ABSTRACT

A rotary air compressor driven by an electric motor and having a control system including a control circuit which enables the compressor to run in a modulated air flow mode of operation, shift automatically at a certain set process pressure to an unloading-reload mode of operation; and shift automatically when the compressor runs unloaded beyond a timed period to a condition in which the compressor is stopped but will automatically re-start operating when the process pressure falls below a certain low setting and the tank pressure drops to a safe starting value. Also disclosed is a dual control system designed to provide automatic transfer from the modulation mode to unloading operation.

5 Claims, 4 Drawing Figures
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ROTARY COMPRESSOR HAVING IMPROVED CONTROL SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to control systems for power driven air compressors; and its general objective is to provide an improved control system having desirable operating characteristics.

It is a further object to provide a control system which enables inlet air flow to be modulated in matching relation to demand flow; which automatically unloads the compressor when a predetermined maximum process pressure is reached and reloads it when the process pressure drops to a certain level; and which automatically stops operation of the compressor when the compressor runs unloaded beyond a set period of time, and automatically restarts its operation when the tank pressure has dropped to a certain safe pressure.

It is still another object to obtain the foregoing tri-mode operation of the compressor without damage to the compressor.

A particular advantage of the tri-mode operating characteristics of the compressor under the improved control system is a saving of power, as well as wear and tear of the components of the compressor.

A feature of the invention lies in the particular association of a control system, including a control circuit, with the components of a motor driven rotary air compressor.

A further feature of the invention lies in the nature of the control system whereby the compressor is enabled to pass automatically according to the demands of the compressor through stages of flow modulation, unloading and reloading, and start and stop operations.

Other features of the invention are various safety and warning controls which prevent undesirable oil flooding of the compressor, ensure adequate cooling and lubrication during start-up, signal normal operation, guard against damage because of overtemperature development, and stop operation entirely in the event of a power failure.

The foregoing, as well as other objects, features and advantages will become apparent from the detailed description which follows, and as it is read in conjunction with the accompanying drawing wherein an embodiment of the invention is illustrated. It is to be expressly understood, however, that the drawing is for purposes of illustration and description and is not to be construed as defining the limits of the invention.

BRIEF DESCRIPTION OF DRAWING

In the accompanying drawing:

FIG. 1 is a schematic showing of an air compressor system embodying the invention;
FIG. 2 is a diagram of the control circuit associated with the compressor system;
FIG. 3 is a control circuit for the dual-mode system; and
FIG. 4 is a graph for selection of the unload cutin point.

DESCRIPTION OF PREFERRED EMBODIMENT

In FIG. 1 of the drawing is disclosed an air compressor system which is controlled in its operation by the control circuit shown in FIG. 2. The circuit may be characterized as an automatic tri-mode control circuit in that the compressor is so controlled that, depending upon the attendant demands of an associated process system, it passes automatically in its operation, as needed, back and forth from a stage of continuous modulation mode of operation to an unload-reload mode, or from the latter to a start-stop mode.

The compressor system, generally designated 9, includes a rotary compressor 10, here of a screw type. It is driven by an electric motor 11, and is provided with a cooling fan motor 12. Air enters the compressor through a butterfly valve 13 in an inlet passage 14. During operation of the compressor, oil is caused to be injected into the compressor over an oil feed line 15 from an air pressurized oil sump 16. The oil serves to lubricate, seal and cool the compressor as the latter operates.

After leaving the compressor, the mixture of compressed air and oil passes through a check valve 17 in an outlet line 18 to a tank 19. The check valve prevents blow-back of air and oil from the tank to the compressor. In the tank, the oil is separated from the air-oil mixture by gravity and drops into the sump 16 below. A solenoid valve S2 in the oil feed line, normally closed when the compressor is stopped, is caused to open as the motor circuit is activated. When the compressor is stopped, the solenoid valve closes so as to prevent the compressor from being flooded with oil as would otherwise happen because of the pressurized condition of the tank.

The oil-free air flows, in order, from the tank through a venturi or sonic choke 21 and a final check valve 22 located in the tank line 23 to a process or high pressure air supply demand system at 24. The choke serves to restrict air flow from the tank so that during start-up of the compressor operation the tank pressure will build up quickly enough to timely force oil flow over the line 15 to the compressor. The final check valve 22 permits the compressor to be unloaded or operated at low tank pressure without bleeding off the high pressure air supply demand system 24 with which the tank is connected.

