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A. M. HENS

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METHOD FOR PREVENTING SURGING OF COMPRESSORS

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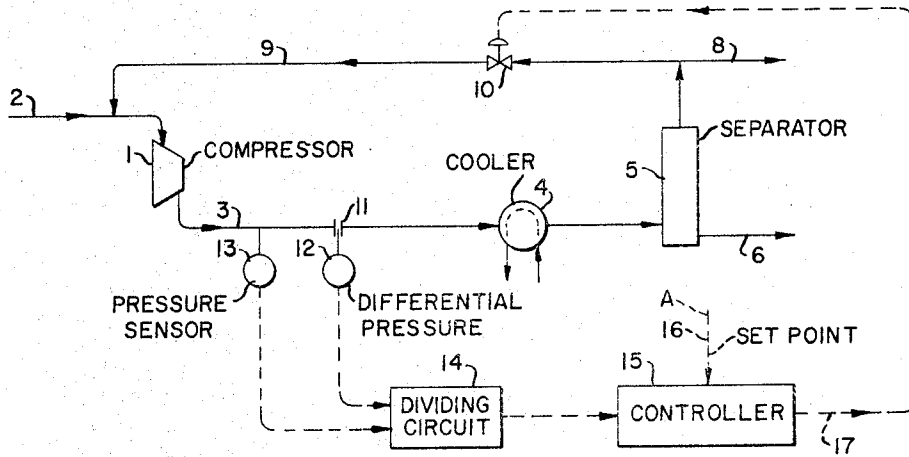


FIG. 1

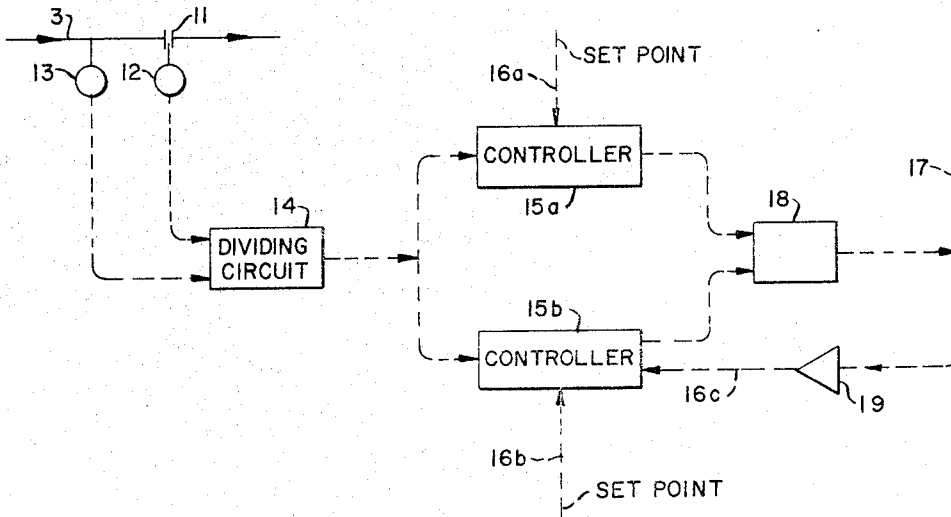


FIG. 2

INVENTOR:

A. M. HENS

BY: *Harold E. Bisher*

HIS ATTORNEY

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Antonius M. Hens, The Hague, Netherlands, assignor to
Shell Oil Company, New York, N.Y., a corporation of
Delaware

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289,828

6 Claims. (Cl. 230—115)

The invention relates to a method and apparatus for protecting a centrifugal compressor in order to entirely or substantially prevent so-called surging of the compressor. Surging may occur in a compressor when, at a certain pump pressure, the gas velocity through the compressor becomes too low, or when, at a certain gas velocity the pressure becomes too high. In order to counteract this surging the compressor is provided with a by-pass or a blow-off line, which during normal operation (i.e., when the gas load is sufficiently high), is closed by a control valve. When the possibility of surging arises, the valve is opened to a greater or lesser extent, so that the gas flow through the compressor increases and surging is avoided. Since the by-passing or the blow-off of gas through the by-pass or the blow-off line represents a loss, in both power and gas, the valve is only opened when and to the amount necessary to avoid surging.

