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OVER-PRESSURE PROTECTION OF PIPE LINES

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2 Sheets-Sheet 1

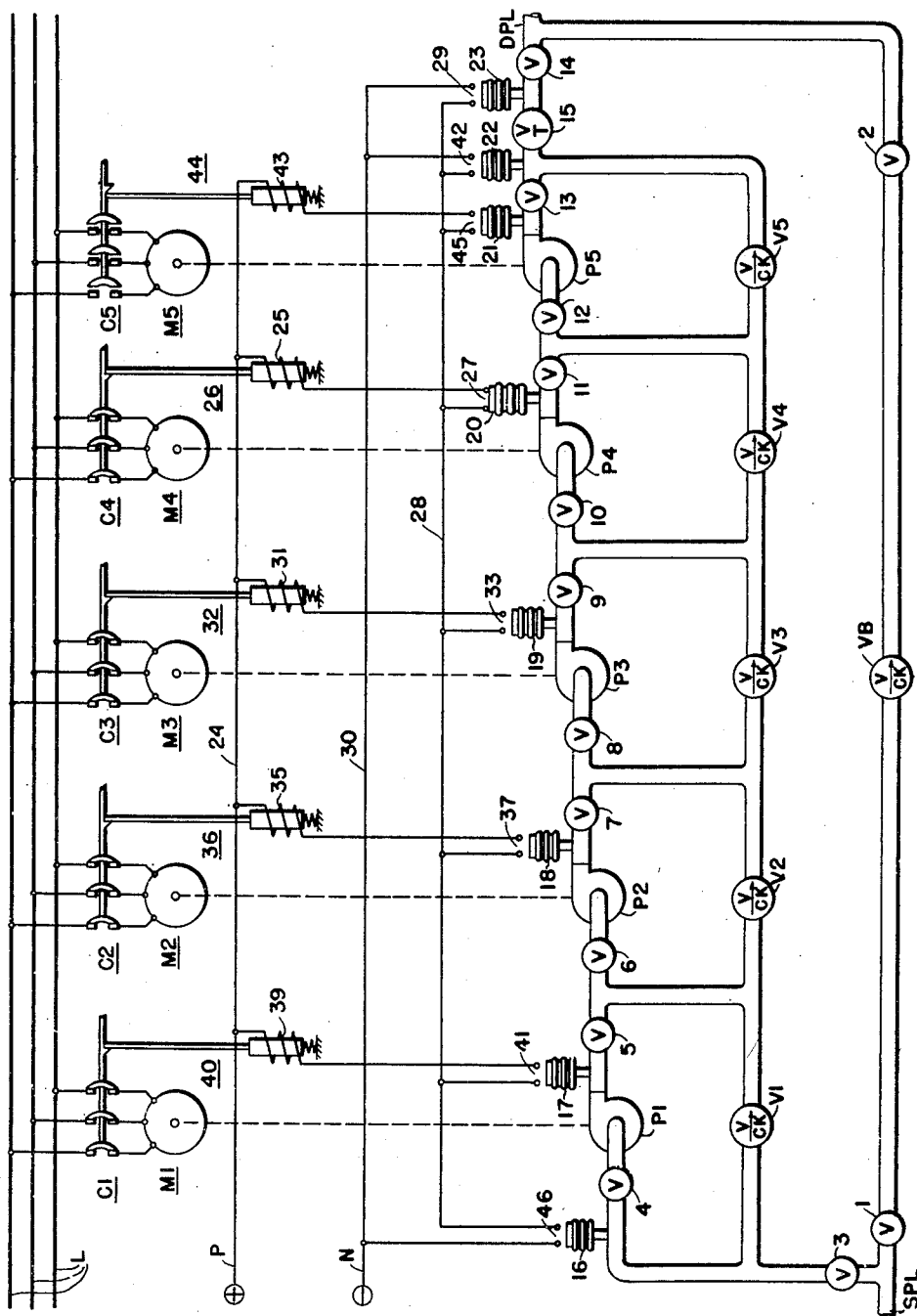


Fig. 1.

