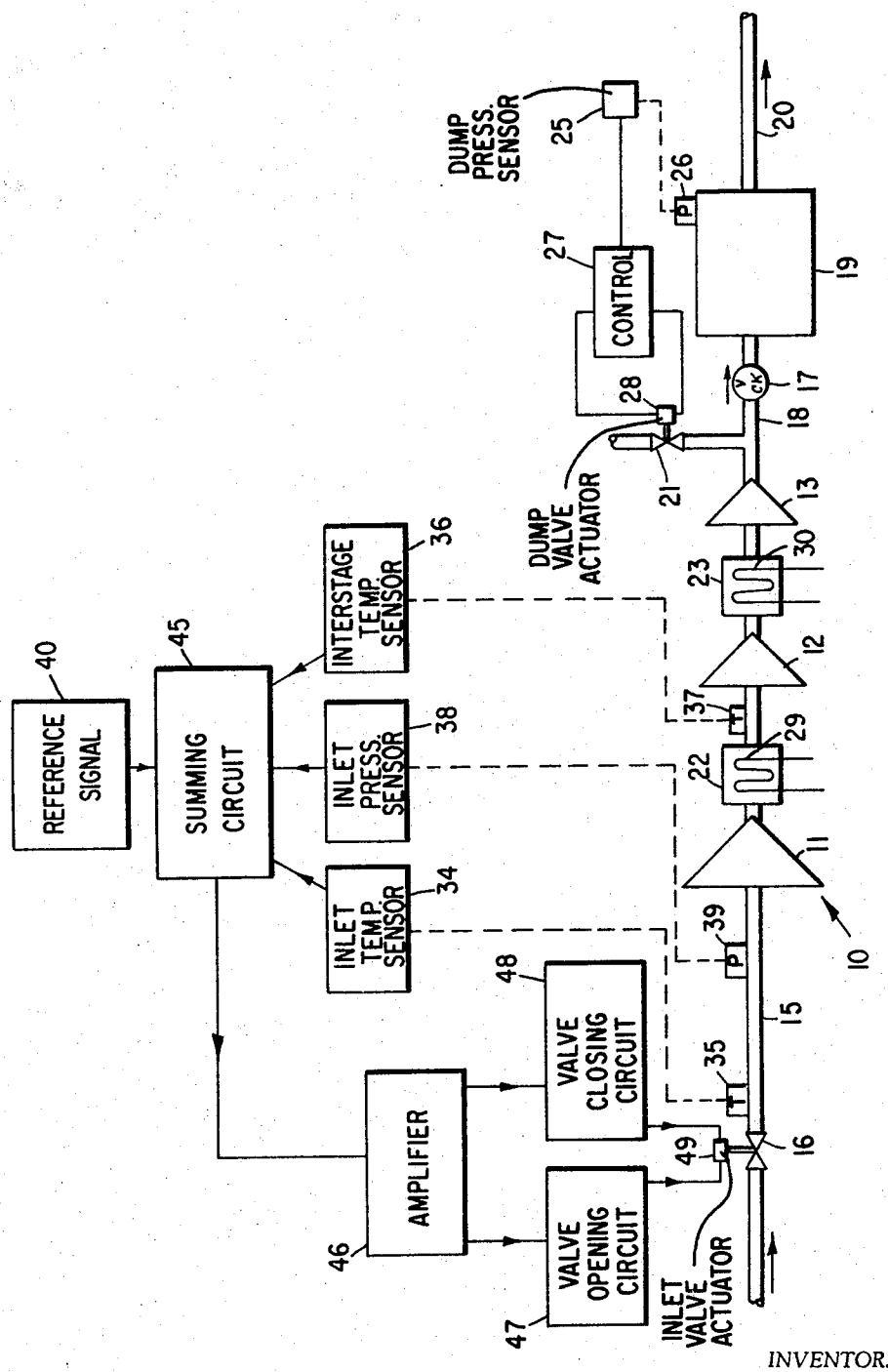
April 29, 1969 E. L. HUESGEN 3,441,200

GAS COMPRESSION SYSTEM HAVING INLET GAS CONTROL

Filed March 13, 1967



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United States Patent Office

3,441,200
Patented Apr. 29, 1969

3,441,200

GAS COMPRESSION SYSTEM HAVING INLET GAS CONTROL

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Filed Mar. 13, 1967, Ser. No. 622,513
Int. Cl. F04b 49/00
U.S. Cl. 230—5 5 Claims

