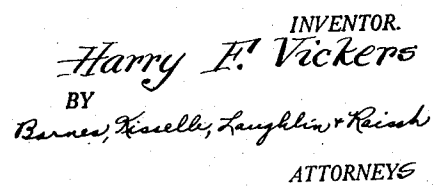


2,218,565

2 Sheets-Sheet 1



Oct. 22, 1940.

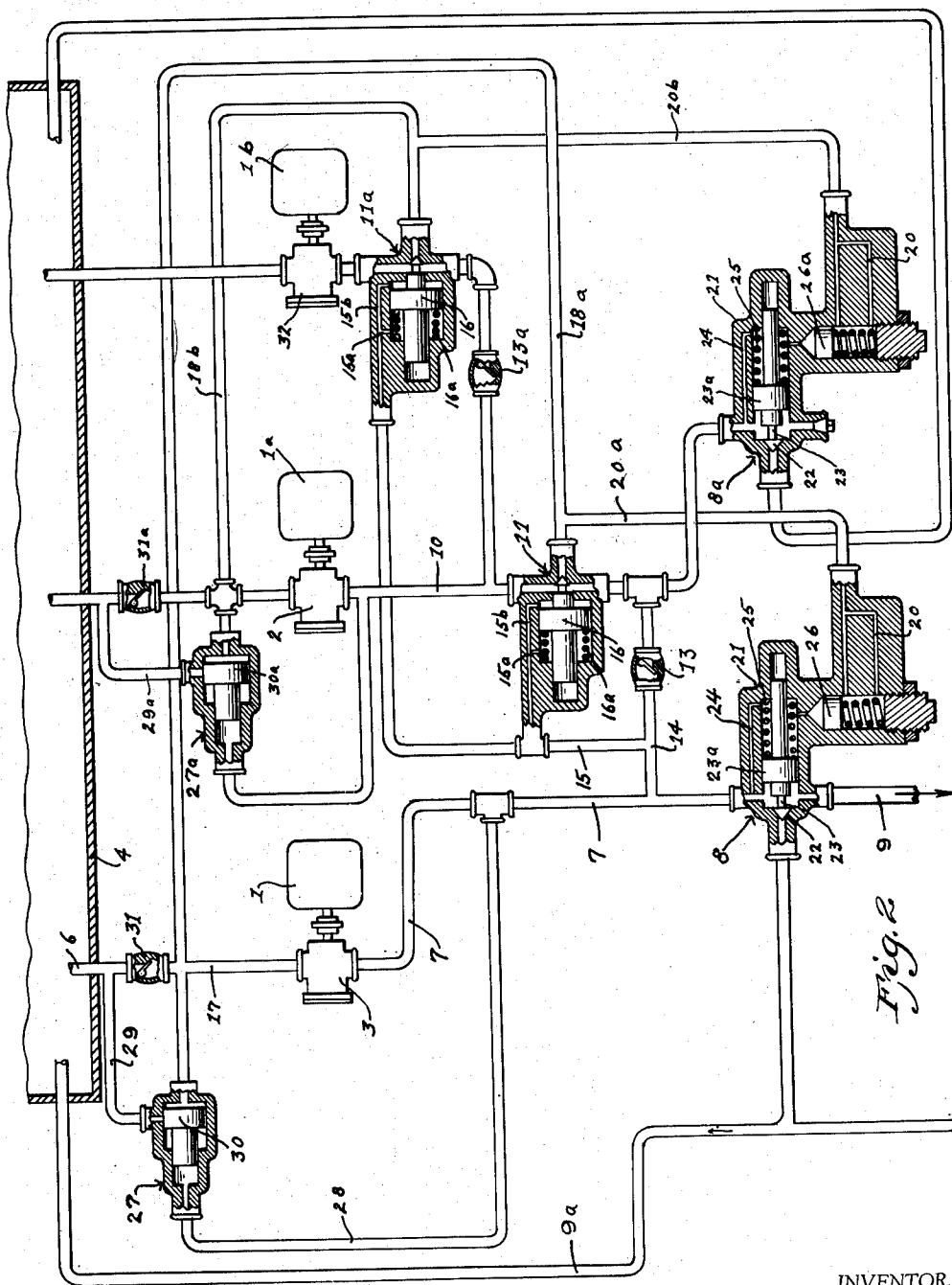
H. F. VICKERS

2,218,565

COMPOUND POSITIVE DISPLACEMENT PUMP CIRCUIT

Original Filed May 1, 1937

2 Sheets-Sheet 2



INVENTOR.

