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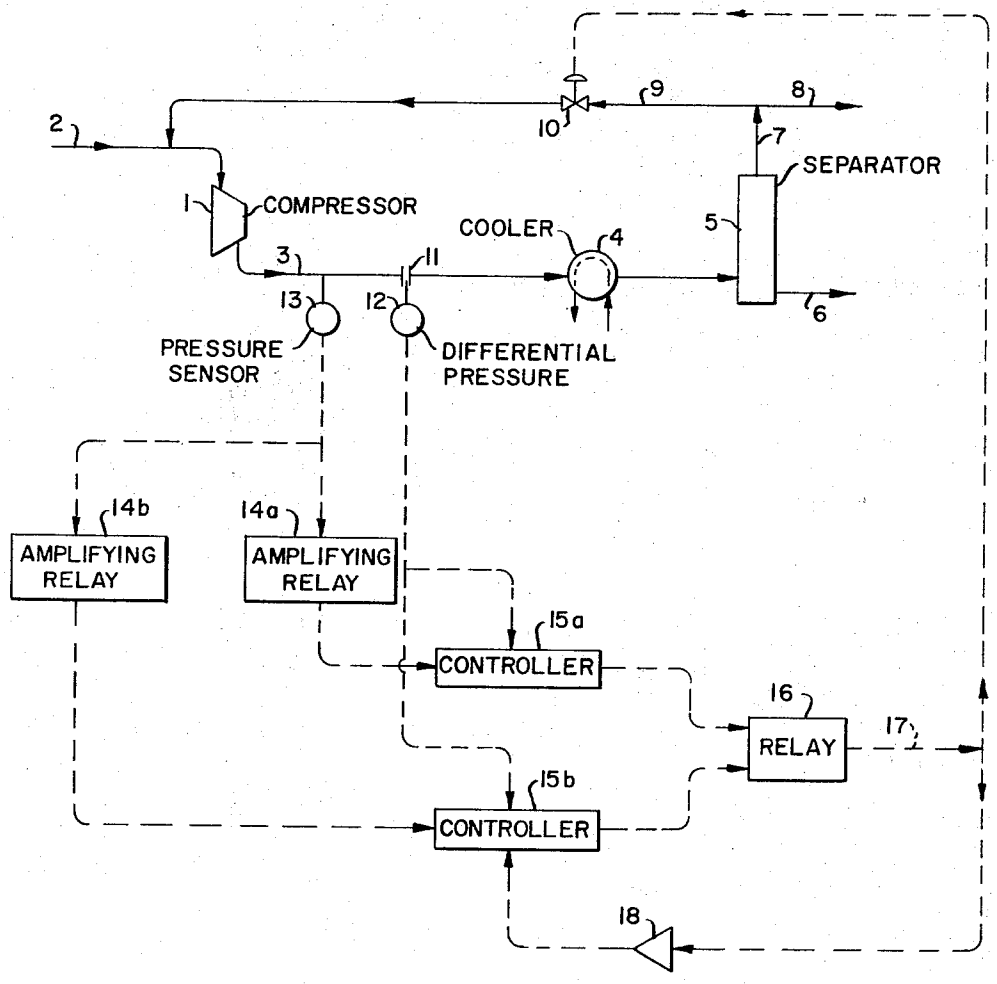

INVENTORS:

A. M. HENS
J. A. LANDSTRA
N. C. MARIS

BY Theodore E. Bieber

THEIR ATTORNEY

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METHOD FOR PREVENTING SURGING OF COMPRESSORS

Antonius M. Hens, The Hague, Jelle A. Landstra, Amsterdam, Netherlands, and Nicolaas C. Maris, Curacao, Netherlands Antilles, assignors to Shell Oil Company, New York, N.Y., a corporation of Delaware

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The invention relates to a method and apparatus for protecting a centrifugal compressor in order to entirely or substantially prevent the 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 of the compressor 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 a control system 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 control system used is a single controller having only integral action. Such a system operates slowly and provides no protection against surging when rapid load variations occur. In the case of a system having proportional action a relatively wide proportional band is required to ensure stable operation but this means that the compressor unit can only operate economically (i.e., with closed control valve) when the load exceeds to a large extent the surge limit of the compressor.

The invention now provides a method by means of which an effective protection against surging is obtained, even when rapid load variations occur. The controller also operates economically in that the control valve remains open or is opened no further than is necessary to avoid surging.