It has already been proposed to operate the control valve by a control system, to which signals dependent on the pressure level of the compressor and of the gas flow through the compressor are supplied. Thus, it has been suggested, for example that a signal proportional to the discharge pressure of the compressor be compared in the controller with the sum of two signals, one of which depends on the flow rate of the gas feed and the other being dependent on the flow rate of the gas stream in the by-pass. The controller in turn controls the position of the control valve in the by-pass line. This control system can only work efficiently at a single pressure level, i.e., the pressure level at which the controller has been set. If the suction pressure varies, it would be necessary to obtain an effective protection against surging, to continually alter the setting of the controller. Hence, when the inlet pressure of the gas to be compressed is not constant or substantially constant, which often occurs when a plurality of compressors are connected in series, no effective protection of the compressor against surging is possible with this system.

This invention provides a method by means of which an effective protection against surging is obtained, which is substantially independent of the pressure level at which the compressor operates. Moreover the protection is independent or substantially independent of the inlet temperature of the gas to be compressed.

Special embodiments of the invention also afford the possibility of making the compressor operate safely without or substantially without loss of power up to the range in which surging may occur. This is particularly important when the gas load of the compressor varies considerably. It is then particularly advantageous, since the range within which the gas load can vary without loss is as wide as possible. However, when, as the result of a gas load which is too low or pressure which is too high, operations cannot be conducted without loss, the loss is kept at a minimum while at the same time a stable control of the control valve is ensured.

According to the invention the throughput of the control valve is controlled by the output signal of a controller, to which as an input signal the quotient of two signals is supplied, one of which (Δp) is dependent on the gas flow through the compressor and the other (p) is

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dependent on the pressure level of the compressor, the direction of action of the control being such, that when $-\Delta p/p$ (respectively $p/\Delta p$) attains a value which is smaller (respectively greater) than the set value of the controller the output signal of the controller tries to open the control valve. The signal representing the gas flow through the compressor is preferably a differential pressure signal measured across an orifice, a venturi or a similar device. Preferably the differential pressure is measured at the discharge side of the compressor. The signal dependent on the pressure level is also preferably obtained by measuring the discharge pressure of the compressor. Good results are obtained by a combination of Δp measured at the suction side of the compressor (referred to as Δp_1) with the pressure measured at the discharge side of the compressor (and referred to as p_2). Excellent results can also be obtained by measuring the differential pressure at the discharge side of the compressor (referred to as Δp_2) and the pressure at the suction side of the compressor (referred to as p_1). In practice the best control is achieved by measuring both Δp and p at the discharged side of the compressor (referred to as Δp_2 and p_2). The point at which the control valve begins to open may be varied by changing the set value of the controller. Thus, the opening of the control valve can be adjusted with relation to the surge limit of the compressor.

The above-described embodiment of compressor protection of this invention is particularly useful when the gas load is normally well outside the surge limit of the compressor and does not vary very much. In this case the controller is usually provided with proportional action only and moreover with a wide proportional band. The wide proportional band is necessary for a stable control. If an unexpected deviation from the normal state now occurs, for example because the discharge of compressed gas becomes blocked, the controller prevents surging.

However, when the normal operation of the compressor entails a considerable variation in the load and thereby comes close to or exceeds the surge limit (so that the control valve has to act repeatedly or is permanently in action in order to avoid surging) the protection by means of a controller with proportional action only is less satisfactory. The relatively great width of the proportional band of the controller results in a control that is not economic. If, however, an improvement in the economy were attempted by the introduction of integral action, it would increase the possibility of compressor damage when there are rapid variations in the load.

According to another embodiment of the invention it is desirable to use two controllers connected in parallel, has both proportional and integral action and moreover a relatively narrow proportional band, while the other has both proportional and integral action and moreover a relatively wide proportional band; the output signals of these controllers being passed to an auxiliary relay, which causes the control valve to be controlled only by that controller signal which would impart the greatest throughput for the by-pass line. As a rule both controllers are connected to the same dividing circuit or relay that supplies the quotient $\Delta p/p$ or $p/\Delta p$. It is possible to use various dividing circuits or relays in order to determine and use various quotients (for example $\Delta p_2/p_2$ and $\Delta p_2/p$).

A similar result may be achieved by using a single controller, which in addition to proportional and integral action also has derivative action and preferably a wide proportional band.

The protection system to this invention may be operated by various means, for example hydraulically, pneumatically or electrically. If a pneumatically operated system is employed, the output signal of the auxiliary relay

used in the control system having two controller may in addition be used to feed that part of the controller which produces the integral action.

This invention will be more easily understood from the following description when taken in conjunction with the attached drawing in which:

FIGURE 1 is a block diagram of one embodiment of this invention using a single controller; and,

FIGURE 2 is a block diagram of a second embodiment of this invention using two controllers in parallel.

FIGURE 1 shows diagrammatically a method for the compression of natural gas by means of a centrifugal compressor 1. The gas is supplied through a line 2 and leaves the compressor through a line 3. The compressed gas is subsequently cooled by means of a cooler 4 and is freed in a separator 5 from any condensate which may have been formed. The condensate is discharged through a line 6 and the compressed gas through lines 7 and 8, after which it may be pumped back to the earth formation for repressurizing or passed to a process where the gas is used or further processed. As gas by-pass 9 connects the lines 7 and 2; a control valve 10 which is normally closed is incorporated in this by-pass. If surging of the compressor occurs or if there is a danger of surging, the control valve is opened so that surging is eliminated or prevented. The by-pass 9 could have been connected to the discharge side of the compressor at an earlier point, for example, just before the cooler 4.

In the line 3 an orifice 11 is inserted, which is connected to a differential pressure measuring device 12. This device produces a signal (Δp_2), which is proportional to the differential pressure occurring across the orifice. A suitable device would be a model 13A differential pressure transmitter manufactured by the Foxboro Company of Foxboro, Massachusetts. A pressure sensor 13 is likewise connected to the line 3 and produces the signal (p_2) which is proportionate to the discharge pressure of the compressor. A suitable device would be a Foxboro model 44 pressure transmitter.

The signals of the differential pressure measuring device 12 and pressure sensor 13 are passed to a dividing circuit or relay 14, the output signal of which is proportional to $\Delta p_2/p_2$. A suitable device would be a Foxboro model 556 pneumatic analog computer. This signal is supplied to a controller 15 which has a set point 16. The controller may be a Foxboro model 43A controller. The set point may be set at a certain value of the quotient $\Delta p_2/p_2$ which is otherwise adjustable according to magnitude. The controller is preferably only provided with proportional action, which means that for a given change in $\Delta p_2/p_2$ it makes a proportional change in the setting of the valve 10. The controller 15 compares the measured value of the quotient $\Delta p_2/p_2$ with the set value A. The output signal 17 of the controller 15 controls or positions the control valve 10. If

$$\frac{\Delta p_2}{p_2} \geq A$$

the control valve 10 is or remains closed. When, however

$$\frac{\Delta p_2}{p_2} < A$$

(for example, owing to the fact that no gas or less gas than usual is withdrawn at 8) the control valve is opened to a greater or lesser degree, in any case to such an extent required to eliminate surging of the compressor. By altering the set value A, the moment at which the control valve 10 begins to open is shifted. In addition, the relay 14 and controller 15 may be commercial units manufactured by Moore Products Company of Philadelphia, Pennsylvania.

The protection of the compressor described above has the advantage of being practically independent of the compressor pressure. When there is a change in the pressure level, for example when there is a rise or fall in the

pressure of the natural gas fed, the protection against surging continues to operate without adjustment.

When the system is pneumatically operated the signal pressure 17 is in general chosen so that when the signal pressure disappears the valve 10 is opened.