INVENTOR.
Harry F. Vickers

BY

Barnes, Kisselle, Laughlin & Risch
ATTORNEYS

UNITED STATES PATENT OFFICE

2,218,565

COMPOUND POSITIVE DISPLACEMENT
PUMP CIRCUITHarry F. Vickers, Detroit, Mich., assignor to
Vickers, Incorporated, Detroit, Mich., a corpora-
tion of MichiganApplication May 1, 1937, Serial No. 140,074
Renewed August 28, 1939

18 Claims. (Cl. 103—11)

This invention relates to a compound positive displacement pump circuit.

It has particularly to do with a pump circuit having two or more positive displacement pumps in series to produce high pressures.

There have been numerous attempts to connect two or more positive displacement pumps in series to increase operating pressure but they have proved unsuccessful because no means or method could be devised which would prevent one pump taking the whole pressure.

The object of the present invention is to provide a variable pressure pumping system for positive displacement pumps which will allow two or more of such pumps to be connected in series when high pressure exists in the system, said pumps each bearing a proportionate share of the load. A further object is to provide a pumping system which will allow two or more pumps to operate at their highest efficiency points to provide a pressure greater than either is capable of efficiently obtaining.

A still further object is to provide a compound pump system having a relief valve which normally handles the combined high pressure of both pumps, when operating in series, but which will also relieve the pressure output line at the proper relief pressure of a single pump if one of the pumps fails to operate in series for one reason or another.

Briefly, the invention consists of a pump circuit which includes two or more positive displacement pumps, suitable valves and conduits which permit (assuming two pumps) both pumps to deliver the sum of their two volumes into a common line or conduit until the pressure reaches a certain predetermined point, at which point a valve is automatically operated to cause one pump to deliver its volume into the intake of the other pump, both pumps thereafter working in series to deliver the sum of the pressures of the two pumps with the volume of the last pump in the series. The increase in pressure in the system can be handled with substantially the same horsepower as is necessary for low pressure delivery. Illustrations of the invention utilizing two and three pumps are disclosed in the accompanying drawings and the following description. The pumps are said to be in series when the output of one is directed into the inlet of another and so on, the first and last in the series being respectively connected to the liquid supply source and the main pressure line.

In the drawings:

Fig. 1 shows the relationship of the tank,

pumps, and motor of the compound pumping circuit, and shows the valves in said circuit in cross-section.

Fig. 2 illustrates the circuit with three pumps arranged to operate in parallel and in series.

With reference to Fig. 1 of the drawings, a motor 1 drives positive displacement pumps 2 and 3, said pumps being connected to a tank 4 filled with oil or other suitable liquid by conduits 5 and 6, respectively. Pump 2 a lower stage pump is designed to have a slightly larger volume output or capacity than pump 3. An outlet conduit 7 from an upper stage pump 3 leads to a pressure utilizing means (not shown), as for instance a machine tool, through a relief valve 8 and a conduit 9. The operating principles of the relief valve 8 are explained in my Patent #2,043,453. Conduit 9a serves as a return from the pressure utilizing means to the tank.

The outlet of pump 2 is connected to the conduit 7 through a conduit 10, a bypass valve 11, an elbow 12, a check valve 13, and a pressure conduit 14. Pressure conduit 14 and the housing of the bypass valve 11 are also connected by a conduit 15 which leads, through passageways 15a and 15b, to opposite sides of a piston 16 in the valve 11, said piston being backed by a light spring 16a. It will be seen that, since both sides of the piston 16 are exposed to the main pressure line 7, the effective working pressure area is equal to the difference in working pressure areas of the two sides. This permits the use of the relatively light spring 16a.

Between an inlet conduit 17 of pump 3 and the relief valve 11 is a conduit 18, which is open to the pressure outlet 10 of pump 2 when the piston valve 16 opens a port 19. The elbow 12 in the pressure outlet of pump 2 is connected to the relief valve 8 by a conduit 20. The relief valve 8 consists of valve housing 21 which contains a valve seat 22 and a piston valve 23 which is formed integrally with a piston 23a. One side of the piston 23a is directly exposed to the pressure outlet of pumps 2 and 3 in conduit 7 while the other side is open to the liquid pressure in said conduit 7 through a small passageway 24 in the valve housing 21. The chamber behind the valve piston 23a contains a light spring 25 which tends to close the valve 23, and said chamber is also open to the conduit 20 except for a spring operated valve 26.

