(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 140 499**
A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **84305463.6**

(22) Date of filing: **10.08.84**

(51) Int. Cl.⁴: **F 04 D 27/02**

(30) Priority: **07.10.83 US 539773**

(43) Date of publication of application:
08.05.85 Bulletin 85/19

(84) Designated Contracting States:
DE FR GB IT

(71) Applicant: **THE BABCOCK & WILCOX COMPANY**
1010 Common Street P.O. Box 60035
New Orleans Louisiana 70160(US)

(72) Inventor: **Dziubakowski, Donald**
7650 Walnutwood Drive
Seven Hills Ohio 44131(US)

(72) Inventor: **Shaffer, Jeremiah**
5453 Pinehill
Mentor Ohio 44060(US)

(72) Inventor: **Keyes, Marion A.**
120 Riverstone Drive
Chagrin Falls Ohio 44022(US)

(74) Representative: **Cotter, Ivan John et al,**
D. YOUNG & CO. 10 Staple Inn
London WC1V 7RD(GB)

(54) Compressor surge control.

(57) A surge control system (18) for a compressor anticipates the actual surge condition and initiates anti-surge protection in proportion to the magnitude of the anticipated surge condition. This is done by providing a feed forward signal from a control station (20) to a summing station (48), along with a normally generated surge control line point, to offset this point by an amount determined by the feed forward signal. The offset point is used as an input to a controller (56) for controlling a bypass valve (28) in a bypass loop around the compressor.

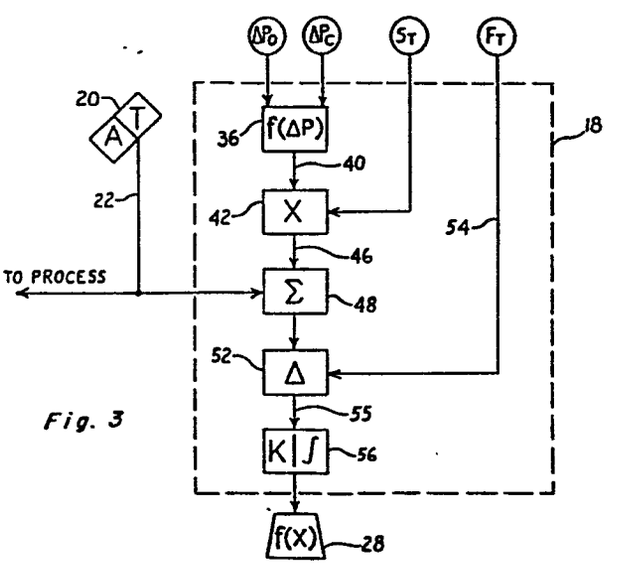


Fig. 3

EP 0 140 499 A2

COMPRESSOR SURGE CONTROL

This invention relates to surge control systems for compressors and to methods of controlling compressors.

Surge conditions occur in a centrifugal compressor when the inlet flow is reduced to the extent that the compressor, at a given speed, can no longer pump against the existing pressure head. At this point, a momentary reversal of flow occurs, along with a drop in pressure head. Normal compression resumes and the cycle repeats. This causes a pulsation and shock to the entire compressor and piping arrangement. If left uncontrolled, damage and danger to the compressor could result.

All centrifugal compressors are supplied with characteristic and setpoint curves defining the zones of operation for the compressor. These compressor "maps" illustrate the surge area and the "stonewall" area or pumping limit of the turbomachinery. As shown in Figure 1a of the accompanying drawings, the surge limit line is plotted against a discharge pressure versus flow rate relationship. Taking into account no changes in speed, flow, pressure, or inlet gas temperature the surge control line can be plotted with this equation.

(EQ.1)

$$\text{SURGE CONTROL LINE} = \%\ \text{OF CONTROL MARGIN DESIRED} \times \frac{\Delta P \text{ ACROSS COMPRESSOR}}{\Delta P \text{ ACROSS INLET ORIFICE}}$$

Three common forms of presently used surge control lines are shown in Figures 1a to 1c of the accompanying drawings. The one position of this line is parallel to the surge limit line (Figure 1a). To minimize recirculation, the surge control line should be set as close to the surge limit line as possible. Setting the control line with a slope less than that of the limit line (Figure 1b) can lead to excess recirculation at high pressures, and surge at low pressures during stopping and startup. The third method is to select a minimum safe volumetric flow, and set a vertical control line (Figure 1c). This can lead to excess recirculation at low pressures, and surge at high

pressures. Many systems measure flow in the discharge without correcting for suction conditions. This gives maximum recirculation with minimum surge protection.