ABSTRACT OF THE DISCLOSURE

A gas compression system for supplying compressed air at a uniform pressure which employs a multistage compressor. A main control is provided to maintain the discharge pressure constant. The temperature and pressure of gas admitted to the first stage of the compressor and the temperature of gas admitted to the second stage of the compressor are sensed and functions thereof are summed to provide a control signal. An inlet gas throttling valve is modulated in response to the control signal to reduce overloading of the compressor and/or to keep the compressor from surging by varying the inlet air pressure.

BACKGROUND OF THE INVENTION

This invention relates to gas compression systems and more particularly to gas compression systems of the type employing a multistage axial or centrifugal compressor driven by a prime mover. A main control system may be provided which senses the discharge gas pressure and controls various system functions such as a discharge valve so as to maintain the discharge pressure of the system constant.

Two problems, however, are often experienced in attempting to maintain high operating efficiency with such systems, due to changing air temperatures and pressures. First, decreases in ambient air temperature or increases in ambient air pressure may increase the flow of air through the compressor, which tends to overload the prime mover employed to drive the gas compressor. The overloading of the prime mover may result in injury or destruction of it, and attempting to avoid an overload at all conditions at which may be encountered tends to establish an artificial limit on the range of conditions of operation of the gas compression system which results in reduced efficiency. Second, reductions in density of the ambient air admitted to the compressor, such as may occur with increasing ambient air temperature, may result in a reduction in mass flow through the compressor to the point that surge is encountered. Surge is a highly undesirable, unstable condition of the compressor which results in a loss of capacity and may cause serious damage to the compressor.

It has been proposed to employ a throttling valve in the line supplying inlet air to the compressor and to modulate the throttling valve in accordance with the density of the inlet air. This type of control provides greatly improved operation of the gas compression system over a range of inlet air conditions. However, such a control still does not provide optimum efficiency of operation because the operating characteristics of the system must be a compromise which is selected so that neither surge nor

prime mover overload occurs at any anticipated condition. Furthermore, where an interstage gas cooler is employed in the operation of the system, this type of control must normally operate sufficiently away from the overload and surge regions so that changes in cooling fluid flow rate or temperature as well as variations in latent heat of the gas do not result in overloads or surging. Consequently, the optimum compressor operating efficiency and pressure lift cannot always be safely achieved due to the required compromise in operating characteristics.

SUMMARY OF THE INVENTION

In accordance with a preferred embodiment of this invention, a gas compression system is provided which employs a multistage air compressor having a suitable main control system to maintain a uniform discharge pressure. An inlet air throttling valve controls the pressure of air admitted to the first stage of the compressor. The temperature and pressure of inlet air as well as the interstage air temperature are sensed and compared against a reference signal to provide a control signal for varying the inlet air pressure by modulating the inlet throttling valve.

A control system in accordance with this invention provides improved operating efficiency and capacity, while at the same time it reduces the occurrences of overloads on the prime mover and surging of the compressor by taking into account the interstage gas temperature in controlling the operation of the system. Consequently, by employing the type of control system described herein, a gas compression system can be operated at more nearly optimum conditions over a wide range of ambient inlet air and interstage cooling conditions than previous systems.

BRIEF DESCRIPTION OF THE DRAWING

The figure schematically illustrates a gas compression system having a control system in accordance with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention will be described with respect to a preferred embodiment thereof wherein the gas compression system is employed to supply compressed air to desired locations for operations of pneumatic equipment.

Referring particularly to FIGURE 1 there is shown a gas compression system embodying a multisage centrifugal or axial compressor **10** having a first stage **11** in series with a second stage **12** and a third stage **13**. Inlet gas line **15** is provided to admit ambient inlet air through a throttling valve **16** to first stage **11** of compressor **10**. Interstage gas coolers **22** and **23** having suitable cooling medium heat exchange passages **29**, **30** therein are provided to cool gas passing between the stages of compressor **10**.

Compressed air is discharged from compressor **10** through a check valve **17** in gas discharge gas line **18** into receiver **19**. A suitable compressed gas discharge line **20** distributes air from receiver **19** to the desired locations at which it is employed.