A valve assembly 27 with a slidable piston 30 is located near the entrance to the pump 3 and is open on one side through a conduit 28 to the pressure outlet conduit 7 and on the other side

to conduit 18 and pump inlet 17. Between the tank conduit 6 and the valve 27, is a bypass conduit 29 which is open to conduits 17 and 18 when the slidable piston 30 is moved to the left from its position in the drawings. A check valve 31 is located in the line 6 between the tank 4 and the inlet 17.

The liquid in the system is preferably oil, and will hereafter be referred to as oil. By design, pump 2 has a slightly larger capacity than pump 3.

In the operation: Assuming for purposes of illustration that a high pressure of 1500 pounds is required by a machine tool in the pump circuit, the bypass valve 11 will be set for 750 pounds. The pumps 2 and 3 each have a maximum capacity of around 1500 pounds though neither is expected to carry that load. When the motor 1 is started the pumps 2 and 3 will deliver a large volume of oil into the pressure line 9, the pump 3 discharging through conduit 7, and the pump 2 discharging past the bypass valve 11 and the check valve 13 through the conduit 14 to conduit 7.

If for any reason there occurs a restriction in the pressure line 9 or if the machine tool requires a higher pressure so that the oil pressure in the system rises to 750 pounds, the bypass valve 16 will be moved to the left against the spring 16a due to the differential action of pressure on the piston 16. This will open the port 19 and bypass the discharge of the pump 2 to conduit 18 and in turn to the inlet 17 of the pump 3. Pump 3 was previously pulling oil from tank 4, the valve 30 being closed. However, after the opening of the valve 11 the pump 3 will receive its supply from the conduit 18 and, since the pump 2 has a slightly larger capacity than the pump 3, the check valve 31 will be closed and the valve 30 may open slightly to allow the surplus oil to return through conduits 29 and 6 to the tank. The valve piston 30 is so constructed that the working pressure area exposed to the conduit 28 has a definite relationship to the working pressure area exposed to the inlet of pump 3. Assuming, for example, that this relationship is one to two, the pressure behind the pump 3 will be one-half the pressure in the main lines 7 and 9. With this relationship it will be seen that the pump 2 will be bearing a definite proportion of the main pressure. For instance, if the pressure in the main line is 1500 pounds the load on the pump 3 will be 750 pounds, and the load on the pump 2 will also be 750 pounds.

As long as the pressure in the main line is over 750 pounds, which is the opening point of the valve 11, pump 2 will bear one-half of the pressure. If the pressure drops to 750 pounds, then the pumps will cease to operate in series and pump 2 will discharge directly into the main line. The check valve 13 prevents the backing up of the main line pressure after the valve 11 has opened. The discharge capacity of the pumps when operating in series will equal the capacity of the last pump in the series.

The relief valve 8 is a combination relief and bypass valve. The valve is set for 750 pounds, but under normal conditions, when the pumps are working in series at 1500 pounds, the spring operated valve 26 is backed by 750 pounds liquid pressure in conduit 20, so that the valve 8 really has the effect of 1500 pounds. If, however, the pumps failed to work in series, then the pressure on the upper stage pump 3 might rise to over 1500 pounds and cause a failure of the pump. Under these conditions, however, if the lower stage pump 2 has failed, the valve 26 will no longer be backed by the pressure therefrom and the valve 8 will open

at 750 pounds to allow the oil to bypass through port 22 to the tank. If pump 3 alone fails, discharge of pump 2 will be through valve 30 to the tank.

As previously indicated, more than two pumps can be introduced into this circuit in such manner that each will bear a proportionate share of the line pressure after a certain point. It is preferable, of course, that each pump in the series have a slightly larger capacity than the one next adjacent it on the work side of the series so that the last pump in the series opening into the pressure lines has the smallest volume capacity. This compound circuit allows all the pumps to operate at a pressure within their highest efficiency ranges, even though the maximum pressure in the system is such that none of the pumps could economically carry it alone. The term "positive displacement pump" is used in the specification to designate what is generally known as a constant displacement pump, this type of pump being most suitable for the circuits herein described.