In the various surge controls, control is accomplished by opening a bypass valve around the compressor or blowing off gas to atmosphere to maintain minimum flow through the compressor. Since bypassing or blowing off gas wastes power, it is desirable to determine surge flow as accurately as possible to avoid bypassing gas unnecessarily while maintaining safe operation. However, determining surge flow is often not a simple matter, but a complex one. Surge flow for a compressor is not a fixed quantity, but is related to other variables. Where other variables substantially affect surge flow, they must be measured and included in the surge system. However, present surge systems control surge only as a function of surge control line and make no provisions for anticipatory action from a controlled variable by way of a feed forward signal of such variable.

According to the present invention there is provided a surge control system for a centrifugal compressor having an associated surge line and a bypass line, the surge control system comprising:

first means for establishing a main surge control line a predetermined distance from the compressor surge line and identifying a point thereon;

second means for establishing a feed forward control signal of a process variable which may cause a surge condition in the centrifugal compressor;

summing means for combining the signals of the first means and second means to provide an anticipatory surge control line offset from the main surge control line of the first means in proportion to the magnitude of the signal from the second means and a control signal indicative thereof; and

bypass valve control means connected to the summing means for varying the amount of bypass across the centrifugal compressor in response to the control signal from the summing means.

The invention also provides a method of controlling surge in a centrifugal compressor having a predetermined surge condition line, the method comprising the steps of:

establishing a main surge control line offset from the compressor surge condition line according to a function of pressure differentials associated with the compressor;

establishing a feed forward control signal which is a function of a system variable which may cause the surge condition in the compressor; and

establishing an anticipatory surge control line offset from the main surge control line as a function of the established main surge control line and the established feed forward control signal.

A preferred embodiment of the present invention described hereinbelow solves or at least alleviates the problems associated with prior art surge controls by providing a surge control system for a compressor which will anticipate a surge condition in advance of the normal surge control line and will initiate anti-surge action prior to that initiated by the surge control line. To accomplish this, a feed forward control signal from a controlled variable other than one used to establish the surge control line is utilised to establish a second or anticipatory surge control line which is offset from the main surge control line and which will initiate anti-surge protection in advance of the main surge control line. This second surge control line will provide a variably offset control point from the main surge control line which will depend on the variation of the controlled variable. Thus, a large change in the controlled variable will provide a larger offset than a small change and will give more advanced warning of an oncoming surge. The preferred surge control system thus has an advanced warning capability of an oncoming surge condition, and has more advance warning for larger anticipated surge conditions.

The invention will now be further described, by way of illustrative and non-limiting example, with reference to the accompanying drawings, in which:

Figure 1 is a series of three curves showing prior art or known compressor surge control lines;

Figure 2 is a schematic view of reciprocating and centrifugal compressors using a surge control system embodying the present invention;

Figure 3 is a schematic view of the surge control system of Figure 2; and

Figure 4 is a curve of compressor discharge pressure vs flow rate showing the relationship of an anticipatory surge control line of the system embodying the present invention to the known compressor surge control lines.

Figure 2 of the drawings shows a parallel compressor system 10 having a reciprocating compressor 12 parallel connected to a centrifugal compressor 14 used to provide an output pressure at an output line 16. The reciprocating compressor 12 acts as a base load machine and can operate normally in one of two different capacities; 50% and 100% of its output pressure. This change of capacity from 100% to 50% initiates a surge condition in the compressor 14 and forms the basis of the advance warning system for a surge control system 18.

The centrifugal compressor 14 acts as a booster in the parallel arrangement, and because it is a dynamic machine (vs positive displacement like the reciprocating compressor 12) it has the potential of surging because of the decrease in flow.

As a command from a MNL/AUTO (manual/automatic) station 20 for the base load compressor decreases the demand from the reciprocating compressor 12 from 100% to 50%, an incipient surge condition is produced.