2,813,231

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2 Sheets-Sheet 2

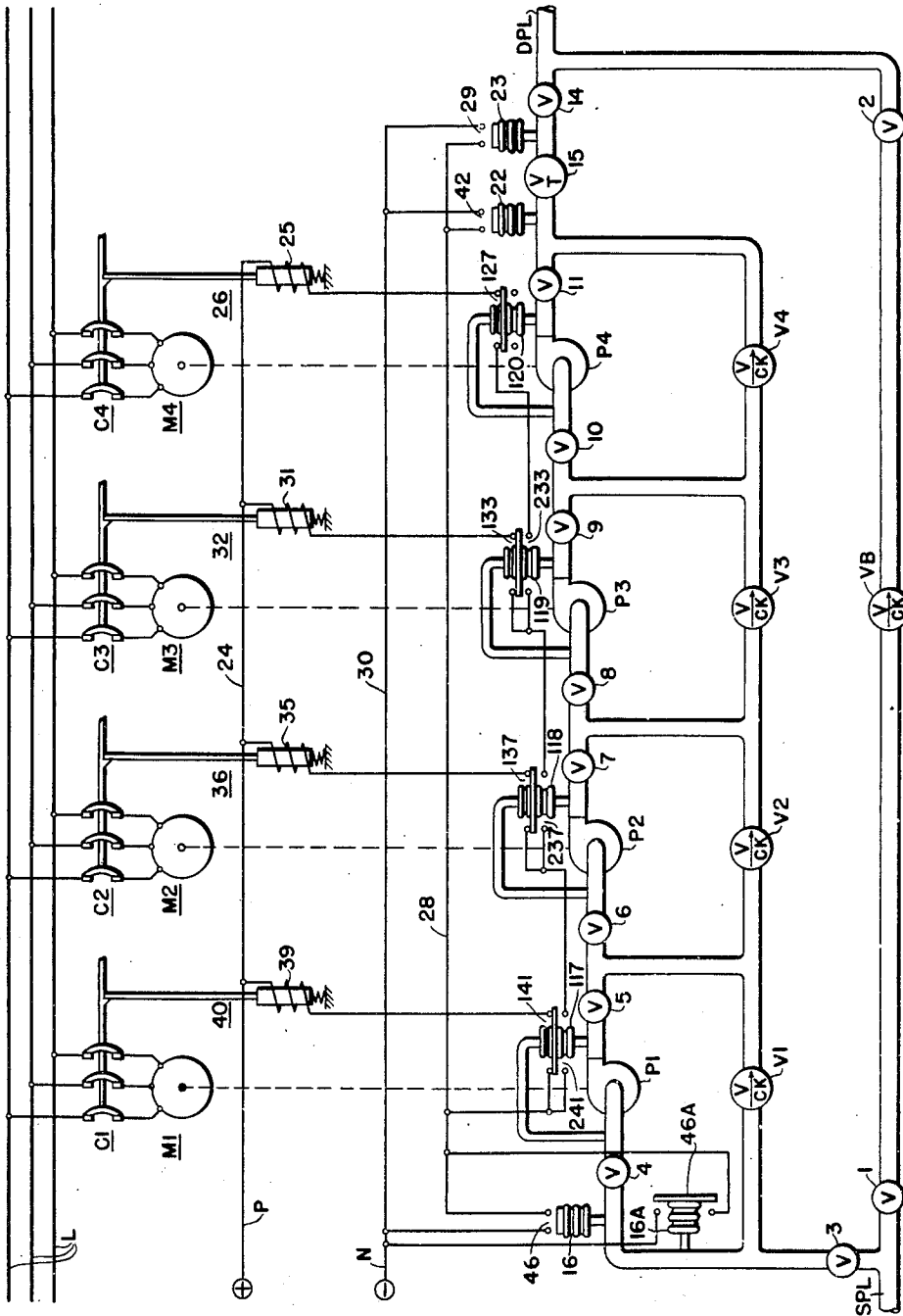


Fig. 2.