Referring to Fig. 2, a circuit is shown with three positive displacement pumps which are also adapted to operate in parallel up to a certain pressure and to operate in series for pressures above a certain minimum. Like reference numerals indicate like parts in Figs. 1 and 2. In Fig. 2, an additional pump is indicated as 32 so that when the pumps are in series the low stage pumps will be 32 and 2 and the upper stage pump will be 3. A differential proportioning valve 27a is provided for pump 2 while the proportioning valve 27 operates in conjunction with pump 3. The bypass valve 11 serves as before to direct pressure from the pump 2 to the inlet of pump 3 and a similar bypass valve 11a serves to direct the outlet pressure from pump 32 to the inlet of pump 2. The relief valve 8 is the same as that shown in Fig. 1 except that the control element 26 is now adapted to be backed by the combined pressures of pumps 32 and 2 when such are operating in series. An additional relief valve 8a serves specifically for pump 2.

In the operation of the circuit shown in Fig. 2, assuming for purposes of illustration that a pressure of 1500 pounds is required by a machine tool in the pump circuit, each of the bypass valves 11 and 11a will be set for 500 pounds. Pumps 32, 2 and 3, each have a capacity of around 1500 pounds but no single pump is expected to carry that load when the most efficient load for each pump is around 500 pounds. The pumps 32, 2 and 3 have different volume capacities, these capacities being slightly decreasing in the order named. When the pump motors 1, 1a and 1b are started, the pumps 32, 2 and 3 acting in parallel will deliver a large volume of oil into the pressure line 9. If for any reason there occurs a restriction in the pressure line 9 or if the machine tool requires a higher pressure so that the oil pressure in the system rises above 500 pounds, the bypass valves 11a and 11 will be opened in the order named so that the discharge of pump 32 will be directed to the inlet of pump 2 through conduit 18b and the discharge of pump 2 will be directed to the inlet of pump 3 through conduit 18a. The differential areas of valve pistons 30 and 30a and valves 27 and 27a are so proportioned that each of the pumps will bear one-third of the total pressure in the line 9. For example, assuming that the pressure in line 9 is 1500 pounds, the pressure at the discharge of pump 2 and the inlet of pump 3 will be 1000 pounds, while the pressure at the

discharge of pump 32 and the inlet of the pump 2 will be 500 pounds.

The relief valve 8 is a combination relief and bypass valve as described in connection with Fig. 1, and is normally set for the pressure of pump 3 which, in the example above given, would be 500 pounds. However, when the pumps are operating in series, the pressure from the discharge of pump 2 will be transmitted from the conduit 18a through conduit 20a to the control element 26 in the relief valve 8 so that the actual effect of the relief valve 8 will be 1500 pounds. Relief valve 8a is similarly arranged so that the control element 26a is backed by 500 pounds through the conduit 20b which is exposed during the series operation to the pump 32. The effective pressure of this valve is 1000 pounds. In practice, the spring 25 in relief valves 8 and 8a would be set for slightly higher than 500 pounds to insure opening of the valves 11 and 11a prior to the opening of the relief valves. Likewise the spring in valve 11 would be set slightly higher than the spring in valve 11a to insure the pump 32 cutting into the series operation before the pump 2.

If pump 32 alone should fail, the pump 2 would draw liquid directly from the tank. Since there would be no pressure in conduits 18b and 20b, the effective pressure of relief valve 8a would be 500 pounds; consequently, the load on pump 2 could not exceed that amount. However, the bypass valve 11 would operate as above so that at least 500 pounds pressure could be exerted through the conduit 28 to the control element 26 of the relief valve 8. Effective pressure of the relief valve 11 would then be 1000 pounds and the load on the pump 3 cannot exceed 500 pounds.

If pump 2 alone should fail, pressure on both sides of the piston 30a would be equal and, due to the larger area on the right end, piston 30a would move to the left and allow the delivery of pump 32 to return to the tank through conduit 29a. Pump 3 in this case would continue to operate but since pressure could not exist in line 20a, relief valve 8 would open at 500 pounds. If pump 3 alone should fail, the effect would be had on the piston 30 and the entire discharge of pumps 32 and 2 would pass to the tank through the conduit 29.