This potential surge condition is provided as an input along a line 22 to the surge control system 18 which, as may be best seen in Figure 4, establishes an offset anticipatory surge control line 24 offset from the usual surge control line 26. Thus, control of the bypass valve 28 allowing the bypass of flow across the centrifugal compressor along a line 30 is initiated by the surge control system 18 prior to the surge being initiated across the centrifugal compressor 14.

With particular reference to Figures 3 and 4, the surge control system 18 is schematically depicted in SAMA Standard RC22-11-1966 notation with the symbols applicable to mechanical, pneumatic, or electronic control systems.

Measured variables ΔP_o and ΔP_c represent, respectively, the pressure differentials across an orifice 32 in an inlet line 34 of the centrifugal compressure 14 and the differential pressure across the centrifugal compressor. These measured variables are inputted into a function generator 36 which develops an output at a line 40 representative of the surge control line 26 which is substantially parallel to a compressor surge line 38 and a predetermined distance K to the right of the surge line 38.

A comparison station 42 compares the surge control line output developed at the line 40 with the measured speed S_T of the centrifugal

compressor 14, thus locating the intersection 44 of a particular compressor rotation speed point N_i and the surge control line 26.

This intersection point 44 is transmitted along a line 46 to an adding station 48 where the anticipatory surge signal is added from the line 22. This anticipatory signal is from a process variable; namely, a manual or automatic demand variation on the base load, which will cause the surge condition. Clearly, the greater the signal from this process variable the greater the additive signal to the summing station 48 and the greater the offset of the anticipatory surge control line 24 from the main surge control line 26. Thus, the end result of the summing station 48 is to move the point 44 to a point 50 on the line 24.

This point 50 defines a certain flow rate of the compressor 14 which is compared in a difference station 52 with an actual measured compressor flow rate F_T supplied along a line 54 to the difference station 52. This adds a cascaded control to the surge control system 18 by providing a measured secondary variable to the feed forward anticipatory variable, thus providing better performance by coupling stability with fast response and rapid compensation for process disturbances.

The output of the difference station 52 is provided along a line 55 to a proportional and integral action controller 56 having a predetermined set point which will then control the final control element 28; namely, the valve controlling the amount of bypass in the line 30 to stop the surge condition by allowing the starved compressor 14 inlet 34 to utilise compressor 14 outlet fluid from a line 58.

The proportional plus integral controller 56 has an antiwindup feature. The antiwindup feature is necessary due to the nature of the proportional and integral functions. Normally, the compressor 14 operates in an area some distance from the surge control line 16, resulting in an offset between the measurement and the set point of the controller 56. As a result, the output signal winds up to its high or low limit.

Antiwindup adjusts the integral loading to shift the proportional band to the same side of the control line that the measurement is on when the controller reaches its output limit. Then, if the control line is approached rapidly, the measurement enters the proportional band and control starts before the valve reaches the control line. Therefore, overshoot is eliminated.

Derivative control is not used, because it can open the anti-surge valve far from the surge line and can cause system oscillations. Rapid oscillations in flow, even in the safe operating zone, can cause the valve to open because of the characteristics of the derivative response.

As soon as the controller 56 sees a deviation in set point and process variable, it will commence to control the valve 28 to open to offset an incipient surge condition. This is the normal mode of control. Because of the anticipatory feed forward signal along the line 22 to the summing station 48, this control of the surge condition will occur before the compressor 14 begins to see the effects and large or small surge causing conditions are easily taken care of by providing earlier anticipation for larger surge conditions.

CLAIMS

1. A surge control system for a centrifugal compressor (14) having an associated surge line (38) and a bypass line (30), the surge control system (18) comprising:

first means for establishing a main surge control line (26) a predetermined distance (K) from the compressor surge line (38) and identifying a point (44) thereon;

second means for establishing a feed forward control signal of a process variable which may cause a surge condition in the centrifugal compressor (14);

summing means (48) for combining the signals of the first means and second means to provide an anticipatory surge control line (24) offset from the main surge control line (26) of the first means in proportion to the magnitude of the signal from the second means and a control signal indicative thereof; and

bypass valve control means (56) connected to the summing means (48) for varying the amount of bypass across the centrifugal compressor (14) in response to the control signal from the summing means.

