United States Patent [19]

Cole

[11] **3,847,511**

[45] **Nov. 12, 1974**

[54] **HYDRAULICALLY POWERED TRIPLEX PUMP AND CONTROL SYSTEM THEREFOR**

[75] Inventor: **Clinton W. Cole,** Duncan, Okla.

[73] Assignee: **Halliburton Company,** Duncan, Okla.

[22] Filed: **Oct. 16, 1973**

[21] Appl. No.: **406,967**

[52] **U.S. Cl.**.................. **417/342,** 417/346, 137/596, 137/625.68

[51] **Int. Cl.**........................ **F04b 17/00,** F04b 35/04

[58] **Field of Search**............ 417/342, 346, 339, 900

[56] **References Cited**

UNITED STATES PATENTS

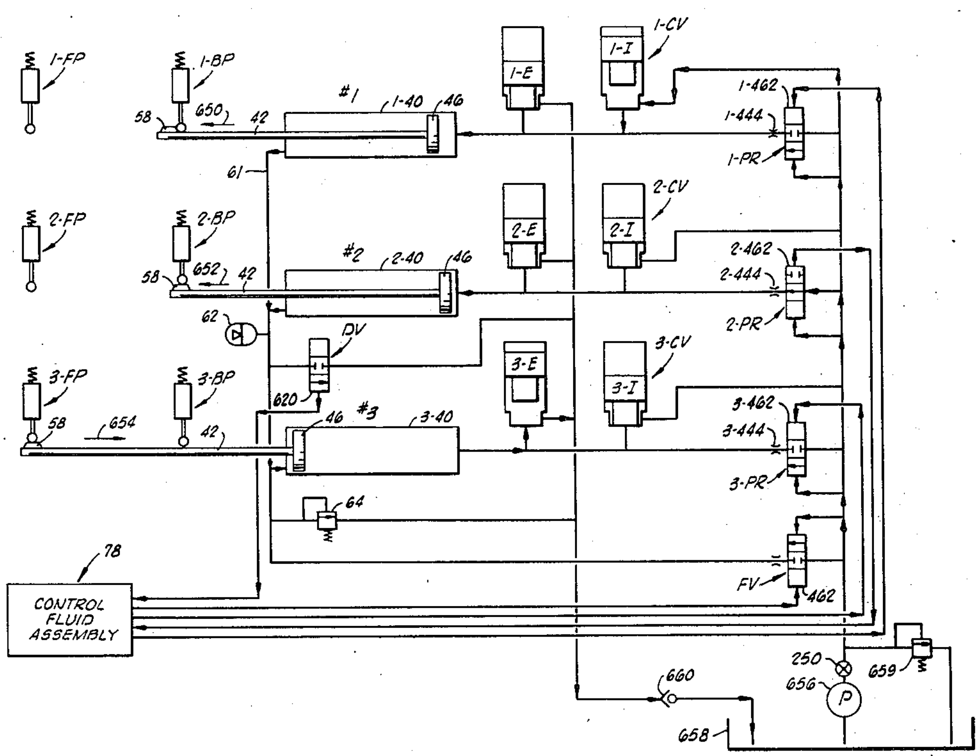
3,650,638	3/1972	Cole	417/346
3,773,438	11/1973	Hall et al.	417/346
3,778,193	12/1973	Reinert	417/342

Primary Examiner—John J. Vrablik
Assistant Examiner—Richard E. Gluck
Attorney, Agent, or Firm—John H. Tregoning

[57] **ABSTRACT**

A hydraulically powered triplex 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 various phases of the pumping cycle. Precompression valves, a fill valve and a dump valve are operated by the control circuit to provide additional conditioning of power circuit flow to provide the precompression phase and to correct for variations in pumping unit stroke length. A hydraulically operated shut off valve is employed to selectively isolate the multiplex pump from a source of pressurized power fluid. The power end of the pumping units include power cylinders which may be fluid interconnected at their rod ends so that operations in each power cylinder affect operations in the other cylinders.

3 Claims, 20 Drawing Figures



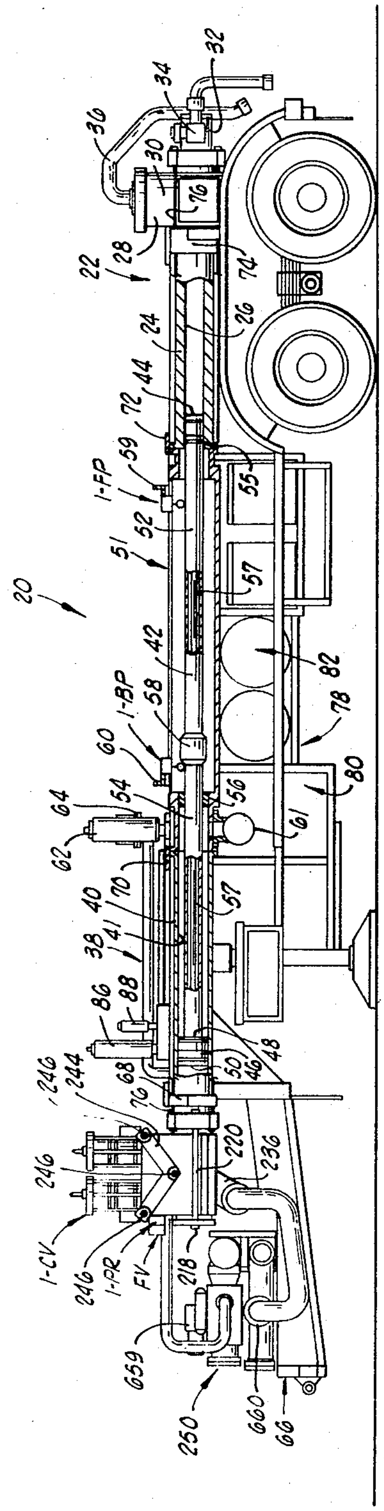


FIG. 1

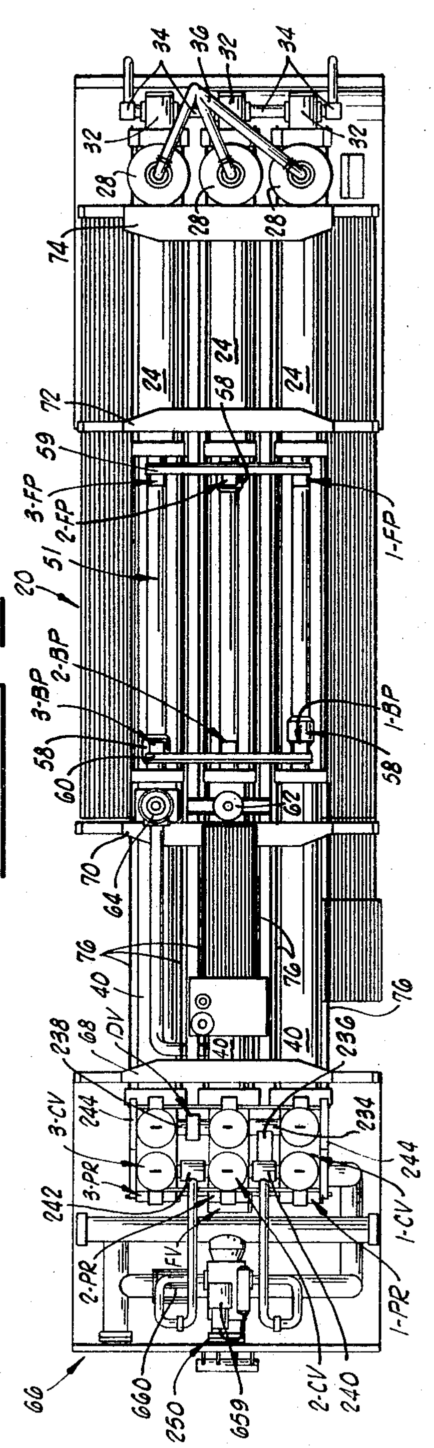


FIG. 2

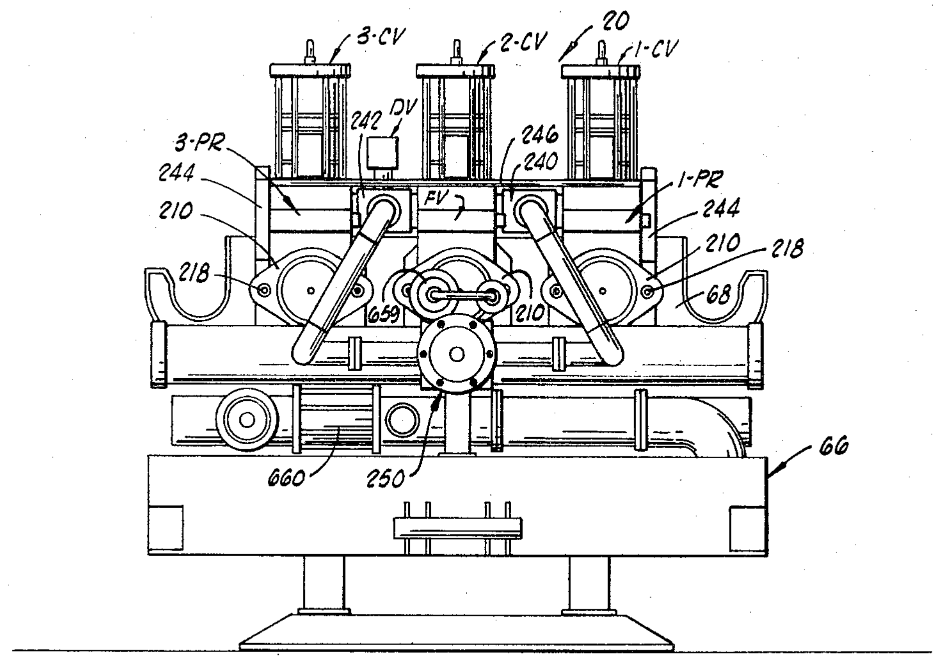

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FIG. 3

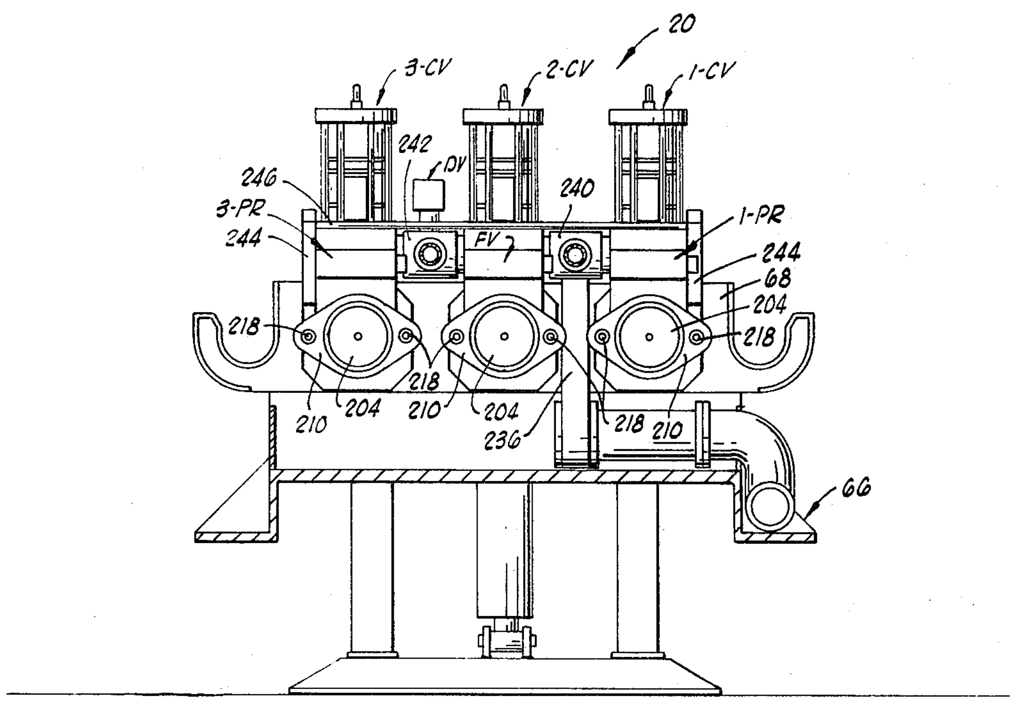
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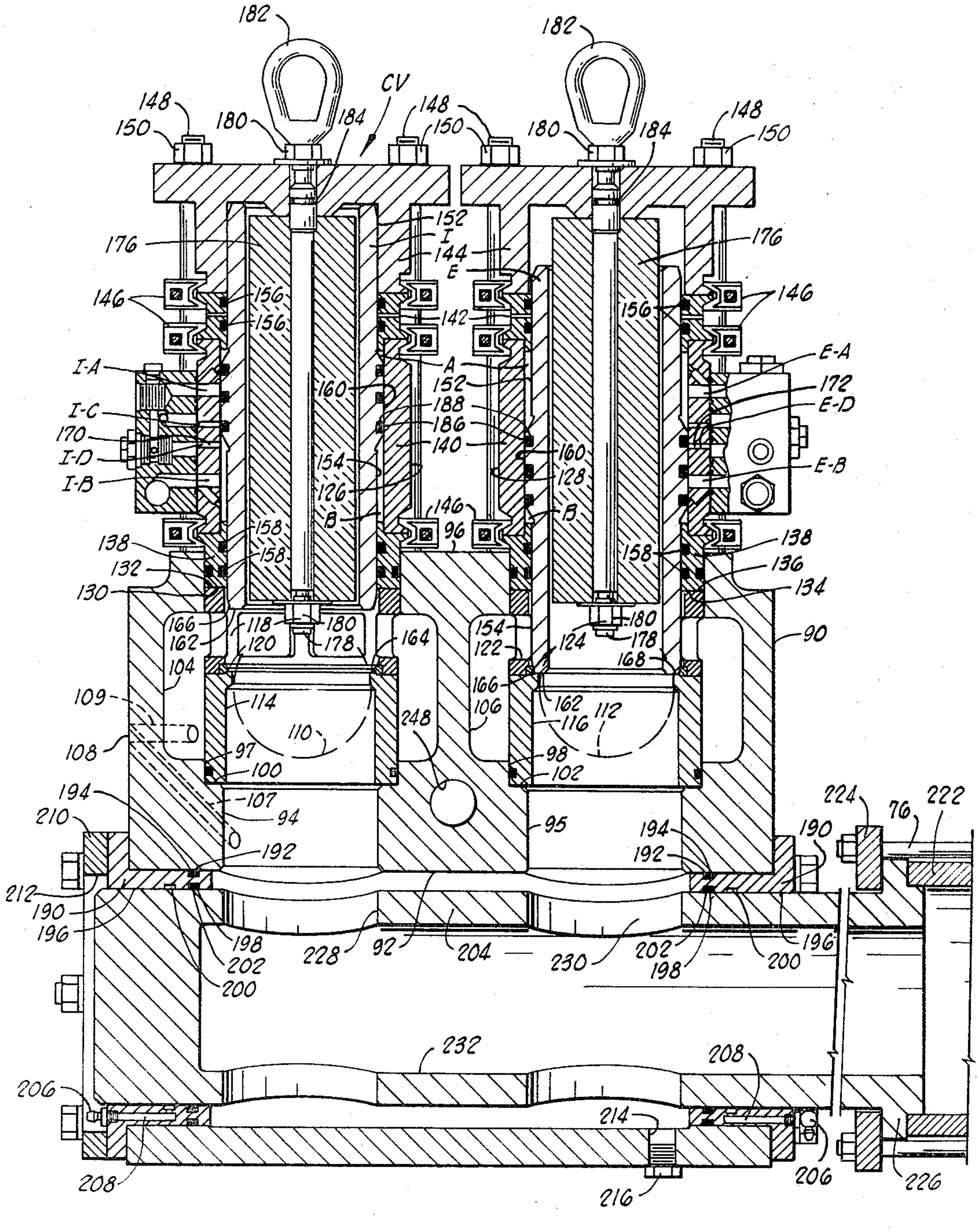
FIG. 4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E-A
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E-D
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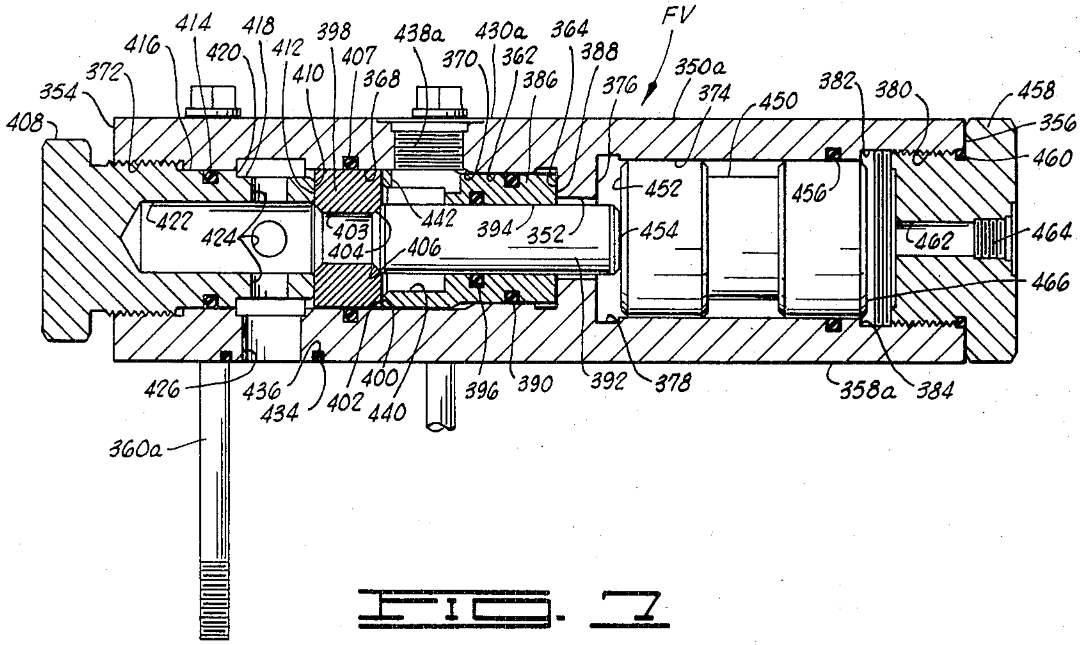
FIG. 5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350a
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380
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464
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FIG. 7