Control means is provided for automatically modulating inlet air flow to the compressor so as to match the demand flow while maintaining substantially constant pressure at the demand outlet. The control means includes a closed loop conduit 25. Conduit 25 connects at one end with the tank line 23 and connects at its opposite end both with the piston chamber of an actuator 26 for the inlet valve 13 and also with a restricted passage or return orifice 27. The orifice connects with the inlet passage 14 downstream of the inlet valve.

The actuator includes a piston 28 connected with the inlet valve. It is adapted when pressurized by air bled from the tank line over the loop 25 to move the inlet valve in a closing direction; and is adapted under force of a return spring 29 to return the valve in an opening direction as pressure over the piston is relaxed.

Interconnected in the loop is a controller or back pressure regulator valve 31. The latter is set to open in response to a predetermined pressure developing in the tank line to bleed pressure air from the tank to both the actuator and to the return orifice. The air volume bleeding through the regulator varies directly with the pressure developing in the tank line. The actuator responds to a predetermined pressure developing over its piston 28 to move the inlet valve in a closing direction and, as the pressure relaxes, the return spring moves...
the inlet valve in an opening direction. As the tank pressure varies above a predetermined value, the air bleeding through the regulator to the actuator and to the restricted orifice varies accordingly. This opening and closing action of the inlet valve serves to modulate the inlet air flow to the compressor.

It can be seen during operation of the compressor that, as the demand flow decreases, the tank line pressure will increase since more air is being pumped into the tank than is leaving. As this pressure rises above a certain value at which the regulator valve 31 has been set for response, the regulator valve opens and bleeds off pressure air from the tank to both the actuator and the return orifice. The bleed air passing through the orifice 27 is returned to the compressor. The bleed air to the actuator upon overcoming the force of the return spring 29 throttles the inlet valve to restrict inlet air flow. Throttling of the inlet valve continues until the inlet flow matches the demand flow. Conversely, as the demand flow increases and the tank pressure decreases, the bleed air through the regulator valve to the actuator and orifice decreases thus causing the inlet valve to move in an opening direction. This throttling continues until inlet and demand air flow match. Through this modulations of inlet flow, the air pressure at the demand outlet accordingly obtains a substantially constant value.

The control system is designed to enable the compressor to automatically begin an unloading operation when the pressure in the process line 24 obtains a certain set maximum, and to automatically reload and run in a modulated manner when the process pressure drops to a certain lower setting. To this end, the control system includes a differential pressure switch PS1 located in the process system beyond the final check valve 22. It also includes in the closed loop 25 a by-pass conduit 32 which by-passes the regulator valve 31 and is controlled by a normally closed unloading solenoid valve 33.

The pressure switch PS1 is adjustable in its settings to automatically effect a desired process upper pressure point at which the compressor will run unloaded, and a desired lower process pressure point at which the compressor will begin to reload to prevent dropping of the process pressure below a certain minimum. Opening of the by-pass valve 33 allows sufficient volume flow of tank pressure air to the actuator 26 to close the inlet valve. The maximum or upper setting at which the operator desires this to occur is determined by the corresponding percentage demand flow at which the operator desires the system to begin unloading. A bleed valve 33 to atmosphere located beyond the unloading valve 33 is adjustable to obtain pressure actuation of the actuator substantially at the time the process demand pressure reaches the maximum setting and the demand flow drops to a certain percentage. The bleed valve in effect serves to obtain a more accurate or precise control over the time of operation of the actuator. A suitable chart may be calculated for determining the desired upper and lower setting of the pressure switch PS1 to meet the demands of the process system. As an illustrated example, should it be desired that the process pressure not exceed 110 psi nor fall below 100 psi so as to obtain a desired percentage demand flow, the pressure switch will be set to an upper setting of 110 psi at which it is intended to unload. By calculation or from a previously calculated chart, it may be determined that the lower setting should be 105 psi as a point at which the compressor will timely reload so that the process pressure will not drop below 100 psi.

Unloading operations are desirable as they result in lower power consumption since the most economical manner of operation of the compressor is one in which the compressor runs unloaded as much as possible.

To obtain a further economy of operation, the control system is designed to provide for a third or a start-stop mode of operation. In this mode of operation, the compressor is caused to stop should it run unloaded beyond a set period of time. To this end, a timer TM, and a second pressure switch PS2 controlled by the timer, are incorporated in the control system. The pressure switch PS2 is located in the tank line 23. Switch PS2 is normally closed at tank pressure of 25 psi and lower. It opens in response to pressure above 25 psi.

In this third mode of operation, the compressor is caused to stop operation when it has run unloaded beyond a timed period and it is caused to automatically restart operation when the tank pressure has dropped to a predetermined safe low pressure, for example, 25 psi. The low restart pressure is desired to prevent oil flooding of the compressor as might occur if the compressor were allowed to restart at a higher tank pressure. Flooding of the compressor forces the latter to work harder and thus wastes power and increases wear upon the compressor components.

In summary of the operation of the compressor as controlled by its control system whereby the compressor is enabled to shift automatically from one mode of operation to another: First, the process pressure switch PS1 is set (as desired to suit the requirements of the process system) to, say an upper setting of 110 psi and a lower setting of 105 psi, the lower setting being calculated so that reloading will automatically occur before the process pressure drops to 100 psi. The off-on switch in the control circuit (FIG. 2) is then closed. (The door interlock switch is normally closed. It opens automatically as a safety feature when the circuit cover is removed.) The reset contacts are momentarily closed to energize relay R1 causing contacts R1b to close a holding circuit to relay R1 and causing contacts R1a to close.

Closing of contacts R1a establishes a starting circuit through the normally closed switch PS2. This circuit lights the normal indicator light A, actuates the hour meter HR which indicates the operating period, activates the normally open solenoid blow-off valve S1 to closed condition, opens contacts R1c to extinguish the red warning light R, and activates the coil of the magnetic starter MS so as to establish an energizing circuit to the cooling fan motor 12 and to the compressor motor 11, causing contacts MS2 to activate solenoid oil feed valve V2 to open condition, and causing contacts MS1 to close to maintain the circuit to the magnetic starter since PS2 will open as the tank pressure rises above 25 psi. The function of the solenoid valve S1, which has an open condition when the compressor has stopped, is to blow off or relieve the tank of excess pressure, as is conventional in air compressor systems.

As the compressor now operates, air pressure rapidly builds up in the tank because of the choke element 21 causing oil from the sump to be forced through the solenoid valve S2 to the compressor. The compressor commences operation, as explained earlier, in a contin-
uous modulation mode during which inlet flow is modulated to match the process demand flow.

Now, should the process demand flow fall below a predetermined percentage as to cause the process pressure to exceed the upper 110 psi setting, the normally open pressure switch PS1 will close to cause the normally closed unloading solenoid valve S3 in the by-pass line 32 to open. This enables back pressure air from the tank to cause the actuator piston 28 to close the inlet valve 13. As a result, the compressor then runs unloaded as long as the inlet valve is held closed.

While the compressor is running unloaded, bleed air is re-circulated over the return orifice 27 through the compressor. This is desired to avoid undesirable vibration and consequent damage that might otherwise occur in the compressor when the latter runs unloaded.

Closing of pressure switch PS1 also energizes relay R2 causing contacts R2 to open. This causes the solenoid blow-off valve S1 in the tank line to reopen and effect a progressive reduction of the tank pressure.

Closing of pressure switch PS1 also energizes the timer TM to commence operating.

Now, when the process pressure eventually drops to 105 psi, the pressure switch PS1 reopens. This action recloses contacts R2 to close the blow-off switch valve S1, stops the timer TM and recloses the unloading solenoid valve S3 in the by-pass line allowing the actuator spring 29 to return the inlet valve to open condition as tank pressure over the actuating piston is relaxed through the return orifice 27. The compressor now begins to reload and once more obtains a modulation mode of operation.

Now, if the compressor had run unloaded for a period beyond that for which the timer TM had been set, the normally closed timer contacts TM would have opened. Opening of the TM contacts breaks the circuit to the magnetic starter MS causing the motors 11 and 12 and the compressor to stop, reopens the solenoid blow-off valve S1, reopens the MS1 contacts and also reopens the MS2 contacts allowing the oil solenoid valve S2 to close and thereby prevent oil flooding of the compressor.

The control system is so designed that once the compressor has been stopped through the action of the timer, it will not restart until the tank pressure has dropped to a safe restart pressure, such as 25 psi, at which pressure the second pressure switch PS2 is designed to reclose. Accordingly, when the process pressure drops, while the compressor is stopped, to the lower 105 psi setting, the pressure switch PS1 reopens. This disconnects the timer causing the timer contacts TM to reclose, deactivates the unloading solenoid valve S3 to closed condition in the by-pass line, and deactivates relay R2 causing contacts R2 to reclose. Reclosing of the contacts R2 does not affect the open condition of the blow-off valve S1 since the MS1 and the PS2 contacts are still open. Accordingly, the compressor will remain stopped until the pressure switch PS2 is reclosed and the magnetic starter MS is reactivated.

When the tank pressure eventually drops to 25 psi through action of the open blow-off valve or demand flow, switch PS2 recloses. This reestablishes circuits to close the solenoid blow-off valve S1, relights the normal light A, reactivates the hour meter HR and reenergizes the magnetic starter to restart the compressor. The system once more runs in a modulated mode of matching inlet flow to demand flow.

The pressure switch PS2, which is closed at tank pressures of 25 psi and lower, reopens as tank pressure rises above the 25 psi setting.

A normally closed overtemperature switch T is located in the compressor outlet 18. It opens in response to a temperature rise above a certain degree to break the circuit to relay R1. This would open contacts R1a to deactivate the magnetic starter and consequently stop operation of the motors and the compressor. In effect, anything breaking the circuit to relay R1 will cause the compressor to stop operating.

It is apparent from an examination of the automatic tri-mode control system that the controls of the compressor system may, if desired, be limited to an automatic dual mode control system by eliminating the pressure of the element TM and the pressure switch PS2, as indicated by the circuit shown in FIG. 3. The dual mode control system provides means for automatically selecting either continuous modulation operation or unloading operation of the compressor. No manual switching operation is required for this action. The decision as to when to switch is left to the control system according to the initial settings made in the PS1 switch and the adjustments made in the bleed valve 33.

The automatic switching point at which the compressor system should change over from continuous modulation to unloading operation is preferably based upon minimizing the cost of operation. For a given size plant, it can be shown that the optimum switching point is a function of the volume of the air supply system (or, analogously, of the time constant of the system). The optimum switching points for plants according to their time constant may be calculated, and a workable chart or graph for easy switch point selection may be formed, as indicated in FIG. 4.

For example, reading from the graph, when the plant time constant is 5 seconds and the undershoot is given as 5 psi, the switch point for maximum economy of operation should be set at 50 per cent of maximum flow. This means that for maximum operating economy the compressor should operate in the continuous modulation mode for flow greater than 50 per cent of maximum flow. And, when the demand flow falls below 50 per cent of maximum flow, the compressor system should be switched to the unloading-reload mode where the power consumed by the compressor system is less than that during the continuous modulation mode.

Examination of the graph in FIG. 4 shows that there is a unique compressor flow for each system time constant above which continuous modulation of the inlet is optimum. It defines the set point for unloading the compressor for any plant time constant and allowable undershoot. It permits the compressor controls to be set to match any operator's requirement.

Now, as a further example, assuming that the requirements are that the process pressure not exceed 110 psi nor fall below 100 psi and that the compressor meet all flow demands from zero to 100 percent of the compressor capacity, should the time constant of the system, upon being measured, be found to be five seconds, and should the allowable undershoot for this time constant be selected at 7 psi, the system should be set to unload at 70 percent flow. Accordingly, the lower switch setting or reload signal should be set at 107 psi. This allows the pressure undershoot to be as large as 7 psi without falling below the lower allowable process pressure of 100 psi. It is to be noted that the flow in the lat-
ter instance at which the compressor is unloaded has moved up to 70 percent of full flow for a time constant of 5 seconds, and will provide a greater economy of operation than when the undershoot at the same time constant is chosen to be 5 psi, as earlier mentioned.

The pressure switch PS1 here has a differential between the upper and lower setting of between 3 and 25 psi. It is apparent from the examples presented that if the minimum pressure switch differential is used, the compressor will be unloaded over a larger flow range and this will assure minimum operating costs.

Now in making initial settings of the compressor system, after the pressure differential switch PS1 has been set to the determined upper and lower settings for a particular flow percentage, say 70 percent of full flow, then the control bleed valve 33 is opened and its area adjusted. The bleed valve is opened until the desired demand flow of 70 percent is obtained at the unload cut-in point of 110 psi.

The system is now set for automatic operation. The compressor will unload each time the process demand flow falls below 70 percent since the pressure switch PS1 will be triggered at the upper set point. Next, when the process pressure falls below 107 psi, the compressor will be commanded, all as earlier explained, to reload, which it does before the pressure can fall below 100 psi (i.e. with an undershoot of 7 psi).

The automatic tri-mode control system earlier described is merely a refinement of the dual mode control just explained, in that it adds the functions of the timer TM and the second pressure switch PS2 so as to cause automatic shut-down of the compressor (as earlier explained) when the compressor remains unloaded for periods longer than a characteristic time chosen by the operator. The compressor and motor are shut down completely and no power is used; and automatic restart occurs in the manner earlier described. Switching in the tri-mode system through the various modes of operation is completely automatic as determined by the initial settings made with respect to the differential pressure switch PS1, the timer TM, and the adjustments made to the bleed valve 33.

Selection of the mode of operation of the compressor system, whether it be simply a continuous modulation mode, the automatic dual mode, or the automatic tri-mode is at the option of the operator.

While an embodiment of the invention has been illustrated and described in detail, it is to be expressly understood that the invention is not limited thereto. Various changes of form, design or arrangement may be made in its parts without departing from the spirit and scope of the invention; and it is our intention, therefore, to claim the invention, not only as shown and described, but also in all such forms and modifications thereof as might be reasonably construed to be within the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. A compressor system including an electric motor driven rotary air compressor having an inlet and outlet passages, a receiver tank connected to the outlet passage having a discharge line, a demand process line connected to the discharge line, a check valve in the discharge line preventing backflow from the process line to the tank, a butterfly flow control inlet valve in the inlet passage, actuator means connected with the inlet valve responsive to a predetermined air pressure in the tank to throttle the butterfly valve to modulate air flow in the inlet passage to match demand process flow; sensing means responsive to a set maximum pressure developing in the process line beyond the check valve to close the butterfly valve to cause the compressor to run unloaded, and responsive to a set lower pressure developing in the process line beyond the check valve to reopen the inlet valve to cause the compressor to reload; means adjustable for determining the closing of the butterfly valve substantially at the time of development of the set maximum pressure; timing means responsive to said action of the sensing means in sensing the maximum pressure developing in the process line to de-energize the motor and cause the compressor to stop running in the event said lower pressure does not develop in a set period of time; and other sensing means responsive to the development of both said lower pressure in the process line and a set low pressure in the tank to reenergize the motor to restart operation of the compressor.

2. A compressor system comprising an electric motor driven rotary air compressor having an inlet and an outlet; a receiver connected to the outlet having a discharge line; a first check valve between the compressor and the receiver preventing flowback to the compressor, a demand process line connected to the discharge line; a second check valve in the discharge line preventing flowback from the process line to the receiver; a piston operable butterfly inlet valve in the inlet, the piston controlling movement of the inlet valve relative to open and closed positions; a spring constantly biasing the piston at one end to draw the inlet valve to open condition; a conduit connecting the opposite end of the piston with the receiver, the piston being responsive at its opposite end to variations of receiver air pressure in excess of the spring bias to move the inlet valve in a closing direction; a pressure regulator in the conduit controlling application of receiver air pressure to the piston below a predetermined value to effect a modulation mode of operation of the inlet valve; a normally closed by-pass line connected between the piston and the receiver by-passing the pressure regulator; first pressure sensing means responsive to a predetermined maximum rise in pressure in the process line beyond the second check valve to open the by-pass line, the piston being responsive to receiver pressure caused to flow through the by-pass line to move the inlet valve to closed position to effect an unloaded mode of operation of the compressor; bleeder valve control means connected in the conduit between the by-pass line and the said opposite end of the piston subject to adjustment for predetermining the moment of operation of the piston substantially at the time of maximum rise in pressure; the said pressure sensing means being responsive to a predetermined drop in pressure in the process line to effect closing of the by-pass line and restoration of the compressor to a modulation mode of operation; and timing means initially actuable in response to said operation of the first pressure sensing means in response to the maximum rise in pressure in the process line, and subsequently responsive to a failure of the said first pressure sensing means to sense said predetermined pressure drop within a set period of time to effect opening of the circuit to the electric motor.

3. A compressor system as in claim 2, including an oil sump continuously subject to pressure of the receiver having an oil feed line connection with the compressor,
A normally closed oil feed valve in the feed line blocking pressurized flow of oil from the sump to the compressor, a restriction in the discharge line before the second check valve allowing rapid build-up of receiver pressure following closing of a circuit to the motor at start-up, and means for effecting opening of the oil feed valve at the time the circuit to the motor is closed.

4. A compressor system as in claim 3, wherein means is provided for causing closing of the oil feed valve upon opening the circuit to the motor.

5. A compressor system as in claim 4, including a second pressure sensing means responsive to a predetermined low pressure drop of receiver pressure to condition an energizing circuit to restart the motor; and means for completing the latter circuit in response to the first pressure sensing means sensing a predetermined pressure drop in the process line.

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