In order to maintain the pressure of discharge air in receiver **19** in line **20** relatively constant at a predetermined pressure, a dump valve **21** is employed to dis-

charge compressed air from compressor **10** when the pressure demands of receiver **19** are satisfied. Dump valve **21** may be operated either as a fully opened or fully closed valve or it may be modulated according to the desired characteristics of the gas compression system.

A main control system is provided to control the operation of dump valve **21**. The main control system employs a discharge pressure sensor **25** at a suitable location **26** in line **18** or receiver **19**. A main control system **27** is actuated in response to a pressure signal generated by discharge pressure sensor **25** and sense a valve opening or closing signal to valve actuator **28**. Control system **27** maintains the discharge pressure at substantially predetermined value irrespective of the load imposed on the gas compression system.

In accordance with this invention, an additional control system is provided for controlling the inlet air pressure to first stage **11** of compressor **10** by modulating inlet gas valve **16** in accordance with the condition of operation of the system.

For this purpose, an inlet air temperature sensor **34** is provided at a suitable location **35** between inlet valve **16** and first stage **11** for sensing the temperature of air admitted to the first stage of the compressor.

An interstage temperature sensor **36** is also provided at a suitable location **37** between first stage **11** and second stage **12**. Interstage temperature sensor **36** is located to sense interstage gas temperature between the inlet of scond stage **12** and the outlet of interstage gas cooler **22**. Consequently, interstage temperature sensor **36** is able to compensate for variations in the flow rate and temperature of the cooling medium in the interstage cooler, as well as for unknown factors like scaling of the heat exchanger which may effect the actual interstage gas temperature.

An inlet air pressure sensor **38** is provided at a suitable location **39** between inlet gas valve **16** and first stage **11** for sensing the pressure of the air admitted to compressor **10**.

Inlet air temperature sensor **34** generates an inlet air temperature signal which is a known function of the inlet air temperature. For this purpose, sensor **34** may comprise a temperature responsive resistance element such as a thermistor. Because the actual characteristic of the desired inlet air temperature functions may not be linear or because the sensor may be nonlinear over the desired range of operating temperatures, a preferred embodiment of this invention employs a pair of thermistors in a suitable resistance network to provide a desired continuous, nonlinear temperature function signal. Interstage temperature sensor **36** may also comprise a thermistor in a resistance network which generates the desired interstage temperature function signal. Inlet pressure sensor **38** may comprise a pressure transducer in the form of a potentiometer having a wiping element movable in response to pressure variations and having the desired resistance characteristic to generate the required pressure function signal by dividing current flow in a differential amplifier.

A reference signal generator **40**, which may also comprise a potentiometer for dividing current flow in a differential amplifier, is employed to generate a reference signal corresponding to a predetermined desired condition of operation of the gas compression system, whereby the load on the compressor prime mover will not be excessive and the compressor will not be subject to surge.

The inlet temperature function signal, the interstage temperature function signal, the inlet pressure function signal and the reference signal are all summed in a summing circuit **45** to provide a control signal. The summing circuit serves to compare the sensed function signals with the reference signal to provide a difference or error control signal which indicates the need for adjustment of the inlet air pressure condition to maintain the desired condition of operation determined by the reference signal.

The control signal is passed to amplifier **46** which provides either an inlet valve opening signal or an inlet valve closing signal depending on the direction of error indicated by the control signal. The valve opening signal is passed, when present, to a valve opening circuit **47**, which in turn causes valve actuator **49** to open inlet gas valve **16**, thereby increasing the absolute pressure of air admitted to first stage **11** of compressor **10**. The valve closing signal, when present, is passed to valve closing circuit **48** which in turn causes valve actuator **49** to close inlet gas valve **16** thereby reducing the absolute pressure of air supplied to first stage **11** of compressor **10**.

In the preferred embodiment of the invention, amplifier **46** may comprise a differential amplifier and summing circuit **45** may comprise a terminal or other network arrangement for summing current signals generated by sensors **34**, **36** and **38** and reference signal generator **40**. Thus, the summation of the net current injected into the differential amplifier circuit from the current reference and the sensors has a magnitude and a direction which unbalances the differential amplifier in a direction to provide a suitable inlet valve opening signal or closing signal, depending on the direction of the unbalance.

In the preferred embodiment of this invention, the output from differential amplifier **46** is a voltage signal from one or the other of a pair of transistors depending on the direction of the unbalance indicated by the control signal. The voltage output from one of the transistors is employed to switch a Triac or other switching device to its conducting state in the valve opening circuit and the voltage output from the other transistor is employed to switch a Triac to its conducting state in the valve closing state. The Triacs in turn control the passage of current through the windings of a motor which rotates to open or close the inlet gas valve in a direction to reduce the unbalance in the differential amplifier by changing the sensed inlet air pressure.

In operation, compressor **10** is driven by a suitable prime mover (not shown) such as an electric motor. Compressed air is discharged from the compressor into receiver **19** until discharge pressure sensor **25** indicates that the set point pressure has been reached. When the set point pressure is reached, control **27** causes dump valve actuator **28** to move toward an open position thereby preventing passage of excess air into receiver **19** until the pressure in the receiver is reduced below the set point pressure of the main control.

Inlet gas temperature sensor **34** and interstage gas temperature sensor **35** sense the temperature of the gas admitted to the first and second stages respectively of compressor **10** and provide suitable temperature function current signals to summing circuit **45**. Likewise, inlet pressure sensor **35** provides a pressure function current signal to summing circuit **45** as does reference signal generator **40**. If the sum of the currents generated by the sensors is substantially equal to that generated by reference signal generator **40**, no control signal will be supplied to amplifier **46**. Preferably, a dead band is provided which will span a sufficient range of control signal magnitude to prevent hunting in the control characteristic. If, however, the deviation of the summed sensed function signals from the reference signal is greater than the predetermined dead band, a control signal will be passed to amplifier **46** having a direction and magnitude corresponding to the necessary change in inlet pressure that is required to again balance the operation of the system. From amplifier **46**, the valve opening or closing signal required for rebalancing the system will be passed to the appropriate valve opening or closing circuit to move the inlet valve actuator **49** in the proper direction to reduce the deviation from the desired operating condition.

For example, if for some reason, the interstage temperature should suddenly rise as might happen if the interstage cooling water temperature rose or its flow rate decreased, an unbalance between the reference signal and

the sensed function signals would be reflected in a control signal from summing circuit **45** causing a valve opening signal to be passed to valve actuator **49** thereby preventing the compressor from surging by increasing the inlet pressure to first stage **11** and thus decrease the overall compressor pressure ratio. If the temperature of the inlet air to first stage **11** rises, as for example due to increase in ambient temperature, or if the inlet pressure should drop, the summing circuit will provide a control signal to amplifier **46** to unbalance it in a direction to open inlet gas valve **16** thereby reducing the pressure lift across compressor **10** and preventing a surge condition from occurring. Similarly, if the interstage temperature or inlet temperature drop, or the inlet pressure rises, differential amplifier **46** will provide a valve closing signal to actuator **49** to prevent overloading of the prime mover by reducing the mass flow through the compressor.

In accordance with this invention, there is provided a gas compression sytem having a control over inlet air admitted to the compressor which serves to compensate for both variations in inlet air temperature and pressure and also for variations in interstage conditions. The point of maximum prime mover load can be closely approached without damage of an accidental overload due to changing gas conditions at any point in the system. Likewise, the so-called "surge line" of the gas compression system may be closely approached without causing the compressor to go into a surge condition due to unexpected changes in ambient or interstage gas conditions. Therefore, the gas compression system of this invention can be operated at optimum conditions over a wider range of gas conditions than could be tolerated by prior systems. Consequently, a gas compression system embodying this invention can be operated at high capacity and with great operating efficiency.

While the invention has been described with reference to a preferred embodiment thereof wherein the gas compression system supplies compressed air, it will be understood that the principles of this invention are applicable to other systems embodying other gases and for other purposes, if desired.