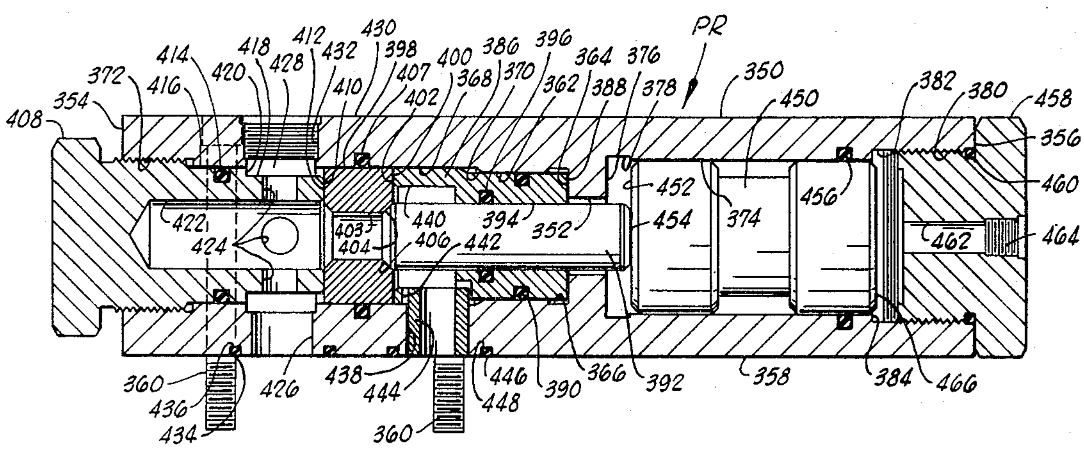
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FIG. 6

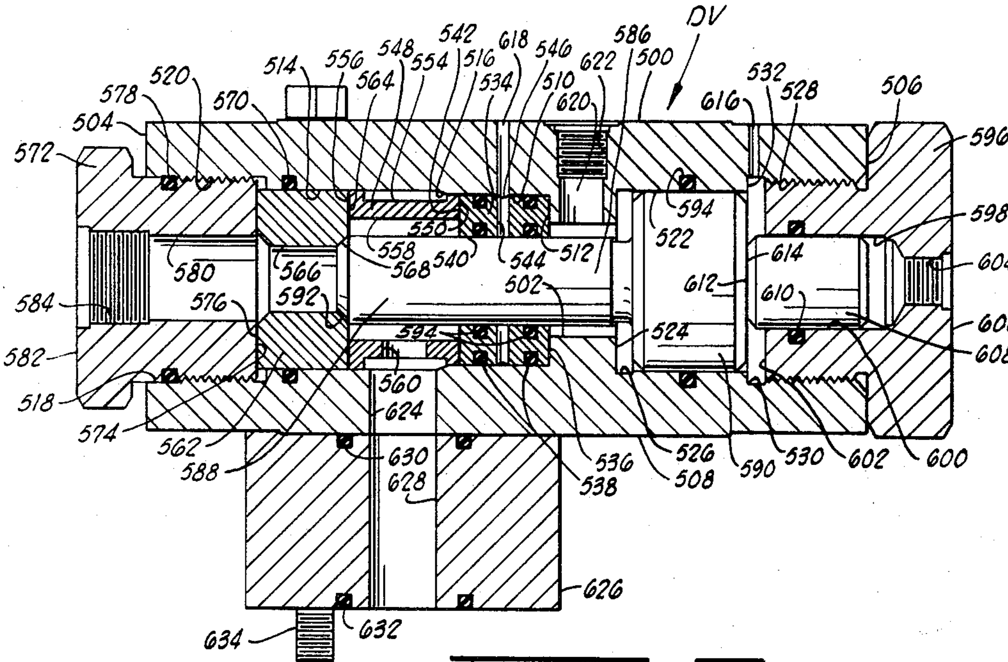


FIG. 8

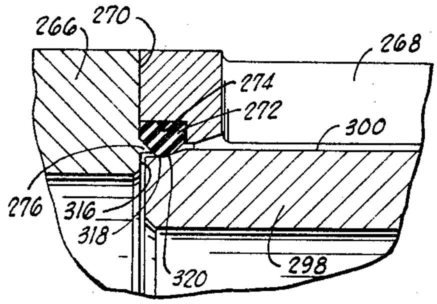


FIG. 9A

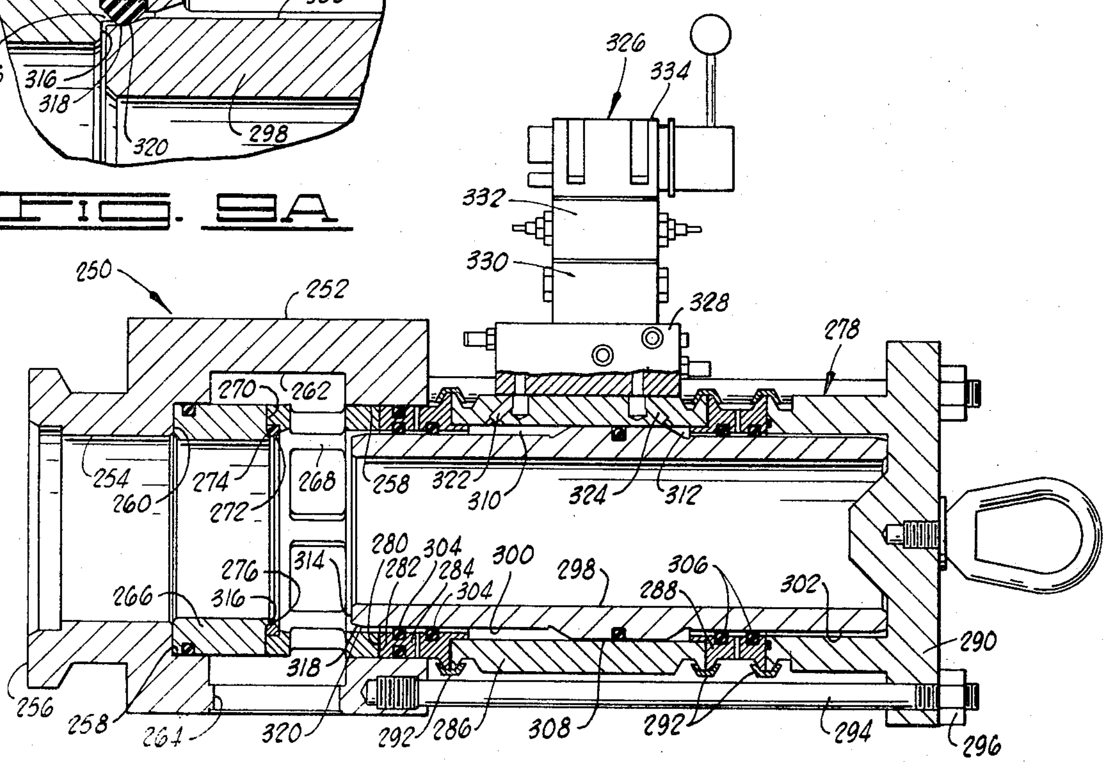
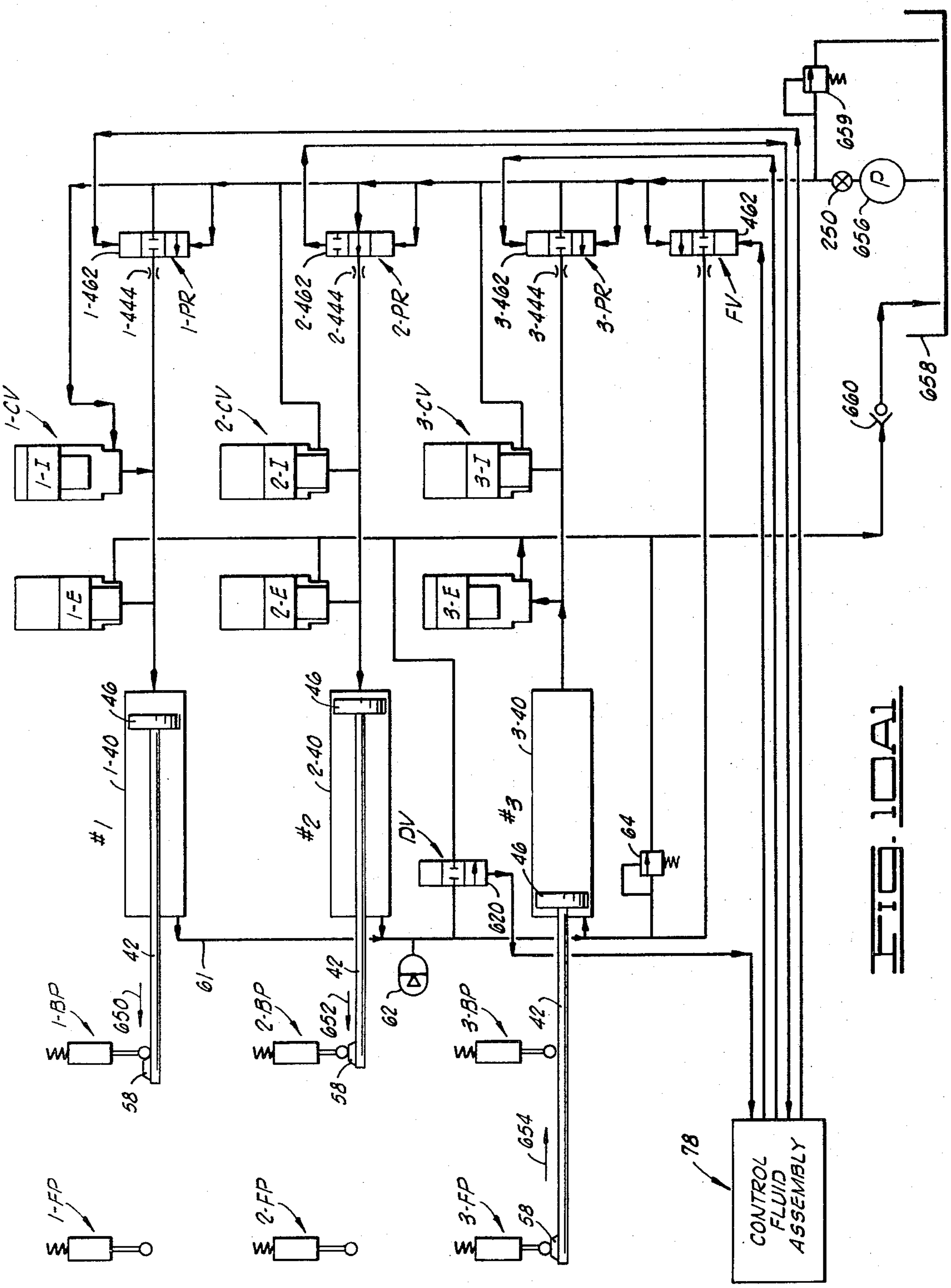


FIG. 9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62
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CONTROL
FLUID
ASSEMBLY

FIG. 10A

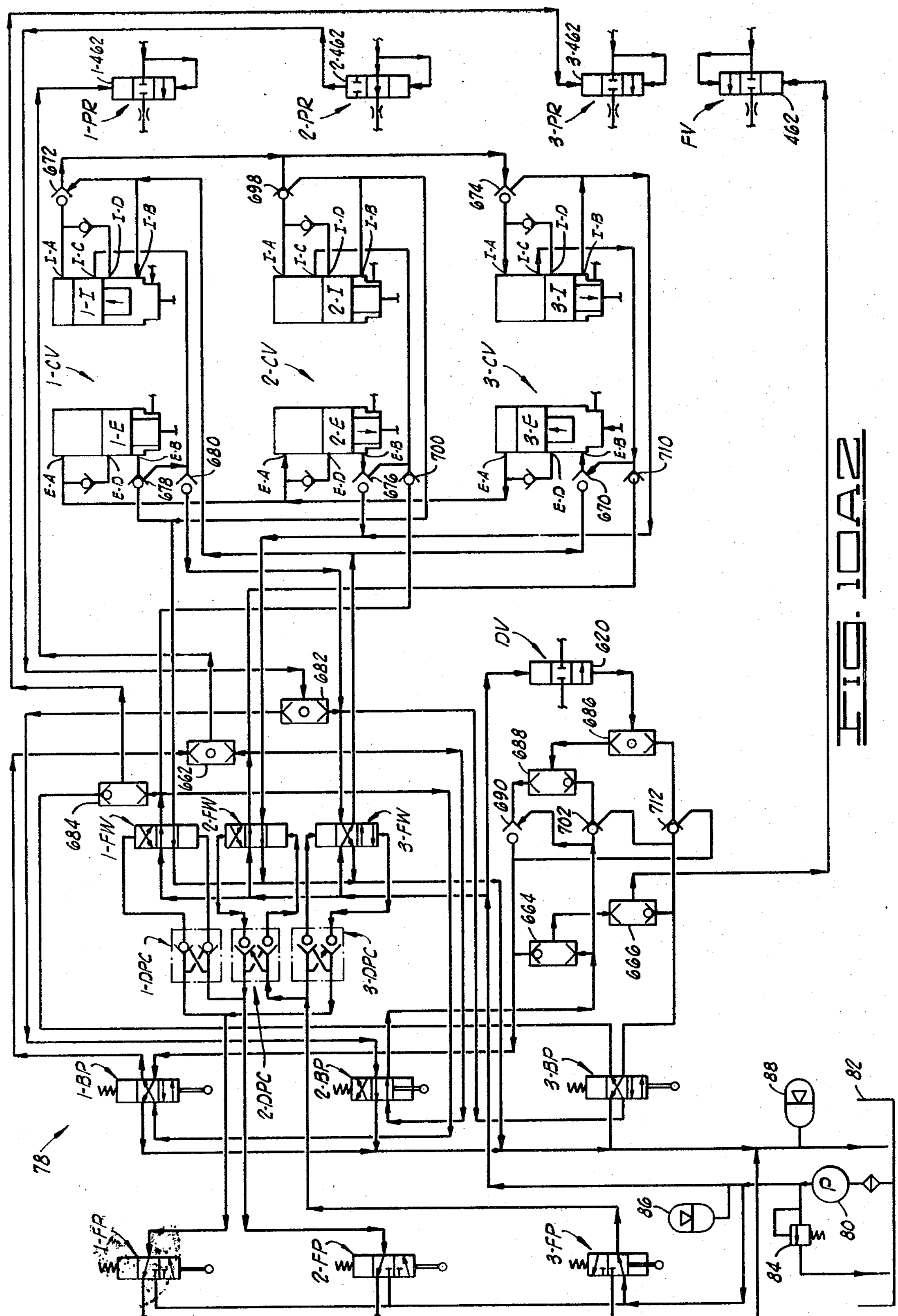
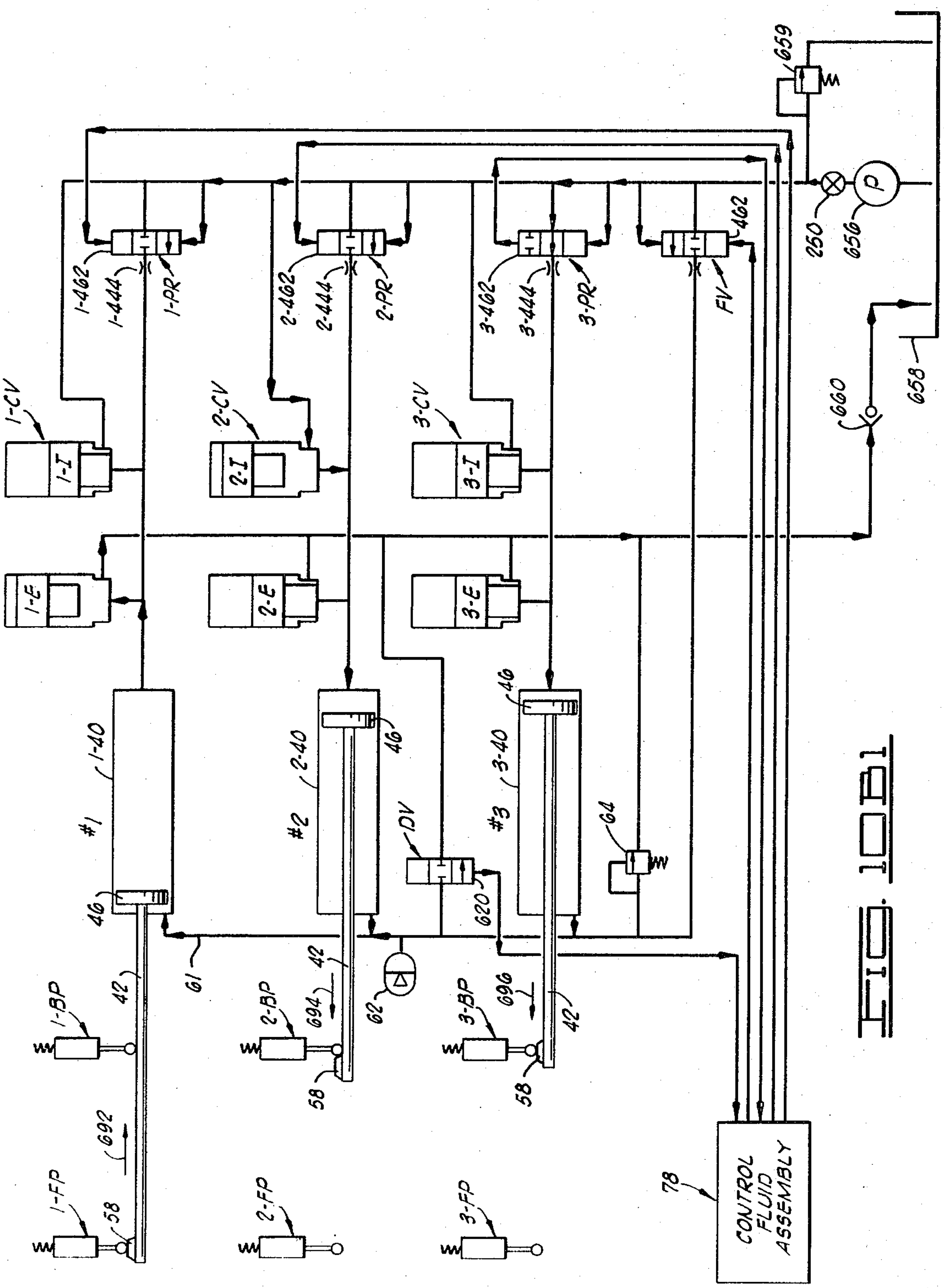