1

2,813,231

OVER-PRESSURE PROTECTION OF PIPE LINES

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13 Claims. (Cl. 317—139)

My invention relates to electric systems of control and, more particularly, to systems of control for controlling and protecting the operation of machines for moving fluid under pressure.

This application is a continuation-in-part of application Serial No. 294,280, filed June 18, 1952, now abandoned, and assigned to the Westinghouse Electric Corporation.

The majority of modern pipe lines for the transportation of liquid petroleum and petroleum products utilize centrifugal pumps. Such pumps move the liquid from one station to the next, and the third, and so on. The number of pumps per station and the spacing of the stations is determined by the hydraulic requirements. For flexibility of operation, each station usually contains from two to four pumps, with frequently an additional or spare pump at each station, all connected directly in series, each pump handling the full line "throughput," and developing a part of the total station differential pressure. The total station differential pressure can, therefore, be varied in steps in accordance with the number of pump units operated.

The pressure at the station discharge position in the pipe line is the sum of: the receiving pressure, or so-called suction pressure, and the station differential pressure. The incremental pressure developed by each pump is subject to variations with pump speed, specific gravity and viscosity of the fluid being pumped, and to some extent with the pumping rate depending upon slope of the head-capacity characteristics for the particular pump design. For similar reasons, and depending on the contour and distance between stations, which distance varies in existing lines between twenty-five and one hundred miles, the suction pressure also varies over a considerable range.

Practical considerations of pipe strength, strength of valves and valve housings, strength of the fittings and the pump cases, etc., require that the station discharge pressure and the pressure within the pumps and station piping system be limited to safe working values.

It is a broad object of my invention to provide electric means for automatic control of a fluid transporting system to prevent the improper operation of such system pressurewise.

A somewhat more specific object of my invention is the provision of an electric system of control in a pumping station including a plurality of pumps so that only such number of pumps are operated to keep the fluid pressure in the system between a certain range.

The objects recited are merely illustrative. Other objects and advantages will become more apparent from a study of the following more detailed specification and the accompanying drawings, in which:

Figure 1 is a diagrammatic showing of a pumping station provided with an embodiment of my invention; and

Fig. 2 is a diagrammatic showing of a pumping station provided with a modification of my invention.

2

In Fig. 1 the pump P1 has its intake port connected through the valves 3 and 4 to the supply pipe line SPL. Pump P1 normally supplies liquid to the intake port of pump P2, pump P2 supplies pump P3, pump P3 supplies pump P4, and pump P4 may supply a fifth or spare pump P5 if it is used, but more often this pump P4 supplies the throttle valve 15 from which throttle valve the liquid passes through the open motor-operated shut-off valve 14 to the discharge pipe line DPL.

Aside from the suction, discharge, and bypass valves for each unit, the number and arrangement of valves and piping layout is subject to variation to suit the requirements of each installation.

Each pump is driven by a motor as the motors M1, M2, M3, M4 and M5, respectively. The valves 1 to 14, inclusive, are all motor-operated shut-off valves for controlling the flow of the liquid. For example, when valves 3 and 14 are closed and valves 1 and 2 are open the liquid is shunted past the entire pumping station. The liquid flows from the supply pipe line SPL through the shut-off valve 1, the reverse flow check valve VB, the shut-off valve 2 directly to the discharge pipe line DPL.

In Fig. 1 I have shown five pumps and the control and drive means for each pump. Only four pumps are necessary for the particular station shown. Any one of the pumps may thus be considered as a spare. In the discussion to follow the fifth pump P5 will be considered as not in use. For this purpose, shut-off valves 12 and 13 are closed, the liquid will thus in operation flow from the discharge end of pump P4 through valve 11, the bypass piping for pump P5 and the check valve V5 directly to the throttle valve 15. Since there is no pressure developed in the pump housing of pump P5 the contacts 45 of the pressure actuated switch 21 will be open.