According to the invention the throughput of the control valve is controlled by the output signal of a relay (auxiliary relay) to which two controllers are connected. Each controller compares two meansured signals, one (Δp) being dependent on the gas flow through the compressor and being measured as a differential pressure signal across an orifice, a venturi or a similar device, the other (p) being dependent on the pressure level of the compressor. One controller has only proportional action and moreover a relatively narrow proportional band, and the other controller has both proportional action and

integral action and in addition a relatively wide proportional band. The first-mentioned controller is set in such a manner that its operating level lies relatively near to the surge limit of the compressor, and the operating level of the second controller is further away from this surge limit and moreover outside the control range of the first controller. The direction of action of each controller is such that decreasing Δp or increasing p correspond to the opening of the control valve, and the auxiliary relay causes the control valve to be controlled only by that signal which at any moment would cause the greatest opening of the control valve.

Preferably the differential pressure is measured at the discharge side of the compressor. The signal dependent on the pressure level is 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 (Δp_1) with p measured at the discharge side of the compressor (p_2), or vice versa (Δp_2 and p_1). In practice the best control is achieved by measuring both Δp and p at the discharge side of the compressor (thus with the combination Δp_2 and p_2).

In order to set the operating level of each controller at the proper level (the operating level being $\Delta p = Ap$, where A represents a constant) an amplifier is inserted in at least one of the signal supply lines of each controller. By adjusting the amplifier the value of the constant A just mentioned may be altered and thereby adjust the operating level of the controller with respect to the surge limit of the compressor. In general each controller is provided with such an amplifier to permit independent adjusting and setting of each controller. As a rule an amplifier in one of the signal supply circuits (either for the signal p or for the signal Δp) of each controller is sufficient.

A similar result may be achieved by using a controller having in addition to proportional and integral action also derivative action to compare the signals Δp and p. The output signal of this controller controls the control valve and in this case also the direction of action is such that decreasing Δp or increasing p corresponds to the opening of the control valve. In order to ensure a stable operation the controller should have a relatively wide proportional bands, on the order of 100–250%. The operating level of the controller can be placed relatively near to the surge limit of the compressor. In at least one of the signal supply circuits an adjustable amplifier is inserted in order to be able to adjust the operating level with respect to the surge limit.

The protection system according to the invention may use various operating media, for example hydraulical, pneumatical, or electrical; a pneumatic embodiment is often used. If a pneumatic embodiment is employed the output signal of the auxiliary relay, after amplification if necessary may be used in order to supply a signal to that part of the controller which produces the integral action with which one of the controllers is provided.

The invention will now be further illustrated with reference to the accompanying drawing. The figure is a block diagram of a method for the compression of natural gas by means of a centrifugal compressor **1**. The gas to be compressed 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**, which convey the gas to a use location. A 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**, instead of after the separator **5** as is now the case.