2. A surge control system according to claim 1, wherein the second means includes a control station (20) for varying the load requirements of the centrifugal compressor (14).

3. A surge control system according to claim 1, wherein:

a reciprocating compressor (12) is parallel connected with the centrifugal compressor (14);

a control station (20) is provided for varying the output pressure of the reciprocating compressor (12); and

the second means includes a control line (22) connected between the control station (20) and the summing means (48) for allowing the anticipatory surge control line (24) to be offset by the pressure change requirements on the reciprocating compressor (12).

4. A surge control system according to claim 1, claim 2 or claim 3, wherein the first means includes:

a function generator (36) responsive to input signals indicative of pressure differentials (ΔP_o, ΔP_c) associated with the centrifugal compressor (14) for establishing the main surge control line (26) parallel to the surge line (38);

means for establishing a signal (S_T) indicative of speed of the centrifugal compressor (14); and

means (42) for combining the signals of the function generator (36) and the compressor speed establishing means into a signal indicative of the point (44) of centrifugal compressor operation on the main surge control line (26).

5. A surge control system according to claim 4, wherein the first means generates a cascaded signal (54) indicative of compressor flow combined with a signal from the second means to ensure a predetermined flow through the centrifugal compressor (14).

6. A method of controlling surge in a centrifugal compressor (14) having a predetermined surge condition line (38), the method comprising the steps of:

establishing a main surge control line (26) offset from the compressor surge condition line (38) according to a function of pressure differentials (ΔP_o, ΔP_c) associated with the compressor (14);

establishing a feed forward control signal which is a function of a system variable which may cause the surge condition in the compressor (14); and

establishing an anticipatory surge control line (24) offset from the main surge control line (26) as a function of the established main surge control line and the established feed forward control signal.

7. A method according to claim 6, wherein the main surge control line (26) is established parallel to the surge condition line (38) and offset a predetermined amount (K) therefrom.

8. A method as set forth in claim 7, wherein the anticipatory surge control line (24) is offset from the main surge control line (26) by an amount proportional to the magnitude of the established feed forward control signal.

9. A method according to claim 6, claim 7 or claim 8, wherein a reciprocating compressor (12) is parallel mounted with the centrifugal compressor (14) and has a switchable pressure output operation, the feed forward control signal being a signal monitoring the condition of the switchable pressure output.

10. A method according to claim 9, wherein a valve (28) for controlling the flow of fluid in a bypass path (30) across the centrifugal compressor (14) is controlled according to the relative position of a measured point with respect to the anticipatory surge control line (24).

0140499

Fig. 1a

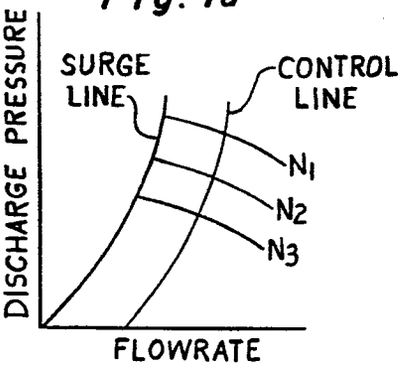


Fig. 1b

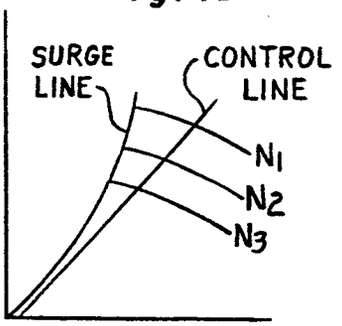
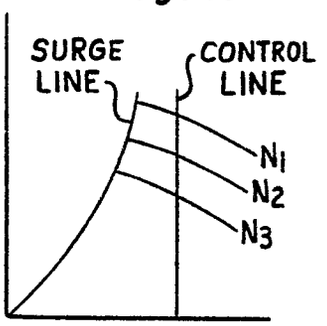