The quotient $p_2/\Delta p_2$ could have been used instead of the quotient $\Delta p_2/p_2$ and the former could have been passed to the controller 15. The set value then changes, as does the direction of the control. In this case the valve is of course opened as soon as $p_2/\Delta p_2$ becomes greater than the set value

$$A' \left(A' = \frac{1}{A} \right)$$

FIGURE 2 shows the changes required when using two controllers 15a and 15b connected in parallel and both connected to the same dividing circuit 14. The controller 15a only has proportional action and is moreover adjusted to a relatively narrow proportional band, for example 10%. The controller 15b has both proportional and integral action and moreover a wide (compared with controller 15a) proportional band, for example 100 to 250%. A suitable controller would be a Foxboro model 40. The term "integral" is used to refer to the ability of a controller to respond to the integral of the change in the input signal. The set points 16a and 16b of controllers 15a and 15b, respectively differ, in such a way that the controller 15b will be the first to act. The operating level of the controller 15a is adjusted to lie on that side of the operating level of the controller 15b where the surge limit also lies and usually near to the said operating level (the operating level being when

$$\frac{\Delta p}{p} = A)$$

The output signals of the controllers are passed to an auxiliary relay 18 which passes only the signal that would impart the greatest throughput to the by-pass line. In the present embodiment (in which the control valve closes when the pneumatic signal 17 increases in magnitude) this means that the relay 18 continually transmits the smaller of the two signals 15a, 15b.

The input 16c of the controller 15b which provides the integral action thereof is preferably fed by the output signal of the relay 18. In FIGURE 2 the signal 17 is therefore supplied to the amplifier 19 with the amplifier being coupled to the controller 15b. This results in a more rapid operation of the integral action.

If the load of the compressor 1 approaches the surge limit, the controller 15b first comes into action since the relevant operating level is the first to be exceeded. Since the operating level of controller 15b can be placed relatively close to the surge limit the operation of the compressor installation remains economic; for losses as a result of by-passing of gas through the by-pass do not occur as long as the operating level of controller 15b (insofar as it concerns the discharge at 8) is not overshoot, since the control valve is then closed; and the control valve is only slightly opened when the operating level is only slightly overshoot, so that the losses are small.

If, however, a further change in the load brings the compressor closer to or in the danger area, the other controller 15a can immediately come into operation and open the control valve. Without controller 15a there is a risk of surging of the compressor, since the controller 15b, as a result of the wide proportional band and the action resulting from the integral action, cannot open the control valve 10 in time.

On the other hand a permanent unstable control (owing to the narrow proportional band of controller 15a) will not occur since eventually the controller 15b re-assumes control. Controller 15b assumes control as soon as the integral action has been able to build up a signal of suitable magnitude.

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Finally, the integral action also ensures that, when the compressor must operate permanently with a more or less widely opened control valve, no difference between measured value and set value occurs which could otherwise lead to surging of the compressor.

While a pneumatic system has been described in detail, other systems could be used as for example electronic or combination pneumatic electronic. When electronic systems are used, operational amplifiers with proper feedback circuits could be substituted for the dividing and controller circuits.

I claim as my invention:

1. A method for protecting a centrifugal compressor from surging by using a by-pass line having a control valve disposed to control the flow through the by-pass line, the position of the control valve being controlled by a control system, said method comprising:
 15 measuring both the gas flow through the compressor and a pressure level of the compressor flow;
 obtaining the quotient of the pressure level divided by the gas flow;
 20 comparing the quotient of the gas flow and pressure level with a preset value; and
 opening the control valve when the quotient varies from the set value.

2. The method of claim 1 wherein both the gas flow

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and pressure level are measured at the discharge side of the compressor.

3. The method of claim 1 wherein both the gas flow and pressure level are measured at the inlet side of the compressor.

4. The method of claim 1 wherein the gas flow and pressure level are measured on opposite side of said compressor.

5. The method of claim 1 wherein the comparing of the quotient and preset value includes proportional and reset actions.

6. The method of claim 5 including in addition to proportional and reset actions an integral action.

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LAURENCE V. EFNER, *Primary Examiner*.