I claim:

1. A gas compression system including a multistage gas compressor having a first gas compression stage and at least one following gas compression stage connected in series relation with said first stage, a prime mover connected to drive said compressor, an inlet passage for admitting inlet gas to the first stage of said gas compressor, a throttling valve for controlling flow of inlet gas to said first stage of said compressor, an outlet passage for discharging compressed discharge gas from said system, and a main control system for sensing discharge gas pressure and adjusting the conditions of operation of said system in accordance with the sensed discharge gas pressure to maintain a substantially predetermined discharge gas pressure, wherein the improvement comprises the combination of:

(a) inlet gas temperature sensing means disposed for sensing the temperature of inlet gas admitted to the first stage of said compressor, and for providing an inlet gas temperature signal functionally related thereto;

(b) interstage gas temperature sensing means for sensing the temperature of gas admitted to a following stage of said compressor, and for providing an interstage gas temperature signal functionally related thereto;

(c) inlet gas pressure sensing means disposed for sensing the pressure of inlet gas admitted to the first stage of said compressor, and for providing an inlet gas pressure signal functionally related thereto;

(d) means for summing said inlet and interstage temperature signals and said pressure signal to provide a summed function signal which is functionally related to each of the combined sensed conditions of operation of said gas compressor;

(e) reference signal means for providing a reference signal functionally related to a predetermined combination of each of said sensed conditions which results in a desired condition of operation of said gas compressor;

(f) means for detecting deviation of said summed function signal from said reference signal and for providing a control signal which is a function of said deviation; and

(g) means for adjusting said throttling valve in response to said control signal to reduce said deviation by varying the inlet gas pressure in a manner so as to shift the condition of operation of said gas compressor toward said desired condition, thereby tending to prevent overloading of said prime mover and surging of said compressor.

2. A gas compression system as defined in claim **1** wherein said compressor includes an interstage cooler between the first stage thereof and said following stage thereof; means to pass a cooling medium in through said interstage cooler in heat exchange relation with gas compressed from the first stage of said compressor to cool said compressed gas prior to entry into said following stage; and said interstage temperature sensor being located to sense the tempertaure of gas admitted to said following stage of said compressor after being cooled in said interstage cooler.

3. A gas compression system as defined in claim **1** wherein said inlet gas temperature signal generated by said inlet gas temperature sensing means is a nonlinear function corresponding to a predetermined nonlinear condition of operation of said gas compression system.

4. A method of operating a gas compression system having a multiple stage gas compressor driven by a prime mover to reduce overloading of said prime mover and surging of said compressor, which includes the steps of sensing the discharge gas pressure of said system and adjusting the condition of operation of said system in response to sensed discharge gas pressure to maintain a substantially constant predetermined discharge pressure, wherein the improvement comprises:

(a) sensing the temperature of gas admitted to a first stage of said compressor and generating an inlet gas temperature signal functionally related thereto;

(b) sensing the temperature of gas admitted to a stage of said compressor following said first stage thereof, and generating an interstage temperature signal functionally related thereto;

(c) sensing the pressure of gas admitted to the first stage of said compressor and generating a pressure signal functionally related thereto;

(d) generating a reference signal having a magnitude related to a desired condition of operation of said gas compression system;

(e) summing said inlet tempertaure signal, said interstage temperature signal, said inlet pressure signal and said reference signal to provide a control signal which is functionally related to the difference between the condition of operation of said gas compression system and the desired condition of operation thereof; and

(f) controlling the rate of flow of gas to the inlet of said first stage of said compressor in response to said control signal to change inlet gas pressure to said compressor in a manner to approach the desired condition of operation of said system, thereby reducing overloading of said prime mover and surging of said compressor.

5. A method of operating a gas compression system as defined in claim **4** including the step of cooling the compressed gas discharged from said first stage of said compressor prior to entry thereof into said following stage of said compressor, and sensing the temperature of the gas

admitted to said following stage subsequent to cooling thereof so that the effect of cooling of said gas is sensed and compensated for in controlling the rate of flow of gas to the inlet of said first stage.

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WILLIAM L. FREEH, *Primary Examiner.*

U.S. Cl. X.R.

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PO-1050
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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,441,200 Dated April 29, 1969

Inventor(s) Eugene L. Huesgen

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

Column 2, line 46, for "operations" read -- operation --; line 48, for "multisage" read -- multistage --.
Column 3, line 28, for "scond" read -- second --.
Column 6, line 33, after "predetermined" insert -- desired --.

SIGNED AND
SEALED
MAR 10 1970

(SEAL)
Attest:

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Commissioner of Patents