FIG. 10A2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CONTROL FLUID ASSEMBLY

FIG. 10B

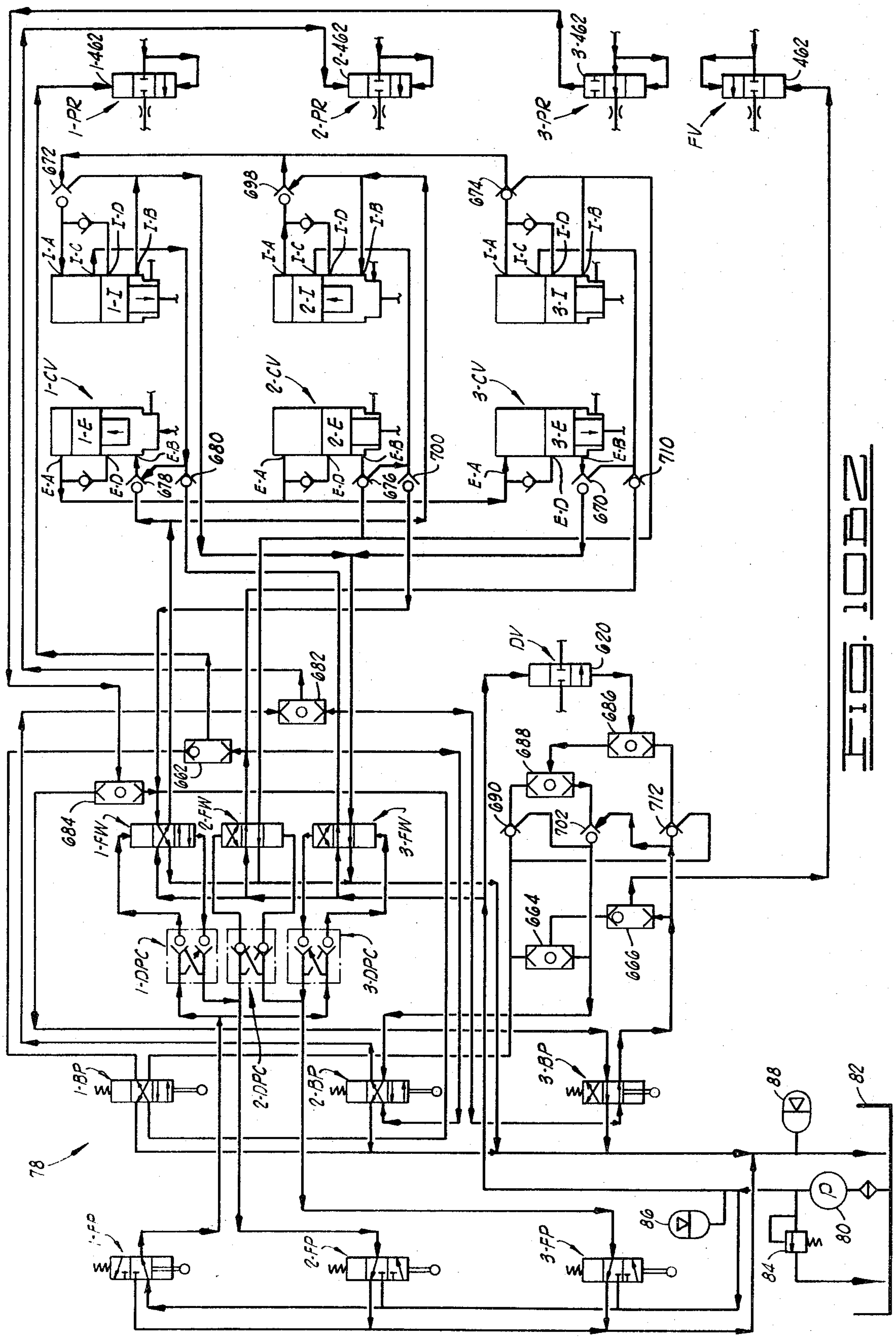
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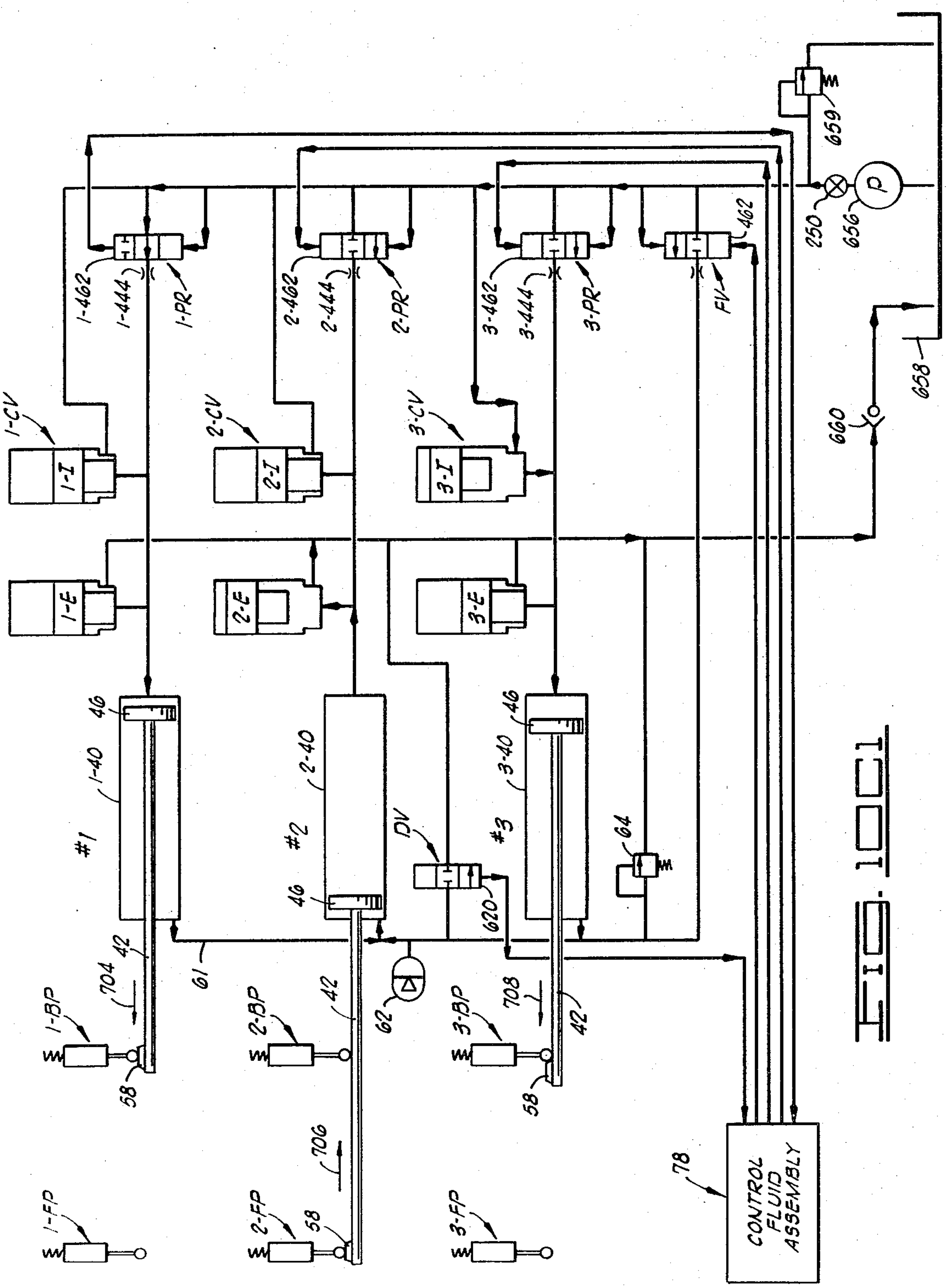
FIG. 10B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CONTROL FLUID ASSEMBLY

FIG. 10C1

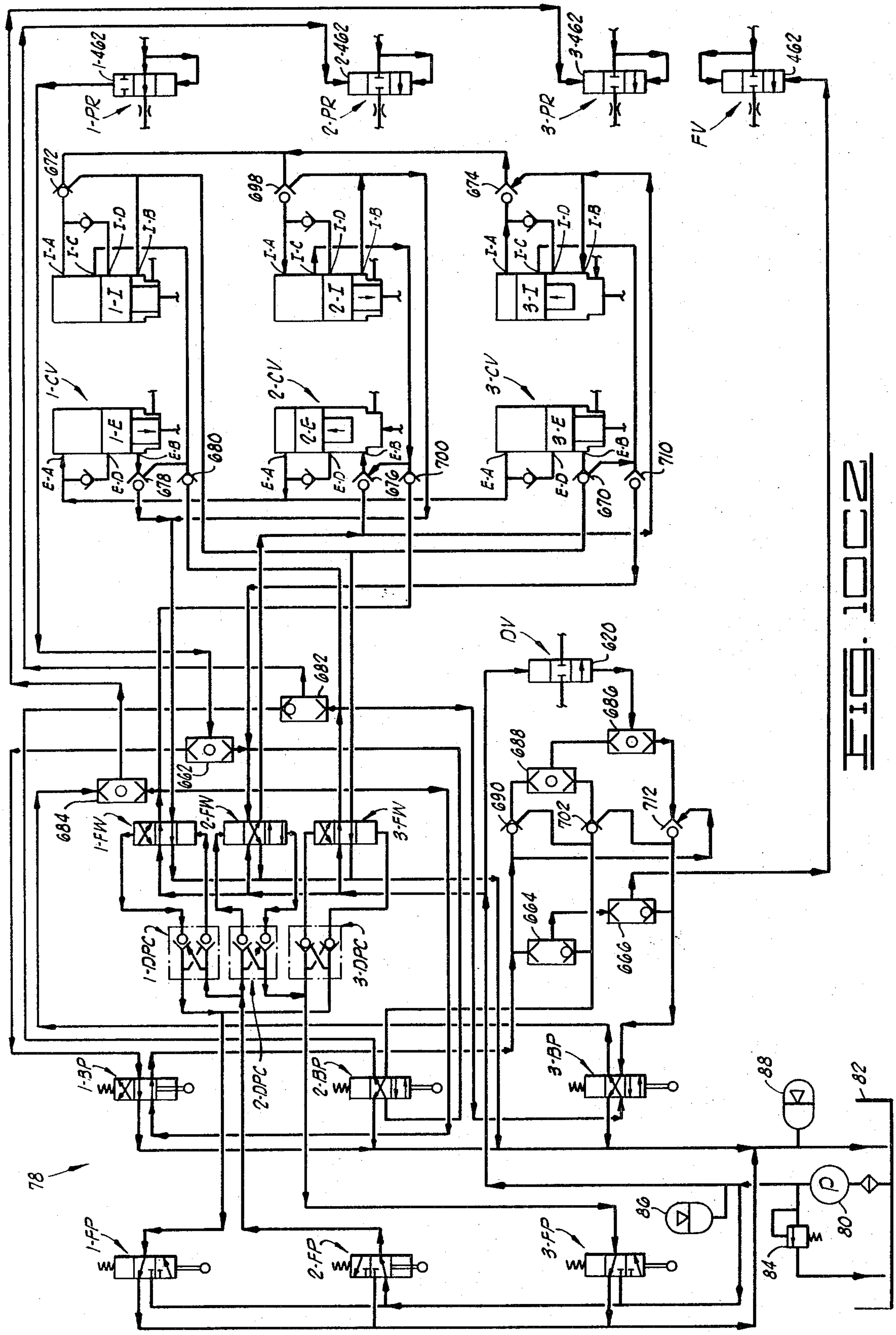
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FIG. 10C2

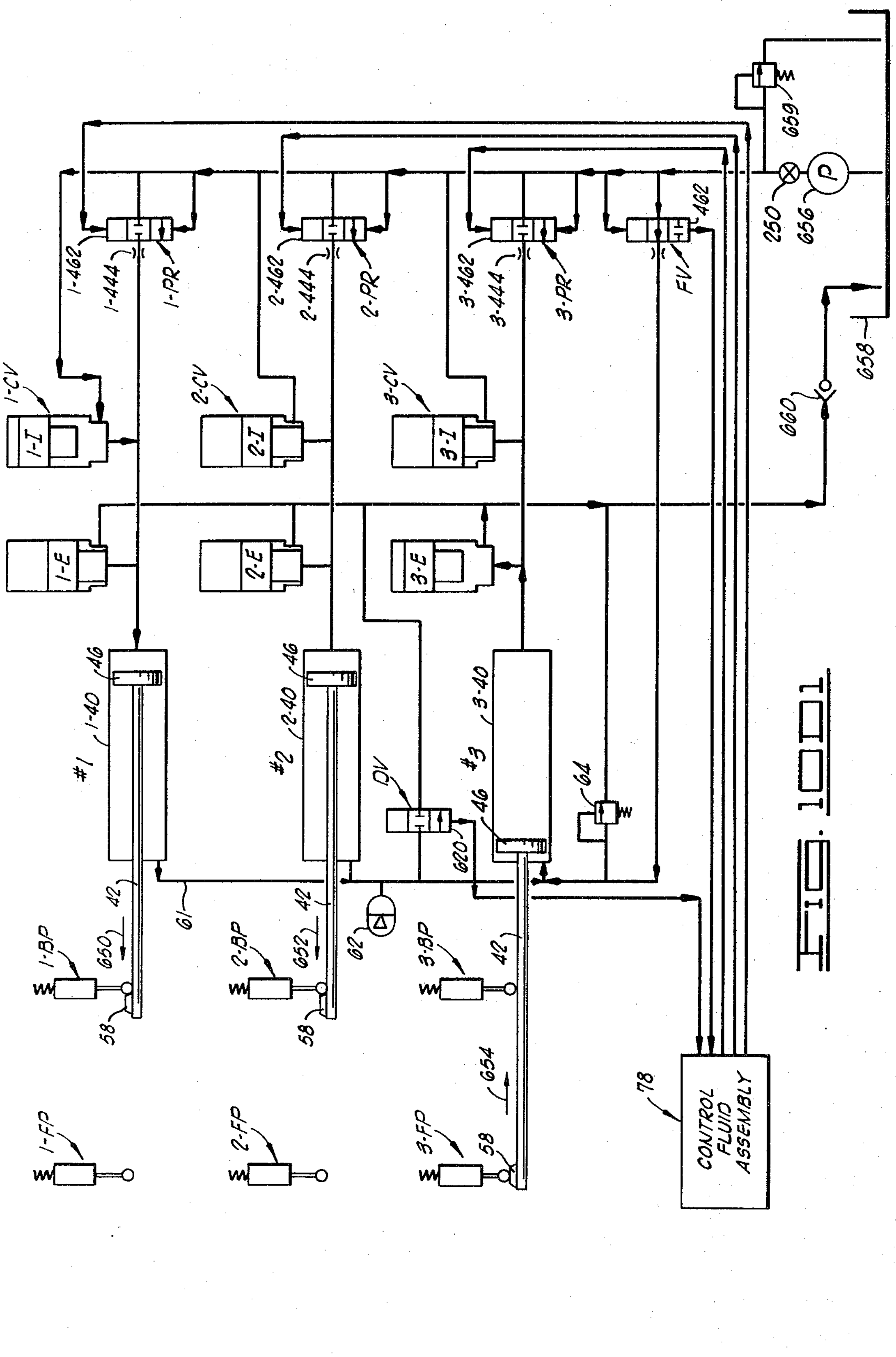
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FIG. 10