If lower stage pumps 1 and 2 should fail, no pressure could exist in conduit 20a and consequently, the relief valve 8 would be effective at 500 pounds to prevent overloading of pump 3. Failure of pumps 2 and 3 would permit pressure over 500 pounds from pump 32 to pass to both sides of the piston 30a through the conduit 18b. This would move the piston 30a to the left and bypass the discharge of pump 32. Similarly, in case of failure of pumps 32 and 3, the discharge of the remaining pump 2 would bypass through line 29 to the tank.

What I claim is:

1. In a compound pump circuit, a plurality of positive displacement pumps normally connected to a main pressure line, pressure controlled valve means operative to connect said pumps in series at a certain predetermined pressure in the main line, valve means responsive to the inlet and outlet pressures of each of said pumps but the first in series to predetermine the relative proportions of pressure to be carried by each pump when operating in series, and relief valve means connected to said main pressure line and normally set for the pressure of the last pump in series and provided with a control element backed up by the

pressure of the remaining pumps in series when such are operating.

2. In a compound positive displacement pump circuit having a liquid supply source, a plurality of positive displacement pumps normally connected to a main pressure line, and adapted to be connected in series, conduit means for connecting the outlet of each pump but the last in series to the inlet of the next succeeding pump, pressure controlled valve means in said conduit means operative at a certain predetermined line pressure to open said conduits and connect the outlet of each of said pumps to the inlet of the next succeeding pump, thereby placing the liquid supply source in series with the main pressure line through each of said pumps in turn, differential valve means at the inlet of each of said pumps but the first in series to regulate the relative proportions of the total pressure to be carried by each pump when operating in series, said differential valve means comprising a bypass conduit and a differential area piston for controlling the opening of said bypass conduit, said piston being open on one side to the inlet of a pump and open at the other side to the outlet of said pump, and relief valve means adapted to open only at a maximum circuit pressure when said pumps operate in series, and adapted to open at a proportionately lower predetermined pressure when any of said pumps fail to operate in series.

3. In a compound positive displacement pump circuit adapted to produce a total circuit pressure greater than the pressure load on any one pump in the circuit when said pumps are connected in series, upper and lower stage pumps, means for regulating the relative proportions of the circuit pressure to be carried by upper and lower stage pumps when said pumps are connected in series, said means comprising a casing and a differential pressure area piston valve open on one side to the circuit pressure and on the other side to the discharge pressure of the lower stage pump, the respective pressure areas of said piston valve having a ratio substantially equal to the ratio to be maintained between the lower stage pump pressure and the circuit pressure, said casing having a bypass outlet for the lower stage pump normally closed by said piston, and relief valve means normally set for the pressure of the last pump in series and provided with a control element backed up by the pressures of the remaining pumps when such are operating.

4. In a compound positive displacement pump circuit adapted to have pumps in series each bearing a pressure load lower than the total circuit pressure, upper and lower stage pumps designed to have progressively decreasing volume capacities when in a series circuit, a fluid supply source and main fluid pressure line, means for each of said pumps but the first in series for regulating the relative proportions of pressure to be carried by each pump when said pumps are connected in series, said means comprising a casing and a piston valve in said casing having differential pressure areas, said piston valve being open on one side to the inlet pressure and on the other side to the discharge pressure of each particular pump, said casing being provided with a bypass outlet for said particular pump normally closed by said piston, the respective pressure areas of said piston valve having a ratio substantially identical to the ratio to be maintained between the inlet pressure of the particular pump and the outlet pressure, and relief valve means normally

set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the remaining pumps when such are operating.

5. A liquid power circuit, comprising in combination, a source of liquid supply, a main pressure line, two continuously operating positive displacement pumps normally drawing liquid from the liquid source, passageways leading from said pumps for conducting liquid under pressure to said main line, bypass valves operatively connected to one of said pumps and adapted to conduct liquid from said one pump to the inlet of the other pump when said bypass valves are open to place said pumps in series, a connection between the main pressure line and said bypass valves to allow opening of said bypass valves to turn the discharge of each of said pumps into the inlet of the next succeeding pump only upon the building up of a predetermined pressure in the main line, means for closing the liquid supply from all but the first one of said series of pumps when said bypass valves are open, differential pressure means responsive to the inlet and outlet pressures of the last pump in series for regulating the proportions of pressure to be carried by each pump when said bypass valves are open, and relief valve means normally set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the first pump in series, said pumps combining to produce their combined volume when the main line pressure is below said predetermined pressure, and to produce the volume of the last pump in the series when operating in series.

6. A liquid power circuit, comprising in combination, a source of liquid supply, a main pressure line, two continuously operative positive displacement pumps each normally drawing liquid from the liquid source and having progressively decreasing volume capacities, passageways leading from said pumps for conducting liquid under pressure to said main line, a bypass valve in the outlet of the highest capacity pump adapted to admit liquid under pressure from said pump to the next succeeding pump when said bypass valve is open, connections between the main pressure line and said bypass valve to allow opening of said bypass valve to place said pumps in series only upon the building up of a predetermined pressure in the main line, means for closing the liquid supply from all of said pumps except the pump first in series when said bypass valve is open, means responsive to the inlet and of outlet pressures of each pump in series for regulating the proportions of pressure to be carried by each pump when said bypass valves are open, and relief valve means normally set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the first pump when such is operating, said pumps combining to produce their combined volume when the main line pressure is below said predetermined pressure, and to produce the volume of the last pump in the series when operating in series.

7. A liquid power circuit comprising, in combination, a liquid supply, a main pressure line, two continuously operating positive displacement pumps, supply conduits between each of said pumps and the liquid supply, pressure conduits between each of said pumps and the main pressure line, a one-way check valve in one of said last named conduits, a bypass valve in said last named conduit between said check valve and one

of said pumps, a bypass conduit connecting said bypass valve and the supply conduit of the other of said pumps, a one-way check valve in said last named supply conduit between said bypass conduit and the liquid supply, a connection between the main pressure line and said bypass valve to allow opening of said bypass valve to turn the discharge of the pump first in series with the supply conduit of the pump second in series only upon the building up of a predetermined pressure in the main line, valve means responsive to the inlet and outlet pressures of each pump for regulating the proportion of main line pressure to be carried by each pump when in series, and a pressure balanced relief valve means normally set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the remaining pump when such is operating, and adapted to open at a lower pressure when said first named pump fails to operate, said pumps combining to produce their combined volume when the main line pressure is below said predetermined pressure, and to produce the volume of the last pump in the series when operating in series.

8. In a compound pump circuit, a plurality of upper and lower stage pumps normally connected in parallel to a main pressure line, pressure controlled valve means operative to connect said pumps in series at a certain predetermined pressure in the main line, valve means responsive to the inlet and outlet pressures of each of said pumps but the first in series to predetermine the relative proportions of pressure to be carried by each pump when operating in series, and relief valve means having a control element responsive to pressures in the lower stage pumps when such are operating and adapted to open only at a maximum circuit pressure when said pumps operate in series and to open at a lower pressure when a lower stage pump fails to operate.

9. In a compound positive displacement pump circuit, a plurality of positive displacement upper and lower stage pumps connected in series, differential area valve means responsive to pressures in the inlet and outlet of each of said pumps but the first in series to predetermine the relative proportions of pressure to be carried by each pump when operating in series, and relief valve means having a control element backed by pressures from said lower stage pumps and adapted to open only at a maximum circuit pressure when said pumps all operate in series and to open at a lower pressure when a lower stage pump fails to operate.

10. In a compound pump circuit adapted to produce a total pressure greater than the effective pressure load on any one pump in the circuit when connected in series, a plurality of positive displacement pumps, conduit means for connecting the outlet of each pump but the last in series to the inlet of the next succeeding pump in series, a main conduit leading from said last pump in series for directing fluid under pressure, means responsive to the inlet and outlet pressures of all but the first pump in series for regulating the proportion of main line pressure to be carried by each pump when in series, and a relief valve means connected to said main conduit normally set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the remaining pumps in series when such are operating.

11. In a compound pump circuit, a plurality of positive displacement pumps normally connected

to a main pressure line comprising an upper stage pump and one or more lower stage pumps, valve means operable by a predetermined pressure in said main pressure line and adapted, when operated by said predetermined pressure, to shunt the output of said one or more lower stage pumps to the input of the next succeeding pump whereby said pumps are connected in series, the upper stage pump being the last in the series, a differential valve means connected to the respective outlets of each set of two adjacent pumps for regulating the relative proportions of pressure to be carried by each pump when operating in series, said differential valve means comprising a housing and a differential pressure area piston valve open on one side to the outlet pressure of a specific pump and on the other side to the outlet pressure of an adjacent specific pump, said piston valve normally closing a bypass outlet for said pump inlet, and relief valve means normally set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the remaining pumps in series when such are operating.

12. In a compound positive displacement pump circuit adapted to produce a total pressure greater than the effective pressure load on any one pump in the circuit when connected in series, a plurality of pumps, conduit means connecting the outlet of each pump but the last in series to the inlet of the next succeeding pump in the series, a main conduit leading from said last pump in series for directing fluid under pressure, and a relief valve connected to said main conduit comprising a housing, a bypass opening in said housing, and a control element in said housing normally blocking said bypass opening and normally set for the pressure of the last pump in series and backed up by the pressure of the remaining pumps in series when such are operating.

13. In a compound positive displacement pump circuit adapted to produce a total pressure greater than the effective pressure load on any one pump in the circuit when connected in series, a plurality of pumps, conduit means connecting the outlet of each pump but the last in series to the inlet of the next succeeding pump in the series, a main conduit leading from said last pump in series for directing fluid under pressure, and a relief valve means connected to said main conduit normally set for the pressure of the last pump in series and provided with a control element backed up by the pressure of the remaining pumps in series when such are operating.

14. In a compound positive displacement pump circuit having a liquid supply source, a plurality of positive displacement pumps normally connected to a main pressure line, and adapted to be connected in series, conduit means for connecting the outlet of each pump but the last in series to the inlet of the next succeeding pump, pressure controlled valve means in said conduit means operative at a certain predetermined line pressure to open said conduits and connect the outlet of each of said pumps to the inlet of the next succeeding pump, thereby placing the liquid supply source in series with the main pressure line through each of said pumps in turn, and differential valve means at the inlet of each of said pumps but the first in series to regulate the relative proportions of the total pressure to be

carried by each pump when operating in series, said differential valve means comprising a bypass conduit and a differential area piston for controlling the opening of said bypass conduit, said piston being open on one side to the inlet of a pump and open at the other side to the outlet of said pump.

15. In a compound positive displacement pump circuit adapted to have pumps in series, each bearing a pressure load lower than the total circuit pressure, a plurality of pumps designed to have progressively decreasing volume capacities when in a series circuit, a fluid supply source and main fluid pressure line, and means operatively connected to adjacent pumps for regulating the relative proportions of pressure to be carried by each pump when said pumps are connected in series, said means comprising a casing and a piston valve in said casing having differential pressure areas, said piston valve being open on each side to the respective discharge pressure of said adjacent pumps, said casing being provided with a bypass outlet for the first in series of said adjacent pumps normally closed by said piston, the respective pressure areas of said piston valve having a ratio substantially identical to the ratio to be maintained between the outlet pressure of the said adjacent pumps.

16. In a compound pump circuit, a plurality of positive displacement pumps to be connected in series, said pumps having progressively decreasing volume capacities in the series circuit, and a pressure control valve operably located between each two adjacent pumps in the series and arranged to control the excess volume of the first in series of the adjacent pumps to maintain a definite relationship between the discharge pressures of the two adjacent pumps whereby to insure said pumps will always operate at maximum efficiency.

17. In a compound pump circuit, a plurality of positive displacement pumps to be connected in series, said pumps having progressively decreasing volume capacities in the series circuit, and a differential pressure control valve operably located between each two adjacent pumps in the series and arranged to control the excess volume of the first in series of the adjacent pumps to maintain a definite relationship between the discharge pressures of the two adjacent pumps whereby to insure said pumps will always operate at maximum efficiency, said valve comprising a differential piston and a bypass opening to be controlled thereby, said piston being exposed on each side to the respective discharge pressures of said adjacent pumps whereby excess volume from the first in series of said adjacent pumps will be bypassed to effect the maintenance of proportionate loads on said pumps.

18. In a compound pump circuit, a plurality of positive displacement pumps mounted on a common driving shaft and to be connected in series, said pumps having progressively decreasing volume capacities in the series circuit, and a differential pressure control valve operably located between each two adjacent pumps in the series arranged to control the excess volume of the first in series of the adjacent pumps to maintain a definite relationship between the discharge pressures of the two adjacent pumps.

HARRY F. VICKERS.