Fig. 1c



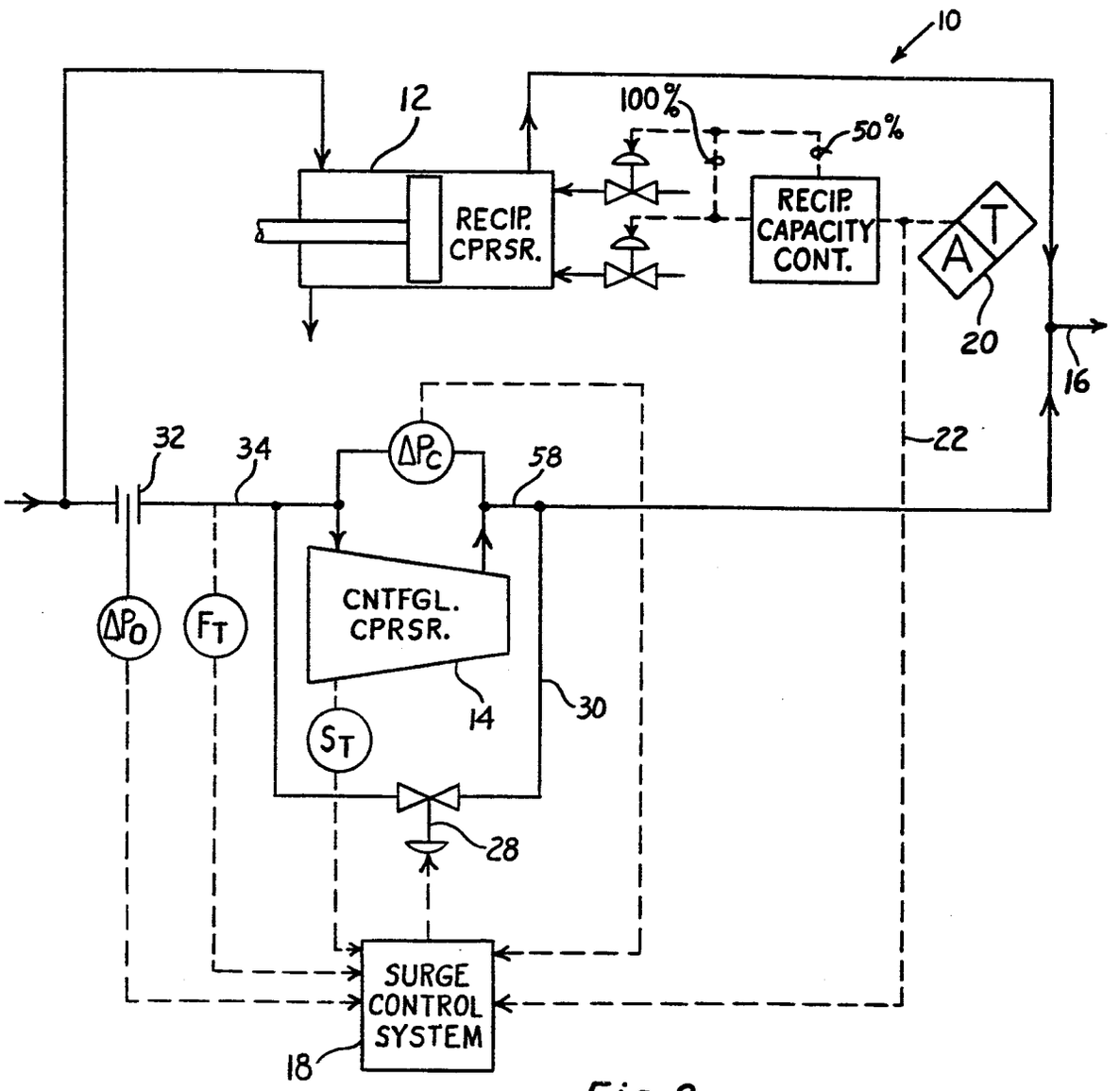


Fig. 2

0140499

