydraulics Bulletins are hereby incorporated by reference.

The Pumping Cycle

Referring now to FIG. 9A1 and Table A1, a first phase of the pumping cycle will be explained. In this phase, the 1-40 power cylinder is in the suction stage of the cycle while the 2-40 and 3-40 power cylinder assemblies are respectively in the discharge and precompression stages. Movement of the piston rod assemblies 42 associated with these cycle stages is indicated by the arrows 290, 292 and 294.

In order for the 2-40 power cylinder assembly to perform its discharging function, it will be appreciated that the 2I sleeve valve must be open while the 2D sleeve valve is in a closed position. In other words, the sleeve of the 2I valve is in its lower position, as indicated by the open rectangle 296 in FIG. A1, and the sleeve of the 2D valve is in its uppermost position, as indicated by the crossed rectangle 298 in FIG. A1. The open and crossed rectangle symbols, unnumbered, are retained throughout the illustrations of the pumping cycle to indicate the open and closed positions of the various sleeve valves I and D.

Thus, with the sleeve valves 2I and 2D in the illustrated positions, power fluid provided by the power circuit pump 210 may pass through the 2I valve and into the common chamber 2-82 of the 2-CV control valve assembly. This pressurized fluid is prevented from passing through the closed 2D valve so that it is caused to flow to the 2-40 power cylinder, along the flow path indicated by the arrows 300 through 304.

During the discharging function of the 2-40 cylinder assembly, fluid displaced from the rod end of that assembly enters into the rod end of the 1-40 power cylinder assembly through the common conduit means 61. The pressure of this fluid entering the rod end of the 1-40 power cylinder assembly causes this power cylinder assembly to undergo the major portion of its suction function.

Performance of this suction function is permitted by reason of the positions of the sleeve valves I and D in the 1-CV control valve assembly. As indicated in FIG. 9A1, the 1I valve is in its upper or closed position, while the 1D valve is in its lower or open position.

Because of the closed 1I valve pressurized fluid provided by the power circuit pump 210 is prevented from entering the common passageway 1-82 of the 1-CV control valve assembly. Thus, this pressurized fluid does not resist displacement of power circuit fluid out of the 1-40 power cylinder by the 1-46 power piston. The open 1D valve permits this displaced power fluid to pass through the common chamber 1-82 of 1-CV, and thereafter through the 1D valve to the power circuit reservoir or sump 208. This flow path is indicated by the arrows 305 through 309.

As illustrated by the arrow 310 in FIG. 9A1, the 3PR (precompression) valve is in an open position so that pressurized fluid provided by the power circuit pump 210 is directed to the 3-40 power cylinder through the orifice 3-179 along the flow path shown by the arrows 311 through 313. This small flow of fluid causes the 3-46 piston to move toward the pump fluid end forcing the fluid end piston slowly into the fluid end cylinder to precompress fluid within that cylinder to a pressure approaching discharge pressure.

It will be appreciated that the closed position of the 3I valve prevents discharge instigating flow of pressurized power fluid to the 3-40 power cylinder assembly. Moreover, the closed 3D valve prevents the exhausting of precompression fluid to the power circuit reservoir 208.

It should be noted that the 1PR valve remains in a closed position through-out the cycle phase shown in FIG. 9A1 and the 2PR valve assumes a closed position in that cycle phase because pilot pressure exists on these valves at their pilot ports 1-194 and 2-194. As previously discussed, this pilot pressure emanates from the output ports 182 of other PR valves (FIG. 5), which ports are not specifically delineated in the circuit drawings. The source of this flow from the output ports 182 is, however, shown. Thus, it is readily apparent, in terms of the illustrated fluid circuit, that the pilot pressure is maintained on the 1PR valve by pressurized fluid entering the common chamber 2-82 of the 2-CV control valve assembly through its open 2I valve. Pilot pressure flow of this fluid is indicated by the arrows 314 and 315.

When the 3-40 cylinder has precompressed to the pressure determined by the power circuit pressure and the difference in piston areas on the valve member 190 (FIG. 5), pilot pressure on the 2PR valve is produced by pressurized fluid passing through the 3PR valve. This 3PR valve is in fluid communication with the pilot port 2-194 of the 2PR valve by its output port. The arrows 316 through 318 indicate this flow of pilot fluid in terms of the schematic circuit.

As noted earlier, the 3PR valve is in its open position in the cycle phase illustrated in FIG. 9A1. The opening of the 3PR valve in this phase of the cycle is permitted by reason of the opening of the 1D valve. Since the pilot port 3-194 of the 3PR valves is in communication with the common chamber 1-82 of the 1CV valve assembly by means of the output port 182 of the 1PR valve, the initiation of communication between the power circuit reservoir 208 and the 1-182 chamber removes pilot pressure from the pilot port 3-194 of the 3PR valve. The pilot plunger 190 (FIG. 5) is thus permitted to move upwardly and displace pilot fluid to the reservoir 208. The circuit indication of this displacement is illustrated by the arrows 319 and 320.

A summary of the sleeve valve and precompression valve positions associated with the cycle functions of the power cylinders, as shown in FIG. 9A1, may be found in Table A1. In Table A1 the symbol "C" indicates a closed valve position and "O" indicates an open valve position. These symbols are retained in connection with Tables B1 and C1, hereinafter discussed.

With reference to Table A1, it may readily be seen that a suction function is associated with a closed I valve and an open D valve whereby the appropriate common chamber 82 of one control valve assembly CV is placed in communication with the power circuit sump 208. On the other hand, a discharge function is associated with an open I valve and a closed D valve whereby their common chamber 82 is main-

tained in communication with the power circuit pump 210. In both the discharge and suction functions, the precompression valve is closed.