With some prior art pumping systems, entire reliance is placed on the throttle valve, as the valve 15 shown in Fig. 1, for the protection of the discharge pipe line. This valve 15, it will be noted, is disposed on the downstream side of the final pump, namely, pump P5 in Fig. 1, and this valve, by control means responsive to the outbound line pressure, is effective to prevent this pressure from exceeding a safe maximum.

While valve 15 is useful in limiting the downstream pressure by dissipating the required portion of the total station pressure, it does not in the least reduce the total station pressure. The latter reduction must be accomplished by a reduction in suction pressure, or in the number of pump units operating or in the operating speed of one or more of the pump units where speed control is available.

End pump has a by-pass check valve as the check valves V1, V2, V3, V4 and V5, respectively. With all the shut-off valves, for the portion of the pumping system being used, open, which open condition is the normal condition of these valves, the electric supply lines L, P and N energized, the circuit breakers C1, C2, C3 and C4 closed and held closed by the latches 40, 36, 32 and 26, respectively, the pumps P1, P2, P3 and P4 are all operated and fluid flows from the supply pipe line SPL through these pumps, check valve V5 and valves 15 and 14 to the discharge pipe line.

At the discharge end of the pump line is the throttle valve 15 and on the downstream side of this valve 15 is the high-pressure protective switch 23. Each pump at its discharge conduit is provided with a similar pressure responsive switch as the switches 17, 18, 19 and 20. The attachment of these switches to the pressure system is such that switch 17 is responsive to the pressure in the pump case, at the discharge side, for the pump P1; switch 18 is responsive to the pressure in the pump case, at the discharge side, for pump P2, and so on.

The pressure developed by each pump may be assumed to be any practical value, however, for purposes of discussion let the assumption be that the station suction pressure, the pressure at the pressure responsive switch 16, is 50 p. s. i. and that each of the pumps in use develops a pressure of 200 p. s. i. The pressures in the system for normal operation thus changes so that at the pressure responsive device 16 it is 50 p. s. i., at the pressure responsive device 17 it is 250 p. s. i., at device 18 it is 450 p. s. i., at device 19 it is 650 p. s. i., at devices 20 and 22, since pump P5 is not in use, it is 850 p. s. i. The throttle valve is so adjusted that the pressure at device 23 is 800 p. s. i.

Pressure responsive device 23 is so selected and so adjusted that its contacts open when the pressure in the conduit beyond the throttle valve 15, that is, the region between valves 15 and 14, drops to 830 p. s. i. and below, but are closed for all pressures above 830 p. s. i. The pressure responsive devices 17, 18, 19, 20 and 21 are so selected and adjusted that their switch contacts 41, 37, 33, 27 and 45 close when the pressure is at 815 p. s. i. and above, but remains open for all pressures below 815 p. s. i.

Under the conditions specified, it is apparent that switch contacts 27 will be closed whereas switch contacts 46, 41, 37, 33, 45, 42 and 29 will all be open. However, if pump P4 were idle and pump P5 operating, then contacts 45 would be closed at pressures of 815 p. s. i. and greater and all the other switch contacts would be open. Thus whichever pumps are running, of the operating units only the last downstream one will have its pressure responsive switch contacts closed.

If for any reason the throttle valve does not operate properly so that the pressure just beyond the throttle valve rises to a value greater than 830 p. s. i., then the pressure responsive device 23 will close the contacts 29 and an energized circuit is immediately established from the positive line P through conductor 24, actuating coil 25 of the latch 26, contacts 27 of pressure responsive device 20, conductor 28, contacts 29, and conductor 30 to the negative line N.

The latch 26 thus operates to release the circuit breaker C4 and in consequence motor M4 is disconnected from the leads L and pump P4 is stopped. The pressure differential produced by pump P4 is thus eliminated from the pumping station and normally the pressure at device 23 will drop so as to open contacts 29.