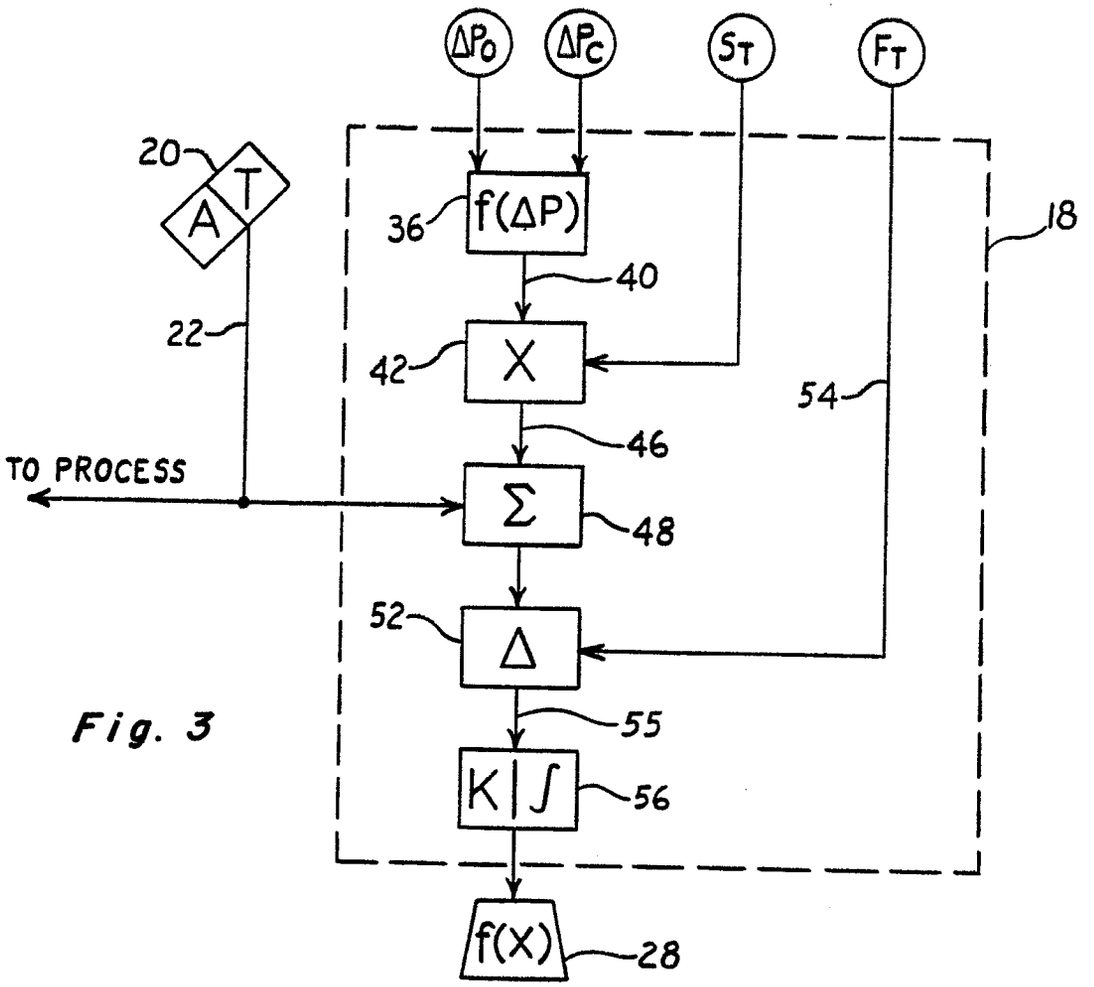


Fig. 3

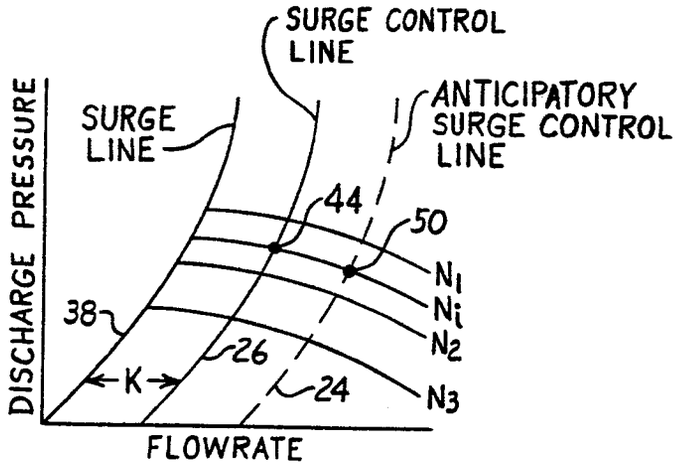


Fig. 4