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Perry et al.

[11] **3,785,749**

[45] **Jan. 15, 1974**

[54] **CONTROL SYSTEM FOR TWO-STAGE COMPRESSORS**

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[73] Assignee: **Phillips Petroleum Company**, Bartlesville, Okla.

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[52] **U.S. Cl.** **417/12**, 417/27, 417/28

[51] **Int. Cl.** **F04b 49/02**, F04b 49/08

[58] **Field of Search** 417/26, 27, 28, 12

[56] **References Cited**

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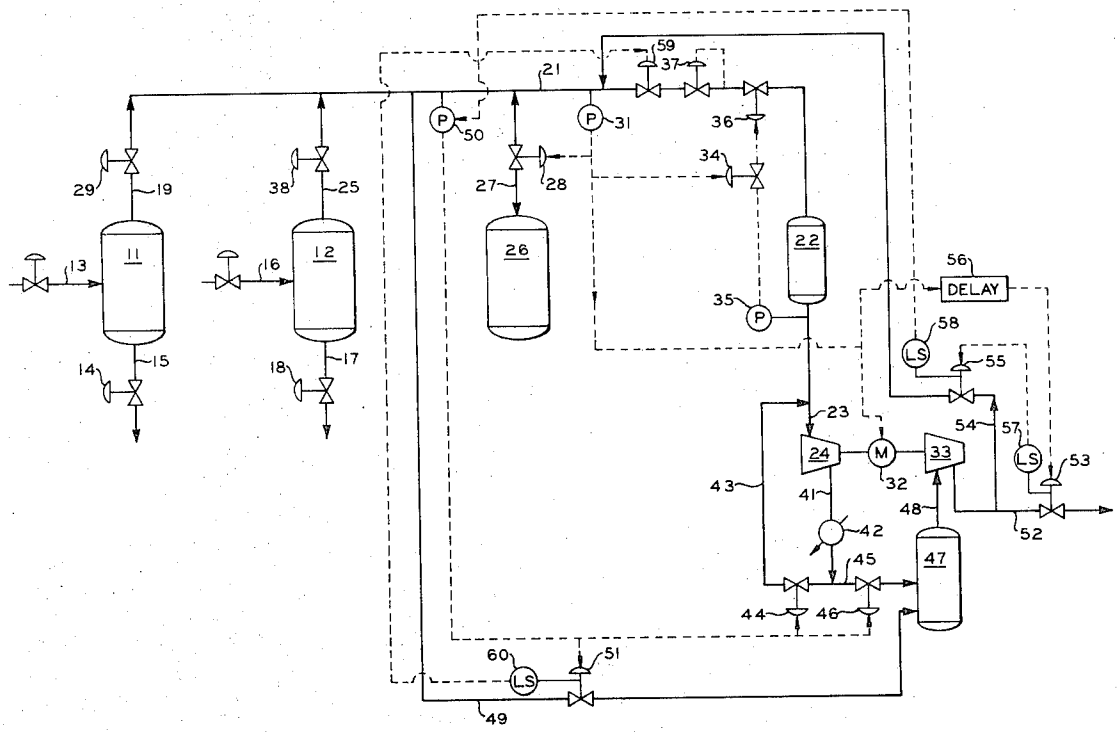
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Assistant Examiner—Richard E. Gluck
Attorney—Quigg and Oberlin

[57] **ABSTRACT**

A control system for a first stage compressor and a second stage compressor provides for the startup of the compressors under no load conditions, and the operation of the compressors with intermittent supply of gases of widely varying pressures. The first stage is bypassed when the supply pressure is above a predetermined value.