In some pumping stations, the pumps are driven by diesel engines, in others by turbines. For this type of pumping station, operation of a device corresponding to latch 26 may operate to stop the diesel engine operating pump P4 or change the throttle setting to decrease the pressure differential of pump P4. If a turbine is used, a similar operation is effected. In any event, the aim is to decrease the pressure differential at the pump affected.

Since stopping of pump P4 decreases the total pressure by 200 p. s. i., it follows that ordinarily no further pump stoppages occur, but if abnormal operating conditions still prevail keeping contacts 29 closed then the pressure at pump P3 will exceed 815 p. s. i. It follows that pressure responsive device 19 will close its contacts 33. When this takes place, a circuit is established from positively energized conductor 24 through the actuating coil 31 of latch 32, contacts 33 to the negatively energized conductor 28.

If the abnormal pressure conditions are still not eliminated, a third circuit is established from positively energized conductor 24 through the actuating coil 35 of the latch 36, and contacts 37 to the negatively energized conductor 28.

If the pressure at device 23 is still too high, a further circuit is established from the positively energized conductor 24 through the actuating coil 39 of latch 40, and contacts 41 to the negatively energized conductor 28.

From the foregoing it will be apparent that the pumps P4, P3, P2 and P1 go out of service in the order named.

In addition to protecting the outbound line when a station throttling valve, as valve 15, is used, it is also very

desirable to protect the pumps and piping within the station. The allowable pressures within the station are usually higher than the permissible pressures on the downstream line. For the protection of the pumps and station fittings and pipes I provide the pressure responsive device 22. This device is selected and so adjusted to effect closing of its contacts when the pressure acting on it is at 950 p. s. i. or greater. When such excessive pressure occurs, the contacts 42 are closed whereupon a circuit is established from the positively energized conductor 24, through actuating coil 25 of the latch 26, contacts 27 (or possibly contacts 33, or 37, or 41, or 45, depending on which pump happens to be the last downstream pump), conductor 28, contacts 42 to the negatively energized conductor 30. Pump P4 is thus shut down.

Since the abnormal pressure conditions may be evidenced by a high suction pressure, I provide alternatively to or in combination with device 22 the pressure responsive device 16. This device is responsive to a pressure higher than 50 p. s. i., for example a pressure of 100 p. s. i. At this high pressure, device 16 closes its contacts, whereupon a circuit is established from the positively energized conductor 24, through the actuating coil 25 of latch 26, contacts 27, conductor 28, contacts 46 to the negatively energized conductor 30.

The pressure values used in the preceding discussion are, of course, subject to choice in accordance with the needs of the particular installation, and will vary with the allowable pressures on the line, station piping, fittings and pumps, the pressure developed per pump and the number of pumps operating in series.

In Fig. 2 I have shown a modification of my invention for protecting the pump station and pipe line against excessive pressures. The spare pump is not shown. For like parts the same reference characters used in Fig. 1 are used in this Fig. 2.

In this modification the pressure responsive devices 117, 118, 119 and 120 are each responsive to the pressure differential developed by the pumps P1, P2, P3 and P4, respectively. Each pressure responsive device is provided with two sets of contacts.

Assuming for example that each pump develops a pressure differential of 200 p. s. i., the pressure responsive devices 117, 118, 119 and 120 are so selected and adjusted that their upper contacts are all closed when the pressure differential is normal, but when the pressure differential drops to 125 p. s. i. or lower then the upper contacts open and the lower contacts close.

If abnormal pressure conditions effect the closing of contacts 29, or contacts 42, or contacts 46, then a circuit is established from the positive line P through conductor 24, actuating coil 39 of the latch 40, contacts 141, conductor 28, the one of the three contacts 29, or 42, or 46 that happens to be closed, and conductor 30 to the negative line N. Motor M1 is thus stopped and pump P1 is taken out of service. As pump P1 stops, the pressure differential developed by this pump P1 disappears and as a result contacts 241 close. Since contacts 241 are in series with coil 35 of latch 36 and the contacts 137, it follows that latch 36 will be tripped if the abnormal pressure conditions are still present.

