

SPECIFICATION

Compressor surge control

5 DESCRIPTION

The invention relates to control systems for gas compressors for the avoidance of surge conditions, that is to say for regulating the ratio of outlet to inlet pressure to prevent surge.

Gas compressor systems which supply, for example, air pressure to pneumatic loads are subject to an undesirable condition commonly referred to as surge. Although the reason for surge is not fully understood, its effect is extremely detrimental. For example, when a surge condition occurs in the compressor system, the airflow may suddenly reverse, cease or be interrupted. If the surge condition continues, the compressor can enter a deep surge condition causing damage to its internal components.

The invention provides a surge control system for a gas compressor comprising means for providing a signal proportional to the absolute value of the rate of change of the pressure at the outlet of the compressor; means for generating a vent valve command signal if the signal proportional to the rate of change varies from a selected reference rate of change; and a vent valve responsive to the vent valve command signal for venting a portion of the gas at the outlet.

The invention includes a method of preventing surge in a gas compressor comprising measuring the outlet pressure; providing a signal proportional to the absolute rate of change of the outlet pressure; and venting a portion of the outlet gas if the signal proportional to the absolute value of the rate of change of the outlet pressure exceeds a selected value.

The rate of change of the outlet pressure beyond a particular value is indicative of an ensuing surge condition. The outlet pressure is measured according to the invention and differentiated and a signal representing the absolute value of the differentiated signal is provided to a transfer function which provides a vent valve command signal. The vent valve command signal controls a valve which vents a portion of the air supplied to the load. If the absolute value of the rate of change of the outlet pressure increased beyond the particular value, a vent valve is opened to reduce the outlet pressure, thereby preventing a surge condition from occurring. As the absolute value of the rate of change of the outlet pressure decreases to a level lower than the preset level, the valve is closed.

DRAWINGS

Figure 1 is a block diagram of the surge control system of the present invention;

Figure 2 depicts the characteristics of the transfer function shown in Fig. 1;

Figure 3 depicts the characteristics of the valve opening circuit of Fig. 1; and

Figure 4 depicts the characteristics of the valve closing circuit of Fig. 1.

The outlet pressure of a compressor oscillates at an increased amplitude as the pressure ratio of the outlet pressure of the compressor increases for a given weight flow rate, W . Increased oscillations of the outlet pressure are a precursor to the undesirable surge condition and are utilized herein to provide a vent valve command signal which controls the position of a venting valve. The venting valve vents a portion of the air provided to a pneumatic load to reduce the pressure ratio, thus avoiding an ensuing surge condition. The vent valve command signal causes the valve to close when the oscillations have returned to an acceptable level.

Referring to Fig. 1, a surge control system for a fixed or variable speed, fixed or variable geometry compressor 10 is shown. The compressor shown in Fig. 1 is an axial compressor, although the present invention is capable of providing surge control for any type of compressor having surge maps similar to those shown in the two applications of Timothy F. Glennon et al, both entitled "COMPRESSOR SURGE CONTROL," filed contemporaneously herewith and assigned to the assignee of the present invention.

The compressor 10 has an air-receiving inlet 12 and an outlet 14 which supplies compressed air to a pneumatic load 16 by a pneumatic conduit 18 coupled between load 16 and outlet 14. A venting conduit 20 is coupled in parallel with load 16. The position of a dump valve 22 determines the amount of air vented from a vent 24.

A pressure transducer 26 provides a signal proportional to the outlet pressure P_{out} and may be of any suitable type well known to those in the art. The signal proportional to P_{out} is applied to a band pass filter 28 to remove noise and undesirable signal frequencies. The signal from the band pass filter 28 is applied to the $\frac{dP_{out}}{dt}$ circuit 30. Circuit 30 differentiates P_{out} with respect to time and then provides the absolute value of the $\frac{dP_{out}}{dt}$. The output from circuit 30 is a voltage which represents the absolute value of the rate of change of the output pressure P_{out} with respect to time.