6 Claims, 2 Drawing Figures



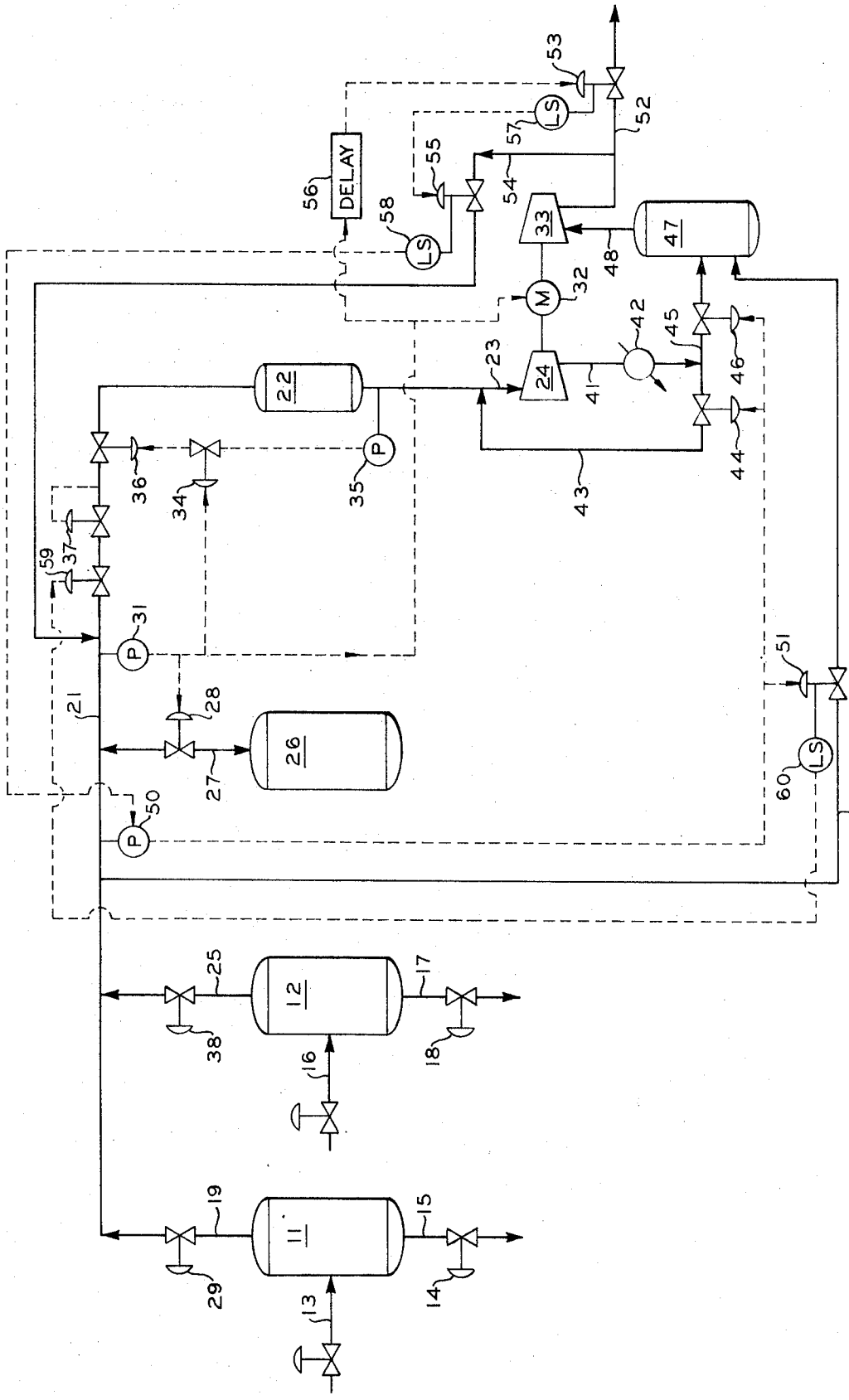

53
52
LS
57
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56
DELAY
58
LS
33
47
48
32
M
42
45
46
23
24
41
22
44
43
36
34
35
P
59
37
31
P
21
28
26
27
51
LS
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13

FIG. 1

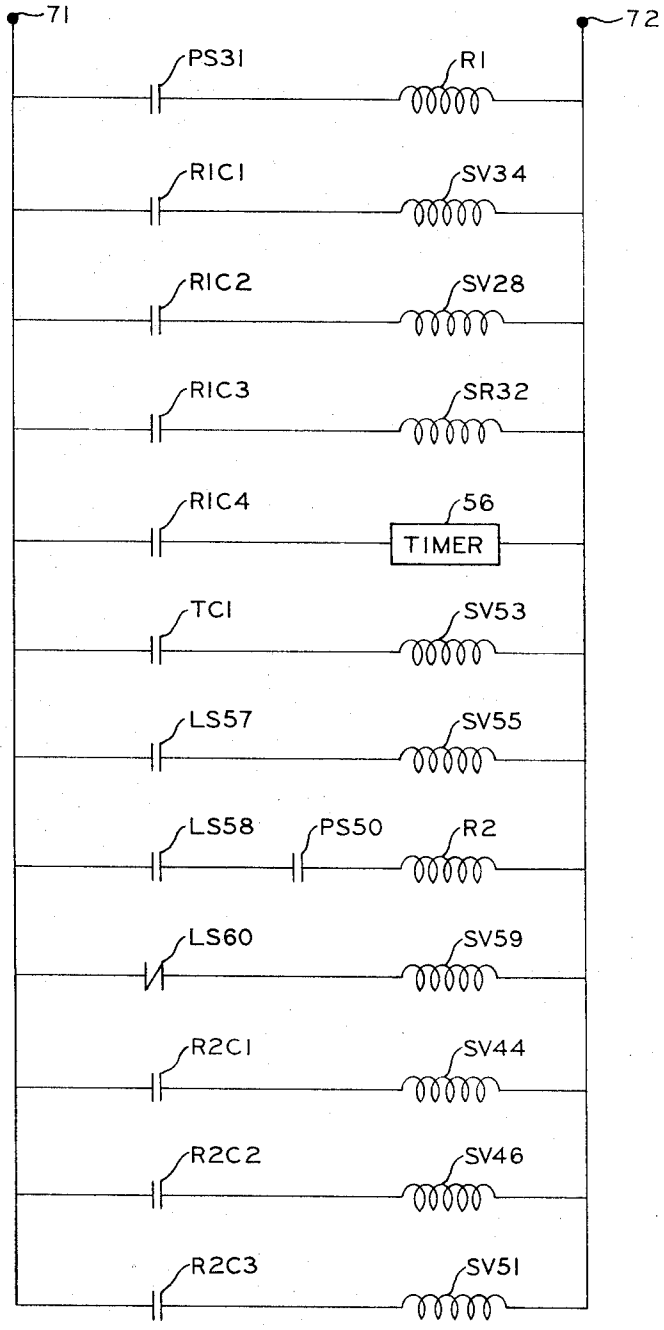

71
72
PS31
R1
RIC1
SV34
RIC2
SV28
RIC3
SR32
RIC4
56
TIMER
TC1
SV53
LS57
SV55
LS58
PS50
R2
LS60
SV59
R2C1
SV44
R2C2
SV46
R2C3
SV51

FIG. 2

CONTROL SYSTEM FOR TWO-STAGE COMPRESSORS

This invention relates to a control system for operating two-stage compressors.

The operation of compressors which are employed on an intermittent basis with widely varying supply pressures presents problems with respect to startup and with respect to efficiency of operation. For example, compressors which are intermittently operated to vent batch reactors frequently encounter shock stresses upon being initially activated under the load of the high reactor pressures. The efficiency is also impaired by having the compressor of sufficient size to handle the maximum load and then having to operate the compressor over the full range of reactor pressure.

In accordance with the present invention, a control system is provided for the intermittent operation of a first stage compressor and a second stage compressor in accordance with the pressure of the gases to be compressed as well as the availability thereof. Valves are employed in the supply line to the compressors and in a recycle line from the outlet of the second stage compressor to the inlet of the first stage compressor to permit the compressors to be started up under no load conditions and with minimum shock. Valves are also provided to completely bypass the first stage compressor when the supply pressure is above a predetermined value and to employ both compressors when the supply pressure is below such value.

Accordingly, it is an object of the present invention to provide a new and improved control system for the operation of compressors. Another object of the invention is to minimize the shock to a compressor upon startup. It is also an object of the invention to improve the efficiency of the operation of compressors where there are wide variations in the supply pressure. Other objects, aspects and advantages of the invention will be apparent from a study of the specification, the drawings and the appended claims to the invention.

In the drawings,

FIG. 1 is a diagrammatic representation of a process embodying the present invention, and

FIG. 2 is a schematic representation of an electrical circuit which can be utilized to effect the control functions illustrated in FIG. 1.

Referring now to the drawings and to FIG. 1 in particular, there is illustrated a batch reaction system comprising batch reaction vessels 11 and 12. The reactants for the batch reaction are introduced into reactor 11 through one or more input lines 13. When the reaction has reached the desired state, valve 14 in conduit 15 is opened to withdraw the liquid reaction product from reactor 11. Similarly, the reactants can be introduced into batch reactor 12 through one or more inlet conduits 16, and at the end of the desired reaction time the liquid reaction effluent can be withdrawn through conduit 17 and valve 18. After or during the removal of the liquid reaction product from reactor 11 or reactor 12, it is desirable to vent the gases from the respective reactor. Conduits 19 and 21, suction drum 22, and conduit 23 are connected in series between an upper portion of reactor 11 and the inlet of first stage compressor 24, to provide for fluid communication between an upper portion of reactor 12 and the inlet of compressor 24. Conduits 25 and 21, drum 22 and conduit 23 provide for fluid communication between an upper portion of vessel 12 and the inlet of compressor 24.

A vent equalization vessel 26 is connected to conduit 21 by means of conduit 27 and normally closed valve 28. It is presently preferable for vessel 26 to be at least as large as vessels 11 and 12. Conduits 19, 21 and 27 are of sufficient size to permit the gas pressures in vessels 11 and 26 to reach equilibrium in a reasonably short period of time. When it is desired to vent reactor 11, valve 29, located in conduit 19, is opened. Pressure sensor 31 is operatively connected in conduit 21 and produces a control signal upon the pressure in conduit 21 going above a minimum value, for example 10 psig. This control signal from sensor 31 is utilized to open valve 28 to provide communication between reactor 11 and vent equalization vessel 26. The control signal from pressure sensor 31 effects the actuation of motor 32, which drives first stage compressor 24 and second stage compressor 33. This control signal from sensor 31 is also utilized to actuate valve 34 to provide control signal communication between pressure sensor 35, mounted in conduit 23, and normally closed valve 36, positioned in conduit 21 at a point between suction drum 22 and the intersection of conduits 21 and 27. Upon the startup of compressor 24 the pressure in conduit 23 drops below a value at which sensor 35 causes valve 36 to open, thereby providing fluid communication between vessels 11 and 26 and the inlet of the first stage compressor 24 in those instances when valve 59 is open Valve 37 is positioned in conduit 21 upstream of valve 36 and is manipulated responsive to the pressure at the downstream side of valve 37 to maintain this pressure at least substantially constant. After the pressures in vessels 11 and 26 have reached equilibrium, or at such time as the pressure in vessel 11 is reduced to a desired value, valve 29 can be closed and reactor 11 is ready for the next batch reaction while compressor 24 continues to draw suction from vessel 26. If desired, a timer can be employed in the control of valves 28 and 29 so that after valve 28 is initially opened by the control signal from pressure sensor 31, valve 28 is permitted to remain open for a first time period sufficient for the gas pressures in vessels 11 and 26 to at least substantially reach equilibrium, and then valve 28 is closed for a second time period of sufficient length to permit compressors 24 and 33 to reduce the pressure in reactor 11 to the desired value, after which valve 29 would be closed and valve 28 would be opened to permit the pressure in vessel 26 to be reduced to the value desired therefor. When the pressure in vessel 26 reaches the desired value, the signal from pressure sensor 31 would close valve 28 and deactivate the timer.

When it is desired to vent reactor 12, valve 38, located in conduit 25 is opened. Pressure sensor 31 opens valve 28, closes valve 34, and actuates motor 32. Conduits 25, 21, and 27 are of sufficient size to permit the gas pressures in vessels 12 and 26 to reach equilibrium in a reasonably short period of time. Valve 38 can then be closed, and the pressure in vessel 26 can be reduced to the desired level by compressor 24. If desired, a timer can be employed to close valve 28 after equilibrium is reached, for a period of time sufficient for the pressure in vessel 12 to be further reduced to a desired value. At the end of this period of time, valve 38 would be closed and valve 28 reopened to permit the reduction of the pressure in vessel 26.

The intermediate pressure gases from first stage compressor 24 are passed by way of conduit 41 to cooler 42. The resulting cooled, compressed gases can be

passed through conduit 43, containing normally closed valve 44, to the inlet of first stage compressor 24 or through conduit 45, normally open valve 46, interstage surge drum 47, and conduit 48 to the inlet of second stage compressor 33. Conduit 49, containing normally closed valve 51, provides fluid communication between drum 47 and conduit 21 at a point upstream of valve 59. The high pressure gas effluent from the second compressor stage 33 can be withdrawn from the system by way of conduit 52 and normally closed valve 53 or passed through conduit 54, normally closed valve 55, conduit 21, valves 59, 37 and 36, drum 22 and conduit 23 to the inlet of first stage compressor 24. Normally closed valve 53 is actuated to its open position by the control signal from pressure sensor 31 after a desired time delay determined by delay 56. Limit switch 57 is actuated when valve 53 reaches its fully open position, and the actuation of limit switch 57 results in the closing of valve 55.

Limit switch 58, which is actuated upon the closing of valve 55, serves as an interlock for the control signal from pressure sensor 50, mounted in conduit 21. When valve 55 is closed and the pressure in conduit 21 as measured by sensor 50 exceeds a predetermined value, the control signal from sensor 50 effects the opening of normally closed valves 44 and 51 and the closing of normally open valve 46. Limit switch 60 is actuated upon the opening of valve 51 and effects the closing of valve 59 located in conduit 21 downstream of pressure sensor 50.

Referring now to FIG. 2, there is illustrated a specific embodiment of an electrical control circuit which can be utilized to automatically perform the control functions shown in FIG. 1. Pressure switch PS31 and relay coil R1 are connected in series between electrical power terminals 71 and 72. Switch R1C1 and solenoid SV34 are connected in series between terminals 71 and 72, as are switch R1C2 and solenoid SV28. Switch R1C3 and the starting relay SR32 for motor 32 are also connected in series between terminals 71 and 72. Pressure switch PS31 is closed upon the pressure in conduit 21 as measured by pressure sensor 31 exceeding a predetermined minimum low pressure operating value, for example 10 psig. Relay R1 is energized upon the closing of switch PS31 and closes normally open switches R1C1, R1C2 and R1C3, thereby energizing solenoids SV34 and SV28 to open valves 34 and 28 and energizing starting relay 32 to activate motor 32. At this point in time valve 53 is closed and valve 55 is open to recycle the output of the second stage compressor 33 to the inlet of the first stage compressor 24, and valve 46 is open while valve 44 is closed, thereby passing the output of the first stage compressor 24 to the inlet of the second stage compressor 33. Valve 36 is initially fully closed while valve 59 is fully open. The opening of valve 28 significantly reduces the pressure surge in conduit 21 downstream of conduit 27. Valve 37, which is set at a suitable pressure, for example 30 psig, further reduces the pressure surge and eliminates or minimizes the transient pressure spike. The closing of valve 34 permits pressure sensor 35 to slowly open valve 36 to control the pressure in the suction drum 22 at a desired value, for example 5 psig. Thus the startup of compressor stages 24 and 33 is in the unloaded condition, thereby minimizing strain on the compressor stages 24 and 33 and motor 32.

Switch R1C4 and timer 56 are connected in series between terminals 71 and 72. Switch R1C4 is closed upon the actuation of relay R1. After a suitable time delay, for example on the order of 30 seconds, timer 56 closes switch TC1, which is connected in series with solenoid SV53 between terminals 71 and 72. Normally closed valve 53 is opened upon the actuation of solenoid SV53, thereby opening the high pressure discharge conduit 52. Upon valve 53 reaching its open position, limit switch 57 is actuated, closing switch LS57 which is connected in series with solenoid SV55. Valve 55 is moved to its closed position upon the actuation of solenoid SV55, thereby providing for all of the high pressure gas to pass through conduit 52 and valve 53 for withdrawal from the system. Upon valve 55 reaching its closed position, limit switch 58 is actuated, closing switch LS58 which is connected in series with pressure switch PS50 and relay R2 between terminals 71 and 72.

Pressure switch PS50 is closed when the pressure in conduit 21 as measured by pressure sensor 50 exceeds a predetermined minimum high pressure operation value, for example 104 psig. When both switches LS58 and PS50 are in the closed condition, relay R2 is energized, thereby closing switches R2C1, R2C2 and R2C3. Solenoids SV44 is connected in series with switch R2C1 between terminals 71 and 72 and effects the opening of normally closed valve 44 upon the closing of switch R2C1. Solenoid SV46 is connected in series with switch R2C2 between terminals 71 and 72 and effects the closing of normally opened valve 46 upon the closing of switch R2C2. Solenoid SV51 and switch R2C3 are connected in series between terminals 71 and 72, and solenoid SV51 opens normally closed valve 51 upon the closing of switch R2C3. Normally closed limit switch 60 is actuated open upon valve 51 reaching its open position, thereby deenergizing solenoid SV59 which is connected in series with switch 60 between terminals 71 and 72. Valve 59 is moved to its closed position upon the deenergization of solenoid SV59. Under these conditions, the gases from vessels 11, 12 and/or 26 as the case may be, pass through conduit 49, surge drum 47, and conduit 48 to the inlet of the second stage compressor 33, thereby bypassing first stage compressor 24. With valves 46, 55, and 59 closed and valve 44 opened, the output of the first stage compressor 24 is recycled by way of conduit 43 to the inlet thereof as the sole feed thereto, thereby minimizing the load on first stage compressor 24 while maintaining it in operation to take suction when required. Subsequently, when the pressure in conduit 21 as measured by pressure sensor 50 drops below the preset value, pressure switch PS50 is opened, thereby deenergizing relay R2 and opening switches R2C1, R2C2 and R2C3 to open valve 44 and to close valves 46 and 51. Upon the closing of valve 51, limit switch LS60 closes to energize solenoid SV59 and thereby open valve 59. Under these conditions all of the feed gases pass directly to the inlet of first stage compressor 24, the intermediate pressure gases from the outlet of first stage compressor 24 are passed to the inlet of the second stage compressor 33, and the high pressure gases from second stage compressor 33 pass from the system through conduit 52 and valve 53.

When the pressure in conduit 21 as measured by pressure sensor 31 falls below the preset value, pressure switch PS31 opens, thereby deenergizing relay R1,

resulting in the closing of valves 34 and 28 and the deactivation of motor 32. After the time delay, valve 53 closes and valve 55 opens to return the system to a no load condition. The opening of valve 55 results in the opening of switch LS58, thereby preventing actuation of relay R2 until in a subsequent operation valve 55 is again closed and the pressure in conduit 21 exceeds 104 psig.

Reasonable variations and modifications are possible within the scope of the foregoing disclosure, the drawings and the appended claims to the invention. For example, while it is presently preferable to employ a pneumatic control of valve 36 by pressure sensor 35, an electrical control circuit could be employed, wherein valve 34 would be replaced by an electrical switch. While the invention has been described in terms of solenoid actuated process valves, pneumatic process valves can be employed with the solenoid valves being in the pneumatic supply lines to the pneumatic valves. Also, the electrical control system of FIG. 2 can be entirely replaced with a pneumatic control system.

We claim:

1. Apparatus comprising a first stage compressor and a second stage compressor, each having an inlet and an outlet, a vessel containing gas to be at least partially evacuated, first conduit means connecting said vessel with the inlet of said first stage compressor, second conduit means connecting the outlet of said first stage compressor to the inlet of said second stage compressor, third conduit means connecting the outlet of said first stage compressor to the inlet of said first stage compressor, fourth conduit means connecting said vessel to the inlet of said second stage compressor, fifth conduit means connected to the outlet of said second stage compressor, for the withdrawal of compressed gases from the system, first valve means in said first conduit means adapted to interrupt the fluid communication between said vessel and the inlet of said first stage compressor, second valve means in said second conduit means adapted to interrupt the fluid communication between the outlet of said first stage compressor and the inlet of said second stage compressor, third valve means in said third conduit means adapted to interrupt the fluid communication between the outlet of said first stage compressor and the inlet of said first stage compressor, fourth valve means in said fourth conduit means adapted to interrupt the fluid communication between said vessel and the inlet of said second stage compressor, fifth valve means in said fifth conduit means, means for measuring a pressure representative of the gas pressure in said first conduit means upstream of said first valve means and in said fourth conduit means upstream of said fourth valve means, and control means for maintaining said third, fourth, and fifth valve means open and for maintaining said first and second valve means closed when the thus measured pressure exceeds a predetermined minimum high pressure operation value, for maintaining said third and fourth valve means closed and maintaining said first, second, and fifth valve means open when said measured pressure is greater than a minimum low pressure operation value and less than said predtermined high pressure operation value, and for maintaining said first, fourth and fifth valve means closed when said measured pressure is less than said minimum low pressure operation value, and means for driving said first and second stage compressors when said measured pressure exceeds said minimum low pressure operation value.

2. Apparatus in accordance with claim 1 further comprising sixth conduit means connecting the outlet of said second stage compressor to the inlet of said first stage compressor, sixth valve means in said sixth conduit means adapted to interrupt the fluid communication between the outlet of said second stage compressor and the inlet of said first stage compressor, and wherein said control means further comprises means for maintaining said fourth valve means closed regardless of the value of the measured pressure unless said sixth valve means is closed.

3. Apparatus in accordance with claim 2 wherein said control means further comprises means for maintaining said second and third valve means open when said measured pressure is less than said minimum low pressure operation value, means for actuating said means for driving when the measured pressure increases from a value less than said minimum low pressure operation value to a value greater than said minimum low pressure operation value, and means for opening said fifth valve means and closing said sixth valve means at the end of a predetermined time period after the actuation of said means for driving.

4. Apparatus in accordance with claim 3 wherein said first conduit means contains a normally closed seventh valve means located therein at a point between said first valve means and the inlet of said first stage compressor, a pressure sensing means for determiniming the pressure at the inlet of said first stage compressor, and wherein said control means further comprises means for manipulating said seventh valve means responsive to the pressure determined by said pressure sensing means only when said measured pressure exceeds said minimum low pressure operation value.

5. Apparatus in accordance with claim 4 wherein said first conduit means further comprises an eighth valve means contained therein at a point between said first valve means and said seventh valve means, and means for manipulating said eighth valve means responsive to the pressure in said first conduit means at the downstream side of said eighth valve means.

6. Apparatus in accordance with claim 1 further comprising a vent equalization vessel, sixth conduit means connecting said vent equalization vessel to said first conduit means at a point upstream of said first valve means, sixth valve means in said sixth conduit means adapted to interrupt fluid communication between said vent equilization vessel and said first conduit means.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,785,749 Dated January 15, 1974

Inventor(s) Robert J. Perry and Bobbie L. Whitson

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

Column 1, line 64, delete "12" and insert -- 11 --. Column 2, line 53, delete "closes" and insert -- opens --. Column 3, line 11, delete "closed" and insert -- open --; line 48, delete "32" (first occurrence) and insert -- SR32 --; line 60, delete "closing" and insert -- opening --. Column 4, line 38, delete "60" and insert -- LS60 --; line 55, delete "44" and insert -- 46 --; line 55, delete "46" and insert -- 44 --. Column 5, line 35, delete the comma. Column 6, line 3, delete "predtermined" and insert -- predetermined --; line 4, delete "first," line 23, delete "third" and insert -- sixth --; line 37, delete "determiniming" and insert -- determining --.

Signed and sealed this 24th day of June 1975.

(SEAL)
Attest:

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Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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