Should pump P2 be stopped, the pressure differential developed by pump P2 disappears and as a result contacts 237 close. Since contacts 237 are in series with coil 31 of latch 32 and the contacts 133, it follows that pump P3 will be stopped if the abnormal pressure conditions are still present.

As pump P3 stops, the pressure differential developed by pump P3 disappears and in consequence contacts 233 close. Since contacts 233 are in series with coil 25 of latch 26 and in series with contacts 127, it follows that pump P4 will be stopped if the pressure conditions are still present after the stopping of pump P3.

In the system shown in Fig. 2, the pump may be protected against low suction pressure by employing a device

5

16A connected to the same point in the piping as 16 but responsive to low pressure, whose contacts 46A close when the pressure declines to a value approaching a dangerous condition, such as 5 p. s. i.

From the foregoing discussion of Fig. 2 it is apparent that I provide a system of control for shutting down several units, in which system of control only the minimum number of units are shut down to attain the necessary correction in pressure. In practice this is important, to minimize reduction in line flow and to cause the minimum hydraulic disturbance in the fluid transportation system. Also the shutdown of the units is progressive always beginning with the upstream operating unit which is shut down immediately upon an occurrence of abnormal pressure, and then if continuation of abnormal pressure requires shutdown of additional units, the next operating unit in the direction of upstream is shut down and so on until pressure conditions have been satisfied. The sequence of shutting down units from the upstream end is desirable to permit subsequent restarting with minimum pump case pressure. Experience has shown that it is preferable in such series-connected pump installation to start the downstream pump first and the remaining pumps progressing upstream, and to shut the units down in reverse order.

While I have shown and described but an embodiment and a single modification of my invention, it is understood that the invention is capable of various adaptations and that changes and modifications may be made or substitutions resorted to which come within the spirit of the invention.

I claim as my invention:

1. In an electric system of control, in combination, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a selected number of electromagnetic devices, fluid pressure responsive switching means each having normally closed contacts and normally open contacts, said normally closed contacts being connected, respectively, in series with said devices and said normally open contacts being connected in a series circuit with one end thereof connected to said auxiliary conductor and the other end to one of the series circuits including one set of normally closed contacts and one device; a second one of said series circuits, including one set of normally closed contacts and one device, being connected across one supply conductor and said auxiliary conductor; the remaining series circuits, including the normally open contacts and a device, respectively, having one set of corresponding ends connected to one supply conductor and the other set of corresponding ends connected, respectively, between the said normally open contacts, and further fluid pressure responsive switching means for connecting the second supply conductor to the auxiliary conductor upon the occurrence of certain pressure effects on said further fluid pressure responsive switching means.

2. In an electric system of control, in combination, a pair of energized conductors, an auxiliary conductor, three fluid pressure responsive switches for connecting one energized conductor to the auxiliary conductor upon occurrence of any one of the three fluid pressure conditions for which said fluid pressure responsive switches are adjusted, a plurality of electromagnetic devices and a fluid pressure responsive switch for each of said electromagnetic devices for effecting sequential connection of said electromagnetic devices across the auxiliary conductor and the other energized conductor.

3. In an electric system of control, in combination, a pair of energized conductors, and an unenergized conductor, a normally closed switch and an electromagnetic device connected in series across one energized conductor and the unenergized conductor, a fluid pressure responsive device coupled to said switch and adapted to open said switch upon a drop of the fluid pressure on the fluid pressure responsive device below a given value, a pair of normally open switches disposed to connect the second ener-

6

gized conductor to the unenergized conductor, and fluid pressure responsive means for selectively effecting the closing of one or the other of said normally open switches upon the application of a selected high or a selected low pressure to said fluid pressure responsive means.