In the line **3** an orifice **11** is inserted, which is connected to a differential pressure meter **12**. This meter produces a pneumatic signal (Δp_2) which is proportional to the differential pressure occurring across the orifice. A pressure sensing device **13** is likewise connected to the line **3** and produces the pneumatic signal (p_2) which is proportionate to the discharge pressure of the compressor. The output signal of the pressure sensing device **13** is passed to two amplifying pneumatic relays **14***a*, **14***b*; the output signal of the amplifying relay **14***a* is supplied to a pneumatic controller **15***a* and the output signal of amplifying relay **14***b* passes to a pneumatic controller **15***b*. The amplifying relays **14***a* and **14***b* may be Foxboro model M56–6 computing relays manufactured by the Foxboro Co. of Foxboro, Massachusetts. This type of relay supplies an output equal to A times an input signal where A is a manually set constant. Each of the controllers **15***a* and **15***b* also receives a signal from the differential pressure meter **12**. The controller **15***a* may be a Foxboro model M58 controller with proportional action. Accordingly, in controller **15***a* the differential pressure signal is compared with $A_1 \cdot p_2$, whereas in controller **15***b* the differential pressure signal is compared with $A_2 \cdot p_2$. The controller **15***b* may be a Foxboro model M58 Batch Stabilog Controller having proportional and integral (reset) actions. In this case A_1 and A_2 are the set values of the amplifying relays **14***a* and **14***b* respectively. The controller **15***a* has only proportional action and has moreover a relatively narrow proportional band (for example 10%); the controller **15***b* on the other hand has both proportional and integral action and moreover a relatively wide proportional band (for example 100 to 250%). The combination relay **14***a* and controller **15***a* have been so set that the operating level of controller **15***a* is relatively near to the surge limit of the compressor **1**; the combination relay **14***b* and controller **15***b* have been so set that the operating level of controller **15***b* is further away from the surge limit than that of controller **15***a* and moreover lies outside the control range of the controller **15***a*. The output signals of the controllers **15***a* and **15***b* are passed to an auxiliary relay or auctioneering circuit **16** which only allows the signal to pass through which at any moment would cause the greatest opening of the control valve **10**. The auxiliary relay **16** may be a Minneapolis-Honeywell model R–048B Diverting Relay manufactured by Minneapolis-Honeywell Co. of Minneapolis, Minnesota. The output signal **17** of the auxiliary relay **16** controls the control valve **10**. The controllers and associated devices are adjusted so that as long as $\Delta p_2 \geqq A p_2$ the control valve remains closed. As soon as Δp_2 falls below the value $A \cdot p_2$ (for example owing to the face that no gas or less gas than usual is withdrawn at **8**), the control valve is opened to the extent required to prevent surging of the compressor. In the pneumatic embodiment the signal pressure is in general so chosen that when the signal pressure decreases the valve **10** is opened. This also means that the relay **16** in the present embodiment always transmits the smaller of the two signals from the controllers **15***a*, **15***b*.

The part of the controller **15***b* which relates to the integral action thereof is preferably supplied by the output signal of the auxiliary relay **16**. To this end the figure shows that the output signal **17** is passed via an amplifier **18** to this part of the controller **15***b*. This results in a more rapid operation of the integral action.

The operation of the two controllers is as follows:

If the load of the compressor **1** (insofar as it concerns the gas discharge at **8**) approaches the surge limit, the controller **15***b* first comes into action since its relevant operating level is the first to be exceeded. Since the operating level of controller **15***b* 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 **15***b* (insofar as it concerns the gas discharge at **8**) is not exceeded. The control valve is only slightly opened when the operating level is only slightly exceeded, 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 **15***a* can immediately come into operation and open the control valve. Without controller **15***a* there is, however, a great risk of surging of the compressor, since the controller **15***b*, as a result of the wide proportional band and the action resulting from the integral action would not be able to open the control valve **10** in time.

If only a controller of the type **15***a*, i.e., with a narrow proportional band, were employed, an unstable control would result. This need is avoided since eventually the controller **15***b* reassumes control, viz. as soon as the integral action of this controller has been able to build up a signal of suitable magnitude. Finally, it is pointed out that the integral action of controller **15***b* ensures that even 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 pnuematic system has been described in detail, other systems could be used as for example electronic or combination electronic pneumatic. When electronic systems are used, operational amplifiers with proper feedback circuits could be substituted for the dividing and controller circuits.

We claim as our 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:

measuring both the gas flow through the compressor and a pressure level of the compressor flow;

comparing the measured gas flow with the measured pressure level times a first constant in a first controller having only a narrow proportional action to obtain a first signal;

comparing the measured gas flow with the measured pressure level times a second constant in a second controller having a broad proportional and integral action to obtain a second signal;

comparing said first and second signals to obtain the one of said first and second signals that will cause the largest opening of the control valve;

opening said control valve in response to the one signal.

2. An apparauts for protecting a centrifugal compressor from surging comprising:

pressure detecting means communicating with the flow stream of the compressor, said pressure detecting means measuring the flow through the compressor and a pressure level;

a first controller having a narrow band proportional action, said pressure detecting means being coupled to said first controller to compare said measured flow with said measured pressure level;

a second controller having a broad band proportional action and integral action, said pressure detecting means being coupled to said second controller to

compare said measured flow with said measured pressure level;

an auctioneering circuit, said first and second controllers being coupled to said auctioneering circuit to pass the signal from the controller that results in the largest control action;

a by-pass line communicating with the discharge and suction sides of said compressor, a flow control valve disposed to control flow through said by-pass line, said auctioneering circuit being coupled to said control valve to position said control valve.

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LAURENCE V. EFNER, *Primary Examiner.*