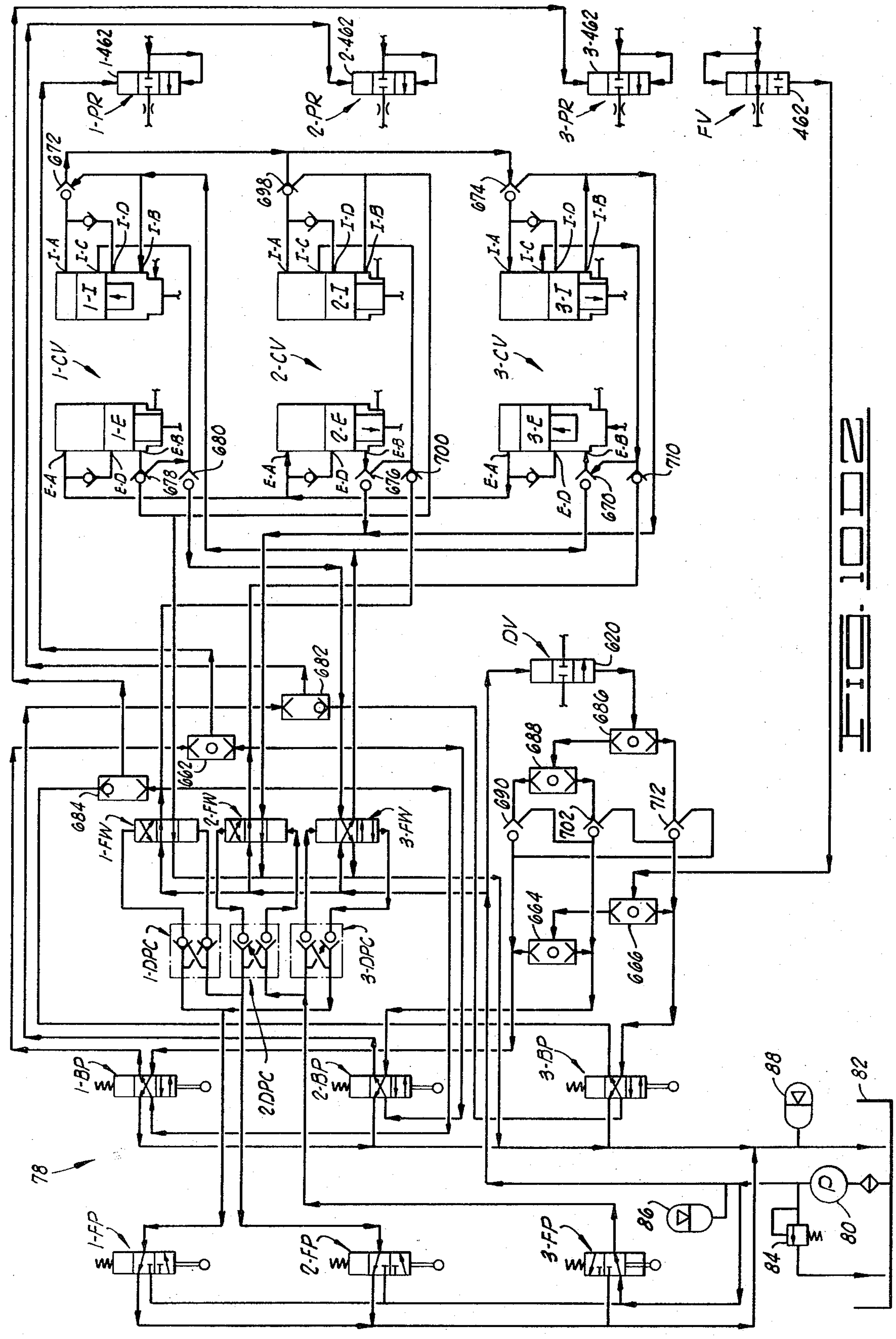
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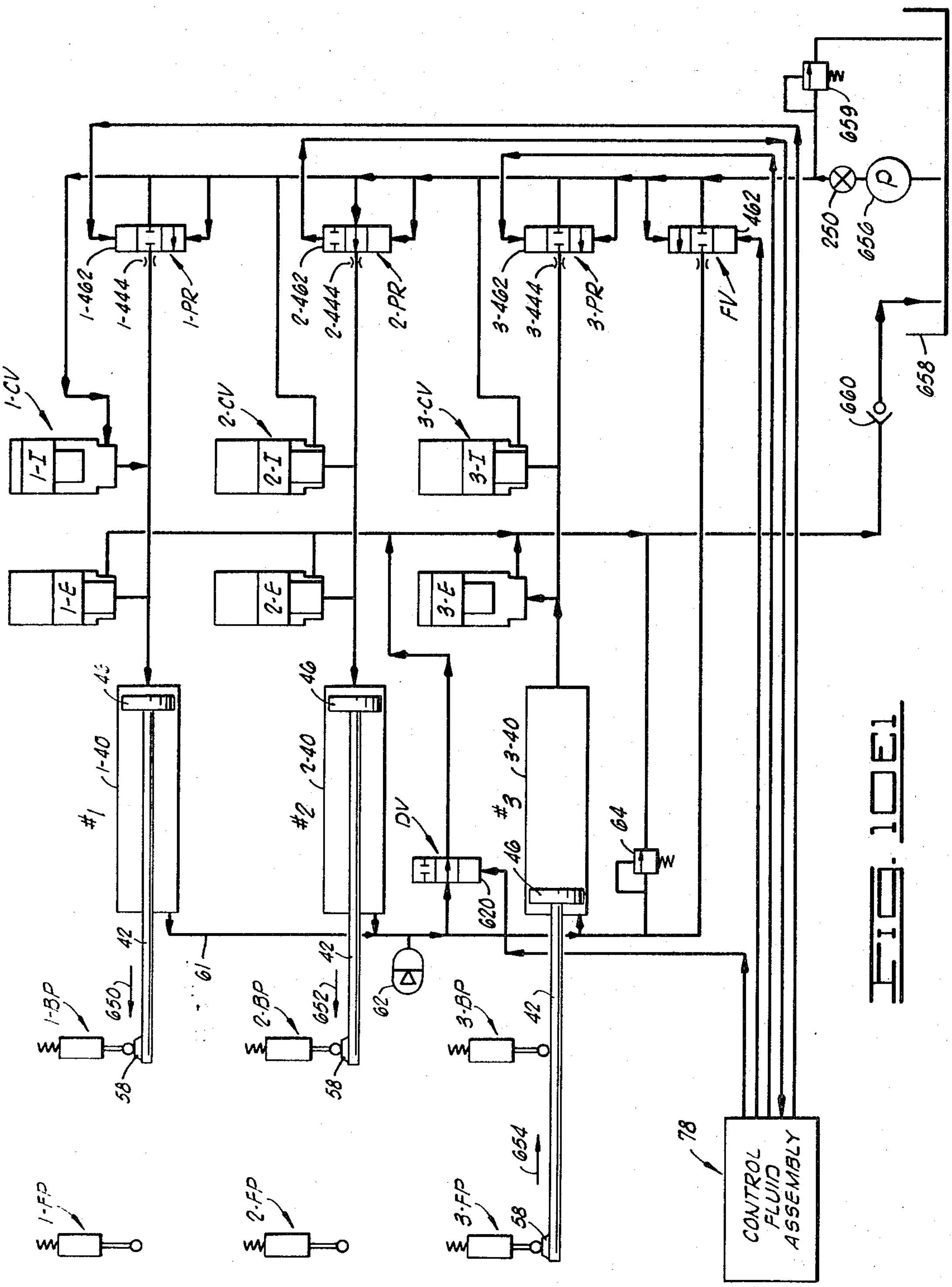
FIG. 10Z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CONTROL FLUID ASSEMBLY

FIG. 10E1

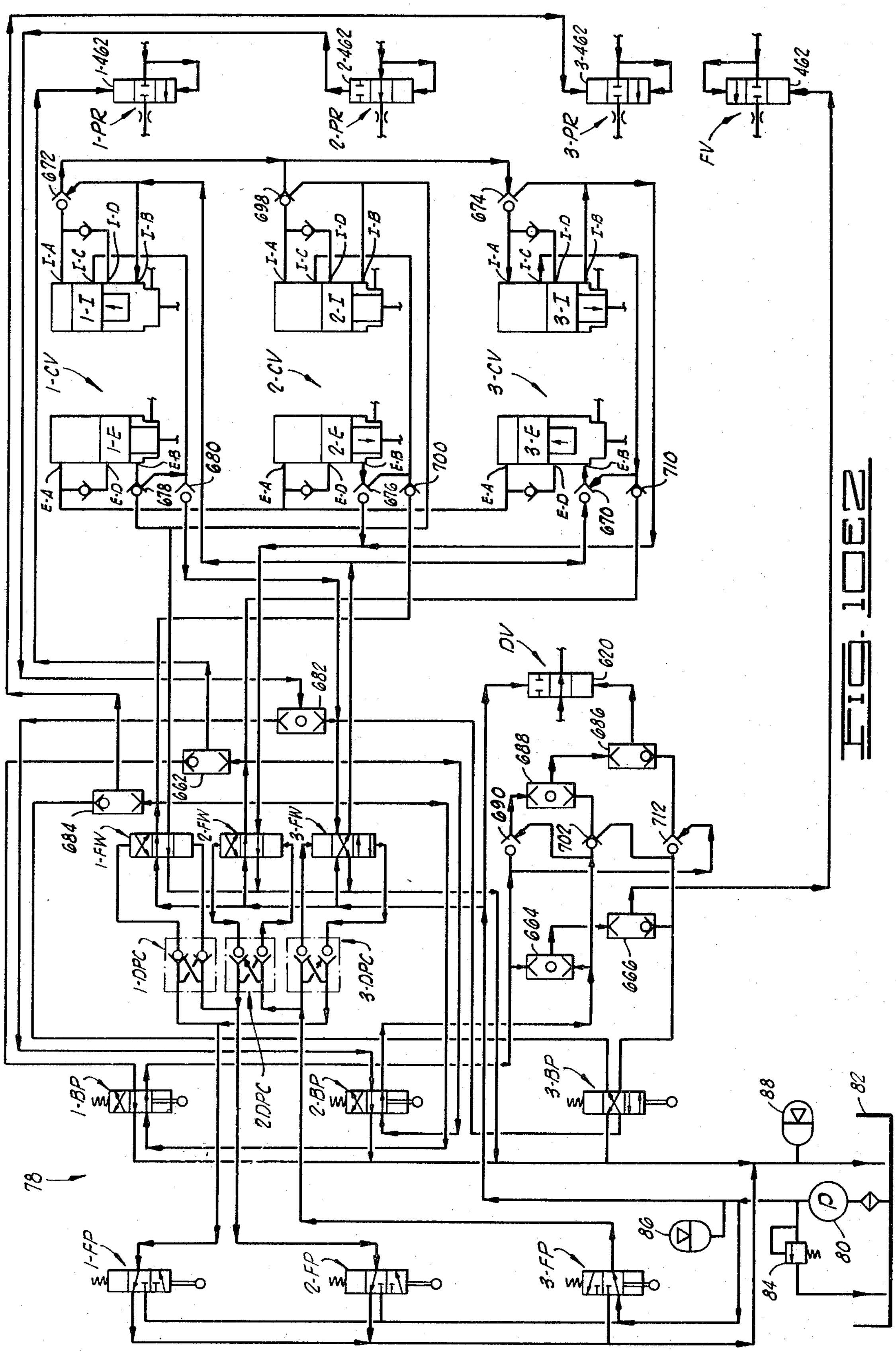
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FIG. 10E2

HYDRAULICALLY POWERED TRIPLEX PUMP AND CONTROL SYSTEM THEREFOR

BACKGROUND OF THE INVENTION

This invention relates to pumps of the multiplex type. More particularly, but not by way of limitation, this invention relates to a triplex pump of the type in which the pump fluid is precompressed prior to discharge.

In the oil industry it has become common in the past to utilize multiplex pumps designed to deliver pumped fluid at high pressures on the order of 15,000 psi or greater. It has been found that even the slight compressibility of relatively incompressible pumped liquid medium may result in pulsating discharge pressure conditions since a portion of the power intended to accomplish the discharge phase of each pumping cycle is inherently utilized to first compress the liquid 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 which might cause failure.

A significant advance in hydraulically powered triplex pumps has been disclosed in U.S. Pat. No. 3,650,638, entitled "Hydraulically Powered Pump Having a Precompression Function" and issued to Clinton W. Cole on Mar. 21, 1972. This patent is assigned to the assignee of the present invention.

SUMMARY OF THE INVENTION

The present invention contemplates an improved hydraulically powered pump employing an improved control system which constantly monitors the operation of the pump during each phase of the pumping cycle to immediately correct any variations from optimum operating conditions.

An object of the invention is to provide an improved triplex pump having a precompression function.

Another object of the invention is to provide a hydraulically powered triplex pump which provides nonpulsating suction flow as well as discharge flow.

A further object of the invention is to provide a fluid operated triplex pump and control system therefor which provides constant monitoring of the functioning of the pump and correction of variations from optimum operating conditions during each phase of the pumping cycle.

A still further object of the invention is to provide improved fluid controlled valving for the operation and control of a hydraulically powered triplex pump.

Still another object of the invention is to provide an improved hydraulically powered triplex pump having high volume and pressure capabilities which is readily mobile and economical in construction and operation.

The preferred embodiment of the invention comprises a hydraulically powered triplex 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 communicating 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 their closed positions, a precompression valve is opened, and power fluid is directed to the power cylinder through the 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 in response to control signals provided by the control circuit which constantly monitors the operation of the three pumping units throughout each phase of the pumping cycle.

Other objects and advantages of the invention will be evident from the following detailed description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

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 illustrated in FIG. **1.**

FIG. **4** is a front elevational view of the pump similar to FIG. **3** with portions removed to more clearly illustrate the control valve assemblies associated with the power end of the pump and the location of the precompression, fill and dump valves.

FIG. 5 is a cross-sectional view of one control valve assembly.

FIG. 6 is a cross-sectional view of one precompression valve.

FIG. 7 is a cross-sectional view of the fill valve.

FIG. 8 is a cross-sectional view of the dump valve.

FIG. 9 is a cross-sectional view of the shut off valve.

FIG. 9A is an enlarged partial cross-sectional view illustrating valve seat construction of the shut off valve of FIG. 9.

FIGS. 10A1, 10B1 and 10C1 are 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.

FIGS. 10D1 and 10E1 are schematic illustrations depicting the control valve conditions, the power circuit fluid flow and the power cylinder assembly functions respectively associated with first and second variations in the operating conditions illustrated in FIG. 10A1.

FIGS. 10A2, 10B2, 10C2,10D2 and 10E2 are schematic illustrations showing the positions of the control circuit conditioning valves, the resulting movement of the control valves and the control circuit fluid flow which accomplish the control valve movement and the actuation of the precompression, fill and dump valves in the phases of the pumping cycle respectively associated with FIGS. 10A1, 10B1, 10C1, 10D1 and 10E1.

DETAILED DESCRIPTION

Referring now to FIGS. 1 and 2, the triplex pump of the present invention is generally designated by the reference character 20.

The pump 20 includes a fluid end assembly 22 comprising three substantially identical cylinders 24. The internal passages 26 of each of the fluid end cylinders 24 are each in communication with a valved pump cylinder head 28, each of which is provided with a suction check valve assembly 30 and a discharge check valve assembly 32. The discharge check valve assemblies 32 communicate with a common discharge manifold 34, providing one-way fluid flow therethrough from the cylinder heads 28 into the manifold 34 and the suction valve assemblies 30 communicate with a common suction header 36 providing one-way fluid flow therethrough from the suction header 36 into the cylinder heads 28. Each of the discharge check valve assemblies referred to is continuously available to yieladably resist fluid flow into the discharge manifold 34. The yieldable resistance is operable during the precompression stage of a pumping cycle as well as during the discharge stage as will be described in detail hereinafter.

Extending from the fluid end assembly 22, in a direction away from the pump cylinder heads 28, is a power end assembly 38. The power end assembly includes three substantially identical power cylinders 40 each having an internal passage 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 respective aligned fluid end cylinder 24. The ends of the piston rod assemblies 42 which extend into the internal passages 26 of the fluid end cylinders 24 are provided with capped plunger ends which function as pumping pistons 44. The pumping pistons 44 are operable to bring about suction and discharge action in a conventional manner, and precompression action in a manner to be more fully described hereinafter.

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 to be 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. The rods 52 and 54 are each hollow, cylindrical members sealingly received in the fluid end internal passages 26 and the power end internal passages 41, respectively, 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 the members 52 and 54 are tie-rods 57 which are joined at the outer ends thereof to the pistons 44 and 46 and at the inner ends thereof with a cam actuator 58 to form, together with the rods 52 and 54 and their associated pistons 44 and 46, the integral piston rod assembly 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 to a respective power end cylinder 40 and a forward position adjacent to the respective fluid end cylinder 24.

In a manner hereinafter more fully described, each cam actuator 58 is operable, in connection with a respective cycling valve FP, to provide a signal that a particular piston rod assembly 42 has reached its forward position. These cycling valves FP are mounted on the pump 20 at that forward position on a transverse valve mounting bar, indicated at 59. The location of this mounting bar 59 is such that the lengths of the valve engaging surfaces of the cam actuators 58 cooperate with and periodically remain in engagement with the valves FP in a tripped condition for a time sufficient to permit the necessary circuit functions to take place.

In a similar manner, each cam actuator 58 is operable, in connection with a precompression and stroke control valve or back position valve BP, to provide a signal that its associated piston rod assembly 42 has reached its back position. The precompression and stroke control valves BP are also mounted on the pump 20 at that back position on a transverse valve mounting bar, indicated at 60.

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

In the discharge phase of the cycle in a given power cylinder **40,** power fluid acts on the outer face **50** of the power piston **46** to transmit force through the piston rod assembly **42** so as to cause the fluid end pumping piston **44** to move to its forwardmost stroke position whereby fluid in the cylinder head **28** is expelled through the discharge valve assembly **32** into 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 relatively slowly forward by an increment sufficient to compress the fluid to be pumped in the fluid end cylinder **24** 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 the 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 **36** and the common discharge manifold **34.**

For purposes of accomplishing automatic stroke correction, as hereinafter more fully described, the common conduit **61** connecting 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 fill valve, FV. The conduit **61** and the rod ends of the power cylinders **40** are also in fluid circuit with a power fluid reservoir, remote from the pump **20,** through a normally closed dump valve DV. Also a rod end relief valve **64** provides selective communication between the rod ends of the power cylinders **40** and the remote power fluid reservoir in the event the power fluid pressure at the rod ends of the power cylinders exceeds a predetermined pressure.

As will be further described, the control valve assemblies CV, the precompression valves PR, the fill valve FV and the dump valve DV which direct the power fluid, preferably water, are, in the illustrated embodiment, monitored by a separate control fluid circuit. The control fluid circuit preferably utilizes a different fluid such as oil, air or a combination thereof. It will, however, be apparent that controls other than a control fluid circuit (e.g., an electrical sensing arrangement) may be utilized to monitor the power circuit. In the illustrated embodiment it will be assumed that oil will be employed as the control fluid.

It will be appreciated that the elements of the control circuit, the control valve assemblies CV, the power end assembly **38,** the fluid end assembly **22** and the spacer frame assembly **51,** may all be mounted on a suitable common frame. In the illustrated embodiment, a tandem wheel semi-trailer **66** provides the common frame for supporting these elements. Preferably the mounting on the semi-trailer **66** is designed to permit the fluid end cylinders **24,** the spacer frame assembly **51,** and the power end cylinders **40** to move longitudinally relative to the semi-trailer for a limited distance, during reciprocation of the piston rod assemblies **42,** so as to relieve any stresses on those members. Provision for such movement is made by slidably supporting the power end cylinders **40** within apertures formed in trailer crossmembers **68** and **70** and by slidably supporting the forward ends of the fluid end cylinders **24** within apertures formed in trailer crossmember **72** formed on the semi-trailer **66.** The rearward ends of the fluid end cylinders **24** are rigidly secured to trailer crossmember **74** as are the cylinder heads **28.** The fluid end cylinders **24,** spacer frame assembly **51** and power end cylinders **40** are suitably joined by longitudinal tie bars **76.** The transverse valve mounting bars **59** and **60** are each preferably secured to two of the uppermost longitudinal tie bars **76.**

A suitable control fluid assembly **78** is mounted on the semi-trailer **66** below the power end assembly **38** and the spacer frame assembly **51.** The control fluid assembly **78** includes a pump assembly **80,** control fluid reservoir assembly **82,** relief valve **84** and accumulators **86** and **88.**

THE CONTROL VALVE ASSEMBLY

Referring now to FIGS. **4** and **5,** the previously identified identical control valve assemblies **1-CV, 2-CV** and **3-CV** will be described.