The precompression function is associated with a control valve assembly condition wherein both the I and D valves are closed and the precompression valve is moved from its normally closed position to an open position, thus permitting only a small amount of flow to the associated power cylinder assembly.

Referring now to FIG. 9A2 and Table A2, the function of control circuit conditioning valves A, B and C will be described in connection with the positioning of the I and D valves of the control valve assemblies, as previously detailed in the discussion of FIG. 9A1 and Table A1.

In FIG. 9A2, (as well as FIGS. 9B2 and 9C2, subsequently described) the final positions of the I and D valves associated with the phase of the pumping cycle described in connection with FIG. A-1 are indicated by the solid line open and crossed blocks. The open and crossed blocks in dashed lines indicate the positions of the I and D valves in the immediately preceding phase of the pumping cycle. The absence of a dashed block associated with an I or D valve indicates that such valve remains stationary during the transition of the control circuit valve assemblies from the prior to the illustrated phase of the pumping cycle.

With reference to FIG. 9A2, and according to the symbols outlined above, it will be apparent that the 2-CV control valve assembly is conditioned for the illustrated phase of the pumping cycle by movement of the 2I valve from its upper or closed position to its lower or open position as indicated generally at 322. The opening of this 2I valve is caused by the position of the control circuit condition valve labeled A. With this A valve in the position indicated by the arrow 324, pressurized fluid emanating from the control circuit pump 226 is caused to flow through the A valve and to the 1-A port of the 2I valve. This flow path is indicated by the arrows 325 and 326.

Pressure at the 2I-A port provides opening actuator fluid in the A chamber (FIG. 4) causing the 2I sleeve valve to move downwardly to its open position. This movement in turn closes the 1I valve by causing fluid discharged from the 2I-B port to enter the 1I-B port. This fluid flow, indicated by the arrows 327 and 328, expands the B chamber (FIG. 4) of the 1-I valve, thereby urging that valve to its upper closed position.

As a result of expansion of the B chamber of the 1I valve, the A chamber contracts displacing control fluid through the 1I-A port. Since the control condition valve labeled C is in the condition indicated by the arrow 330, this displaced fluid is exhausted through that valve C to the control circuit reservoir or sump 228. It will be apparent that such flow, indicated by the arrows 331 through 336, is permitted only when the control circuit condition valve C is tanked, i.e., in the illustrated position communicating with the control circuit sump 228.

At the same time that the 1I valve is being closed in response to opening of the 2I valve, the position of the 1D valve is being conditioned to be altered. Because of the pressurized condition of the control circuit condition valve labeled A (i.e. the valve A is in communication with the control circuit pump 226), pressurized control fluid is directed to the cylinder port 272 of the pilot operated check PO-1 associated with the 1D valve. Subsequently, as indicated by the arrows 337 through 339, flow to the pilot port of this valve PO-1 is provided through the 1I-C port. As previously stated in connection with FIG. 4, this flow through the 1I-C port is produced only when the 1I sleeve valve is moved to its upper closed position, thereby placing the 1I-C port in communication with the 1I-B control fluid chamber and the pressurized flow of control fluid thereto.

It will thus be appreciated that the closing of the 1I valve permits flow of a pilot volume of fluid to actuate the pilot piston 282 (FIG. 7A) of the PO-1 valve, thereby opening that valve PO-1 in two stages as previously discussed. Upon opening of the PO-1 valve, pressurized control fluid (that has passed through control circuit conditioning valve A from the

control circuit pump 226) enters the opening actuator chamber A of the 1D valve through the port 1D-A. This entering fluid illustrated by the arrows 340 and 341 causes the 1D valve to move from its upper closed position to its lower open position.

From the foregoing it is apparent that the position of the 1D valve is not altered until the 1I valve has completed, or nearly completed, its upward closing movement. Thus, pressurized power fluid is prevented from freely circulating between the power fluid pump 226 and the power fluid reservoir through the 1CV valve.

With reference to FIG. 7A, it may be seen that the check valve C-1 remains closed during the opening of the PO-1 valve and 1D. This closed position is maintained on the C-1 valve since the pressure on its piston 288 provided by the flow from the 1I-B chamber is balanced by the pressure of the opening actuator fluid for the 1D valve (which exists in the connecting chamber 176) and the valve spring.

Opening movement of the sleeve of the 1D valve results in responsive closing movement of the 3D valve (the 2D valve being already closed) by reason of the common connection of the B actuator chambers of these valves. Thus, actuator fluid displaced by the 1D valve through the 1D-B actuator port, moves along the path indicated by the arrows 342 through 344 into the 3D-B actuator port of the 3D valve.

It is readily apparent that closing movement of the 3D valve is permitted since the 3D-A actuator port is in communication with the control circuit sump 228 through the tanked control circuit condition valve labeled C. Flow of the actuator fluid displaced by the closing 3-D valve is illustrated by the arrows 345 and 346.

At this point it may be noted that the opening of the 1D valve not only causes responsive closing of the 3D valve but also signals the opening of the 3-PR valve. As previously mentioned in connection with the discussion of FIG. 9A1, the open 1D valve zeros the pressure on the pilot port of the 3-PR valve thereby permitting it to open. Because of the sequence of the signal which permits this opening, initiation of the precompression stroke lags the beginning of the suction and discharge strokes in time.

As will be subsequently discussed in connection with FIG. 9C2, the pilot operated check valve PO-3 has, in the previous phase of the pumping cycle, been opened by a pilot volume of fluid in a manner similar to that described above in connection with the PO-1 valve. Since the I-C ports pass fluid in only one direction, it will be appreciated that this pilot volume of fluid must be exhausted. In the FIG. 9A2 phase of the pumping cycle, this fluid is exhausted by closing of the PO-3 valve, before the pump cycle would again cause pressure to be presented to the pilot port of that valve.