4. In an electric system of control, in combination, a pair of energized conductors, and an unenergized conductor, a normally closed switch and an electromagnetic device connected in series across one energized conductor and the unenergized conductor, a fluid pressure responsive device coupled to said switch and adapted to open said switch upon a drop of the fluid pressure on the fluid pressure responsive device below a given value, a first normally open switch disposed to connect the other energized conductor to the unenergized conductor, a second normally open switch similarly connected, a second fluid pressure responsive device adapted to close said first normally open switch upon the action of a relatively high fluid pressure on the second fluid pressure responsive device, a third fluid pressure responsive device adapted to close the second normally open switch upon the action of a relatively low fluid pressure on the third fluid pressure responsive device.

5. In an electric system of control for a fluid pressure system, in combination, a fluid pressure system in which the fluid pressure normally rises in steps from a selected suction pressure to a selected discharge pressure, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a number of electromagnetic devices equal to the number of steps of pressure rise in the fluid pressure system, a number of fluid pressure responsive switches equal to the number of steps of pressure rise in the fluid pressure system and paired, respectively, with said electromagnetic devices and all of them being responsive to a selected fluid pressure to connect one supply conductor and the paired electromagnetic device to said auxiliary conductor, and a pair of switching means selectively operable in response to an abnormal fluid suction pressure condition and an abnormal discharge fluid pressure condition in the fluid pressure system for connecting the auxiliary conductor to the second supply conductor.

6. In an electric system of control for a fluid pressure system, in combination, a fluid pressure system in which the fluid pressure normally rises in steps from a selected suction pressure to a selected discharge pressure and normally drops in pressure a selected amount from said normal discharge pressure to a selected normal output pressure, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a number of electromagnetic devices equal to the number of steps of pressure rise in the fluid pressure system, a number of fluid pressure responsive switches equal to the number of steps of pressure rise in the fluid pressure system and paired, respectively, with said electromagnetic devices and all of them being responsive to a selected fluid pressure to connect one supply conductor and the paired electromagnetic device to said auxiliary conductor, and a pair of switching means selectively operable in response to an abnormal fluid suction pressure condition and an abnormal fluid output pressure condition of the fluid pressure system for connecting the auxiliary conductor to the second supply conductor.

7. In an electric system of control for a fluid pressure system, in combination, a fluid pressure system in which the fluid pressure normally rises in steps from a selected suction pressure to a selected discharge pressure and normally drops in pressure a selected amount from said normal discharge pressure to a selected normal output pressure, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a number of electromagnetic devices equal to the number of steps of pressure rise in the fluid pressure system, a number of fluid pressure responsive switches equal to the number of steps of pressure rise in the fluid pressure system and paired, respectively, with said electromagnetic devices

and all of them being responsive to a selected fluid pressure to connect one supply conductor and the paired electromagnetic device to said auxiliary conductor, and three switching means selectively operable in response to an abnormal fluid suction pressure, an abnormal fluid discharge pressure, and an abnormal fluid output pressure in said fluid pressure system for connecting the auxiliary conductor to the second supply conductor.

8. In an electric system of control for a fluid pressure system, in combination, a fluid pressure system in which the fluid pressure normally rises in steps from a selected suction pressure to a selected discharge pressure and normally drops in pressure a selected amount from said normal discharge pressure to a selected normal output pressure, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a number of electromagnetic devices equal to the number of steps of pressure rise in the fluid pressure system, a number of fluid pressure responsive switches equal to the number of steps of pressure rise in the fluid pressure system and paired, respectively, with said electromagnetic devices and all of them being responsive to a selected fluid pressure to connect one supply conductor and the paired electromagnetic device to said auxiliary conductor, and a pair of switching means selectively operable in response to an abnormal fluid discharge pressure and an abnormal fluid output pressure of said fluid pressure system for connecting the auxiliary conductor to the second supply conductor.

9. In an electric system of control for a fluid pressure system in which the pressures are built up in steps, from a variable suction pressure, in successive different parts of the system to a variable discharge pressure and drops in a step from said variable discharge pressure to a variable output pressure and in which system the algebraic summation of the pressures may vary over a considerable range, in combination, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a selected number of electromagnetically operable devices each having an actuating coil with corresponding terminals of said coils being connected to one supply conductor, an equal number of fluid pressure actuated switches responsive to fluid pressure in different parts of the system, said switches being connected in series with said actuating coils to form series circuits, respectively, circuit connections for connecting said selected number of series circuits, including a pressure actuated switch and an actuating coil, respectively, in parallel across one supply conductor and said auxiliary conductor, a second selected number of fluid pressure actuated switches each responsive to a selected fluid pressure at a given part of the fluid pressure system, as for example, respectively, a selected suction pressure, a selected discharge pressure, and a selected output pressure, connected in parallel across said auxiliary conductor and the other of said supply conductors, whereby the closure of any one and only one of the second selected number of pressure actuated switches will suffice to effect energization of the particular actuating coil whose series connected pressure actuated switch is closed determined by the selected pressure response of the switches of the first selected number of fluid pressure actuated switches.

10. In an electric system of control for a fluid pressure system in which the pressures are at respectively different variable pressure levels in different parts of the fluid pressure system, in combination, a pair of energized conductors and an auxiliary conductor, a fluid pressure responsive device and coupled thereto a first electric switch for connecting one energized conductor to the auxiliary conductor upon occurrence of a certain pressure effect on said pressure responsive device, two electromagnetic devices each including an actuating coil, two other fluid

pressure responsive devices and second and third electric switches coupled respectively to said other devices, said other devices being connected in said different parts of the fluid pressure system, and being responsive to selected fluid pressures in said different parts of the fluid pressure system to effect sequential connection of said coils across the auxiliary conductor and the second energized conductor.

11. In an electric system of control, in combination, a pair of energized conductors and an unenergized conductor, a normally closed switch and an electromagnetic device, connected in series with said switch, connected across one energized conductor and the unenergized conductor, a fluid pressure responsive device coupled to said switch and adapted to open said switch upon a drop of the fluid pressure on the fluid pressure responsive device below a given value, a circuit, including a normally open switch as the sole switch in said circuit, for connecting the other energized conductor to said unenergized conductor, and a second fluid pressure responsive device coupled to close the normally open switch upon the application of fluid pressure of a value falling in a given pressure range to said second fluid pressure responsive device.

12. In an electric system of control for a fluid pressure system in which the fluid pressure normally rises in steps from a selected suction pressure to a selected discharge pressure, in combination, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a number of electromagnetic devices equal in number to the number of steps of pressure rise in the fluid pressure system, a number of fluid pressure responsive switches equal in number to the number of steps of pressure rise in the fluid pressure system and paired, respectively, with said electromagnetic devices and all of them being responsive to a selected fluid pressure to connect one supply conductor and the paired electromagnetic device to said auxiliary conductor, a fluid pressure responsive device responsive to an abnormal fluid pressure condition in said fluid pressure system, and a control switch coupled to said fluid pressure responsive device and together constituting the sole means for connecting the auxiliary conductor to the second supply conductor.

13. In an electric system of control for a fluid pressure system in which the fluid pressure normally rises in steps from a selected suction pressure to a selected discharge pressure and normally drops in pressure a selected amount from said normal discharge pressure to a selected normal output pressure, in combination, a pair of supply conductors energized from a suitable source of electric energy, an auxiliary conductor, a number of electromagnetic devices equal in number to the number of steps of pressure rise in the fluid pressure system, a number of fluid pressure responsive switches equal in number to the number of steps of pressure rise in the fluid pressure system and paired, respectively, with said electromagnetic devices and all of them being responsive to a selected fluid pressure to connect one supply conductor and the paired electromagnetic device to said auxiliary conductor, a fluid pressure responsive device responsive to an abnormal fluid output pressure condition in said fluid pressure system, and a control switch coupled to said pressure responsive device and together constituting the sole control means for connecting the auxiliary conductor to the second supply conductor.

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