From the cross-sectional view of one control valve assembly illustrated in FIG. **5,** it will be seen that each control valve assembly includes a housing **90** having a longitudinal bore **92** extending therethrough. An inlet bore **94** and an exhaust bore **95** are formed in the housing **90** and communicate between the longitudinal bore **92** and the upper surface **96** of the housing **90.** Counterbores **97** and **98** are formed respectively in the bores **94** and **95** forming respective annular shoulders **100** and **102** therein. Annular inlet and exhaust chambers **104** and **106** are formed respectively in the counterbores **97** and **98.** A precompression passageway **107** is formed in the housing **90** and communicates between the inlet bore **94** and the front side **108** of the housing **90.** A power fluid pasaageway **109** communicates between the inlet chamber **104** and the front side **108** of the housing **90.** The annular inlet chamber **104** communicates with the opposite vertical sides of the of the housing **90** through a pair of lateral inlet ports **110** formed in the housing **90** and positioned on opposite sides of the chamber **104.** Similarly, the annular exhaust chamber **106** communicates with the vertical sides of the housing **90** through a pair of lateral exhaust ports **112** formed in the housing **90** and positioned on opposite sides of the chamber **106.**

A cylindrically shaped inlet seat mount **114** is positioned within the counterbore **97** abutting the annular shoulder **100.** A substantially identical exhaust seat mount **116** is positioned within the counterbore **98** abutting the annular shoulder **102.** A substantially cylindrically shaped slotted inlet spacer **118** is positioned within the counterbore **97** abutting the upper end face of the inlet seat mount **114.** An annular inlet valve seat **120** is securely mounted between the inlet seat mount **114** and the slotted inlet spacer **118.** A substantially cylindrical slotted exhaust spacer **122** is positioned within the counterbore **98** and abuts the upper surface of the exhaust seat mount **116.** An annular exhaust valve seat **124** is secured between the slotted exhaust spacer **122** and the exhuast seat mount **116.**

An inlet cylinder assembly **126** and a substantially identical exhaust cylinder assembly **128** are mounted with their respective lower end portions disposed in the respective counterbores **97** and **98** of the housing **90.** The lower end face **130** of the inlet cylinder assembly **126** abuts the upper end face **132** of the slotted inlet spacer **118.** The loewr end face **134** of the exhaust cylinder assembly **128** abuts the upper end face **136** of the slotted exhaust spacer **122.**

Each of the identical inlet and exhaust cylinder assemblies **126** and **128** includes a lower bearing and seal member **138** extending into the respective counterbores **97** and **98,** a cylinder **140** extending upwardly from the lower bearing and seal member **138,** an upper bearing and seal member **142** extending upwardly from the cylinder **140** and a cover **144** extending upwardly from the upper bearing and seal member **142** and capping the respective inlet and exhaust cylinder assemblies **126** and **128.** The elements of the inlet and exhaust assemblies **126** and **128** are secured together by means of suitable annular V-retainer couplings **146.**

The inlet cylinder assembly **126** and the exhaust cylinder assembly **128** are each rigidly secured to the housing **90** by means of a plurality of threaded studs **148** extending through apertures in the cover **144** and received in threaded holes in the housing **90** and by threaded nuts **150** secured to the upper ends of the studs **148.** A cylindrically shaped inlet sleeve valve member I is slidably disposed within the inlet cylinder assembly **126.** An identical cylindrically shaped exhaust sleeve valve member E is slidably disposed within the exhaust cylinder assembly **128.** The upper and lower outer cylindrical surfaces **152** and **154** of the valve members I and E are sealingly engaged by the annular seals **156** and **158** carried respectively by the upper and lower bearing and seal members **142** and **138** of the inlet and exhaust cylinder assemblies **126** and **128.** Approximately midway of each of the valve members I and E there is provided an external cylindrically shaped flange **160** whcih engages the internal wall in the respective cylinder **140** of the inlet and exhaust cylinder assemblies **126** and **128.** These flanges **160** function as pistons and define, together with an upper and lower cylindrical surfaces **152** and **154** of the valve members I and E and the upper and lower bearing and seal members **142** and **138** and their annular seals **156** and **158** located at opposite ends of each of the cylinders **140,** upper and lower control fluid chambers A and B.

It will be appreciated that the internal diameters of the upper and lower bearing and seal members **142** and **138** are substantially equal to the diameters of the upper and lower outer cylindrical surfaces **152** and **154** of the valve members I and E. It will be further appreciated that the length of each of the valve members I and E is greater than the distance between the annular seals **156** and **158** of the upper and lower bearing and seal members **142** and **138.** Thus, regardless of the position of the valve members I and E, the control fluid chambers A and B are continually isolated from power fluid passing through and controlled by the control valve CV.

When the valve member I is in its down or lower position, the lower end face **162** thereof is positioned proximate to an annular shoulder **164** of the inlet seat mount **114,** preferably just short of abutment therewith. The outer periphery **166** of the valve member I adjacent to the end face **162** sealingly engages the annular inlet valve seat **120** thereby blocking communication between the annular inlet chamber **104** and the longitudinal bore **92** of the housing **90.**

Similarly, when the exhaust valve member E is in its down or lower position the lower end face **162** thereof is positioned proximate to an annular shoulder **168** of the exhaust seat mount **116,** preferably just short of abutment therewith. The outer periphery **166** of the valve member E adjacent to the lower end face **162** sealingly engages the annular exhaust valve seat **124,** thereby blocking communication between the annular exhaust chamber **106** and the longitudinal bore **92** of the housing **90.**

It will be seen that when the communication between the annular inlet chamber **104** and the longitudinal bore **92** of the housing **90** is blocked by the inlet valve member I, communication between the power fluid source and the power cylinder **49** is blocked. Similarly, when communication between the annular exhaust chamber **106** and the longitudinal bore **92** of the housing **90** is blocked by the exhaust valve member E, communicated between the power cylinder **40** and the power fluid reservoir is blocked. When the inlet valve member I is in the upper or open position, communication is open between the longitudinal bore **92** of the housing **90** and the source of power fluid. Similarly, when the exhaust valve member E is in the upper or open position, communication is open between the longitudinal bore **92** of the housing **90** and the power fluid reservoir.

Movement of the valve members I and E to the upper open position and the lower closed position to control power fluid flow through the control valve CV, is accomplished through the use of a pressurized control fluid. This control fluid causes such valve member movement by entering the cylinders **140** of the inlet and exhaust cylinder assemblies **126** and **128** through control ports extending laterally therethrough. These control ports are labeled I-B, E-B, I-A and E-A respectively, and are defined by (unnumbered) communicating passages of different diameters.

Pressurization of the upper control ports I-A and E-A causes control fluid to enter the upper control chambers A of the inlet cylinder assembly **126** and the exhaust cylinder assembly **128.** The valve members I and E are thus caused to move to their lower or closed positions, as illustrated by the valve member E in FIG. **5.** Conversely, pressurization of the lower control ports I-B and E-B moves the valve members I and E to their upper or open positions, as indicated by the valve member I in FIG. **5,** the actuation of control fluid in the lower chamber B upon the pistons **160.**

The valve members I and E are hydraulically cushioned or decelerated near the end of either an upward or a downward stroke by the restriction offered by the smaller of the two passages comprising the control ports A and B. When a given valve member nears completion of a shift in either direction, the larger passages are covered by the piston **160** causing the fluid exhausting from the actuator chamber to pass through the smaller passage.

It will be seen that the cylinders **140** of the inlet and exhaust cylinder assemblies **126** and **128** are provided with further control ports labeled I-D and E-D. The function of these ports is to supply makeup control fluid to the upper control ports I-A and E-A 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 D ports are blocked by the pistons **160** of the valve members I and E in all positions of the valve members except the uppermost positions thereof, as indicated respectively at **170** and **172.**

In connection with the inlet valve members I and their associated cylinders **140,** it will be seen that a further control port I-C is provided between I-A and I-D ports. In a manner to be described hereinafter, this port I-C functions to supply a signal that the valve member I of the associated control valve assembly CV is in its closed position. When the valve member I is in the lower or closed position, the I-C port communicates with the upper control fluid chamber A. In all other positions of the valve member I, the I-C port is blocked by the piston **160.**

The inlet cylinder assembly **126** and the exhaust cylinder assembly **128** each include a cylindrically shaped plug **176** disposed within the respective valve members I and E. Each plug **176** is secured to the cover **144** by means of a bolt **178** extending through the plug **176** and the cover **144.** A threaded nut **180** is threadedly engaged on each end of the bolts **178** to firmly secure the plug **176** to the cover **144.** A threaded eye **182** is threadedly secured to the upper end of each bolt **178** above the adjacent nut **180.** A suitable annular seal **184** is carried by the bolt **178** to provide a fluid tight seal between the bolt **178** and the cover **144.**

Each flange **160** of the valve members I and E includes three annular piston rings **186** disposed in circumferential grooves **188** formed in the cylindrically shaped periphery of the flange **160.** The piston rings **186** provide a fluid tight sliding seal between the flange **160** and the respective cylindrically shaped inner periphery of the cylinder **140.**

A housing bearing **190** is disposed in each end of the longitudinal bore **92** through the housing **90.** Each housing bearing **190** carries an annular seal **192** in a circumferential groove **194** which provides a fluid tight seal between the housing bearing **190** and the longitudinal bore **92.** Each housing bearing **190** has a cylindrically shaped inner periphery **196** in which annular grooves **198** and **200** are formed. An annular T-piston seal **202** is disposed in each groove **198** and provides a fluid tight seal between the control valve CY and a power fluid entry and exhaust chamber **204** communicating with the corresponding power cylinder **40.** A grease fitting **206** is threadedly secured in each housing bearing **190** and communicates with the annular groove **200** via a passageway **208** formed in the housing bearing **190.**

A retainer flange **210** having an aperture **212** formed therein is positioned adjacent to the housing bearing **190** positioned adjacent to the inlet cylinder assembly **126** of the control valve CV. The retaining flange **210** and the adjacent housing bearing **190** are secured to the housing **90** by means of six threaded cap screws extending through the retainer flange **210** and the housing bearing **190** and threadedly engaged with the housing **90.** The housing bearing **190** at the opposite end of the housing **90** is fixedly secured to the housing **90** by means of six cap screws extending through the housing bearing **190** and threadedly engaged in threaded holes formed in the housing **90.**

A drain hole **214** is formed in the bottom of the housing **90** and communicates between the exterior thereof and the longitudinal bore **92** therethrough. A threaded plug **216** is threadedly engaged in the drain hole **214** to provide a fluid tight sealing closure of the drain hole **214.**

Each of the control valves, **1-CV, 2-CV** and **3-CV** is rigidly secured to the trailer crossmember **68** by means of a pair of threaded bolts **218** extending through the respective retainer flange **210** and threadedly received in the trailer crossmember **68.** Each of the bolts **218** extends longitudinally through a positioning tube **220** which bears at its opposite ends against the retainer flange **210** and the trailer crossmember **68.** This arrangement provides positive longitudinal positioning of the control valves **1-CV, 2-CV** and **3-CV** relative to the trailer **66** and the trailer crossmember **68.**

The cylindrically shaped power fluid entry and exhaust chamber **204** is secured on the forward end portion **222** of each power cylinder **40** by means of a retaining collar **224** encircling a flange **226** formed on one end of the chamber **204** and secured by four tie bars **76.** Each chamber **204** is slidably received in a respective control valve housing **90** and is sealingly engaged about its outer periphery by the seals **202** in the housing bearings **190.** Lateral passages **228** and **230** extend through each chamber **204** and provide communication between the inner chamber **232** thereof and the inlet exhaust bores **94** and **95** of the respective control valve CV.

The sliding relationahip of the chambers **204** to the housings **90** of the control valves **1-CV, 2-CV** and **3-CV** permits the chambers **204** to move longitudinally within the respective housings **90** in response to extension and contraction of the fluid end assembly **22,** power end assembly **38,** and spacer frame assembly **51** of the pump **20** during its operation. It will be seen that the inner chamber **232** of each chamber **204** communicates with the internal passage **41** of a respective power cylinder **40.**

When the control valve assemblies **1-CV, 2-CV** and **3-CV** are assembled on the pump **20,** the adjacent lateral exhaust ports **112** of the **1-CV** and **2-CV** control valve assemblies are interconnected by exhaust manifold **234** which includes a downwardly extending power fluid return conduit **236.** The adjacent lateral exhaust ports **112** of the **2-CV** and **3-CV** control valve assemblies are interconnected by exhaust manifold **238.** Similarly, the adjacent lateral inlet ports **110** of the **1-CV** and **2-CV** control valve assemblies are interconnected by inlet manifold **240** while the adjacent lateral inlet ports **110** of the **2-CV** and **3-CV** control valve assemblies are interconnected by inlet manifold **242.**

The inlet manifolds **240** and **242** are connected by conduits to two of the lateral outlet ports of the shut off valve assembly which will be described in detail below. These conduits supply pressurized power fluid to the control valve assemblies via the inlet manifolds **240** and **242** and the lateral ports **110** of the control valve assemblies **1-CV 2-CV** and **3-CV.**

The control valve assemblies **1-CV**, **2-CV** and **3-CV** are secured together along with the manifolds **234**, **238**, **240** and **242** by means of two V-shaped brackets **244** interconnected by three threaded tie rods **246**. The brackets provide sealing closure of the outer inlet and outlet ports **110** and **112** of the control valve assemblies **1-CV** and **3-CV**. The lower of the three tie rods **246** extends through suitable apertures **248** formed in the housings **90** of the control valve assemblies **1-CV**, **2-CV** and **3-CV**.

THE SHUT OFF VALVE ASSEMBLY

Referring now to FIGS. **3** and **9**, the construction of the shut off valve assembly **250** will be described in detail.

From the cross-sectional view of the shut off valve assembly illustrated in FIG. **9**, it will be seen that the shut off valve assembly includes a housing **252** having a longitudinal bore **254** extending therethrough. The bore **254** communicates with the inlet end **256** of the housing **252**. A counterbore **258** is formed in the bore **254** and forms an annular shoulder **260** interconnecting the counterbore **258** and the bore **254**. An annular chamber **262** is formed in the counterbore **258** and communicates with the exterior of the housing **252** through three lateral outlet ports **264** formed in the housing **252** with two of the ports **264** positioned on opposite sides of the annular chamber **262**, and the third port **264** positioned angularly intermediate the other two ports. The axes of the three ports **264** are substantially coplanar.

A cylindrically shaped seat mount **266** is positioned within the counterbore **258** abutting the annular shoulder **260**. A substantially cylindrically shaped slotted spacer **268** is positioned within the counterbore **258** abutting the end face **270** of the seat mount **266**. An annular valve seat **272** is securely mounted between the seatmount **266** and the slotted spacer **268**. The valve seat **272** may be suitably formed of a resilient synthetic material such as nylon. The annular valve seat **272** is received in an annular groove **274** formed in the slotted spacer **268** and is securely retained therein by an annular rib **276** extending outwardly from the end face **270** of the seat mount **266**. It will be seen from the drawing that the configuration of the annular groove **274** and the annular rib **276** prevent any possibility of the valve seat **272** becoming dislodged therefrom.

The shut off valve assembly **250** includes a cylinder assembly **278** mounted with one end portion thereof disposed in the counterbore **258**. One end face **280** abuts the upper end face **282** of the slotted spacer **268**.

The cylinder assembly **278** includes a first bearing and seal member **284** extending into the counterbore **258**, a cylinder **286** extending longitudinally from the first bearing seal member **284**, a second bearing and seal member **288** extending longitudinally from the cylinder **286** and a cover **290** extending longitudinally from the second bearing and seal member **288** and capping the cylinder assembly **278**. The elements of the cylinder assembly **178** are secured together by means of suitable annular V-retainer couplings **292**.

The cylinder assembly **278** is rigidly secured to the housing by means of a plurality of threaded studs **294** threadedly engaged with the housing **252** and extending through respective apertures formed in the cover **290**, and threaded nuts **296** secured to the threaded studs **294**.

A cylindrically shaped sleeve valve member **298** is slidably disposed within the cylinder assembly **278**. The first and second outer cylindrical surfaces **300** and **302** of the sleeve valve member **298** are sealingly engaged by annular seals **304** and **306** carried respectively by the first and second bearing and seal members **284** and **288**. Approximately midway of the sleeve valve member **298**, there is provided an external cylindrically shaped flange **308** which engages the internal wall of the cylinder **286** of the cylinder assembly **278**. The flange **308** functions as a piston and defines, together with the first and second cylindrical surfaces **300** and **302** of the sleeve valve member **298** and the first and second bearing and seal members **284** and **288** and their annular seals **304** and **306** located in the opposite ends of the cylinder **286**, opening and closing fluid chambers **310** and **312**.

It will be appreciated that the internal diameters of the first and second bearing and seal members **284** and **288** are substantially equal to the diameters of the first and second outer cylindrical surfaces **300** and **302** of the sleeve valve member **298**. It will be further appreciated that the length of the sleeve valve member **298** is greater than the distance between the annular seals **304** and **306** of the first and second bearing and seal members **284** and **288**. Thus, regardless of the position of the sleeve valve member **298**, the opening and closing control fluid channel members **310** and **312** are continually isolated from power fluid passing through and controlled by the shut off valve assembly **250**.

When the sleeve valve member **298** is in its closed position, the lower end face **314** thereof is positioned proximate to an annular shoulder **316** formed on the seat mount **266** and extending radially inwardly from the annular rib **276**, preferably just short of abutment with the annular shoulder **316**. The outer periphery **318** of the sleeve valve member **298** adjacent to the end face **314** sealingly engages the annular valve seat **272** thereby blocking communication between the longitudinal bore **254** and the lateral outlet ports **264** of the housing **252**.

As shown in FIG. **9**, the clearance between the outer periphery **318** of the sleeve valve member **298** and the annular rib **276** formed on the seat mount **266**, when the sleeve valve member **298** is in the closed position, is of such dimension that extrusion of the annular valve seat **272** between the sleeve valve member **298** and the seat mount **266** is prevented when pressure exists above the valve seat **272** or outside the sleeve valve member **298**, and the pressure below the valve seat **272** or inside the sleeve valve member **298** is substantially lower or zero. The annular sealing contact between the sleeve valve member **298** and the annular valve seat **272** is initially located at the tapered surface **320** interconnecting the outer cylindrical surface **300** and the outer cylindrical periphery **318** of the sleeve valve member **298**. In service the annular valve seat **272** typically experiences plastic flow, causing it to fully mate and sealingly engage the tapered surface **320** and the cylindrical outer periphery **318**.