This exhausting of the pilot volume of fluid is provided for by means of the check valve 164, labeled C-3 in the circuit drawings. Since the spring associated with the PO-3 valve is designed to be capable of producing more pressure than that which the spring associated with the C-3 valve can develop, the pilot volume of fluid is displaced through the C-3 valve and to the control circuit sump as indicated primarily by the arrow 347. Reference to FIG. 7 shows that this flow occurs by means of the connecting bore 176 between the check valve and the D-a1 bore in the manifold block 160.

In further connection with the operation of the pilot operated check valve PO-1, it should be again noted that the fluid path between the 1I-C port and the PO-1 valve is provided with a flow restrictor of the orifice type which is labeled O-1 (see also FIG. 7A) and may also be provided with a filter F-1. The orifice O-1 serves the dual purpose of limiting circuit flow from the port 1I-C when the control circuit conditioning valve A later becomes tanked as well as providing an additional control over the opening rate of the pilot operated check valve PO-1.

It will be remembered that control of the opening rate of the PO valves controls the opening rate of the D valves. This, in turn, limits the rate of decompression of the fluid end of the

power cylinder assemblies so as to prevent shock forces from being imposed upon the pump structure.

A summary of the condition of the control circuit conditioning valve A, B and C, along with the sequence of operation of the appropriate I and D valves associated with the phase of the cycle shown in FIG. 9A2 may be found in Table A2. With reference to this Table A2, it may readily be seen that a pressurized A valve and tanked B and C valves provide the necessary control circuit condition to permit substantially simultaneous, and responsive, shifting of the 2I and 1I valves. Shifting of the 1I valve in turn causes substantially simultaneous and responsive shifting of the 1D and 3D valves. The shifting of the 1D valve also provides for the conditioning of the 3PR valve.

During the simultaneous shifting of the related I and D valves, the valves are open while shifting. Power fluid flow is thus diverted between the power cylinder without imposing any pressure variations on the common pressurized fluid and reservoir conduits. Pulsations are thereby eliminated.

Also, smooth operation is further enhanced when the I and D valves are opened, because as they near their lower open position, the I-D and D-D ports permit fluid to pass from the A chambers to the B chambers (FIGS. 4 and 8). This flow, together with the previously described hydraulic cushion provided by the I-B and D-B dual passageways, prevents the sleeve valves from abruptly coming to a stop. It will also be remembered that the D ports supply needed fluid to the B chambers when there is insufficient fluid in the common closing B actuator chambers. Such a deficiency occurs, for example, when the pilot volume of fluid that opens the PO valves is exhausted to the reservoir 228 as above described.

Referring now to FIG. 9A3 and Table A3, the relationship between the 1FP cycling valve and the control circuit conditioning valves A, B and C (as shown in FIG. 9A2) will be described.

In FIG. 9A3, the control circuit condition flow assembly which operates the power circuit sleeve valves, and the power circuit valve assembly are illustrated schematically at 348 and 350, respectively as being interposed between the control circuit conditioning valves, A, B and C, and the three power cylinder assemblies. To accomplish positioning of the I and D valves of the control valve assemblies as illustrated in FIG. 9A1 by means of conditioned flow of control circuit fluid as illustrated in FIG. 9A2, it is necessary to insure that the C valve is tanked and the A valve is pressurized.

This positioning of the C and A valves is accomplished by tripping of the cycling valve labeled 1FP. Normally, the cycling valves, including 1FP are biased to a closed position as previously described. However, completion of the discharging function in the 1-40 power cylinder assembly causes the cam actuator 58 of the 1-42 piston rod assembly to trip the 1FP valve as indicated in phantom at 360. This discharging function, completed in the immediately preceding phase of the cycle, initiates the phase which is the subject of FIGS. 9A1, 9A2 and 9A3.

The opening of the 1FP valve, as indicated by the arrow 362, permits the flow of pressurized fluid through that valve from the control circuit pump 226 to the shifting port 252 of the A valve. This flow is shown by the arrows 363 through 378. Fluid pressure at this shifting port 252 places the valve A in its pressurized condition, thereby permitting pressurized control circuit fluid to be directed to the appropriate portions of the control circuit condition flow assembly 348, as previously discussed in relation to FIG. 9A-2.

Moreover, pressurized control fluid is also directed through the A valve along the flow path 379 through 384 to the shifting port 232 of the C valve. This pressurized flow results in the movement of the C valve to its tanked position so as to permit control circuit fluid to flow out of the closing sleeve valve actuators to the control circuit sump 228, as heretofore described. It will be appreciated that the control circuit conditioning valve labeled B remains unaffected by the tripping of the 1-FP valve.

It is now apparent that the sleeve valves I and D are shifted ultimately in response to the actuation of the cycling 1FP valves. However, these cam operated FP valves furnish only the pilot pressure signal to the control circuit conditioning valves, A, B and C, which then furnish the pilot pressure signals to the appropriate sleeve valve pilot ports, 2I-A, 1D-A, etc. The interposition of the control circuit conditioning valves in the control circuit is particularly desirable from the standpoint of maintaining pilot pressure on the I and D valves of the control valve assemblies CV after they have shifted and until they are to shift again.

As earlier noted, the control circuit conditioning valves are prevented from drifting after shifting in response to tripping of the cycling valve by means of the double cylinder lock valves, DCL-A, DCL-B and DCL-C, shown in the main circuit diagram of FIG. 8. For convenience these lock valves have not been illustrated in the cycle phase diagrams of FIG. 9.

With continued reference to FIG. 9A3 and Table A3, it may be seen that tripping of the 1FP valve which causes shifting fluid to move, and shifts the A and C valves to pressurized and tanked conditions, also results in flow of fluid to the reservoir 228. When the A valve is pressurized at one shifting port 252, control fluid is directed out of the opposite shifting port 234. This fluid moves along the path 385-389 to the sump 228 through the B valve which has been previously tanked.

Similarly, shifting of the C valve directs fluid to the reservoir 228 from the port 250, along the path 390-395. This path includes flow through the closed 3FP valve and its associated check valve 256.

Referring now to FIGS. 9B1, 9B2 and 9B3 as well as Tables B1, B2 and B3, the second phase of the pumping cycle will be briefly described. The symbols for the closed and open positions for the I and D valves of the control valve assemblies are the same as those used in connection with the description of the first phase of the pumping cycle.

As shown in FIG. B-1 and as indicated in Table B-1, the number 1-40 power cylinder assembly undergoes a precompression function in the second phase of the pumping cycle, while the 2-30 and 3-40 power cylinder assemblies are respectively in the suction and discharge state.

Flow of pressurized power circuit fluids through the open 3-I valve along the path 396-399 charges the 3-40 power cylinder to accomplish a discharge function at the 3-22 fluid end. Fluid displaced by the rod end in this 3-40 power cylinder assembly passes through the common rod end passage 61 to thereby cause the 2-46 power piston to undergo its suction stroke. Power fluid displaced from the blank end of the 2-40 power cylinder, in response to this suction movement, flows along the path indicated by the arrows 400-402, through the 2D valve and to the power circuit sump 208.

The small flow of power fluid through the 1PR valve and to the 1-40 cylinder, along the path 403-405, induces precompression in the 1-40 cylinder. This flow is the result of the opening of the 1PR valve in response to communication of its pilot port 1-194 with the sump 208 through the 2D valve, as indicated by the arrows 406 and 407.

It is readily apparent that the closed 1I, 1D, 2I and 3D valves as well as the closed 2PR and 3PR valves insure that power circuit fluid is directed to and from the power cylinder assemblies as required in this phase of the pumping cycle. Pilot pressure maintains the 3PR and 2PR valves closed by flow along the paths 408-409 and 410-411 respectively.

It should also be noted that the precompression stage in the 1-40 power cylinder assembly results in a displacement of rod end fluid through the passage 61. This fluid is directed to the 2-40 power cylinder assembly to enable completion of its suction function.

FIG. 2B and Table 2B illustrate the relationship between the control circuit conditioning valves A, B and C, and the I and D valves. With the B valve pressurized and the A and C valves tanked, as indicated by the arrows 412, 413 and 414, respectively, and as tabulated in Table B-2, pressurized control circuit fluid passes only through the B valve.

The path 415-417 of this fluid leads to the 3I-A port of the 3I valve, thus moving the 3I sleeve from its upper closed to its lower open position. Opening actuator fluid displaced through the 3I-B port causes the 2I valve to move from its lower, open position to its upper, closed position substantially simultaneously with the shifting of the 3I valve. This fluid flow is indicated by the arrows 418 and 419.

As the 2I valve opens, the 2I-C port is uncovered so as to cause displacement of the PO-2 valve by a pilot volume of control fluid, as indicated by the arrows 420-422. The path of the pilot volume of fluid includes the orifice O-2 and filter F-2.

Upon the opening of PO-2, pressurized power fluid passing through the valve B enters the 2D-A port, as shown at 423-424. This fluid opens the 2D valve so as to cause displacement of closing actuator fluids through the 2D-B port and into the 1D-B port along the path 425-426. This displaced fluid results in closing of the 1D valve substantially simultaneously with the movement of the 2D valve to its open position.

The 2I and 1D valves, having been moved to their closed positions, each displace fluid through the opening actuator ports 2I-A and 1D-A, as indicated by the arrows 427 and 428. This displaced fluid flows through the tanked A valve to the control circuit sump along the path 429-433.

The pilot volume of fluid previously employed to open the pilot operated check valve PO-1, as described in connection with FIG. 9A2, is also displaced to the control circuit sump, as indicated at 434. It will be remembered that the spring in the PO-1 valve is capable of developing more pressure than that in the C-1 check valve.

FIG. 9B3, illustrating the relationship between the cycling valve 2FP and the control circuit conditioning valves A, B and C shows, at 436, that the 2FP valve is tripped by the completion of the discharge function of the 2-40 power cylinder assembly. This discharge function had been initiated in the first phase of the pumping cycle.

Since the 2FP is open to pressure, as indicated at 438, pressurized control circuit fluid from the control circuit pump 226 passes along the control path 439-448 through the 2FP valve and to one shifting port 254 of the B valve. This B valve is thus shifted from the tanked position of the previous phase of the pumping cycle, to its pressurized position indicated by the arrow 449.

Pressurizing of the B valve permits power fluid to flow therethrough, along the path 450-454, to cause movement of the A valve to its tanked position. The C valve remains unaffected during the second phase of the cycle. The flow paths 455-460 and 461-465 respectively, indicate flow to the reservoir from shifting ports of the shifted A and B valves.

Referring now to FIGS. 9C1, 9C2 and 9C3 along with Tables C1, C2 and C3, the third phase of the pumping cycle may readily be understood. It will be appreciated that the valve symbols and flow arrow conventions are the same for these figures as those used in connection with the description of the first and second phases of the pumping cycle.

In Table C1, the discharging function of the 1-40 power cylinder assembly is indicated. This discharging function is accomplished since the 1I valve is opened and the 1D and 1PR valves are each closed, whereby power fluid flows to the blank end of 1-40 power cylinder assembly from the power circuit pump along the path 466-469. Discharging of the 1-40 power cylinder assembly displaces power fluid into the rod end of the 3-40 power cylinder assembly through the fluid end interconnection passage 61.

Thus, the 3-40 power cylinder assembly is urged into the suction state of the cycle. This suction function is permitted by reason of the closed 3I and 3PR valves (which prevent power fluid from resisting such a movement) and the open 3D valve, which places the blank end of the 3-40 power cylinder assembly in communication with the power circuit sump 208 along the path 470-471.

In FIG. 9C1 it will be seen that the 2I and 2D valves are both in their upper closed positions while the 2PR valve is open permitting the precompression flow of power fluid to the 2-40 power cylinder assembly. During precompression, fluid displaced from the rod end of the 2-40 power cylinder moves through the common rod end passage 61 into the 3-40 power cylinder assembly for completion of the suction function therein.

The open state of the 2PR valve which conditions the 2-40 power cylinder assembly for precompression is a result of flow from the pilot port 2-194 to the sump 208 as indicated by the arrows 472 and 473.

FIG. 9C2 and Table C2 reflect the relationship between the control circuit conditioning valves A, B and C and the I and D valves of the control valve assemblies. As indicated in those illustrations, the pressurized C valve provides for opening actuator control fluid to be supplied to the 1I-A actuator port along the path 474-477. Fluid is responsively displaced by the sleeve of the 1I valve through the 1I-B to the 3I-B port (path 478-480) to cause closing of the 3I valve.

The pressurized C valve also passes opening actuator fluid along path 481-483 to the 3D-A port. This fluid is permitted to enter the 3D-A port since the closing of the 3I valve causes opening of the PO-3 valve by flow 484-486 from the 3I-C port through the filter F-3 and orifice O-3.

As the 3D valve is opened, closing actuator fluid is displaced, along the path 487-488, through the 3D-B port to the 2D-B port to thereby cause the 2D valve to close.

Opening actuator fluid at the 2D and 3I valves, each of which had been caused to close in the third phase of the pumping cycle, is displaced through the 2D-A and 3I-A ports to the control circuit sump 228 along paths 489-491 and 492, 490-491. This fluid displacement is facilitated by the tanked position of the B valve.

The previously opened PO-2 valve moves to a closed position and displaces the previously utilized pilot volume of fluid to the control circuit sump also through the tanked B valve. This displacement is indicated at 492a.

Referring to FIG. 9C3 and Table C3 it will be apparent that the pressurized and tanked positions of the C and B valves is caused by the tripping of the FP valve. This cycling valve 3FP is tripped after the discharging function of the 3-40 power cylinder at the end of the second phase of the pumping cycle.

When the 3FP valve is tripped control circuit fluid from the control circuit pump 226 passes along the flow path 493-503 to the one side of the C valve urging it to a pressurized condition. Thereafter, control circuit fluid flowing along the path 504-508 through the C valve to shift the B valve to tanked condition. The A valve remains unaffected, and shifted fluid from the C and B valves flows to the sump 228 along paths 509-512 and 513-519, respectively.

Thus, through the previous description of the pumping cycle it may be seen that each pumping unit operates on a suction, precompression, discharge cycle out of phase with the cycle of the other pumping unit. All three pumping units perform only one function during any phase of the pumping cycle, and each function is continuously performed by at least one of the pumping units. With this arrangement, pulsations are eliminated at the fluid end in both the suction and the discharge lines and at the power end in both the power pressure and power reservoir lines since a constant pressure and flow exists in each of these lines.

The Automatic Stroke Control

In addition to properly conditioning the sleeve valves I and D of the control valve assemblies CV, the control circuit must also maintain the proper volume of fluid within the interconnected rod ends of the three power cylinders 40. At a given pump speed, this volume of fluid can vary because of leakage past a rod seal or a power cylinder piston. Moreover, variations in the distance that the piston rod assemblies 42 travel during precompression may occur because of variations in the

condition of the fluid end or power end valves. Of course, because of the normally closed rod end circuit, this variation in precompression stroke affects the stroke length of the other piston rod assemblies 42 during their suction and subsequent discharge strokes.

Referring again to FIG. 8, the operation of the circuit elements which serve to automatically correct stroking errors will now be described. Prior to this description, it should again be mentioned that the previously identified back position sensing, or BP, valve is the element upon which the initiation of the stroke correction function depends. At the end of each cycle phase in which the 1-40 power cylinder undergoes a suction function (see FIGS. 9A1, 9A2 and 9A3), the cam actuator 58 associated with the 1-42 piston rod assembly trips this BP valve provided that a full suction stroke is made.

In FIG. 8, it may be seen that the result of this tripping is the supply of pressurized control circuit fluid from the control circuit pump 226 to a shifting port 520 of the previously identified stroke control valve 258. This fluid is supplied only the path 521-522. Fluid displaced at the opposite shifting port 523 flows to the control circuit reservoir 228 through the 1FP valve. This flow occurs because the shifting port 252 of the A valve has already been supplied with fluid so that the A valve has been shifted to its pressurized position at this point in the cycle.

With pressure thus supplied to the shifting port 520, the stroke control valve 258 is shifted to a position to pass pressurized control fluid therethrough so as to maintain pilot pressure on the previously identified correction valves 216 and 218 associated with the rod end closed circuit. Unless this pilot pressure is so maintained, the correction valve 216 and 218 will permit power fluid to flow respectively from the accumulator 62 and the power circuit pump 210 to the rod end of the 1-40 power cylinder through the conduit means indicated at 220.

The source of pilot pressure provided through the shifted stroke control valve 258 exists in the circuit line 52 which is continuously pressurized directly from the control circuit pump 226, as illustrated by the path 525-526.

If, on the other hand, the BP valve is not tripped due to a short suction stroke by the 1-42 piston rod assembly, pressurized power fluid will not be supplied to the shifting port 520 of the stroke control valve 258. Therefore, the pilot ports 527 and 528 of the correction valves 216 and 218 will remain in communication with the alternate passage through the stroke control valve, indicated by the circuit line 529.

At this point in the cycle, the line 524 is pressurized through the valve port 530 of the control circuit conditioning valve C, thereby still maintaining pilot pressure on the valves 216 and 218. Previous reference to the tanked position of the valve C in connection with FIG. 9A3, reflected only the condition of the valve port 531 thereof which directs flow to the control circuit conditioned flow assembly 348. The port 430 of the C valve is always reversely conditioned, i.e. in this phase of the cycle it is pressurized. In the next phase of the cycle (see FIGS. 9B1, 9B2 and 9B3, when the 3FP valve is actuated to shift the control circuit conditioning valve C, the port 530 of this valve is then tanked.

Thus, pilot pressure is removed from the correction valves 216 and 228 and the pilot fluid flows to the control circuit sump 228 through the stroke control valve 258, the line 529 and the C valve. When this occurs, the correction valves 216 and 218 are opened to supply fluid to the rod end of the power cylinders. The supplied fluid provides the excess fluid needed to complete the suction stroke of the 3-42 piston rod assembly.

This suction stroke would otherwise have been short because of the short discharge stroke of the 1-42 piston rod assembly which had previously undergone a short suction stroke, failing to trip the BP valve.

It will be apparent that this failure to trip the BP valve when the 1-42 piston rod assembly is to undergo a suction stroke is the only condition that causes the correction valves 216 and

218 to supply power fluid to the rod ends of the power cylinder assemblies. At all other phases of the pumping cycle pilot pressure need not be supplied through the shifted stroke correction valve 258 since, during these other phases, the port 530 of the C valve is pressurized. Therefore pilot pressure is maintained, without shifting, through the line 529.

In normal operation when the correct suction stroke in the 1-40 power cylinder results in tripping of the BP valve and shifting of the stroke correction valve 258, provision must be made for resetting the shifted valve. Such resetting is accomplished at the next phase of the cycle in which the 1FP valve is tripped. The pressurized fluid passing through this 1FP (FIG. 9A3) is also directed to the shifting port 523 of the valve 258, along the path 532-533 (FIG. 8), to cause resetting. Fluid exiting the opposite shifting port 52 passes through a check valve 534 associated with the BP valve, and to the control circuit sump 228.

The fact that a short suction stroke in the 1-40 power cylinder assembly will result in supply of needed power fluid to the rod ends at a correct portion of the cycle having been described, it remains only to indicate the manner in which a short suction stroke will always occur in the 1-40 power cylinder assembly, ultimately, at any time there is a stroking error.

This may readily be appreciated when the interrelation of the rod ends of the power cylinders 40 is considered. Since the volume of fluid displaced from the rod end of a precompressing power piston 46 flows into the rod end of one other power cylinder, and the volume displaced from the rod end of a discharging piston flows into the rod end of the second other power cylinder, variations in the distance traveled during precompression will always affect the suction stroke length of the other two cylinders.

For example, if it assumed that the 3-46 power piston makes an abnormally long precompression stroke, (FIG. 9A1) there will be more than sufficient fluid directed to the rod end of the 1-40 power cylinder than that needed to complete the suction stroke therein. This excess fluid is directed to the accumulator 62 through the conduit means 220 and the check valve 214. The excess distance traveled by the 3-46 piston during precompression necessarily results in a short discharge stroke in the 3-40 power cylinder assembly.

Thus, at this point in the cycle (FIG. 9B1) the 2-40 power cylinder assembly will not undergo a complete suction stroke. This necessarily results in a short discharge stroke in the 2-40 power cylinder assembly at the next phase of the cycle (FIG. 9C1). It will be readily apparent that this short discharge stroke will result in the short suction stroke in the 1-40 power cylinder assembly thereby initiating the stroke correction cycle as described above.

Next, it may be assumed that the 3-46 power cylinder assembly fails to move during its precompression stroke (FIG. 9A1). This immediately results in a short suction stroke in the 1-40 power cylinder assembly, thereby initiating a stroke correction cycle as described above.

It should be here noted that, in such a situation, the 2-40 power cylinder assembly will be provided with more than enough rod end fluid than that needed to move the 2-46 piston to its normal back position when the 3-40 power cylinder assembly subsequently undergoes an abnormally long discharge stroke. This will result in fluid stored in the accumulator. Replenishing will occur by the supply of fluid to the rod end circuit during correction of the next 3-40 suction stroke as described above.

Similarly, it may be shown that all other stroking errors not specifically described above will eventually result in a short suction stroke in the 1-40 power cylinder assembly so as to initiate a stroke correction cycle.

It will be appreciated that the BP valve and the stroke correction valve circuitry which sense and correct a short suction stroke has been illustrated in connection with the 1-40 power cylinder assembly. However, a similar valve arrangement may be associated with any or all of the other power cylinder as-

semblies. In practice, this BP valve has been used in connection with the number 2 power cylinder assembly.

SUMMARY OF ADVANTAGES

Thus, it may be seen that in following the present invention an improved multiplex pump having a precompression function is provided.

Particularly significant is the fact that this multiplex pump provides non-pulsating suction flow as well as discharge flow. Of further significance is the fact that this pump may be fluid operated with constant pressure flow of power fluid into and out of the power end of the pump. Although the non-pulsating flow at the fluid and power ends of the pump has been described in connection with a triplex unit, it will be readily apparent that a double acting duplex pump could be provided with this feature. Therefore, the term pumping unit, as used herein, embraces each of the individual chambers and associated elements which operate on the pumped fluid.

Of independent significance are the control valve assemblies of the present invention which establish constant pressure and flow of power fluid into and out of the pump. The related advantage of smooth decompression of the power cylinder flows from the means for opening the discharge control valves in two stages.

Also of importance is the provision of a multiplex pump, of the precompression type, with means for automatically regulating the pumping strokes. In this connection, the responsive stroking of the pump of the present invention is also significant insofar as it provides for smooth operation.

The particular interrelation between the power circuit and the control circuit of the present invention presents added advantages since, among other features, the control circuit not only causes movement of the control valves of the power circuit, but also monitors these valves so that they remain in position during each phase of the cycle.

Although the present invention has been described in connection with one preferred and illustrated embodiment, it will be appreciated by those skilled in the art that additions, modifications, substitutions and deletions not specifically described may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. In a fluid operated multiplex pump, a power unit comprising,
 - at least three power cylinders each having a power end for receiving and discharging power fluid,
 - a control valve assembly associated with each of said power ends, each of said control valve assemblies comprising,
 - inlet valve means for selectively establishing fluid communication between one of said power ends and a source of pressurized fluid common to each of said inlet valve means,
 - discharge valve means for selectively establishing fluid communication between one of said power ends and a power fluid reservoir common to each of said discharge valve means, and
 - precompression valve means for selectively establishing fluid communication between said source of pressurized fluid and one of said power ends through a fluid flow reducing means, and
 - cyclically operable control means for selectively opening and closing said inlet valve means, said discharge valve means, and said precompression valve means for continuous flow between said power ends and both said said common source of pressurized fluid and said common power fluid reservoir.
2. A power unit in a fluid operated multiplex pump according to claim 1 wherein:
 - said cyclically operable control means provides said selective communication between each of said power ends and said common power fluid reservoir in two stages limiting the rate of decompression of said power ends.

3. A power unit in a fluid operated multiplex pump according to claim 1 wherein said cyclically operable control means includes:
 - pressurized power fluid flow diverting means for shifting a closed inlet valve means of one of said control valve assemblies to an open position while responsively shifting an open inlet valve means of another of said control valve assemblies to a closed position, with both said inlet valve means being open while shifting, and
 - power fluid reservoir flow diverting means for shifting a closed discharge valve means of said another one of said control valve assemblies to an open position while responsively shifting an open discharge valve of a third one of said control valve assemblies to a closed position, with both said discharge valve means being open while shifting.

4. A power unit in a fluid operated multiplex pump according to claim 3 wherein said cyclically operable control means further includes:
 - means for operating said power fluid reservoir flow diverting means in response to operation of said pressurized power fluid flow diverting means.

5. A power unit in a fluid operated multiplex pump according to claim 3 including:
 - precompression power fluid flow diverting means operable to open a closed said precompression valve means of said third one of said control valve assemblies in response to opening of said discharge valve means of said another one of said control valve assemblies.

6. In a fluid operated multiplex pump, a power unit comprising:
 - at least three power cylinders having rod ends interconnected in a normally closed fluid circuit, and
 - each of said power cylinders being operable in a cycle including suction, precompression and discharge stages with the sum of the amounts of rod end fluid displaced during a complete discharge stage in one power cylinder and a complete precompression stage in another power cylinder providing the amount of rod end fluid needed to complete a suction stage in a third power cylinder.

7. A power unit in a fluid operated multiplex pump according to claim 6 and including:
 - accumulator means for removing fluid from said normally closed fluid circuit in response to a stroking error resulting in supply, to the rod end of one of said power cylinders in its suction stage of the cycle, of a greater amount of rod end fluid than that needed to complete that suction stage.

8. A power unit in a fluid operated multiplex pump according to claim 7 including:
 - stroke correction valve means for supplying fluid to said normally closed fluid circuit in response the sensing of an incomplete suction stage, in one of said power cylinders, caused by said stroking error.

9. In a fluid operated multiplex pump, a power unit comprising:
 - at least three power cylinders each having a blank end and a rod end defined by power piston and piston rod assemblies received therein, said power piston and piston rod assemblies being cyclically reciprocable in said power cylinders to perform suction, precompression and discharge strokes,
 - power circuit means for cyclically supplying pressurized power fluid to said blank ends to initiate compression and precompression strokes, in said power cylinders and for exhausting power fluid from said blank ends during a suction stroke,
 - rod end circuit means for providing a normally closed fluid circuit between said rod ends of said power cylinders,
 - said rod end circuit means including accumulator means for removing fluid from said rod end circuit means in response to a stroking error of one of said power piston and piston rod assemblies,

cam actuator means on each of said power piston and piston rod assemblies,

cycling follower means, actuatable by each of said cam actuator means, for sensing the completion of a discharge stroke of each of said power piston and piston rod assemblies, and for initiating cycle change, in response to actuation, by operating said power circuit means, and

at least one stroke correction follower means actuatable by one of said cam actuator means, for sensing the completion of a suction stroke by one of said power piston and piston rod assemblies, and for initiating supply of fluid to said rod end circuit in the absence of actuation by said one of said cam actuator means.

10. A power unit comprising:

at least three power cylinders each having a power end for receiving and discharging power fluid,

a control valve assembly associated with each of said power ends, each of said control valve assemblies comprising, inlet valve means for selectively establishing fluid communication between one of said power ends and a source of pressurized fluid common to each of said inlet valve means,

discharge valve means for selectively establishing fluid communication between one of said power ends and a power fluid reservoir common to each of said discharge valve means, and

third valve means for selectively establishing fluid communication between said source of pressurized fluid and one of said power ends through a fluid flow reducing means, and

cyclically operable control means for selectively opening and closing said inlet valve means, said discharge valve means, and said third valve means for continuous flow between said power ends and both said common source of pressurized fluid and said common power fluid reservoir.

11. A power unit according to claim 10 wherein:

said cyclically operable control means provides said selective communication between each of said power ends and said common power fluid reservoir in two stages limiting the rate of decompression of said power ends.

12. A power unit according to claim 10 wherein said cyclically operable control means includes:

pressurized power fluid flow diverting means for shifting a closed inlet valve means of one of said control valve assemblies to an open position while responsively shifting an open inlet valve means of another of said control valve assemblies to a closed position, with both said inlet valve means being open while shifting, and

power fluid reservoir flow diverting means for shifting a closed discharge valve means of said another one of said control valve assemblies to an open position while responsively shifting an open discharge valve of a third one of said control valve assemblies to a closed position, with both said discharge valve means being open while shifting.

13. A power unit according to claim 12 wherein said cyclically operable control means further includes:

means for operating said power fluid reservoir flow diverting means in response to operation of said pressurized

power fluid flow diverting means.

14. A power unit according to claim 12 including:

restricted power fluid flow diverting means operable to open a closed said third valve means of said third one of said control valve assemblies in response to opening of said discharge valve means of said another one of said control valve assemblies.

15. A power unit comprising:

at least three power cylinders having rod ends interconnected in a normally closed fluid circuit, and

each of said power cylinders being operable in a cycle including retraction, limited extension and extension stages with the sum of the amounts of rod end fluid displaced during a complete extension stage in one power cylinder and a complete limited extension stage in another power cylinder providing the amount of rod end fluid needed to complete a retraction stage in a third power cylinder.

16. A power unit according to claim 15 and including:

accumulator means for removing fluid from said normally closed fluid circuit in response to a stroking error resulting in supply, to the rod end of one of said power cylinders in its retraction stage of the cycle, of a greater amount of rod end fluid than that needed to complete that retraction stage.

17. A power unit according to claim 16 including:

stroke correction valve means for supplying fluid to said normally closed fluid circuit in response the sensing of an incomplete retraction stage, in one of said power cylinders, caused by said stroking error.

18. A power unit comprising:

at least three power cylinders, each having a blank end and a rod end defined by power piston and piston rod assemblies received therein, said power piston and piston rod assemblies being cyclically reciprocable in said power cylinders to perform retraction, limited extension and extension strokes,

power circuit means for cyclically supplying pressurized power fluid to said blank ends to initiate extension and limited extension strokes, in said power cylinders and for exhausting power fluid from said blank ends during a retraction stroke,

rod end circuit means for providing a normally closed fluid circuit between said rod ends of said power cylinders, said rod end circuit means including accumulator means for removing fluid from said rod end circuit means in response to a stroking error of one of said power piston and piston rod assemblies,

cam actuator means on each of said power piston and piston rod assemblies,

cycling follower means, actuatable by each of said cam actuator means, for sensing the completion of an extension stroke of each of said power piston and piston rod assemblies and for initiating cycle change, in response to actuation, by operating said power circuit means, and at least one stroke correction follower means actuatable by one of said cam actuator means, for sensing the completion of a retraction stroke by one of said power piston and piston rod assemblies, and for initiating supply of fluid to said rod end circuit in the absence of actuation by said one of said cam actuator means.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,662,652 Dated May 16, 1972

Inventor(s) Clinton W. Cole

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Figure 9A1, read reference character "3-282" as --3-82--.

In Figure 9A2, add the reference character "C-3" and a lead line extending therefrom to the check valve shown in an open position adjacent the flow arrow "347".

In Figure 9A2, read reference character "30-B" as --3D-B--.

Col. 6, line 9, change "24" (second occurrence) to --40--.

Col. 6, line 37, change "is" to --in--.

Col. 10, line 24, before "flow" italicize the letter "a".

Col. 10, line 50, change all three letters "c" and the term "3-I" to regular roman type.

Col. 10, line 59, change "127" to --172--.

Col. 12, line 7, after "bores", insert --with the apertured fittings--.

Col. 12, line 8, change "188" to --182--.

Col. 13, line 26, change "power" to --control--.

Col. 13, line 46, change "power" to --control--.

Col. 14, line 24, delete "266".

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,662,652

Dated May 16, 1972

Inventor(s) Clinton W. Cole

- 2 -

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 14, line 70, change "266" to --166--.

Col. 16, line 56, delete "1-182" and insert --1-82--.

Col. 17, line 36, change "1-A" to --I-A--.

Col. 20, line 34, change "fo" to --of--.

Col. 20, line 70, change "2B" first occurrence to --9B2--.

Col. 20, line 70, change "2B" second occurrence to --B2--.

Col. 21, line 8, change "opens" to --closes--.

Col. 22, line 68, change "perperly" to --properly--.

Col. 23, line 19, change "only" to --along--.

Col. 23, line 32, change "valve" to --valves--.

Col. 23, line 38, change "52" to --524--.

Col. 23, line 40, delete "525".

Col. 23, line 41, change "dur" to --due--.

Col. 23, line 48, change "524" to --529--.

Col. 23, line 54, change "430" to --530--.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,662,652 Dated May 16, 1972
Inventor(s) Clinton W. Cole - 3 -

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 24, line 15, change "52" to --520--.

Col. 24, line 19, change "sypply" to --supply--.

Col. 24, line 32, change "is" to --in--.

Claim 1, at Col. 25, line 58, delete "and".

Claim 1, at Col. 25, line 68, delete the first occurrence of "said".

Claim 9, at Col. 26, line 67, delete the comma after "strokes" and insert a comma after "cylinders".

Claim 18, at Col. 28, line 39, delete the comma after "strokes" and insert a comma after "cylinders".

Signed and sealed this 6th day of February 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents