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[21] Appl. No. 846,491
[22] Filed July 31, 1969
[45] Patented Apr. 13, 1971
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3,332,605 7/1967 Huesgen..... 415/17
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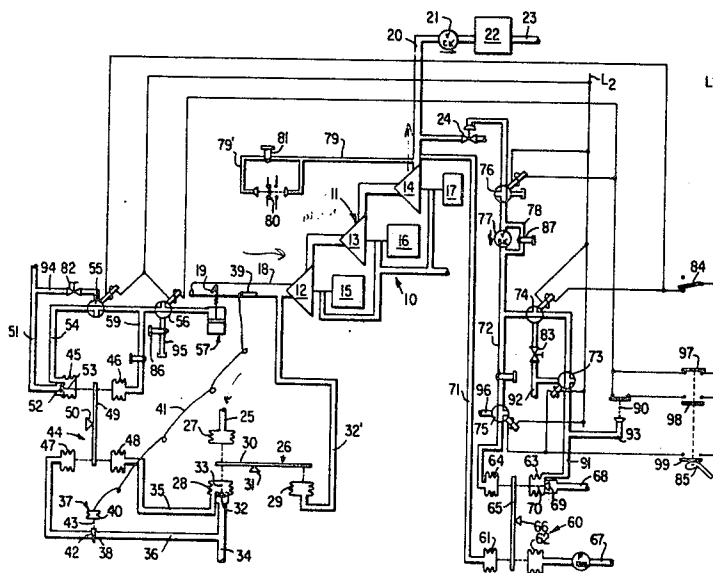
[54] METHOD OF AND APPARATUS FOR
CONTROLLING THE OPERATION OF GAS
COMPRESSION APPARATUS
6 Claims, 2 Drawing Figs.

[52] U.S. Cl..... 415/15,
415/17, 417/282, 417/292, 417/307
[51] Int. Cl..... G05d 13/30,
F01d 17/00, F04b 49/00
[50] Field of Search..... 415/15, 17;
230/114, 9, 7, 5; 417/17, 18, 282, 292, 307

[56] References Cited

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3,097,488 7/1963 Eggenberger et al. 415/15

ABSTRACT: A control system for regulating operation of a gas compression plant, selectively operable on either base mode or on intermittent mode. The control system includes a switch operable to transfer the compression plant from base mode to intermittent mode or from intermittent mode to base mode. Valves, operable in response to the switch, have a first operating position for base mode and a second operating position for intermittent mode. The discharge pressure of the gas from the compression plant is sensed and a signal related thereto is compared to a predetermined signal, to produce a resultant control signal, operable to regulate a dump valve which governs the venting of excess discharge gas to the atmosphere. The dump valve is modulated during base mode operation and is selectively fully open or fully closed during intermittent mode.



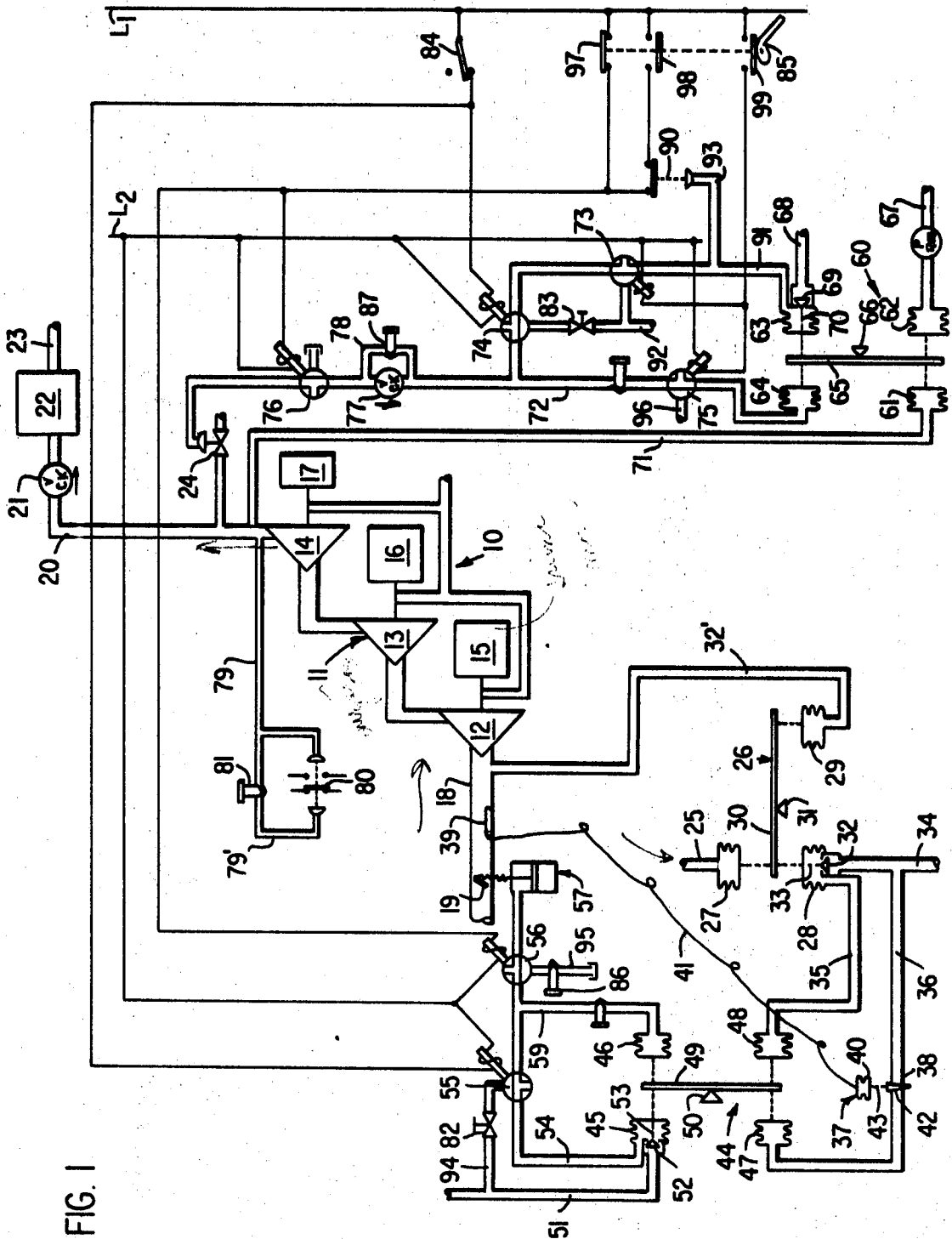


FIG. 1

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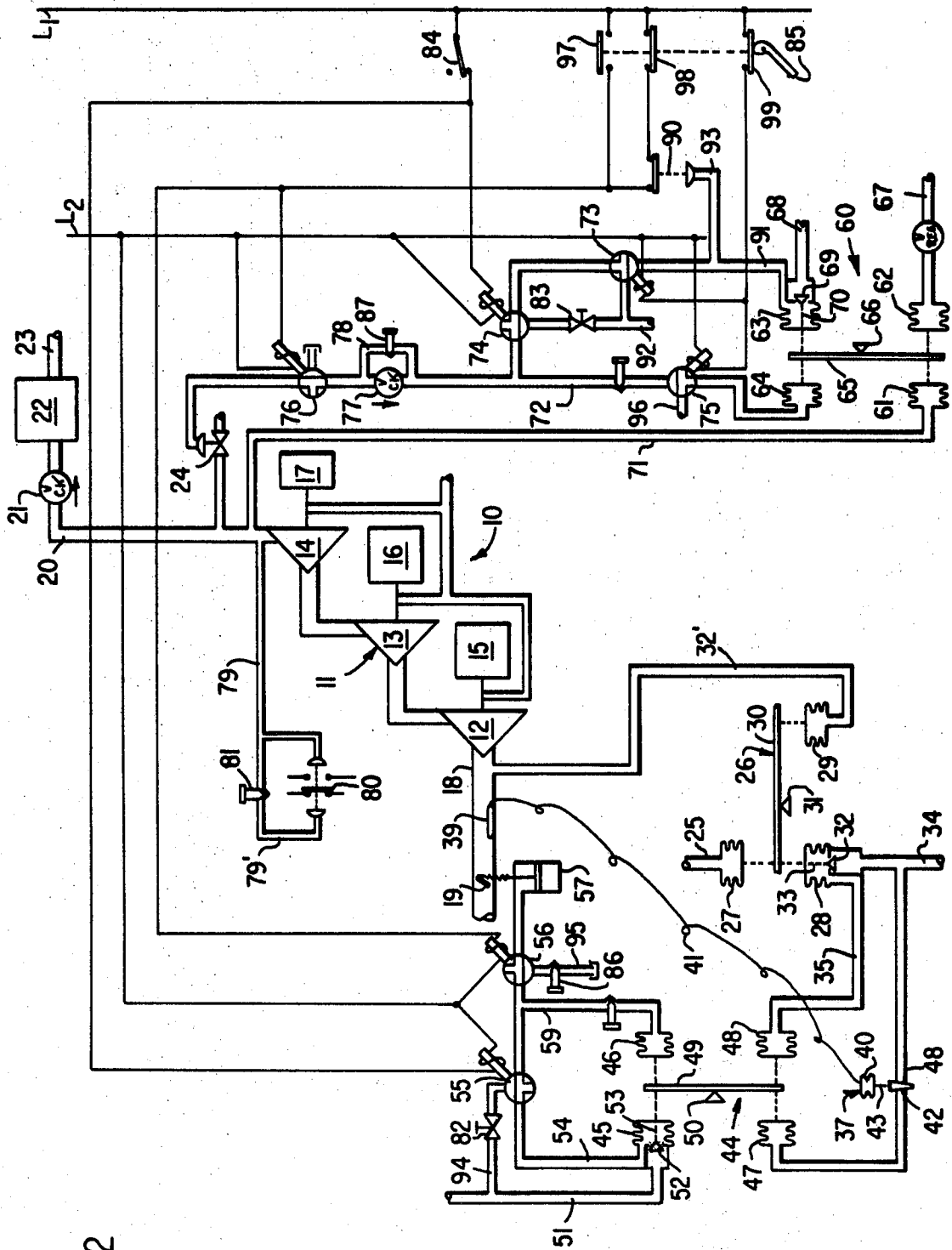


FIG. 2

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METHOD OF AND APPARATUS FOR CONTROLLING THE OPERATION OF GAS COMPRESSION APPARATUS

BACKGROUND OF THE INVENTION

This invention relates broadly to the control of the operation of gas compression apparatus and more particularly to gas compression apparatus of the type employing a multistage axial or centrifugal compressor driven by a prime mover. Still more particularly, this invention relates to a control arrangement for use with gas compression apparatus selectively operable either as a base load machine or as an intermittent load machine.

In gas compression equipment, such as an air compression plant employing a number of air compressors or air compression stages, wherein ambient air is compressed and delivered to a reservoir, for use at a variable rate, there are two general types of operation involved. The first type of operation is called base load operation. The compressor is controlled so as to deliver an output of compressed gas substantially consistent with a demand, variable within predetermined limits. As the plant's compressed gas requirements decrease, an unloading valve disposed in communication with the discharge conduit of the compressor will operate to vent the excess capacity to the atmosphere. The unloading valve will be modulated to maintain the desired discharge pressure.

The second type of operation is called intermittent load operation. When operating on intermittent load, a compressor will either be delivering full capacity to the plant, with the unloading valve completely closed, or will not be delivering any compressed gas to the plant, with the unloading valve completely open. With intermittent mode operation, there is no modulating the unloading valve, as done when operating on base mode.

For some applications, it is desirable to operate a compressor at times on base mode and at other times on intermittent mode. In such applications, it is highly desirable for the compression apparatus to be readily transferable from one mode of operation to the other.

Heretofore, it has been necessary, when transferring modes, to make numerous changes in the control system. A number of valves would either have to be opened or closed. In addition, control orifices would have to be readjusted so the proper signals for the mode being used would be transmitted to such components as the unloading valve.

Very often, those making the requisite adjustments would not do so correctly. As a result, the compressor would not function as desired. Usually, it would then be necessary to obtain specialized help to correct the troubles, thereby increasing the maintenance costs and causing loss of production due to the inoperation of the compressor. To avoid complications, it has become the practice to maintain the machine on one mode of operation even though it would be desirable to change the mode of operation to meet changing conditions, such as operating the compressor on base mode during the regular working week and then switching the mode of operation to intermittent for weekend operation, thus reducing the operating costs.

It is therefore the object of this invention to provide a control circuit that readily permits the operator to transfer the mode of operation, without having to make numerous adjustments heretofore required.

SUMMARY OF THE INVENTION

In accordance with a preferred embodiment of this invention, a gas compression machine is provided which employs an air compressor having a suitable main control circuit, operable to provide means for readily transferring the compression plant from base mode to intermittent mode or from intermittent mode to base mode.

A mode of control switch is provided in the control circuit; the switch will be placed in its proper position for the mode of operation desired. Valve means operable in response to the

switch, having a first operating position for base mode and having a second operating position for intermittent mode, will be placed in their proper position for the mode of operation being used. An unloading valve controls the pressure of air being discharged from the compressor, opening to vent excess compressed gas to the atmosphere. The pressure of the discharge gas is sensed and a signal related thereto is used to produce a control signal operating to modulate the unloading valve during base load operation and selectively operating to fully open or to fully close the unloading valve during intermittent load operation. The valve means operable in response to the mode of operation switch, direct the control signal to the means responsive thereto, for regulating the dump valve in the proper manner for the mode of operation being used.

A control circuit in accordance with this invention provides a gas compression system that may be readily transferred from one mode of operation to the other mode of operation, without having to make the numerous adjustments heretofore required and therefore the novel control circuit eliminates the problems discussed hereinbefore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates a gas compression system having a control circuit in accordance with this invention, the system being operated on base mode; and

FIG. 2 schematically illustrates the gas compression system of FIG. 1, having the control circuit transferred to operate the system on intermittent mode.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawing, and particularly to FIG. 1 thereof, there is shown a gas compression system operating on base mode.

The gas compression system 10 includes an air compressor 11 for the purpose of providing compressed air to a storage vessel or reservoir for use with pneumatic machinery or similar applications where compressed air is utilized as an energy source. It will be appreciated there are many installations requiring compressed air in such large quantities that it is necessary to supply an air compression plant utilizing a multistage axial or centrifugal compressor 11. The compressor 11 has a first stage 12 in series with a second stage 13 and a third stage 14. For the purpose of illustrating a representative machine, each of the stages are connected to a prime mover 15, 16 and 17, respectively. It should be understood that one prime mover may be used to operate all of the stages of the compressor.

Inlet line 18 is provided to admit ambient air through an inlet throttle valve 19 to first stage 12 of compressor 11. Compressed air is discharged from compressor 11 through a check valve 21 in gas discharge conduit 20 into storage tank or reservoir 22. A suitable compressed air discharge line 23 distributes air from the reservoir 22 to the desired locations at which it is employed.

In order to maintain the pressure of discharge air in reservoir 22 in line 23 relatively constant at a predetermined pressure, a dump valve 24 is employed to discharge compressed air from compressor 11 to the atmosphere when the pressure demands of the reservoir 22 are satisfied. Dump valve 24 may be operated either at a fully open position or at a fully closed position, or it may be modulated, according to the characteristics of the mode of operation employed. As noted above, the air compression system of FIG. 1 is operating on base mode, therefore the dump valve 24 may be modulated to maintain the desired pressure in reservoir 22.

The control system serving as the subject of this invention is utilized with equipment of the kind described above. Particularly, the novel control system will permit the operator of the air compressor to transfer the mode of operation from base to intermittent or from intermittent to base as expeditiously as possible, without introducing the

concomitant problems hereinbefore discussed. To fully understand the operation of the novel control system, it is necessary to understand the operation of the system during base mode of operation and during intermittent mode of operation. The manner in which the novel system permits the transfer of mode of operation shall thence become apparent.

Again referring to FIG. 1, the embodiment of the invention utilizes an electropneumatic control system. However, it should be understood the scope of the invention shall not be limited to only an electropneumatic control system, but includes an all-pneumatic system. Therefore, hereinafter when electrically operated valves are specified, they may be replaced by their equivalent pneumatically-operated valves, without departing from the scope of the invention. A source of supply air (not shown), in the range of 45—125 p.s.i.g., is employed to operate certain elements forming a part of the control system. It is to be understood the supply or control air is maintained completely separate from the air being compressed by the compressor 11. A plurality of electrically operated valves are utilized to direct pneumatic control signals in predetermined paths, depending in part upon system conditions and in part upon the mode of operation being used. A detailed explanation of the control system may be found in U.S. Pat. No. 3,332,605, issued on Jul. 25, 1967, to Eugene L. Huesgen. The control system is designed, among other things, to regulate the operation of throttle valve 19, controlling the flow of air to the compressor, and the dump valve 24 regulating the venting of the compressor discharge to the atmosphere.

To this end, there is provided a main air supply conduit (not shown), having a first supply branch 25. Disposed in supply branch 25 is a control assembly 26 including bellows members 27, 28 and 29 and beam member 30, pivotally mounted about fulcrum 31. Connected to bellows 29 is conduit 32' communicating the bellows 29 with inlet gas line 18, thereby making the bellows responsive to inlet air pressure. The inlet pressure, which is normally below atmospheric pressure due to the throttling action of the inlet valve 19, produces a force which tends to pivot beam 30 in a clockwise direction about fulcrum 31.

Acting to limit the force produced by the inlet air pressure is the positive force produced by supply air in supply branch 25 acting on bellows 27, tending to rotate beam 30 counterclockwise about fulcrum 31. Secured to bellows 28 is a valve assembly, including valve element 32 and rod 33. Communicating with bellows 28 is second supply branch 34. When the air inlet pressure exceeds a predetermined point, the counterclockwise motion of beam 30 thus produced unseats valve element 32, thereby communicating supply branch 34 with conduit 35. Valve element 32 thus controls the pressure in conduit 35.

Communicating with supply branch 34 is branch conduit 36. Disposed in branch conduit 36 is a control assembly 37 regulating air flow through orifice 38 disposed in conduit 36. The control 37 acts responsive to changes in the temperature of the air flowing within line 18. A bulb 39 senses the temperature of the air flowing in conduit 18 and is part of a thermal responsive fill system incorporating a bellows 40 and a capillary tube 41, providing communication between the bulb 39 and the bellows 40. Secured to the bellows 40 is control assembly 37, including valve element 42 and rod 43 connected to bellows 40, which moves to enlarge or restrict the effective area of the orifice 38 so as to bleed varying amounts of air from conduit 36, to change the pressure in the conduit downstream of the orifice. Valve element 42 is designed to open upon an increase in ambient air temperature and to close upon a decrease in ambient air temperature.

Communicating with conduit 36, downstream of orifice 38, is bellows member 47 of totalizer relay assembly 44. In addition to bellows 47, relay assembly 44 includes bellows member 45, 46 and 48 and beam member 49 pivotally mounted about fulcrum 50. The force developed by the control air in conduit 36 acting on bellows 47 acts to pivot

beam 49 counterclockwise about fulcrum 50. Bellows 48 is in communication with conduit 35. The force developed by the control air in conduit 35 acting on bellows 48, acts to pivot beam 49 clockwise about fulcrum 50 and therefore opposes the force developed by bellows 47.

Secured to bellows 45 is a valve assembly, including valve element 52 and rod 53. The valve 52 is designed to close when beam 49 moves clockwise and to open when beam 49 moves counterclockwise. Valve 52 regulates the amount of air that will pass from third supply branch 51 to conduit 54. The air passing through conduit 54 acts as a control signal for positioning throttle valve 19 in a manner to be explained more fully hereinafter. Assuming ambient temperature remains constant, if inlet air pressure were to exceed a predetermined amount, the increase in the air in conduit 35, acting on bellows 48, will act to close valve 52 and decrease the control signal through conduit 54. If inlet air pressure were to remain constant, but the ambient air temperature were to increase, the resulting increase in air pressure downstream of orifice 38, acting on bellows 47, would cause valve 52 to be opened, thereby increasing the control signal in conduit 54. If inlet air pressure and ambient air temperature both were to change, totalizer relay assembly 44 would compare the changes, as indicated by the changes in pressure in conduits 35 and 36, and would thereby determine the resulting control signal in conduit 54.

The control signal passes through electrically-operated three-way valves 55 and 56, and is then transmitted to inlet throttle valve positioner assembly 57. The manner in which valves 55 and 56 are controlled will be more fully explained hereinafter. Valves 55 and 56 are shown in their energized positions. An increase in the control signal acts to open the inlet valve 19 and a decrease in the control signal acts to close the inlet valve 19. During normal operation, the inlet valve will be either fully open, fully closed, or may be modulated to any intermediate position therebetween, the position of the valve being determined by the pressure and temperature conditions of the air entering the compressor.

To prevent hunting, conduit 59 communicates conduit 54 with bellows 46, thereby placing the bellows under control signal pressure. The force developed on bellows 46 acts to resist any change in position of the beam 49 and thus of the valve element 52.

An additional feature of the control system involves an arrangement for modulating the dump valve 24 when on base mode of control.

To this end, a second totalizer relay assembly 60 is used in obtaining the control of the dump valve 24 desired. Relay assembly 60 includes bellows members 61, 62, 63 and 64 and beam member 65 pivotally mounted about fulcrum 66. Communicating air discharge conduit 20 and bellows member 61 is conduit 71; thereby bellows member 61 has air at discharge pressure acting on it. The force developed thereby acts to rotate beam 65 counterclockwise about fulcrum 66.

Bellows member 62 is in communication with a fifth supply branch 67 which delivers a predetermined control signal to the bellows, thereby producing a force in opposition to the force of bellows member 61. Secured to bellows 63 is a valve assembly, including valve member 69 and rod 70. The valve assembly is designed so valve member 69 and rod 70. The valve assembly is designed so valve member 69 closes when beam 65 rotates counterclockwise and opens when beam 65 rotates clockwise. The valve assembly controls the bleeding of supply air from conduit 68 to conduit 91. A greater amount of control air will exist in conduit 91 when the discharge pressure is low, and a lesser amount of air will exist in conduit 91 when the discharge pressure is high.

The air in conduit 91 flows through electrically-operated three-way valves 73 and 74 into conduit 72. The manner in which valves 73 and 74 is controlled shall be discussed more fully hereinafter. Valve 73 is shown in its deenergized position and valve 74 is shown in its energized position. Conduit 72 transmits the control signal to dump valve 24. Disposed in the

conduit 72 upstream of dump valve 24 is check valve 77. Check valve 77 is designed to prevent flow in the direction of the dump valve. The control signal is bypassed around check valve 77, via conduit 78. Needle valve 87 disposed in conduit 78 restricts the flow of air towards the dump valve for a reason to be explained hereinafter. Disposed in conduit 72, downstream of check valve 77 and bypass 78, is electrically-operated three-way valve 76. The manner of control of valve 76 will be explained later. Valve 76 is shown in its energized position.

To prevent hunting, conduit 72 communicates with bellows 64 via electrically-operated three-way valve 75. During base mode of operation, valve 75 is in its deenergized position. The force developed on bellows 64 acts to resist any change in position of beam 66 and thus of valve element 69.

Dump valve 24 is designed to be fully open when no control signal is transmitted to it and to be fully closed when the maximum control signal, in the preferred embodiment 32 p.s.i.g., is transmitted. As noted heretofore, during base load operation, the dump valve may be operated at a fully open or at a fully closed position, or may be modulated to maintain a relatively constant discharge pressure.

To protect the compressor during surge conditions, the control system includes pressure-operated, normally open switch 80. Switch 80 operates to detect surge conditions and is designed to close upon a predetermined pressure differential being reached. Switch 80 senses discharge air via conduit 79 communicating with conduit 20. If surge occurs, the pressure in conduit 79 will decrease rapidly during each cycle of reverse flow of air through the compressor. However, needle valve 81 disposed in the lower portion of conduit 79 will restrict the flow of air from conduit portion 79' during the cycle of reverse flow of air, thereby creating a pressure differential and causing switch 80 to close. The closing of switch 80 will cause the dump valve 24 to open immediately. The manner in which switch 80 causes the above to occur shall be explained hereinafter.

When operating automatically, and in base mode, the electrical circuit will be positioned as shown in FIG. 1. Mode-of-operation switch 85 will be positioned for base mode operation, thereby closing switch 97 and opening switches 98 and 99. Selector switch 84, when set for automatic operation as shown, connects three-way valves 55 and 74 to a source of current (not shown) through lines L_1 and L_2 . If it were desired to operate the control system manually, switch 84 would be placed in its manual position, and three-way valves 55 and 74 would then be deenergized. With valve 55 deenergized, the control signal transmitted from relay 44 would be blocked. In place thereof, the valve 55 would then be positioned to communicate supply branch 94 with conduit 54. The control signal to the inlet valve positioner 57 may then be manually regulated via valve 82. Similarly, with valve 74 deenergized, the control signal transmitted from relay 60 would be blocked. The deenergized position of valve 74 communicates supply branch 92 with conduit 72. The control signal to dump valve 24 may then be manually regulated by operating valve 83 disposed in branch 92.

As noted previously, three-way valve 76 is shown in its electrically energized positions. If surge were to occur, switch 80 would close. Switch 80 is electrically connected to cause valve 76 to become deenergized upon the closing of the switch. The manner in which such connection may be made is within the ordinary skill of the art and is not shown.

When valve 76 is deenergized, the control signal emanating from relay 60 is blocked from going to dump valve 24. In addition, conduit 72 downstream of valve 76 is communicated with the atmosphere via the repositioning of the valve 76. The bleeding of control air will cause the dump valve 24 to open. All discharge pressure is exhausted to the atmosphere until the cause of the unstable surge condition is eliminated.

As noted hereinbefore, it may be desirable to operate the same compression plant at times on base mode, and at other times on intermittent mode. When operating on intermittent

mode, dump valve 24 will either be fully opened or fully closed. FIG. 2 shows the gas compressor of FIG. 1 operating on intermittent mode. Heretofore, as noted above, it has been quite difficult to change modes of operation. The invention herein disclosed readily permits the transfer of mode of operation from base to intermittent or from intermittent to base.

Referring to FIG. 2, wherein like numerals shall refer to like parts, selector switch 84 is still positioned for automatic operation. However, mode-of-operation switch 85 has now been placed on its intermittent mode position, thereby energizing valves 73 and 75, by the closing of switches 98 and 99. Switch 97 is opened when mode switch 85 is placed on intermittent position.

With valve 73 in its energized position, the full control signal from relay 60 is directed to pressure-operated switch 90 via conduit 93. In addition, valve 73 in its energized position communicates supply branch 92 with conduit 72; thus dump valve 24 will be receiving a control signal of a predetermined magnitude. In the preferred embodiment, the control signal is 32 p.s.i.g., this pressure being sufficient to fully close valve 24. As will become apparent, valve 24 will either receive the full 32 p.s.i.g., control signal, or will receive no signal and will then be in its fully open position.

As indicated above, valve 75 will also become energized when switch 85 is placed in intermittent mode position. With valve 75 positioned as shown, supply branch 96, having supply air at approximately 20 p.s.i.g., is delivered to bellows 64. The 20 p.s.i.g. air thus develops an operating point for relay 60. If discharge pressure falls below the predetermined point, the force developed by the supply air acting on bellows 64 and 62 will cause the beam 65 to rotate clockwise, opening valve element 69, permitting more control air to bleed from branch 68 to branch 91, thence to branch 93. Pressure switch 90 is designed to close upon an increase in pressure in the embodiment; the switch 90 will close at 22 p.s.i.g. When the switch 90 closes, valves 56 and 76 are energized.

Energization of valve 56 will allow the control signal from relay 44 to flow to the inlet valve positioner 57, thus moving valve 19 to an open position as determined by the conditions of the air.

Energization of valve 76 will allow the predetermined control signal of 32 p.s.i.g. to flow from supply branch 92, through conduit 72, to dump valve 24 thus closing the valve. However, since the signal is forced to flow through conduit 78 and needle valve 87, a time delay is established due to the restricted flow caused by the valve 87. The time delay, preferably of from 8 to 10 seconds, will prevent the valve 24 from closing too rapidly and causing the machine to surge.

Once the predetermined discharge pressure has been reached, the force acting on bellows 61 will cause valve 69 to close, thereby decreasing the pressure holding switch 90 closed. Switch 90 is designed to open when the pressure acting upon it falls to 18 p.s.i.g. Opening of switch 90 causes valves 56 and 76 to become deenergized, thereby exhausting the control signals to the inlet valve positioner 57 and the dump valve 24. As noted previously, the dump valve 24 opens immediately upon the exhausting of the control signal thereto. However, the inlet valve 19 will have a delayed closing of about 8 to 10 seconds due to the restriction caused by needle-valve 86 disposed in exhaust conduit 95. The delayed closing of the inlet valve insures that the compressor is unloaded before inlet air pressure is reduced, thus preventing the machine from surging. In the unloaded position, power input to the machine is about 25 percent of the input when operating during loaded conditions.

It is thus readily apparent, the novel control circuit is operable to modulate the dump valve during base mode operation and either operates to fully close or fully open the dump valve during intermittent mode operation. Additionally, the control circuit provides means operable to transfer the mode of operation from one mode to the other mode, without introducing the problems hereinbefore discussed.

While I have described and illustrated a preferred embodiment of my invention, it will be understood that the invention is not limited thereto but may be otherwise embodied within the scope of the following claims.

I claim:

1. A control system for regulating operation of a gas compression plant, selectively operable on either base mode or on intermittent mode, including a gas compressor, an inlet conduit, valve means governing flow of gas through the inlet conduit to the compressor, means for storage of gas delivered by the compressor, discharge means connecting the compressor and the storage means, and dump valve means for venting the discharge of the compressor to the atmosphere comprising:

A. switch means operable to transfer said gas compression plant from said base mode of operation to said intermittent mode of operation or from said intermittent mode of operation to said base mode of operation;

B. valve means operable in response to said switch means, having a first operating position and having a second operating position, said valve means being operable in said first position during said base mode of operation and being operable in said second position during said intermittent mode of operation;

C. means for sensing the pressure of the gas flowing through said discharge means and for sending a first signal related to said discharge pressure;

D. means for receiving a first signal of a predetermined magnitude and said signal relating to said discharge pressure and transmitting a resultant control signal; and

E. means responsive to said resultant signal for regulating the dump valve means governing the venting of gas to the atmosphere, said means acting to modulate said dump valve means during said base mode of operation and selectively acting to fully open or to fully close said dump valve means during said intermittent mode of operation, said switch responsive valve means being operable to direct said resultant signal through a first flow path during base mode of operation, and through a second flow path during intermittent mode of operation.

2. A control system in accordance with claim 1 wherein said resultant signal responsive means includes pressure-actuated switch means, only operable during the intermittent mode of operation.

3. A control system in accordance with claim 2 wherein valve means operable in response to said pressure-actuated switch means act to fully open or to fully close said dump valve means during intermittent mode of operation.

4. The method of regulating the operation of a gas compressor, selectively operable on either base mode or intermittent mode, having an inlet conduit through which gas to be compressed is supplied to the compressor, an inlet valve in the conduit controlling the flow of gas to the compressor, a discharge conduit connected to the outlet of the compressor,

dump valve means arranged adjacent said compressor outlet for selectively communicating the compressor outlet with the atmosphere to relieve pressure at the discharge side of said compressor, comprising the steps of:

5 A. selectively positioning switch means to transfer the mode of operation of gas compressor from base mode to intermittent mode or from intermittent mode to base mode;

B. operating valve means in response to said switch means, said valve means having a first position and having a second position, said valve means being operable in said first position, during said base mode of operation and being operable in said second position during said intermittent mode of operation;

C. continually sensing the pressure of the gas flowing through said discharge conduit; and

D. transmitting a signal related to said discharge pressure, operable to actuate said dump valve means, said switch responsive valve means being operable in said first position to direct said signal so said dump valve means is modulated during base mode of operation and said valve means being operable in said second position to direct said signal so said dump valve means is either fully open or fully closed during intermittent mode of operation.

5 A control system for regulating operation of a gas compression plant, selectively operable on either base mode or on intermittent mode, including a gas compressor, an inlet conduit, valve means governing flow of gas through the inlet conduit to the compressor, discharge means connected to the compressor and dump valve means for venting the discharge of the compressor to the atmosphere comprising:

A. switch means operable to transfer said compression plant from said base mode of operation to said intermittent mode of operation or from said intermittent mode of operation to said base mode of operation;

B. valve means operable in response to said switch means, having a first position and having a second position, said valve means being operable in said first position during said base mode of operation and being operable in said second position during said intermittent mode of operation;

C. means for sensing the pressure of the gas flowing through said discharge conduit; and

D. means for transmitting a signal related to said discharge pressure, said switch responsive valve means being operable in said first position to direct said signal so said dump valve means is modulated during base mode of operation and said valve means being operable in said second position to direct said signal so said dump valve means is either fully open or fully closed during intermittent mode of operation.

6. A control system in accordance with claim 5 wherein said transmitting means includes pressure-actuated switch means, only operable during the intermittent mode of operation.