During steady state operation, when the compressor is operating on the normal operating line of the surge compressor map, $\frac{dP_{out}}{dt}$ oscillates at a measurable value hereinafter referred to as $\frac{dP_{out}}{dt} ref$. When $\frac{dP_{out}}{dt}$ is greater than $\frac{dP_{out}}{dt} ref$, a surge condition can be anticipated. When $\frac{dP_{out}}{dt}$ is less than $\frac{dP_{out}}{dt} ref$, the compressor is operating in the normal operating region, below the normal operating line on the surge map.

The signal from circuit 30 is applied to a transfer function 32, the characteristics of which are best seen in Fig. 2. The output of the transfer function is a voltage having a magnitude which is a function of $\frac{dP_{out}}{dt}$. Specifically, the output of transfer function circuit 32 is zero for a $\frac{dP_{out}}{dt}$ voltage about $\frac{dP_{out}}{dt} ref$ between point A and point B. The output from the transfer function becomes more positive as $\frac{dP_{out}}{dt}$ increases above point B until it reaches a maximum of $+V$ volts. Similarly, the output of the transfer function circuit 32 decreases from $\frac{dP_{out}}{dt} ref$ in an amount proportional to the decrease in $\frac{dP_{out}}{dt}$ until a minimum of $-V$ volts is reached. Providing zero

volts from transfer function 32 between points A and B, about $\frac{dP_{out}}{dt}$ ref, prevents oscillations in the surge control valve, as will become apparent.

The signal from transfer function 32 is applied to a valve opening circuit 34. Valve opening circuit 34 is responsive to a voltage of one polarity, as a positive voltage, from transfer function 32, and has an output characteristic as shown in Fig. 3. Specifically, as the value of $\frac{dP_{out}}{dt}$ increases beyond point B, the output of the valve opening circuit 34 increases in an amount proportional to the increase. The gain of the valve opening circuit 34, as indicated by a slope 36, is selected to be high to rapidly open valve 22, as will be discussed below.

The signal from transfer function 32 is also applied to valve closing circuit 38. The valve closing circuit 38 has an output characteristic as shown in Fig. 4. Specifically, as the value of $\frac{dP_{out}}{dt}$ decreases beyond point A, the output of valve closing circuit 38 decreases in an amount proportional thereto. The gain of the valve closing circuit 38, as indicated by a slope 40, is selected less than that of valve opening circuit 34 to slowly close valve 22, as will be discussed below.

The outputs from valve opening circuit 34 and valve closing circuit 38 are applied to a summer 42. If $\frac{dP_{out}}{dt}$ is less than $\frac{dP_{out}}{dt}$ ref, the output from summer 42 will be zero, or negative. If $\frac{dP_{out}}{dt}$ is greater than the value of $\frac{dP_{out}}{dt}$ at point B in Fig. 2, the output for summer 42 will be positive. The output from summer 42 is hereinafter referred to as the vent valve command signal and controls the position of valve 22.

The vent valve command signal is applied to clamped integrator 44. The output of clamped integrator 44 is a zero or non-zero value K when the vent valve command signal is zero. If $\frac{dP_{out}}{dt}$ increases past point B, the vent valve command signal becomes positive, causing the output of clamped integrator 44 to increase, following slope 36 (Fig. 3). This causes valve 22 to open. As more air is vented from vent 24, P_r becomes less and $\frac{dP_{out}}{dt}$ decreases. When $\frac{dP_{out}}{dt}$ decreases to a point less than point A, the vent valve command signal becomes negative, causing the output of clamped integrator 44 to return to zero or to K, following slope 40 (Fig. 4).

The output of clamped integrator 44 is applied to an amplifier 46 which tailors the steady state and transient response of the system.

The output of amplifier 46 is applied to a summer 48. The position of valve 22 is controlled by a valve position control circuit 50 in response to the magnitude of the signal applied to summer 48. An increase in voltage from summer 48 causes valve 22 to open farther, and a decrease causes valve 22 to close. A valve position demodulator 52 provides negative feedback to summer 48 to assure that the valve position with respect to the valve command control signal is maintained. An amplifier 54 is coupled between summer 48 and valve position control circuit 50, and its gain is selected in accordance with the operating parameters of the system.

CLAIMS

1. A surge control system for a gas compressor comprising means for providing a signal proportional to the absolute value of the rate of change of the air pressure at the outlet of the compressor; means for generating a vent valve command signal if the signal proportional to the rate of change varies from a selected reference rate of change; and a vent valve responsive to the vent valve command signal for venting a portion of the gas at the outlet.

2. A surge, control system according to claim 1 comprising: means for sensing pressure at the outlet of the compressor; means for generating a signal proportional to the absolute value of the rate of change of this pressure; means for generating a first control signal if the signal proportional to the absolute value is greater than a first selected amount; means for generating a second control signal if the signal proportional to the absolute value is less than a second selected amount; and a valve for venting a portion of the gas at the outlet responsive to the first and the second control signals.

3. A surge control system according to claim 2 including means for summing the first control signal with the second control signal; and means coupled to the summing means for generating a valve open signal when the first control signal is received from the summer, and for generating a valve closed signal when the second control signal is received from the summer.

4. A surge control system according to claim 3 wherein the means for generating a valve open command signal and a valve closed command signal is a clamped integrator circuit for providing a voltage of a selected polarity.

5. A surge control system according to claim 2 wherein the means for generating a first control signal has a higher gain than the means for generating a second control signal.

6. A surge control system according to claim 2 wherein the first selected value is of greater magnitude than the second selected value.

7. A surge control system according to any preceding claim comprising a sensor coupled to the output of the compressor for sensing the outlet pressure; a circuit for providing a signal proportional to the absolute value of the first derivative of the outlet pressure; a transfer function for generating a first voltage if the signal is greater than a first selected value and for generating a second voltage if said signal is less than a second selected value; a first amplifier having a gain of a first voltage coupled to said transfer function for multiplying the first voltage; a second amplifier having a gain of a second voltage coupled to the transfer function for multiplying said second voltage by a constant; means coupled to the first and second amplifiers for summing the signals from the amplifiers to provide a vent valve command signal; a clamped integrator responsive to the summer output for providing an output voltage; and a valve coupled between the output of the compressor and the load for venting air in an amount proportional to the output voltage.



volts from transfer function 32 between points A and B, about $\frac{dP_{out}}{dt}$ ref, prevents oscillations in the surge control valve, as will become apparent.

The signal from transfer function 32 is applied to a valve opening circuit 34. Valve opening circuit 34 is responsive to a voltage of one polarity, as a positive voltage, from transfer function 32, and has an output characteristic as shown in Fig. 3. Specifically, as the value of $\frac{dP_{out}}{dt}$ increases beyond point B, the output of the valve opening circuit 34 increases in an amount proportional to the increase. The gain of the valve open circuit 34, as indicated by a slope 36, is selected to be high to rapidly open valve 22, as will be discussed below.

The signal from transfer function 32 is also applied to valve closing circuit 38. The valve closing circuit 38 has an output characteristic as shown in Fig. 4. Specifically, as the value of $\frac{dP_{out}}{dt}$ decreases beyond point A, the output of valve closing circuit 38 decreases in an amount proportional thereto. The gain of the valve closing circuit 38, as indicated by a slope 40, is selected less than that of valve opening circuit 34 to slowly close valve 22, as will be discussed below.

The outputs from valve opening circuit 34 and valve closing circuit 38 are applied to a summer 42. If $\frac{dP_{out}}{dt}$ is less than $\frac{dP_{out}}{dt}$ ref, the output from summer 42 will be zero, or negative. If $\frac{dP_{out}}{dt}$ is greater than the value of $\frac{dP_{out}}{dt}$ at point B in Fig. 2, the output for summer 42 will be positive. The output from summer 42 is hereinafter referred to as the vent valve command signal and controls the position of valve 22.

The vent valve command signal is applied to clamped integrator 44. The output of clamped integrator 44 is a zero or non-zero value K when the vent valve command signal is zero. If $\frac{dP_{out}}{dt}$ increases past point B, the vent valve command signal becomes positive, causing the output of clamped integrator 44 to increase, following slope 36 (Fig. 3). This causes valve 22 to open. As more air is vented from vent 24, P_r becomes less and $\frac{dP_{out}}{dt}$ decreases. When $\frac{dP_{out}}{dt}$ decreases to a point less than point A, the vent valve command signal becomes negative, causing the output of clamped integrator 44 to return to zero or to K, following slope 40 (Fig. 4).

The output of clamped integrator 44 is applied to an amplifier 46 which tailors the steady state and transient response of the system.

The output of amplifier 46 is applied to a summer 48. The position of valve 22 is controlled by a valve position control circuit 50 in response to the magnitude of the signal applied to summer 48. An increase in voltage from summer 48 causes valve 22 to open farther, and a decrease causes valve 22 to close. A valve position demodulator 52 provides negative feedback to summer 48 to assure that the valve position with respect to the valve command control signal is maintained. An amplifier 54 is coupled between summer 48 and valve position control circuit 50, and its gain is selected in accordance with the operating parameters of the system.

CLAIMS

1. A surge control system for a gas compressor comprising means for providing a signal proportional to the absolute value of the rate of change of the air pressure at the outlet of the compressor; means for generating a vent valve command signal if the signal proportional to the rate of change varies from a selected reference rate of change; and a vent valve responsive to the vent valve command signal for venting a portion of the gas at the outlet.

2. A surge control system according to claim 1 comprising: means for sensing pressure at the outlet of the compressor; means for generating a signal proportional to the absolute value of the rate of change of this pressure; means for generating a first control signal if the signal proportional to the absolute value is greater than a first selected amount; means for generating a second control signal if the signal proportional to the absolute value is less than a second selected amount; and a valve for venting a portion of the gas at the outlet responsive to the first and the second control signals.

3. A surge control system according to claim 2 including means for summing the first control signal with the second control signal; and means coupled to the summing means for generating a valve open signal when the first control signal is received from the summer, and for generating a valve closed signal when the second control signal is received from the summer.

4. A surge control system according to claim 3 wherein the means for generating a valve open command signal and a valve closed command signal is a clamped integrator circuit for providing a voltage of a selected polarity.

5. A surge control system according to claim 2 wherein the means for generating a first control signal has a higher gain than the means for generating a second control signal.

6. A surge control system according to claim 2 wherein the first selected value is of greater magnitude than the second selected value.

7. A surge control system according to any preceding claim comprising a sensor coupled to the output of the compressor for sensing the outlet pressure; a circuit for providing a signal proportional to the absolute value of the first derivative of the outlet pressure; a transfer function for generating a first voltage if the signal is greater than a first selected value and for generating a second voltage if said signal is less than a second selected value; a first amplifier having a gain of a first voltage coupled to said transfer function for multiplying the first voltage; a second amplifier having a gain of a second voltage coupled to the transfer function for multiplying said second voltage by a constant; means coupled to the first and second amplifiers for summing the signals from the amplifiers to provide a vent valve command signal; a clamped integrator responsive to the summer output for providing an output voltage; and a valve coupled between the output of the compressor and the load for venting air in an amount proportional to the output voltage.



8. A method of preventing surge in a gas compressor comprising measuring the outlet pressure; providing a signal proportional to the absolute rate of change of the outlet pressure; and venting a portion of the outlet gas if the signal proportional to the absolute value of the rate of change of the outlet pressure exceeds a selected value.
9. A method according to claim 8 including ceasing the venting if the signal proportional to the absolute value becomes less than the predetermined value.
10. A method according to claim 8 including controlling the venting of the portion of the outlet gas in an amount proportional to the signal proportional to the absolute value when the rate of change of the outlet pressure exceeds the predetermined value.
11. A surge control system as herein described with reference to the drawings.
12. A method of preventing surge as herein described.