Movement of the sleeve valve member **298** to the open position and to the closed position to alternately open and close the shut off valve assembly **250** to power fluid flow therethrough is accomplished through the use of a pressurized control fluid. The control fluid causes the sleeve valve member 298 to move by entering the cylinder 286 of the cylinder assembly 278 through first and second control ports 322 and 324. via

Pressurization of the first control port 322 causes pressurized control fluid to enter the opening fluid chamber 310 of the cylinder assembly 278. The sleeve valve member 298 is thus caused to move from its closed position to its open position, as illustrated in FIG. 9. Conversely, pressurization of the second control port 324 causes control fluid to enter the closing fluid chamber 312 thus causing the sleeve valve member 298 to move to the enclosed position in response to the force of the pressurized control fluid in the closing fluid chamber 312 acting on the flange or piston 308.

Control fluid is directed to either the opening fluid chamber 310 or the closing fluid chamber 312 by means of a shut off valve actuator assembly 326. The shut off valve actuator assembly 326 includes a cylinder manifold 328 bolted to the cylinder 286 and provides suitable connection to a source of pressurized control fluid and to a control fluid reservoir. The shut off valve actuator assembly 326 further includes a double pilot operated check valve 330 of the conventional construction and secured to the manifold 328. The double pilot operated check valve 330 provides suitable means for locking the sleeve valve member 298 in either the open or closed position after actuation thereof.

The shut off valve actuator assembly 326 further includes an adjustable flow control valve 332 secured to the double pilot operated check valve 330 and providing fluid communication therewith. The adjustable flow control valve 332 is of conventional construction and provides means for controlling the velocity of the sleeve valve member 298 as it moves alternately between open and closed positions.

Finally, the shut off valve actuator assembly 326 includes a manually operated four way hydraulic control valve 334 secured to the adjustable flow control vavle 332 to provide manually actuated means for applying the pressurized control fluid received in the manifold 328 to either the opening or closing fluid chamber 310 or 312 while simultaneously connecting the other fluid chamber 312 or 310 to the control fluid reservoir.

The manually operated four way hydraulic control valve 334 employed in the shut off valve actuator assembly 326 is preferably a conventional unit available from Racine Hydraulics and Machinery, Inc., Sarasota, Florida. The adjustable flow control valve 332 is also a conventional unit available from Racine Hydraulics and Machinery, Inc. as is the double pilot operated check valve 330.

PRECOMPRESSION VALVE

As shown in FIG. 6, each of the three precompression valves PR comprises a rectangularly shaped valve body 350. The valve body 350 includes a longitudinal passageway 352 extending therethrough and communicating with the first end portion 354 and the second end portion 356 of the valve body 350. One side 358 of the valve body 350 is provided with a machined surface and is adapted to be secured directly to the front side 108 of the housing 90 of a respective control valve CV. The valve body 350 is typically secured to the housing 90 by means of a plurality of threaded screws 360 extending through the valve body 350 and threadedly engaged in threaded holes formed in the housing 90.

The passageway 352 includes a first counterbore 362 formed therein from the first end portion 354. The first counterbore 362 forms an annular shoulder 364 which extends radially inwardly from an annular relief groove 366 preferably formed in the first counterbore 362 adjacent to the annular shoulder 364. The diameter of the first counterbore 362 is preferably approximately 1 ⅞ inches.

A second counterbore 368 is formed in the passageway 352 from the first end portion 354 with the cylindrical surface thereof communicating with the cylindrical surface of the first counterbore 362 by means of an interconnecting tapered annular surface 370. The diameter of the second counterbore 368 is preferably approximately 2 inches. The passageway 352 includes an internally threaded portion 372 extending from the cylindrical surface of the second counterbore 368 to the first end portion 354.

A third counterbore 374 is formed in the passageway 352 from the second end portion 356 of the valve body 350. An annular shoulder 376 extends radially inwardly from an annular relief groove 378 preferably formed in the cylindrical surface of the third counterbore 374 adjacent to the annular shoulder 376. The diameter of the cylindrical surface of the third counterbore 374 is preferably approximately 2 ¼ inches

The passageway 352 further includes an internally threaded portion 380 extending from the second end portion 356 of the valve body 350 to an annular relief groove 382 which is in turn connected to the cylindrical surface of the third counterbore 374 by an annular shoulder 384.

A sleeve 386 is positioned within the first counterbore 362 and a portion of the second counterbore 368 with one end face 388 thereof abutting the annular shoulder 364. A fluid tight seal is formed between the sleeve 386 and the cylindrical surface of the first counterbore 362 by a T-piston seal 390 disposed in an annular groove formed in the cylindrical periphery of the sleeve 386.

A cylindrically shaped carbide valve member 392 is longitudinally slidably disposed in a longitudinal bore 394 extending through the sleeve 386 along the longitudinal axis thereof. A fluid tight seal is provided between the valve member 392 and the longitudinal bore 394 by means of a T-rod seal 396 carried in an annular groove formed in the cylindrical surface of the bore 394.

A cylindrically shaped carbide valve seat 398 is positioned within the second counterbore 368 with the inner end face 400 thereof abutting the outer end face 402 of the sleeve 386. The valve seat 398 includes a longitudinal bore 403 extending therethrough with a frusto-conical seating surface 404 formed thereon and interconnecting the bore 403 and the inner end face 400 of the valve seat 398. The seating surface 404 is sized and shaped to sealingly engage a mating frutso-conical seating surface 406 formed on the valve member 392 to provide a fluid tight seal between the valve member 392 and the valve seat 398 upon the engagement of the seating surfaces 404 and 406. A fluid tight seal is formed between the valve seat 398 and the cylindrical surface of the second counterbore 368 by a T-rod seal 407 disposed in an annular groove formed in the cylindrical sruface of the counterbore 368.

An externally threaded seat retainer **408** is threadedly engaged with the internally threaded portion **372** of the valve body **350** with the inner end face **410** thereof abutting the outer end face **412** of the valve seat **398**. This positioning of the seat retainer **408** within the valve body **350** secures the valve seat **398** and the sleeve **386** within the passageway **352**. A fluid tight seal is achieved between the seat retainer **408** and the cylindrical surface of the second counterbore **368** by means of a T-piston seal **414** carried in an annular groove formed in the first cylindrical outer periphery **416** of the seat retainer **408**. A second cylindrical outer periphery **418**, of a lesser diameter than the first cylindrical outer periphery extends from the first cylindrical outer periphery **416** to the inner end face **410** of the retainer seat **408**. An annular shoulder **420** interconnects the first and second cylindrical outer peripheries **416** and **418** of the seat retainer **408**. A counterbore **422** is formed along the longitudinal axis of the seat retainer **408** and communicates with the inner end face **410** thereof. A plurality of ports **424** provide fluid communication between the cylindrical surface of the counterbore **422** and the second cylindrical outer periphery **418** of the seat retainer **408**.

A pressure input port **426** communicates between the side **358** of the valve body **350** and the interior of the counterbore **422** via the ports **424**. An additional port **428** is formed in the valve body **350** and communicates between the opposite side **430** thereof and the interior of the counterbore **422** via the ports **424**. The port **428** includes internal threads **432** in which a plug or hydraulic hose fitting may be threadedly secured. An O-ring **434** is disposed in an annular groove **436** formed in the side **358** of the valve body **350** concentric with the pressure input port **426** to provide a fluid tight seal between the side **358** of the valve body **350** and the front side **108** of the housing **90** of the respective control valve CV on which the precompression valve PR is mounted and further provide sealed fluid communication between the pressure input port **426** and the power fluid passageway **109** in the housing **90**.

A pressure output port **438** is formed in the valve body **350** and communicates between the side **358** thereof and the second counterbore **368**. A counterbore **440** is formed in the sleeve **386** and communicates with the outer end face **402** thereof. A lateral port **442** is formed in the sleeve **386** and communicates between the counterbore **440** and the outer periphery of the sleeve **386** adjacent to the port **438**. An orifice **444** is positioned within the pressure output port **438** providing restricted fluid communication between the side **358** of the valve body **350** and the counterbore **440** of the sleeve **386**. An O-ring **446** is disposed in an annular groove **448** formed in the side **358** of the valve body **350** concentric with the port **438** and orifice **444** to provide a fluid tight seal between the side **358** of the valve body **350** and the housing **90** of the respective control valve CV and provide sealed fluid communication between the pressure output port **438** and the precompression passageway **107** in the housing **90**.

A piston **450** is slidably disposed within the third counterbore **374** with its inner end face **452** abutting the adjacent end face **454** of the valve member **392**. A fluid tight seal is provided between the piston **450** and the cylindrical surface of the third counterbore **374** by means of a T-rod seal **456** carried in an annular groove formed in the cylindrical surface of the third counterbore **374**.

An externally threaded bushing **458** is threadedly secured within the internally threaded portion **380** of the valve body **350** with a fluid tight seal achieved therebetween by an O-ring **460**. A longitudinal passageway **462** having an internally threaded portion **464** formed therein extends through the bushing **458** to provide communication between the face **466** of the piston **450** and a source of fluid pilot pressure suitably threadedly connected to the internally threaded portion **464**.

In operation, when the power fluid is applied to the pressure input port **426** at a pressure of approximately 5000 psi, power fluid flow through the precompression valve PR is prevented by the sealing engagement between the seating surfaces **404** and **406** of the valve seat **398** and the valve member **392** as long as a sufficient pilot pressure is applied through the passageway **462** to the relatively large diameter face **466** of the piston **450**. At such time as the pilot pressure is reduced below a predetermined level, the reduced pilot pressure allows the piston **450** to move toward the bushing **458** under the urging of the pressurized power fluid thereby releasing closing pressure on the valve member **392** and allowing the power fluid to flow through the pressure input port **426** and out through the orifice **444** via the ports **424**, counterbore **422**, bore **403**, counterbore **440** and lateral port **442**.

THE FILL VALVE

The fill valve FV is substantially identical in contruction to the precompression valve PR and differs only in employing a slightly modified rectangularly shaped valve body **350***a*, as illustrated in FIG. **7**. The valve body **350***a* differs from the valve body **350** of the precompression valve PR only in the detail construction of ports formed therein communicating with a longitudinal passageway **352** extending therethrough. Those elements identical to the elements employed in the precompression valve PR will be designated by the same reference characters to simplify the description of the structure of the fill valve FV.

The valve body **350***a* of the fill valve FV includes a pressure input port **426** which communicates between one side **358***a* of the valve body **350***a* and the counterbore **422** of the seat retainer **408** via the ports **424**. An O-ring **434** is positioned in an annular groove **436** formed in the side **358***a* of the valve body **350** concentric with the pressure input port **426** to provide a fluid tight seal for purposes which will be explained in detail hereinafter.

An internally threaded output port **438***a* communicates between the opposite side **430***a* of the housing **350***a* and the counterbore **440** of the sleeve **386** via the lateral port **442** formed in the sleeve **386**.

The remainder of the structure of the fill valve FV is identical to that previously described for the precompression valve PR and functions in substantially the same way.

In operation, when the pressurized power fluid is applied to the pressure input port **426** at a pressure of approximately 5000 psi, the power fluid flow through the fill valve FV IS prevented by the sealing engagement between the seating surfaces **404** and **406** of the valve seat **398** and the valve member **392** as long as a sufficient pilot pressure is applied through the passageway 462 to the face 466 of the piston 450. At such time as the pilot pressure is reduced below a predetermined level, the piston 450 will move toward the bushing 458 in response to the urging of the pressurized power fluid thereby releasing pressure on the valve member 392 and allowing the power fluid to flow through the pressure input port 426 and out through the output port 438a via the ports 424, counterbore 422, bore 403, counterbore 440 and lateral port 442.

The fill valve FV is preferably assembled along with a precompression valve PR to the front side 108 of the housing 90 of the control valve 2-CV. When assembled in this manner, the fill valve FV is positioned with its one side 538a engaging the side 430 of the adjacent precompression valve PR. The O-ring 434 engages the side 430 of the valve body 350 of the precompression valve PR and provides fluid tight communication between the port 428 of the precompression valve PR and the pressure input port 426 of the fill valve FV. The fill valve FV and the precompression valve PR associated therewith are secured to the housing 90 of the control valve 2-CV by means of a plurality of threaded screws 306a of sufficient length to pass through the valve body 350a of the fill valve FV and the valve body 350 of the precompression valve PR to be threadedly received in the housing 90 of the control valve 2-CV.

THE DUMP VALVE

The dump valve DV, illustrated in FIG. 8, comprises a generally rectangularly shaped valve body 500. The valve body 500 includes a longitudinal passageway 502 extending therethrough and communicating with the first end portion 504 and the second end portion 506 of the valve body 500. One side 508 of the valve body 500 is provided with a machined surface for purposes which will be described in detail hereinafter.

The passageway 502 includes a first counterbore 510 formed therein from the first end portion 504. The first counterbore 510 forms an annular shoulder 512 which extends radially inwardly from the cylindrical wall of the counterbore 510. The diameter of the first counterbore 510 is preferably approximately 1 ⅞ inches.

A second counterbore 514 is formed in the passageway 502 from the first end portion 504 with the cylindrical surface thereof communicating with the cylindrical surface of the first counterbore 510 by means of an interconnecting tapered annular surface 516. The diameter of the second counterbore 514 is preferably approximately 2 inches.

The passageway 502 further includes a third counterbore 518 communicating with the first end portion 504 of the valve body 500. The passageway 502 also includes an internally threaded portion 520 which extends between and interconnects the second and third counterbore 514 and 518.

A fourth counterbore 522 is formed in the passageway 502 from the second end portion 506 of the valve body 500. An annular shoulder 524 extends radially inwardly from an annular relief groove 526 preferably formed in the cylindrical surface of the fourth counterbore 522 adjacent to the annular shoulder 524. The diameter of the cylindrical surface of the fourth counterbore 522 is preferably approximately 2 inches.

The passageway 502 further includes an internally threaded portion 528 extending from the second end portion 506 of the valve body 500 to an annular relief groove 530 which is in turn connected to the cylindrical surface of the fourth counterbore 522 by an annular shoulder 532.

A seal bushing 534 is positioned within the first counterbore 510 with one end face 536 thereof abutting the annular shoulder 512. A fluid tight seal is formed between the seal bushing 534 and the cylindrical surface of the first counterbore 510 by a pair of O-rings 538 disposed in respective annular grooves formed in the substantially cylindrical periphery of the seal bushing 534. A longitudinal bore 540 extends through the seal bushing 534 intersecting the one end face 536 and the opposite end face 542 thereof. A plurality of radially extending ports or apertures 544 communicate between the bore 540 and an annular groove 546 formed in the cylindrical periphery of the seal bushing 534 intermediate the O-rings 538.

A seat spacer 548 is positioned within a portion of the first counterbore 510 and a portion of the second counterbore 514 with the first end face 550 thereof abutting the second end face 542 of the seal bushing 534. The seat spacer 548 includes a circumferential groove 554 formed in the outer periphery thereof intermediate the first end face 550 and the second end face 556 thereof. A longitudinal bore 558 is FORMED in the seat spacer 548 and intersects the opposite end faces 550 and 556 thereof. The bore 558 has a diameter greater than the bore 540 through the seal bushing 534. At least one port 560 is formed in the seat spacer 548 and communicates between the bore 558 and the circumferential groove 554.

A generally cylindrically shaped carbide valve seat 562 is positioned within the second counterbore 514 with the inner end face 564 thereof abutting the second end face 556 of the seat spacer 548. The valve seat 562 includes a longitudinal bore 566 extending therethrough with a frusto-conical seating surface 568 formed thereon and interconnecting the bore 566 and the inner end face 564 thereof. A fluid tight seal is formed between the valve seat 562 and the cylindrical surface of the second counterbore 514 by an O-ring 570 disposed in an annular groove formed in the cylindrical surface of the counterbore 514.

An externally threaded seat retainer bushing 572 is threadedly engaged with the internally threaded portion 520 of the valve body 500 with the inner end face 574 thereof abutting the outer end face 576 of the valve seat 562. This positioning of the seat retainer bushing 572 within the valve body 500 secures the valve seat 562, seat spacer 548 and the seal bushing 534 within the passageway 502. A fluid tight seal is achieved between the seat retainer bushing 572 and the valve body 500 by an O-ring 578 disposed in an annular groove formed in the seat retainer bushing and sealingly engaging the cylindrical surface of the third counterbore 518. A longitudinal bore 580 is formed in the seat retainer bushing 572 and communicates between the inner end face 574 and the outer end face 582 thereof. The longitudinal bore 580 includes an internally threaded portion 584 formed therein adjacent to the outer end face 582.

A piston 586 is slidably disposed within a longitudinal passageway 502. The piston 586 includes a cylindrically shaped valve member end portion 588, having a diameter of approximately 1 inch, and a cylindrically shaped pilot piston end portion 590, having a diameter of approximately 2 inches. The valve member end portion **588** is longitudinally slidably disposed in the longitudinal bore **540** of the seal bushing **534** along the longitudinal axis thereof. fluid tight sliding seal is provided between the valve member end portion **588** and the longitudinal bore **540** by means of a pair of T-rod seals **592** carried in respective annular grooves formed in the cylindrical surface of the bore **540** on opposite sides of the ports **544.**

A frusto-conical sealing surface **592** is formed on the valve member end portion **588** and is sized and shaped to sealingly engage the mating frusto-conical seating surface **568** of the carbide valve seat **562** upon the abutment of the seating surfaces **592** and **568.**

The pilot piston end portion **590** of the piston **586** is slidably disposed within the fourth counterbore **522.** A fluid tight sliding seal is achieved between the pilot piston end portion **590** and the cylindrical surface of the fourth counterbore **522** by means of a T-rod seal **594** disposed in an annular groove formed in the cylindrical surface of the fourth counterbore **522.**

A pilot cover **596** is threadedly secured within the internally threaded portion **528** of the valve body **500.** The pilot cover includes a longitudinal passageway **598** extending therethrough with a counterbore **600** formed therein intersecting the inner end face **602** of the pilot cover **596.** An internally threaded portion **604** is formed in the passageway **598** communicating between the outer end face **606** and the counterbore **600** of the pilot cover **596.**

A cylindrically shaped pilot stem **608,** having a diameter of approximately **1** inch, is slidably disposed within the counterbore **600** of the pilot cover **596.** A fluid tight sliding seal is provided between the pilot stem **608** and the cylindrical surface of the counterbore **600** by means of a T-rod seal **610** carried in an annular groove formed in the cylindrical surface of the counterbore **600.** The inner end face **612** of the pilot stem **608** is engageable with the outer end face **614** of the pilot piston end portion **590** of the piston **586** in abutting relation.

A vent port **616** is formed in the valve body **500** and communicates between the annular relief groove **530** and the exterior thereof. A second vent port **618** is formed in the valve body **500** and communicates between the cylindrical surface of the first counterbore **510** adjacent to the annular groove **546** of the seal bushing **534** and the exterior of the valve body **500.**

A valve actuating pilot port **620** is formed in the valve body **500** and communicates between the exterior of the valve body **500** and the passageway **502** intermediate the annular shoulders **512** and **524** thereof. The valve actuating pilot port **620** includes an internally threaded portion **622.**

A power fluid output port **624** is formed in the valve body **500** and communicates between the one side **508** and the second counterbore **514** intermediate the seal bushing **534** and the valve seat **562.** The port **624** provides fluid communication with the port **560** and the longitudinal bore **558** of the seat spacer **548.**

A mount spacer **626** having a bore **628** therethrough is positioned in engagement with the one side **508** of the valve body **500** with the bore **628** thereof in alignment with the output port **524.** A fluid tight seal is provided between the mount spacer **626** and the side **508** of the valve body **500** by means of an O-ring **630** disposed in an annular groove formed in the mount spacer **626** concentric with the bore **628** therethrough. A second O-ring **632** is disposed in another annular groove formed in the mount spacer **626** concentric with the opposite end of the bore **628** to provide fluid tight sealing engagement of the dump valve DV with a suitable manifold. The dump valve DV is securable to a suitable manifold by means of a plurality of threaded screws **634** extending through apertures (not shown) formed in the valve body **500** and the mount spacer **626** to be threadedly received in a suitable manifold (not shown). In the present invention, the dump valve DV is secured to the exhaust manifold **238** interconnecting the adjacent exhaust ports **112** of the control valves **2-CV** and **3-CV.**

In operation, a constant control fluid closing pilot pressure of approximately **2000** psi is introduced through the longitudinal passageway **598** of the pilot cover **596** to act on the pilot stem **608,** thereby urging the pilot stem **608** and the piston **586** to the left within the housing **500.** This application of control fluid pressure constantly biases the seating surface **592** of the valve member end portion **588** into sealing engagement with the seating surface **568** of the valve seat **562.** The longitudinal bore **580** of the seat retaining bushing **572** is in fluid communication with the power fluid at the rod ends of the three power cylinders **40.** When a pilot pressure of predetermined magnitude is introduced into the valve actuating pilot port **620,** the constant closing pressure on the piston **586** is overcome and the pilot pressure acting on the pilot piston end portion **590** at its connection with the valve member end portion **588** moves the piston **586** to the right within the valve body **500** unseating the seating surfaces **568** and **592** thereby opening the dump valve DV. At this time power fluid is allowed to flow through the longitudinal bore **580** and out through the output port **624** and bore **628** of the mount spacer **626** via the longitudinal bore **566,** the longitudinal bore **558** and the port **560** of the dump valve DV.

THE PUMPING CYCLE

The power fluid and control fluid circuits of the present invention are illustrated schematically in FIGS. **10A1, 10A2, 10B1, 10B2, 10C1, 10C2, 10D1, 10D2, 10 E1** and **10E2** of the drawing.

Referring now to FIGS. **10A1** and **10A2** and to Table **1** below, a first phase of the pumping cycle will be explained. In this phase, the power cylinder **1-40** is in the discharge stage of the cycle while the **2-40** and the **3-40** power cylinders are respectively in the precompression and suction stages. Movement of the piston rod assemblies **42** associated with these cycle stages is indicated by the arrows **650, 652** and **654.**

In order for the **1-40** power cylinder to perform its discharging function, the **1-I** sleeve valve must be open while the **1-E** sleeve valve is in a closed position. In other words, the sleeve of the **1-I** valve is in its upper position, and the sleeve of the **1-E** valve is in its lower position as shown in FIG. **10A1.**

Thus, with the sleeve valves **1-I** and **1-E** in the illustrated positions, power fluid provided by a power circuit pump **656** passes through the **1-I** valve into the longitudinal bore **1-92** of the **1-CV** control valve assembly. This pressurized fluid is prevented from passing through the closed **1-E** valve so that it is caused to flow to the **1-40** power cylinder along the flow path indicated by the arrows in FIG. **10A1.**

During the discharging function of the **1-40** power cylinder, fluid displaced from the rod end of that cylinder enters into the rod end of the **3-40** power cylinder through the common conduit **61.** The pressure of this power fluid entering the rod end of the **3-40** power cylinder causes this cylinder to undergo the major portion of its suction function.

Performance of the suction function by the **3-40** power cylinder is permitted by the relative positions of the sleeve valves **3-I** and **3-E** in the **3-CV** control valve assembly. As indicated in FIG. **10A1**, the **3-I** valve is in its lower or closed position, while the **3-E** valve is in its upper or open position.

Because of the closed **3-I** valve, pressurized fluid provided by the power circuit pump **656** via the open shut off valve assembly **250** is prevented from entering the longitudinal bore **3-92** of the **3-CV** control valve assembly. Thus, this pressurized fluid does not resist displacement of power circuit fluid out of the **3-40** power cylinder by the power piston **46** thereof. The open **3-E** valve permits this displaced power fluid to pass through the longitudinal bore **3-92** of the control valve assembly **3-CV**, and thereafter through the **3-E** valve to the power circuit reservoir or sump **658** via the check valve **660** as indicated by the arrows in FIG. **10A1.** It should be noted that a pressure relief valve **659** is connected between the high pressure side of the pump **656** and the reservoir **658** to vent pressurized power fluid to the reservoir in the event the power fluid pressure exceeds a predetermined value. As an alternative, the pressure relief valve **659** may be vented to the atmosphere if loss of a small amount of power fluid is not critical to the operation of the pump.

As illustrated in FIG. **10A1,** the **2-PR** valve is in an open position so that pressurized power fluid provided by the power circuit pump **656** is directed to the **2-40** power cylinder through the orifice **2-444** along the flow path indicated by the arrows. This relatively small flow of power fluid causes the piston **46** of the power cylinder **3-40** to move toward the fluid end in the direction of the arrow **652** thereby forcing the fluid end piston slowly into the fluid end cylinder to precompress fluid within that cylinder to a pressure approaching discharge pressure.

The closed **2-I** valve prevents discharge instigating flow of pressurized power fluid to the **2-40** power cylinder assembly. Further, the closed **2-E** valve prevents the exhausting of precompression fluid to the power circuit reservoir **658.**

It should be noted that the **3-PR** precompression valve remains in a closed position throughout the cycle phase illustrated in FIG. **10A1** and the **1-PR** precompression valve assumes a closed position in that cycle phase because pilot pressure exists on these valves at the pilot ports **3-462** and **1-462.** The pilot pressure applied to the pilot ports **1-462** and **3-462** emanates from the control fluid assembly **78** as more clearly illustrated in FIG. **10A2,** the function of which will be described in more detail hereinafter.

The pilot port **2-462** of the open precompression valve **2-PR** communicates with the flow control fluid assembly **78** and is depressured or tanked thereby in a manner as will be described more fully hereinafter.

A summary of the sleeve valve and precompression valve positions associated with the cycle functions of the power cylinders, as illustrated in FIG. **10A1,** will be found in Table 1. In Table 1, the symbol "U" indicates an untripped front position valve FP or back position valve BP, while the symbol "T" indicates a tripped front position valve FP or back position valve BP. The other terms used in Table 1 are believed to be self-explanatory when interpreted in conjunction with the schematic drawings to which the table applies.

TABLE 1

Valve	VALVE CONDITION FIGS. 10A1 & 10A2	FIGS. 10B1 & 10B2	FIGS. 10C1 & 10C2	FIGS. 10D1 & 10D2	FIGS. 10E1 & 10E2
1-FP	U	T	U	U	U
2-FP	U	U	T	U	U
3-FP	T	U	U	T	T
1-BP	U	U	T	U	T
2-BP	T	U	U	U	T
3-BP	U	T	U	U	U
1-FW	Up	Down	Up	Up	Up
2-FW	Up	Up	Down	Up	Up
3-FW	Down	Up	Up	Down	Down
1-I	Open	Closed	Closed	Open	Open
1-E	Closed	Open	Closed	Closed	Closed
1-PR	Closed	Closed	Open	Closed	Closed
2-I	Closed	Open	Closed	Closed	Closed
2-E	Closed	Closed	Open	Closed	Closed
2-PR	Open	Closed	Closed	Closed	Open
3-I	Closed	Closed	Open	Closed	Closed
3-E	Open	Closed	Closed	Open	Open
3-PR	Closed	Open	Closed	Closed	Closed
FV	Closed	Closed	Closed	Open	Closed
DV	Closed	Closed	Closed	Closed	Open

With reference to Table 1, it may be readily seen that a suction function is associated with a closed I valve and and open E valve whereby the appropriate longitudinal bore **92** of one control valve assembly CV is placed in communication with the power circuit reservoir **658.** Further, a discharge function is associated with an open I valve and a closed E valve whereby the longitudinal bore **92** is maintained in communication with the power circuit pump **656.** In both the discharge and suction functions, the associated precompression valve PR is closed.

The precompression function is associated with a control valve assembly condition wherein both the I and E valves are closed and the associated precompression valve PR is moved from its normally closed position to an open position thus providing a restrictive flow of power fluid to the associated power cylinder assembly through the appropriate longitudinal bore **92.**

Referring now to FIG. **10A2** and to Table 1, the function of the control circuit conditioning valves **1-FP, 2-FP** and **3-FP** will be described in connection with the positioning of the I and E valves o the control valve assemblies CV as previously explained in the discussion of FIG. **10A1.**

In FIG. **10A2** the final positions of the I and E valves associated with the phase of the pumping cycle described in connection with FIG. **10A1** are clearly illustrated. The positions of the I and E valves immediately preceding this phase of the pumping cycle are illustrated in FIG. **10C1** and FIG. **10C2.**

With reference to FIG. **10A2** it will be apparent that the **1-CV** control valve assembly is in condition for the illustrated phase of the pumping cycle by movement of the **1-I** valve from its lower or closed position to its upper or open position. The opening of the **1-I** valve is caused by the position of the **3-FP** front position valve. The **3-FP** valve is so positioned by actuation thereof by the cam actuator **58** of power cylinder **3-40.** With the **3-FP** front position valve in the tripped position, pressurized control fluid is directly therethrough from the pump assembly **80** through the **2**-DPC and **3**-DPC double piloted check valves to properly condition and lock the **2**-FW and **3**-FW four way position valves. The **2**-FW four way position valve is actuated to its up position and the **3**-FW four way position valve is actuated to its down position. Pressurized control fluid from the pump **80** is directed through the **2**-FW valve and through shuttle valve **662** to the pilot port **1-462** of the precompression valve **1**-PR. Control fluid through the **2**-FW valve is further directed through the tripped **2**-BP valve and shuttle valves **664** and **666** to the pilot port **462** of the fill valve FV thereby retaining the fill valve in a closed position.

Pressurized control fluid from the pump **80** also flows through the **3**-FW valve to the I-B port of the control valve assembly **1**-CV and to the E-B port of the control valve **3**-CV through piloted check valve **670**. Pressurized control fluid also flows from the pump **80** through the **3**-FW valve to the pilot port of the piloted check valve **672**.

As a result of the expansion of the control fluid in the B chamber of the **1**-I valve, the A chamber thereof contracts displacing control fluid through the I-A port of the **1**-I valve to the I-A port of the **3**-I valve through piloted check valves **672** and **674**. As a result of the expansion of the A chamber of the **3**-I valve, the B chamber thereof contracts displacing control fluid through the I-B port thereof and back to the control fluid reservoir assembly **82** via the **2**-FW valve. When the **3**-I valve reaches its down or closed position, the I-C port thereof is placed in fluid communication with the piloted check valve **670** thereby unseating the piloted check valve **670** and allowing the previously mentioned control fluid flow therethrough from the **3**-FW valve to the E-B port of the **3**-E valve.

As a result of the expansion of the B chamber of the **3**-E valve, the A chamber thereof contracts displacing control fluid through the E-A port of the **3**-E valve and into the E-A port of the **2**-E valve thereby closing the **2**-E valve. As a result of the expansion of the A chamber of the **2**-E valve, the B chamber thereof contracts displacing control fluid through the E-B port thereof through piloted check valve **676** back to the control fluid reservoir assembly **82** via the **2**-FW valve. The control fluid pilot volume from the piloted check valve **678** flows back to the control fluid reservoir assembly **82** via check valve **680** and the **3**-FW valve.

As previously mentioned, pressurized control fluid passes through the tripped **2**-BP back position valve to apply pilot pressure to the pilot port **462** of the fill valve FV to retain the fill valve in a closed position. The **2**-BP back position valve is positioned in its tripped position by the cam actuator **58** of the **2-40** power cylinder while it is in the precompression phase. This conditioning of the **2**-BP back position valve permits the pilot port **2-462** of the precompression valve **2**-PR to communicate therethrough via shuttle valve **682** with the control fluid reservoir assembly **82** thereby releasing pilot pressure on and permitting the opening of the precompression valve **2**-PR.

It will also be seen that the four way position valve **1**-FW remains in its up position from the next preceding phase of the pumping cycle thereby allowing pressurized control fluid flow therethrough to the pilot port **3-462** of the precompression valve **3**-PR via the shuttle valve **684** thereby retaining the precompression valve **3**-PR in a closed condition.

The pilot port **620** of the dump valve DV is in fluid communication with the control fluid reservoir assembly **82** via shuttle valves **686** and **688**, piloted check valve **690** and the back position valve **1**-BP thereby retaining the dump valve DV in its closed position.

Referring now to FIGS. **10B1** and **10B2** and to Table **1**, the second phase of the pumping cycle will be explained. In this phase, the power cylinder **2-40** is in the discharge stage of the cycle while the power cylinders **3-40** and **1-40** are respectively in the precompression and suction stages. Movement of the piston rod assemblies **42** associated with these cycle stages is indicated by the arrows **692, 694** and **696.**

In order for the power cylinder **2-40** to perform its discharging function, the **2**-I sleeve valve must be open while the **2**-E sleeve valve is in the closed position. In other words, the sleeve of the **2**-I valve is in its upper position, and the sleeve of the **2**-E valve is in its lower position as shown in FIG. **10B1.**

Thus, with the sleeve valves **2**-I and **2**-E in the illustrated positions, power fluid provided by the power circuit pump **656** passes through the **2**-I valve into the longitudinal bore **2-92** of the **2**-CV control valve assembly. The pressurized power fluid is prevented from passing through the closed **2**-E valve so that it is caused to flow to the power cylinder **2-40** along the flow path indicated by the arrows in FIG. **10B1.**

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

Performance of the suction function by the **1-40** power cylinder is permitted by the relative positions of the sleeve valves **1**-I and **1**-E in the **1**-CV control valve assembly. As indicated in FIG. **10B1,** the **1**-I valve is in its lower or closed position, while the **1**-E valve is in its upper or open position.

Because of the closed **1**-I valve, pressurized power fluid provided by the power circuit pump **656** is prevented from entering the longitudinal bore **1-92** of the **1**-CV control valve assembly. Thus, the pressurized power fluid does not resist displacement of power circuit fluid out of the power cylinder **1-40** by the power piston **46** thereof. The open **1**-E valve permits the displaced power fluid to pass through the longitudinal bore **1-92** of the control valve assembly **1**-CV, and thereafter through the **1**-E valve to the power circuit reservoir **658** via the check valve **660** as indicated by the arrows in FIG. **10B1.**

As also illustrated in FIG. **10B1** the **3**-PR valve is in an open position so that the pressurized fluid provided by the power circuit pump **656** is directed to the power cylinder **3-40** through the orifice **3-444** along the flow path indicated by the arrows. This relatively restricted flow of pressurized power fluid causes the piston **46** of the power cylinder **3-40** to move toward the pump fluid end in the direction of the arrow **696** thereby forcing the fluid end piston slowly into the fluid end cylinder to precompress fluid within that cylinder to a pressure approaching discharge pressure.

The closed **3**-I valve prevents discharge instigating flow of pressurized power fluid to the power cylinder assembly **3-40.** Further, the closed **3**-E valve prevents the exhausting of precompression fluid to the power circuit reservoir **658.**

It should be noted that the **1-PR** precompression valve remains in a closed position throughout the cycle phase illustrated in FIG. **10B1** and the **2-PR** precompression valve assumes a closed position in that cycle phase because pilot pressure exists on these valves at the pilot ports **1-462** and **2-462.** The pilot pressure applied to the pilot ports **1-462** and **2-462** emanates from the control fluid assembly **78** as more clearly illustrated in FIG. **10B2,** the function of which will be described in detail hereinafter.

The pilot port **3-462** of the open precompression valve **3-PR** communicates with the flow control fluid assembly **78** and is depressured or tanked thereby in a manner as will be described more fully hereinafter.

A summary of the sleeve valve and precompression valve positions associated with the cycle functions of the power cylinders, as illustrated in FIG. **10B1,** will be found in Table **1.**

Referring now to FIGS. **10B2** and to Table **1,** the function of the control circuit conditioning valves **1**-FP, **2**-FP and **3**-FP will be described in connection with the positioning of the I and E valves of the control valve assemblies CV as previously explained in the discussion of FIG. **10B1.**

In FIG. **10B2** the final positions of the I and E valves associated with the phase of the pumping cycle described in connection with FIG. **10B1** are clearly illustrated. The positions of the I and E valves immediately preceding this phase of the pumping cycle are illustrated in FIG. **10A1** and FIG. **10A2.**

With reference to FIG. **10B2** it will be apparent that the **2**-CV control valve assembly is in condition for the illustrated phase of the pumping cycle by movement of the **2**-I valve from its lower or closed position to its upper or open position. The opening of the **2**-I valve is caused by the position of the **1**-FP front position valve. The **1**-FP-valve is so positioned by actuation thereof by the cam actuator **58** of the **1-40** cylinder. With the **1**-FP front position valve in a tripped position, pressurized control fluid is directed therethrough from the pump assembly **80** through the **1**-DPC and **3**-DPC double piloted check valves to properly condition and lock the **1**-FW and **3**-FW four way position valves. The **1**-FW four way position valve is actuated to its down position and the **3**-FW four way position valve is actuated to its up position. Pressurized control fluid from the pump **80** is directed through the **3**-FW valve through shuttle valve **682** to the pilot port **2-462** of the precompression valve **2**-PR. Control fluid through the **3**-FW valve is further directed through the tripped **3**-BP valve and the shuttle valve **666** to the pilot port **462** of the fill valve FV thereby retaining the fill valve in its closed position.

Pressurized control fluid from the pump **80** also flows through the **1**-FW valve to the I-B port of the control valve assembly **2**-CV and to the E-B port of the control valve **1**-CV through the piloted check valve **678.** Pressurized control fluid also flows from the pump **80** through the **1**-FW valve to the pilot port of the piloted check valve **698.**

As a result of the expansion of the control fluid in the B chamber of the **2**-I valve, the A chamber thereof contracts displacing control fluid through the I-A port of the **2**-I valve to the I-A port of the **1**-I valve through the piloted check valves **698** and **672.** As a result of the expansion of the A chamber of the **1**-I valve, the B chamber thereof contracts displacing control fluid through the I-B port thereof and back to the control fluid reservoir assembly **82** via the **3**-FW valve. When the **1**-I valve reaches its down or closed position, the I-C port thereof is placed in fluid communication with the piloted check valve **678** thereby unseating the piloted check valve **678** and allowing the previously mentioned control fluid flow therethrough from the **1**-FW valve to the E-B port of the **1**-E valve.

As a result of the expansion of the B chamber in the **1**-E valve, the A chamber thereof contracts displacing control fluid through the E-A port of the **1**-E valve into the E-A port of the **3**-E valve thereby closing the **3**-E valve. As a result of the expansion of the A chamber of the **3**-E valve, the B chamber thereof contracts displacing control fluid through the E-B port thereof through piloted check valve **670** back to the control fluid reservoir assembly **82** via the **3**-FW valve. The control fluid pilot volume from the piloted check valve **676** flows back to the control fluid reservoir assembly **82** via check valve **700** and the **1**-FW valve.

As previously mentioned, pressurized control fluid passes through the tripped **3**-BP back position valve to apply pilot pressure to the pilot port **462** of the fill valve FV to retain the fill valve in a closed position. The **3**-BP back position valve is positioned in its tripped position by the cam actuator **58** of the **3-40** power cylinder while it is in the precompression phase. This conditioning of the **3**-BP back position valve permits the pilot port **3-462** of the precompression valve **3**-PR to communicate therethrough via shuttle valve **684** with the control fluid reservoir assembly **82** thereby releasing pilot pressure on and permitting the opening of the precompression valve **3**-PR.

It will also be seen that the four way position valve **2**-FW remains in its up position from the next preceding phase of the pumping cycle thereby allowing pressurized control fluid therethrough to the pilot port **1-462** of the precompression valve **1**-PR via the shuttle valve **662** thereby retaining the precompression valve **1**-PR in a closed position.

The pilot port **620** of the dump valve DV is in fluid communication with the control fluid reservoir assembly **82** via shuttle valves **686** and **688,** piloted check valve **702** and the back position valve **2**-BP thereby retaining the dump valve DV in its closed position.

Referring now to FIGS. **10C1** and **10C2** and Table **1,** a third phase of the pumping cycle will be explained. In this phase, the power cylinder **3-40** is in the discharge stage of the cycle while the **1-40** and **2-40** power cylinders are respectively in the precompression and suction stages. The movement of the piston rod assembly **42** associated with these cycle stages is indicated by the arrows **704, 706** and **708.**

In order for the power cylinder **3-40** to perform its discharging function, the **3**-I sleeve valve must be open while the **3**-E sleeve valve is in a closed position. In other words, the sleeve of the **3**-I valve is in its upper position, and the sleeve of the **3**-E valve is in its lower position as shown in FIG. **10C1.**

Thus with the sleeve vaules **3**-I and **3**-E in the illustrated positions, power fluid provided by the power circuit pump **656** passes through the **3**-I valve into the longitudinal bore **3-92** of the **3**-CV control valve assembly. This pressurized fluid is prevented from passing through the closed 3-E valve so that it is caused to flow to the 3-40 power cylinder along the flow path indicated by the arrows in FIG. 10C1.

During the discharging function of the power cylinder 3-40, fluid displaced from the rod end of that cylinder enters into the rod end of the power cylinder 2-40 through the common conduit 61. The pressure of this power fluid entering the rod end of the 2-40 power cylinder causes this cylinder to undergo the major portion of its suction function.

Performance of the suction function by the 2-40 power cylinder is permitted by the relative positions of the sleeve valves 2-I and 2-E in the 2-CV control valve assembly. As indiacted in FIG. 10C1, the 2-I valve is in its lower or closed position, while the 2-E valve is in its upper or open position.

Because of the closed 2-I valve, pressurized fluid provided by the power circuit pump 656 is prevented from entering the longitudinal bore 2-92 of the 2-CV control valve assembly. Thus, this pressurized fluid does not resist displacement of power circuit fluid out of the power cylinder 2-40 by the power piston 46 thereof. The open 2-E valve permits this displaced power fluid to pass through the longitudinal bore 2-92 of the control valve assembly 2-CV, and thereafter through the 2-E valve to the power circuit reservoir 658 via the check valve 660 as indicated by the arrows in FIG. 10C1.

As illustrated in FIG. 10C1, the 1-PR precompression valve is in an open position so that pressurized power fluid provided by the power circuit pump 656 is directed to the power cylinder 1-40 through the orifice 1-444 along the flow path indicated by the arrows. This relatively small restriced flow of power fluid causes the piston 46 of the power cylinder 1-40 to move toward the pump fluid end in the direction of the arrow 704 thereby forcing the fluid end piston slowly into the fluid end cylinder to precompress fluid within that cylinder to a pressure approaching discharge pressure.

The closed 1-I valve prevents discharge instigating flow of pressurized power fluid to the 1-40 power cylinder assembly. Further, the closed 1-E valve prevents the exhausting of precompression fluid to the power circuit reservoir 658.

It should be noted that the 2-PR precompression valve remains in a closed position throughout the cycle phase illustrated in FIG. 10C1 and the 3-PR precompression valve assumes a closed position in that cycle phase because pilot pressure exists on these valves at the pilot ports 2-462 and 3-462. The pilot pressure applied to the pilot ports 2-462 and 3-462 emanates from the control fluid assembly 78 as more clearly illustrated in FIG. 10C2, the function of which will be described in more detail hereinafter.

The pilot port 1-462 of the open precompression valve 1-PR communicates with the flow control fluid assembly 78 and is depressured or tanked thereby in a manner as will be described more fully hereinafter.

A summary of the sleeve valve and precompression valve positions associated with the cycle functions of the power cylinders, as illustrated in FIG. 10C1, will be found in Table 1.

Referring now to FIG. 10C2 and the Table 1, the function of the control circuit conditioning valves 1-FP, 2-FP and 3-FP will be described in connection with the positioning of the I and E valves of the control valve assemblies CV as previously explained in the discussion of FIG. 10C1.

In FIG. 10C2 the final positions of the I and E valves associated with the phase of the pumping cycle described in connection with FIG. 10C1 are clearly illustrated. The positions of the I and E valves immediately preceding this phase of the pumping cycle are illustrated in FIG. 10B1 and FIG. 10B2.

With reference to FIG. 10C2 it will be apparent that the 3-CV control valve assembly is in condition for the illustrated phase of the pumping cycle by movement of the 3-I valve from its lower or closed position to its upper or open position. The opening of the 3-I valve is caused by the position of the 2-FP front position valve. The 2-FP valve is so positioned by actuation thereof by the cam actuator 58 of the power cylinder 2-40. With the 2-FP front position valve in the tripped position, pressurized control fluid is directed therethrough from the pump assembly 80 through the 1-DPC and 2-DPC double piloted check valves to properly condition and lock the 1-FW and 2-FW four way position valves. The 1-FW four way position valve is actuated to its up position and the 2-FW four way position valve is actuated to its down position. Pressurized control fluid from the pump 80 is directed through the 1-FW valve and through shuttle valve 684 to the pilot port 3-462 of the precompression valve 3-PR. Control fluid through the 1-FW valve is further directed through the tripped 1-BP valve and shuttle valves 664 and 666 to the pilot port 462 of the fill valve FV thereby retaining the fill valve in a closed position.

Pressurized control fluid from the pump 80 also flows through the 2-FW valve to the pilot port of the piloted check valve 674 and the I-B port of the control valve assembly 3-CV and to the E-B port of the control valve assembly 2-CV through piloted check valve 676.

As a result of the expansion of the control fluid in the B chamber of the 3-I valve, the A chamber thereof contracts displacing control fluid through the I-A port of the 3-I valve to the I-A port of the 2-I valve through piloted check valves 674 and 698. As a result of the expansion of the A chamber of the 2-I valve, the B chamber thereof contracts displacing control fluid through the I-B port thereof and back to the control fluid reservoir assembly 82 via the 1-FW valve. When the 2-I valve reaches its down or closed position, the I-C port thereof is placed in fluid communication with the piloted check valve 676 thereby unseating the piloted check valve 676 and allowing the previously mentioned control fluid flow therethrough from the 2-FW valve to the E-B port of the 2-E valve.

As a result of the expansion of the B chamber of the 2-E valve, the A chamber thereof contracts displacing control fluid through the E-A port of the 2-E valve and into the E-A port of the 1-E valve thereby closing the 1-E valve. As a result of the expansion of the A chamber of the 1-E valve, the B chamber thereof contracts displacing control fluid through the E-B port thereof piloted check valve 678 back to the control fluid reservoir assembly 82 via the 1-FW valve. The control fluid pilot volume from the piloted check valve 670 flows back to the control fluid reservoir assembly 82 viw check valve 710 and the 2-FW valve.

As previously mentioned, pressurized control fluid passes through the tripped 1-BP back position valve to apply pilot pressure to the pilot port 462 of the fill valve FV to retain the fill valve in a closed position. The 1-BP back position valve is positioned in its tripped position by the cam actuator **58** of the power cylinder **1-40** while it is in the precompression phase. This conditioning of the **1**-BP back position valve permits the pilot port **1-426** of the precompression valve **1**-PR to communicate therethrough via shuttle valve **662** with the control fluid reservoir assembly **82** thereby releasing pilot pressure on and permitting the opening of the precompression valve **1**-PR.

It will also be seen that the four way position valve **3**-FW remains in its up position from the next preceding phase of the pumping cycle thereby allowing pressurized control fluid flow therethrough to the pilot port **2-462** via the shuttle valve **682** thereby retaining the precompression valve **2**-PR in a closed condition.

The pilot port **620** of the dump valve DV is in fluid communication with the control fluid reservoir assembly **82** via shuttle valve **686**, piloted check valve **712** and the back position valve **3**-BP thereby retaining the dump valve DV in its closed position.

Referring now to FIGS. **10D1** and **10D2** there is illustrated schematically therein a variation of the first phase of the pumping cycle previously discussed and illustrated in FIG. **10A1** and **10A2.** In FIG. **10D1** it will be seen that the cam actuator **58** of the power cylinder **2-40** is not in contact with the back position valve **2-BP** thereby placing the **2**-BP valve in an untripped condition. This condition occurs when there is an inadequate volume of power fluid in the rod ends of the three power cylinders **40** and the common conduit **61.** The system senses this condition and causes the fill valve FV to open thereby providing supplementary power fluid to the rod ends of the power cylinders **40** and to the common conduit **61.**

Referring to FIG. **10D2** it will be seen that when the back position valve **2**-BP is in an untripped position, pressurized control fluid communicates between the pump assembly **80** and the pilot port **2-462** of the precompression valve **2**-PR via the **2**-FW valve, the untripped back position valve **2**-BP and the shuttle valve **682** thereby placing the precompression valve **2**-PR in a closed position preventing power fluid flow therethrough.

It will also be seen that the untripped back position valve **2**-BP places the pilot port **462** of the fill valve FV in communication with the control fluid reservoir **82** via the shuttle valves **666** and **664** thereby placing the fill valve FV in an open position so that supplementary power fluid passes therethrough to the rod ends of the power cylinders **40** from the power circuit pump **656.** The pump system will continue its operation in this phase of the pumping cycle until the next phase of the cycle, described above and illustrated in FIGS. **10B1** and **10B2,** is initiated at which time the fill valve FV will be closed if the proper amount of makeup power fluid has been passed therethrough to achieve the normal conditions illustrated in FIGS. **10B1** and **10B2.**

Referrring now to FIGS. **10E1** and **10E2** and to Table **1,** another variation of the basic cycle illustrated in FIGS. **10A1** and **10A2** is shown wherein the cam actuator **58** of the power cylinder **1-40** is actuating the back position valve **1**-BP thereby placing the back position valve **1**-BP in a tripped condition. This situation can occur when an excess amount of power fluid is present in the rod ends of the power cylinders **40** and in the common interconnecting conduit **61.** When this condition exists, it will be seen in FIG. **10E2** that pressurized control fluid communicates between the control fluid pump assembly **80** and the pilot port **620** of the dump valve DV via the **1**-FW valve, the back position valve **1**-BP, the piloted check valve **690** and the shuttle valves **688** and **686.** The pilot operated check valve **690** is unseated to allow such flow therethrough by means of the application of pressurized control fluid to the pilot port thereof from the control fluid pump assembly **80** via the **2**-FW valve and the tripped back position valve **2**-BP. When the dump valve DV is so actuated to its open position, power fluid is allowed to flow therethrough from the rod ends of the power cylinders **40** and the interconnecting common conduit **61** to the power circuit reservoir **658** via the check valve **660,** as illustrated in FIG. **10E1.** The pump system will continue operation in this particular phase of the pumping cycle until the next succeeding phase, described above and illustrated in FIGS. **10B1** and **10B2,** is encountered at which time the pump system will have been correctly compensated and the proper amount of power fluid will be contained in the rod ends of power cylinders **40** and the interconnecting common conduit **61.** The fill valve FV will then be closed as illustrated in FIGS. **10B1** and **10B2** and the pumping cycle will continue in a normal fashion.

It will be seen from the foregoing description of the pumping cycle of the present invention that an extremely reliable, self-compensating system comprising a separate fluid control assembly **78** in combination with an improved power end assembly **38** provides a pump **20** which constantly monitors its own operation during each phase of the pumping cycle.

It should also be noted that the cycle variation described and illustrated in FIGS. **10D1, 10D2 10E1** and **10E2,** while referring generally to the cycle phase described and illustrated in FIGS. **10A1** and **10A2,** may also be encountered during the other two phases of a complete pump cycle. It is not believed, however, to be essential to a complet disclosure of the invention to describe all possible variations which may occur and be corrected by the control system during operation of the triplex pump. It will be readily apparent to those skilled in the art that the present pump and its associated control system provides capability for constantly monitoring and correcting operation of the pump to provide smooth and reliable service under virtually all circumstances.

Changes may be made in the arrangement or combination of parts or elements shown in the drawings and described in the specification without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A fluid operated triplex pump comprising:

three piston and cylinder pumping assemblies, each operable in a suction, precompression and discharge cycle out of phase with the others;

each of said piston and cylinder assemblies including a power end and a fluid end, and a rod end;

power circuit means for cyclically operating each of said piston and cylinder pumping assemblies in said suction, precompression and discharge cycles;

control fluid circuit means for conditioning said power circuit means to cycle said piston and cylinder pumping assemblies;

said power circuit means comprising:

means for connecting the triplex pump to a power fluid reservoir for providing a source of power fluid;

means for connecting the triplex pump to a power fluid pump for delivering pressurized power fluid from said fluid reservoir;

flow regulating means operatively connecting the pressurized fluid delivered by said power fluid pump to said plurality of piston and cylinder assemblies and to said reservoir said flow regulating means including:

a plurality of power circuit valve means, each for selectively placing one of said piston and cylinder pumping assemblies in unrestricted fluid communication with said pressurized power fluid, in restricted fluid communication with a reduced flow of said pressurized power fluid, or in fluid communication with said fluid reservoir;

each of said power circuit valve means comprising:

a power fluid inlet valve body having a power fluid entry passage and a power fluid exit passage;

a power fluid exhaust valve body having a power fluid entry passage and a power fluid exit passage;

precompression valve means having a power fluid entry port, a power fluid output port having a restricted passage, a control fluid pilot port, and means normally blocking the entry port from the output port when control fluid pilot pressure exists in the pilot port;

the power fluid entry passage of said power fluid inlet valve body and the entry port of said precompression valve means being in continuous communication with pressurized power fluid delivered by said power fluid pump;

a common chamber in fluid communication with the power fluid exit passage of said power fluid inlet valve body, and in continuous fluid communication with the power end of a respective one of said piston and cylinder assemblies, with the output port of said precompression valve means, and with the power fluid inlet passage of said power fluid exhaust valve body;

the power fluid exit passage of said power fluid exhaust valve body being in continuous communication with said power fluid reservoir;

the pilot ports of each of said precompression valve means being in control fluid communication with said control circuit means;

power fluid inlet valve means carried by said power fluid inlet valve body for providing selective fluid communication between the power fluid entry passage and the power fluid exit passage of said power fluid inlet valve body; and

power fluid exhaust valve means carried by said power fluid exhaust valve body for providing selective fluid communication between the power fluid entry passage and the power fluid exit passage of said power fluid exhaust valve body.

2. The fluid operated triplex pump as defined in claim **1** wherein said control fluid circuit means comprises:

opening and closing actuator chambers associated with each of said power fluid inlet and exhaust valve means:

control circuit pump means for selectively delivering opening actuator control fluid to said opening actuator chambers of said power fluid inlet and exhaust valve means so as to place said power fluid inlet and exhaust valve means in their selective communication positions; and

control circuit reservoir means for draining control circuit fluid from selected ones of said opening actuator chambers upon movement of selected ones of said power fluid inlet and exhaust valve means to their non-communicating

3. A triplex pump as defined in claim **2** wherein:

control circuit fluid is supplied to said opening actuator chambers of said power fluid exhaust valve means in two stages.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,847,511

DATED : November 12, 1974

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 Claim 2, last line, immediately following "non-communicating" add --positions--.

Signed and Sealed this

Twenty-eighth **Day of** December 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks