KOSAIR 2004

Principle Description of Antisurge Control System

AIR LIQUIDE TM

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Control System Specification

REFERENCE DOCUMENTS

Compressor Unit P&I-Diagram	837 016 878
Instrument Specification	837 017 421
Wiring Diagram	837 017 775
Wiring Diagram Protronic 550	837 017 468
Controller Configuration ASC RIK80	837 019 325 000

CONTENTS

1 GENERAL

CAUTION

A turbocompressor is a pressure generating equipment. Operation of the equipment in contradiction with the instructions may cause damage to the installation or injuries to personnel. Therefore only authorised and trained people are allowed to operate this equipment.

Please read this description carefully before operating the compressor.

1.1 Purpose of Control

(see also Discharge Pressure versus Flow Diagram Fig. 1)
The gas flow through a turbocompressor cannot be reduced at liberty. The useful range of operation is limited by the surge limit. If the compressor is required to supply less gas at a given pressure than corresponding to this limit, the flow through the compressor becomes unstable; the compressor starts to surge. Flow rate and discharge pressure collapse suddenly and rise again in rapid succession, causing a pumping noise.

THE COMPRESSOR MUST BE PREVENTED FROM OPERATING UNDER THESE CONDITIONS !

In order to avoid surging, an antisurge control system is provided, which keeps the compressor flow rate at the admissible minimum value by opening an antisurge valve. The gas in excess of the plant requirements is recycled through the antisurge valve to the suction side so that the compressor continues to work in the stable range (at the right side of the surge limit), even if only a small gas quantity is delivered to the plant.

Possible damages caused by surging are :

- thrust bearing failure
- rubbing of labyrinth strips causing higher clearances and consequently higher leakage / thrust forces
- rubbing of impellers/blades
- failure of blading on axial compressors due to overstress/overheating
- damages on suction filter, silencer, process armatures etc.

CAUTION

The antisurge control system is a safety device for the operation of the turbocompressor. If for some reason this control system fails, the compressor may surge and the above stated possible damages may occur. In order to avoid compressor damages and injuries to personnel, the turbocompressor must not be operated with a faulty or without antisurge control system.

1.2 Mode of Operation

The diagram Fig. 1 shows the mode of operation of the antisurge control system in the discharge pressure - flow diagram. The surge limit is represented by the line "a". If at constant speed, the plant flow resistance is increased from w_1 to w_2, the operating point slides along the characteristic curve from 1 to 2 and the flow rate V_1 is reduced to V_2, i.e. the operating point approaches the surge line. If the flow rate is further reduced to V_3, the compressor would start to surge. To avoid this, the antisurge controller intervenes when the operating point 3* is reached (flow rate V_3*) and starts to open the antisurge valve. With further reduction of the flow rate to V_4, the antisurge valve opens so far that the difference V_3* - V_4 is recycled. As far as the plant is concerned, the compressor operates apparently in point 4 (in the unstable range), while in fact it continues to run in the stable range in point 3*.

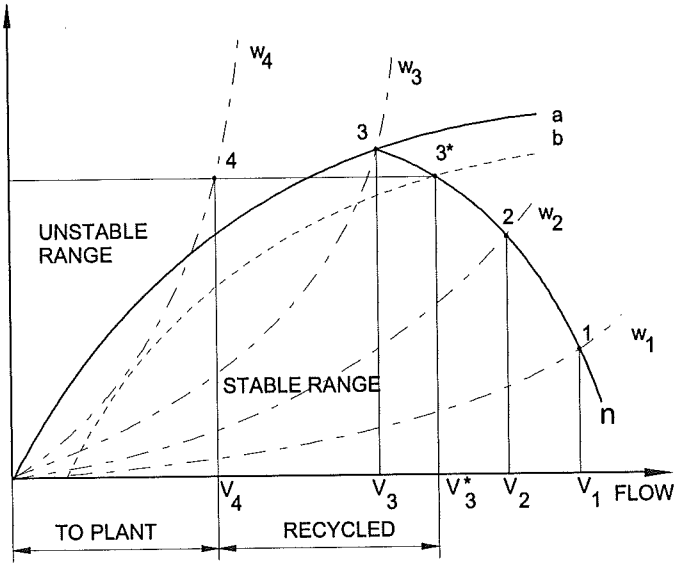


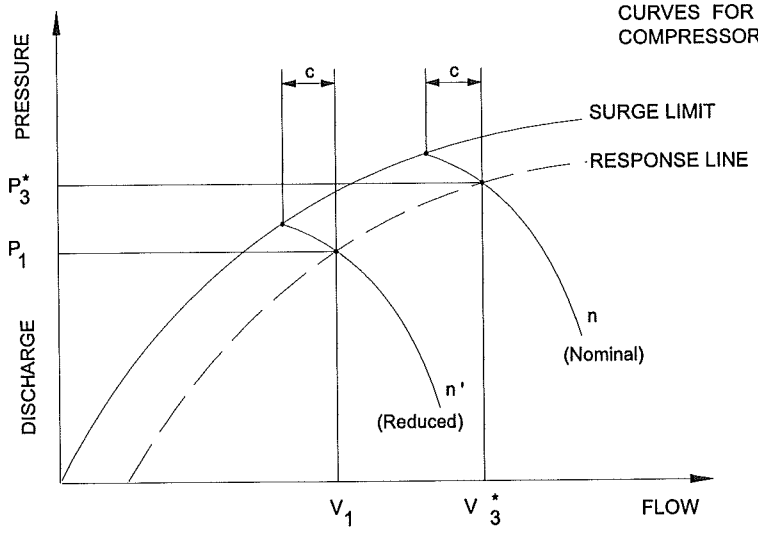
FIG. 1

The diagram Fig. 2 shows that with increasing compressor discharge pressure, the antisurge controller must start its intervention at a larger volume i.e. the greater the discharge pressure is, the greater is the minimum required flow (compare V_3^* and V_1 and the corresponding discharge pressure P_3^* and P_1). A single set point for the controller would therefore not be practicable as the working range of the compressor would be unduly narrowed. In order to prevent unnecessary recycling of compressed gas, the response line "b", which connects all the points where the antisurge valve starts to open, is used as set value curve for the antisurge controller. This curve is shaped as a function of the compressor discharge pressure in such a way that it runs in parallel with the surge limit. Between the surge limit and the response line is the safety margin "c".

The response line thus attributes to every discharge pressure a minimum flow rate.

FIG. 2

CHARACTERISTIC CURVES FOR DIFFERENT COMPRESSOR SPEEDS



2 DESCRIPTION OF THE CONTROL SYSTEM

2.1 Input Signals

2.1.1 Flow Measurement

The gas flow through the compressor is measured by the flow measuring device (placed at compressor discharge) furnishing the differential pressure Dp. The Dp-value is proportional to the square of the mass flow and acts on the differential pressure transmitter FT 11074. The latter delivers an output signal of 4...20 mA which is fed into the **PROTRONIC 550** controller.

2.1.2 Discharge Pressure Measurement

The compressor discharge pressure is measured by the pressure transmitter PIT 11041. The transmitter generates an output signal of 4...20 mA which is fed into the **PROTRONIC 550** controller.

2.1.3 External Manual Control Signal / Optional

The manual control signal HIC 110777 is a 4-20mA analog signal from the DCS or station control system. This signal is fed directly into the **PROTRONIC 550** controller. HIC 11077 is used to open the blow-off valve. Decreasing signal opens the valve (4 mA := valve open, 20 mA := valve closed). (refer to 3.7)

2.2 Antisurge Controller

ABB Normelec (former HARTMANN & BRAUN) developed the digital control system **PROTRONIC 550**. With regard to the various control applications which have to be handled on a turbocompressor, the **PROTRONIC 550** system is a tailor made system. This system combines not only all necessary control functions in one compact instrument, it also simplifies the operation and maintenance. The use of only one hardware component for various applications cuts back drastically the number of spare parts.

Further advantages of the system are :

- The controller can be expanded with different input and output modules to meet the required control application.
- Auto diagnosis
- Isolated analog and binary inputs
- Built-in transmitter power supply of 21 VDC
- User defined control modes
- Bumpless manual - automatic transfer
- 60 milliseconds cycle time (with the user program)
- The user program is stored in a Flash-EPROM. All data will remain in the controller in case of power failure.

3 DESCRIPTION OF ANTISURGE CONTROL PROGRAM

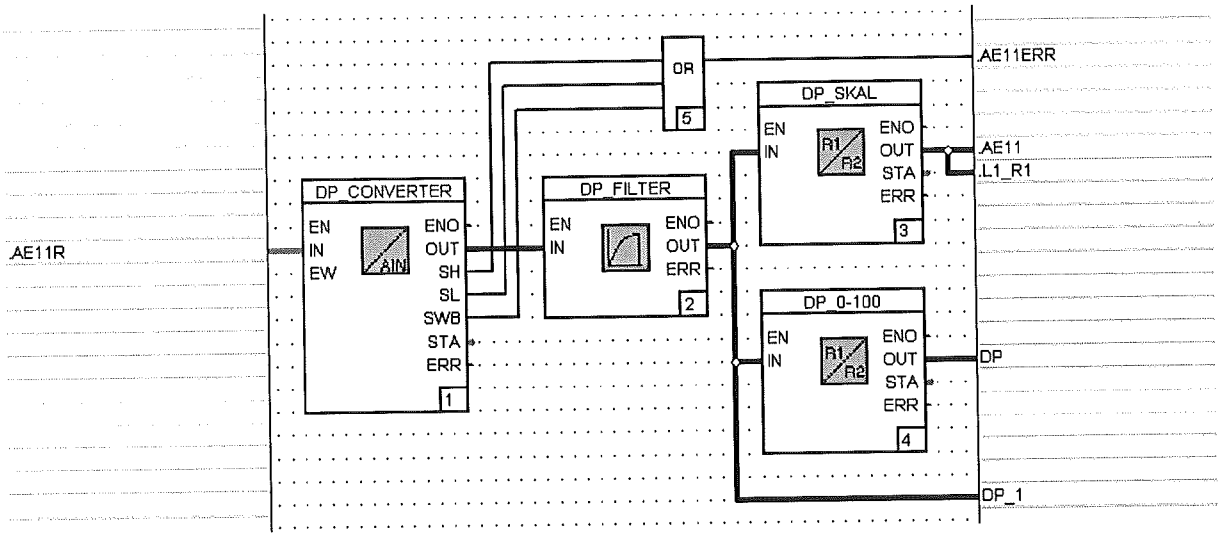
MAN TURBO has developed a program for the special requirements of a turbocompressor. All necessary features to guarantee an optimal operation of the compressor are included. This program contains the following function groups:

- Analog Input Treatment
- Process Value Treatment and Signal Adaptation for Setpoint Treatment
- Setpoint Treatment
- Discharge Pressure Limitation
- Shifting of Response Line
- Dynamic Intervention
- PI-Control Algorithm with Asymmetric Output
- Manual Control
- Automatic Start and Stop Sequence
- Gradient Supervision
- Alarm Logic
- Analog Outputs

The following sections describe the function of these blocks. Please refer to the configuration for detailed information.

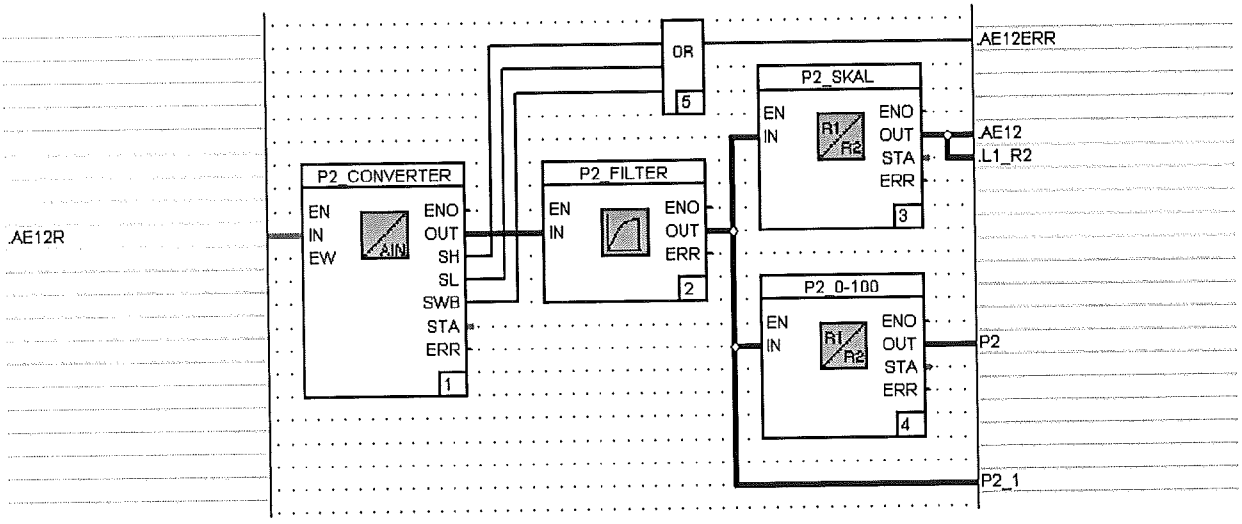
3.1 Analog Input Treatment

3.1.1 Flow Measurement



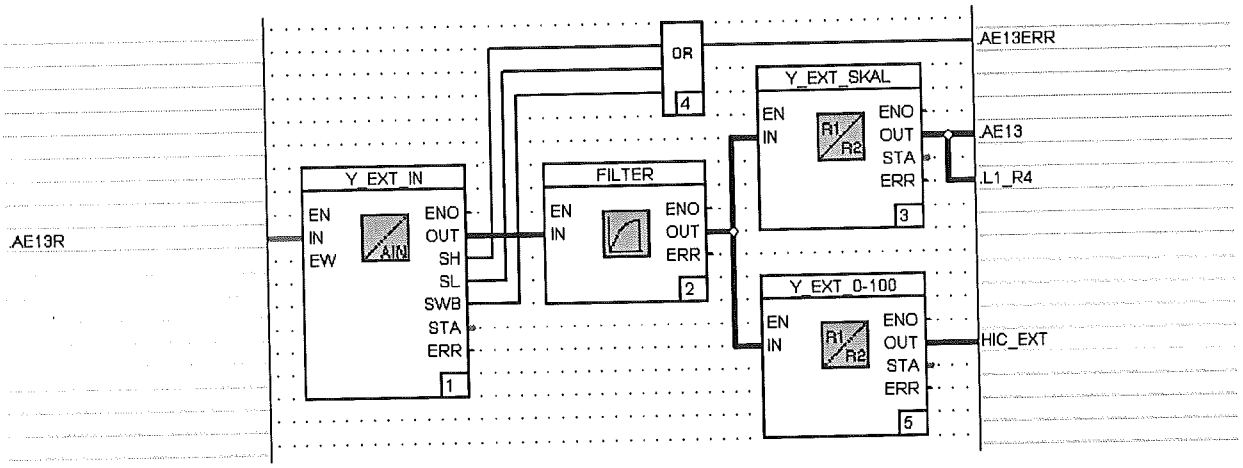
The input signal .AE11R (differential pressure measured by FT 11074) can be spread or squeezed with the scaling module DP_SKAL and the zero point can be elevated to adapt the actual requirements. The scaled output DP is fed to the process value treatment.
In case of an input error a signal is sent to the alarm treatment.
The analog input value is displayed on the panel front in engineering units.

3.1.2 Discharge Pressure Measurement



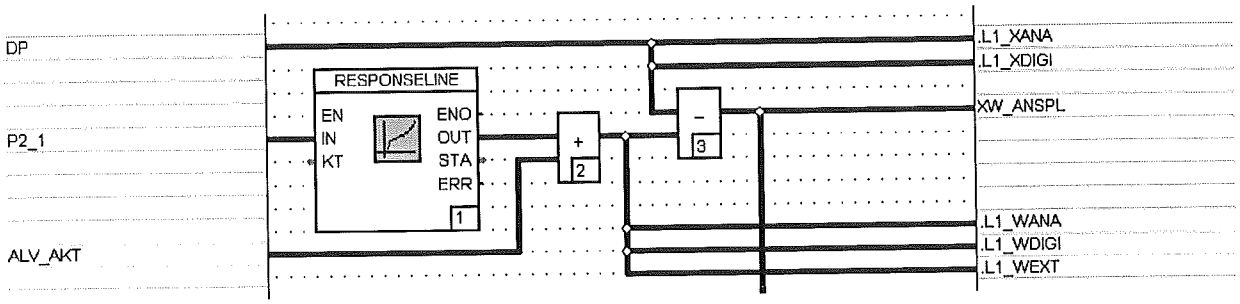
The input signal .AE12R (discharge pressure measured by PIT 11041) can be spread or squeezed with the scaling module P2_SKAL and the zero point can be elevated to adapt the actual requirements. The scaled output P2_1 is fed to the setpoint treatment.
In case of an input error a signal is sent to the alarm treatment.
The analog input value is displayed on the panel front in engineering units.

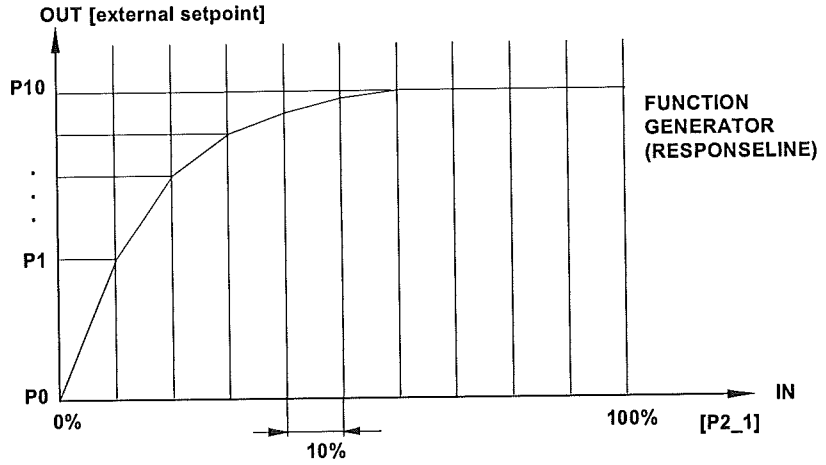
3.1.3 External (Manual) Control



The input signal .AE13R (external manual control HIC 11077) can be spread or squeezed with the scaling module HIC_SKAL and the zero point can be elevated to adapt the actual requirements. The scaled output .AE13 is fed to the manual control treatment.
In case of an input error a signal is sent to the alarm treatment.
The analog input value is displayed on the panel front in percent. (0 % := valve open, 100% := valve closed).

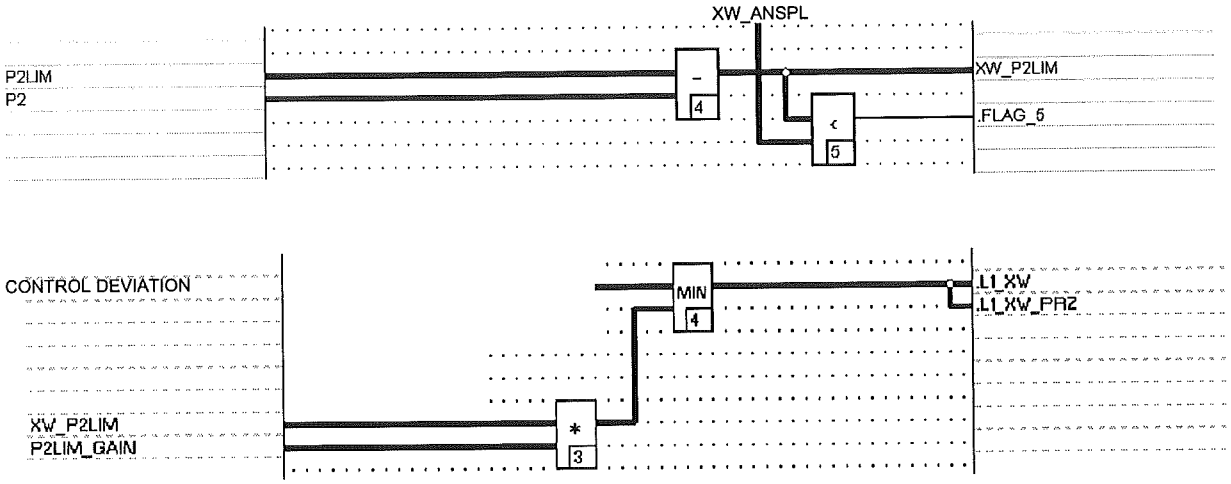
3.2 Setpoint Treatment





The scaled variable P2_1 is then converted by the function generator (linearising module RESPONSELINE) into the response line. The function is made by 10 straight line segments. By a suitable choice of the 11 breakpoints, which can be placed at any place, the function can be adjusted in such a way that the desired parallelism between the surge line and the response line is obtained. The output of the function generator is fed as (external) setpoint to the antisurge controller.

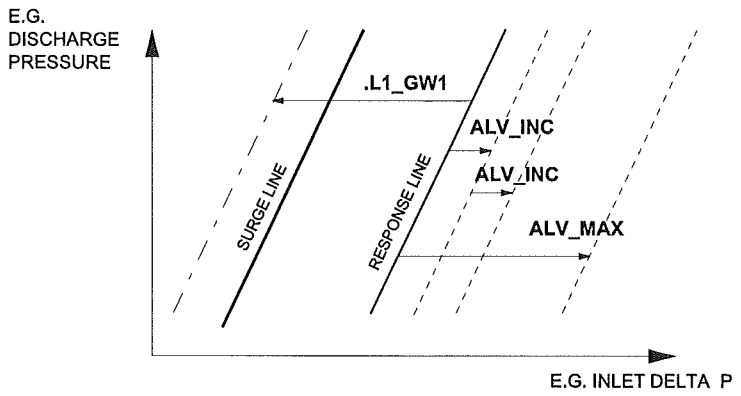
3.3 Discharge Pressure Limitation

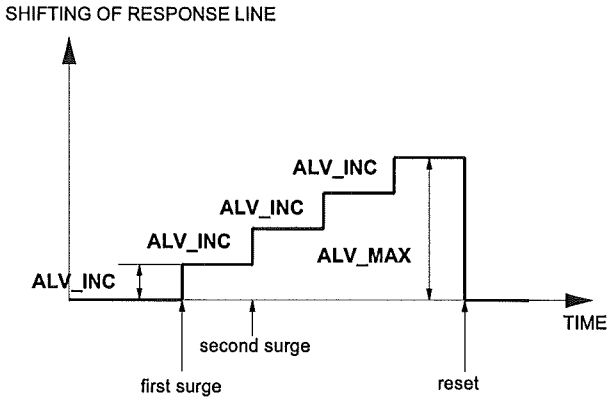


The scaled signal XW_ANSPL is compared with the adjustable limiting value XW_P2LIM (P2LIM – P2).

The dynamic response of the compressor / process may be different when running on the antisurge response line or on the discharge pressure limitation. Therefore, an additional gain factor P2LIM_GAIN has been implemented into the pressure limitation to cope with this requirement. The output of this gain adaptation is fed into a minimal selection function module (MIN), with cuts off the higher one of the two inputs signals (i.e. antisurge or discharge pressure control).

3.4 Shifting of Response Line





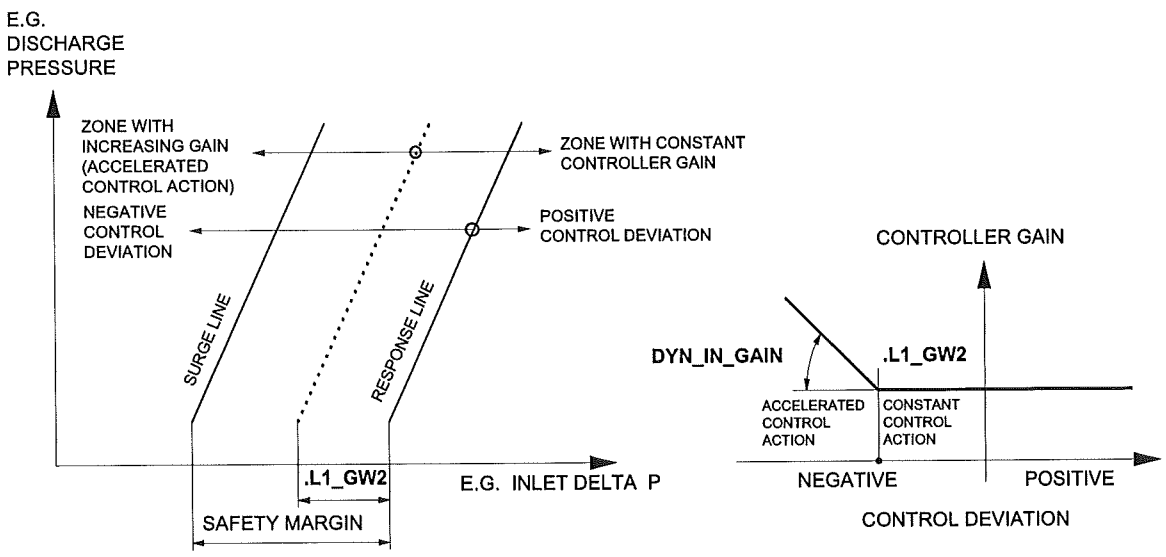
.L1_GW1	Margin from response line, where a surge is defined
ALV_INC	Response line shift increment per surge cycle
ALV_MAX	Maximum response line shift

The surge line of a compressor can change its position during the time of operation due to corrosion or fouling of the blades / impellers, fouling of intercoolers, any change in the gas composition, etc. This displacement can cause surge problems due to the fact that the response line remains invariant (reduction of safety margin between surge and response line).
Once this displacement of the surge line is large enough, the antisurge controller will no longer be able to prevent the compressor from surging.

In this event, the control line can be shifted in such a way that the safety margin will be increased. If a surge cycle has been detected (compressor operating point overshoots the control line by factor .L1_GW1), the response line will automatically be shifted away from the surge line. The value of this shifting can be adjusted with factor ALV_INC. Any further surge cycle will shift the response line again by factor ALV_INC. The maximum allowable shifting can be adjusted with factor ALV_MAX. An alarm will indicate to the operator that the response line has been shifted at least once.

By setting the binary input .BE03 (HS 11077.2) the shifting of the response line can be set back to its original value when the cause of the surge line displacement has been determined and eliminated.

3.5 Dynamic Intervention

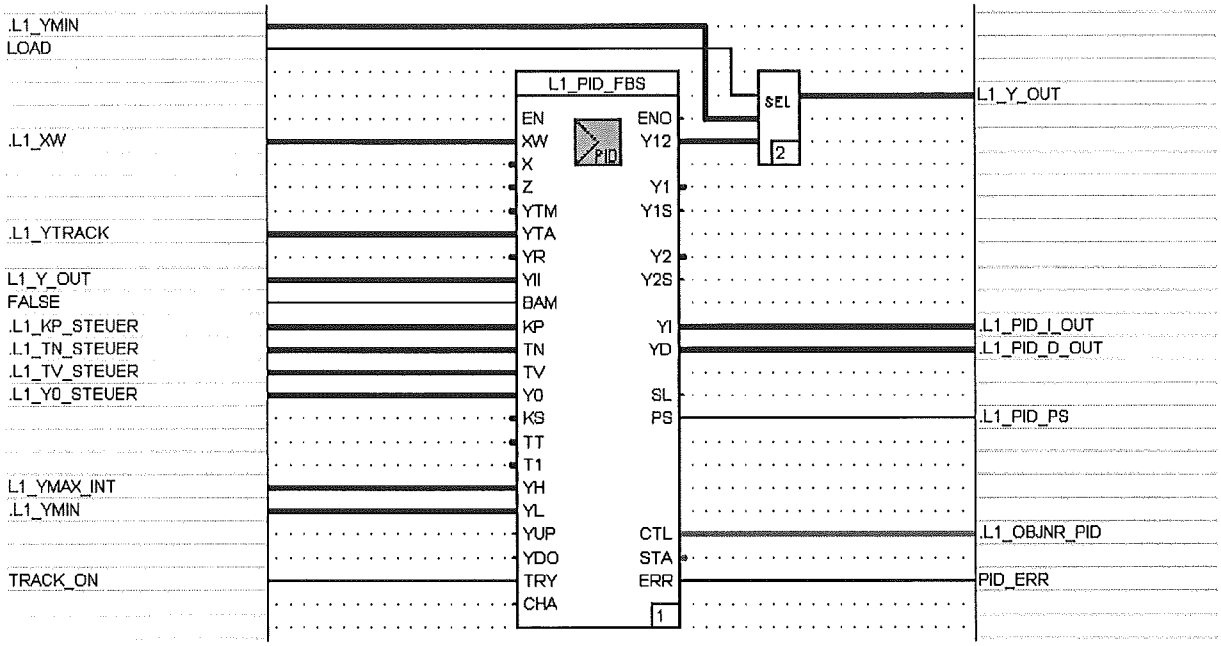


.L1_GW2	Start value for dynamic intervention
DYN_IN_GAIN	Dynamic intervention gain

In case of a very rapid movement of the compressor operating point towards the surge line (e.g. by closing a valve on the discharge), the antisurge controller may not be able to prevent the compressor from surging by its normal PI-action. The controller is therefore equipped with a special dynamic set-up to accelerate its intervention.

The above circuit acts as a non-linear (adaptive) control system. The more the operating point overshoots the control line, the faster the control action becomes and the faster the operating point is brought back onto the control line. This non-linear control action does not obstruct a stable operation on the response line, because the non-linearity only starts in a distance .L1_GW2 beyond the response line.

3.6 PI Control Algorithm with Asymmetric Output



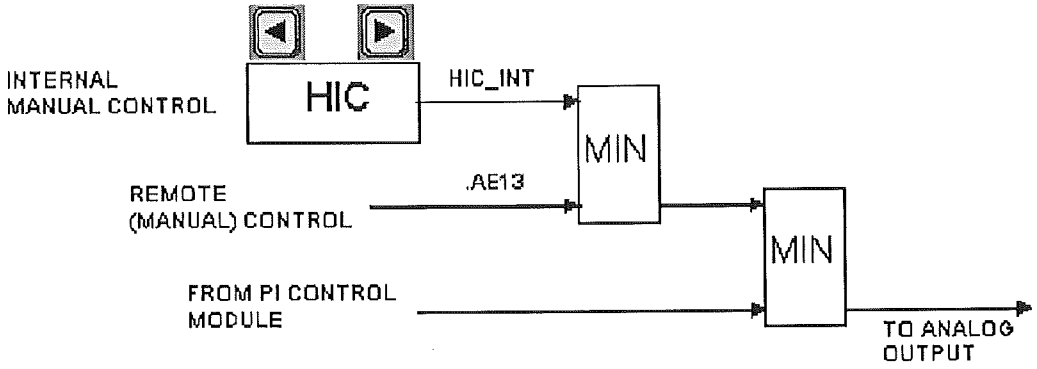
The calculated control deviation .L1_XW of process value and setpoint finally enters the proportional and integral control module. As long as the compressor operates within the stable range, .L1_XW is positive, the output of the controller is high (at 100 % signal output) and the antisurge valve is kept closed. When the operating point approaches the response line, .L1_XW becomes 0 %, the output decreases and the valve opens.

To speed up the normal PI-control action in case the compressor operating point overshoots the response line, a special non-linear control action module has been provided. (See section 3.6).

Too fast closing of the antisurge valve can push the compressor into a surge condition. To eliminate this undesired condition and for better control stability, the asymmetric function (rate limiter) is activated within the PI-controller module. This function delays an increasing controller output signal (slow closing of the antisurge valve), but it lets pass undelayed a decreasing controller signal (fast opening of the valve).

This asymmetric function combined with the non-linear control action optimises the antisurge controller in such a way that a fast control intervention and a stable operation on the response line are ensured.

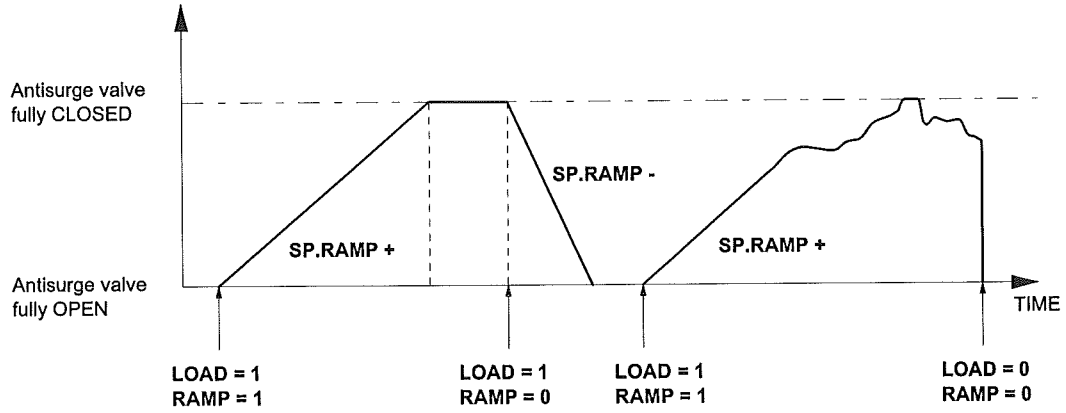
3.7 Manual Control



By means of the manual loading station the antisurge valve can be operated manually.

The output of the internal manual control and the remote control (HIC 11077) and the (proportional/integral) PI-control module output are fed into a minimal selection function module (MIN) which allows only the lowest one to pass to the antisurge valve (FV 11074). The manual loading station (internal and remote) is only allowed to open the antisurge valve wider than the demand of the control section. It is not possible to close the antisurge valve, if the controller requires it to open.
The manual valve adjustment should only be used under special circumstances, e.g. for valve function checks or for starting or stopping the compressor, if the automatic start/stop sequence is not used.

3.8 Automatic Start and Stop Sequence



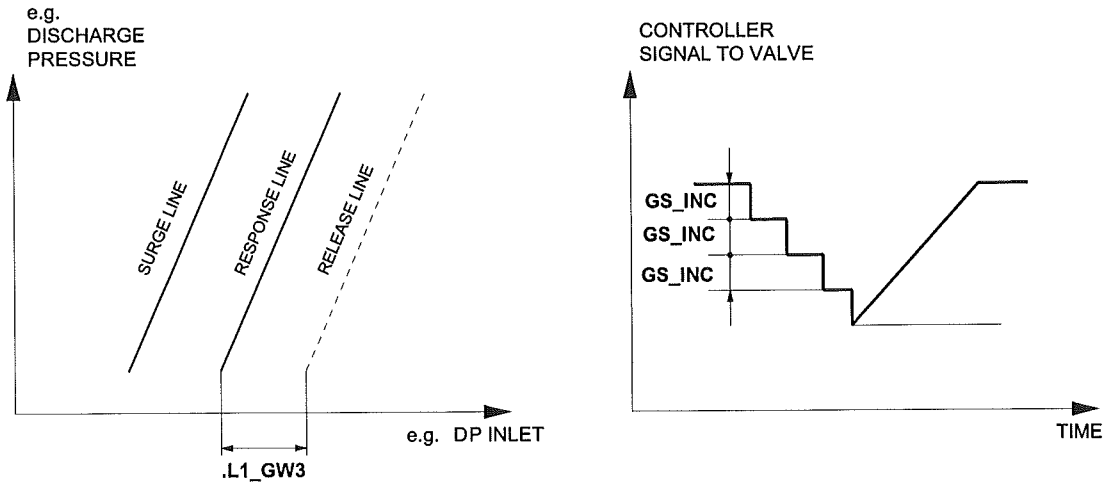
SP.RAMP +	Ramp closing gradient in %/s
SP.RAMP -	Ramp opening gradient in %/s

For an automatic start-up of the compressor, a separate load/unload ramp generator function is provided. After the compressor driver is ready to be loaded (e.g. min. operating speed reached) it is possible to start the ramp action by closing the external contact .BE02, i.e. the antisurge valve begins to close according to the ramp setting SP.RAMP +, if the compressor operates within stable range. Otherwise the PI-control section intervenes as in normal control operation.

In the present application there is the same signal used for LOAD and RAMP (HS 11077.1). It is not possible to unload the compressor smoothly via this RAMP function.

A shut-down of the compressor requires an immediate opening of the antisurge valve (step function). That can be achieved by opening the external contact .BE01.

3.9 Gradient Supervision



.L1_GW3	Start value for gradient supervision (release line)
.L1_GW4	Gradient limit dXw/dt
GS_INC	Opening increment per program cycle

The gradient supervision has been added to the non-linear control action to speed up the control response. It avoids surging in cases where the process resistance increases rapidly.

The controller output will be decreased in steps of the size GS_INC in adjustable intervals (normally 0.1 sec). This procedure goes on as long as the following two criteria are fulfilled.

- The decreasing rate of change of the control deviation Xw (dXw/dt) must be higher than the adjusted limit gradient .L1_GW4, i.e. only fast movements of the compressor operating point towards the response line will cause any action.

- The compressor operating point must be on the left of the release line which is in a distance of .L1_GW3 from the response line.

Positive .L1_GW3 setting: action starts already on the right hand side of the response line (early action).
Negative .L1_GW3 setting: action starts on the left hand side of the response line (late action).

After one of the two criteria is ceased, the controller will be brought back to normal control mode with the asymmetric function in the PI controller module.

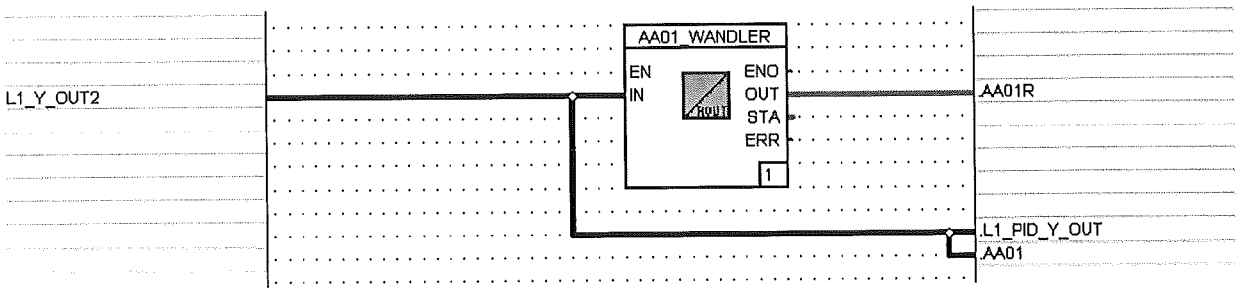
The gradient supervision acts directly onto the controller output (open loop control), so it is independent of the normal PI-controller setting.

3.10 Alarm Logic

The common alarm "System Failure" indicates that at least one of the controller inputs or outputs is in an incorrect state or that the self testing routine found an error in the controller. The faulty device is displayed on the controller front panel.

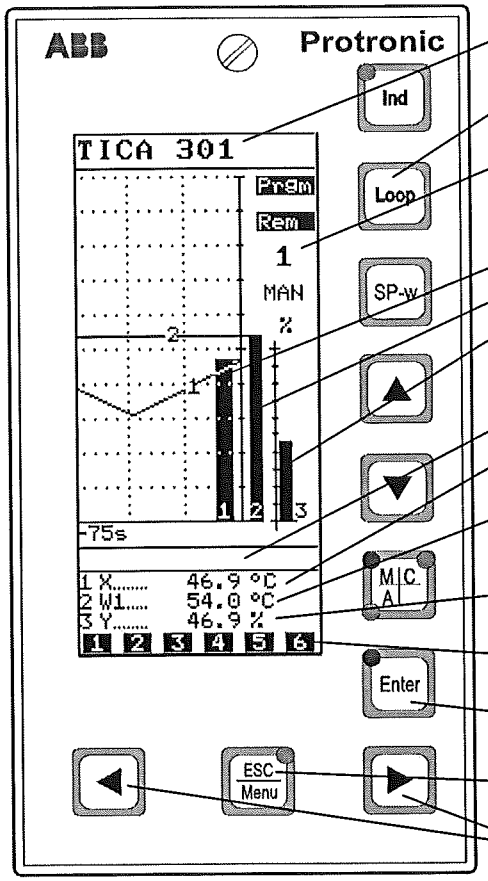
- Indication ERR_FT11074: Input failure FT 1110 (differential pressure)
- Indication ERR_PIT11041: Input failure PIT 11041 (discharge press.)
- Indication ERR_HIC11077: Input failure "Ext. Manual Control Signal" HIC 11077
- Indication ERR_OUT_AA01: Load at output AA01 too high (output to antisurge valve)
- Indication RL_SHIFT: Response line has been shifted
- Indication SYSTEM_ERR: PI-Control module failure

3.11 Analog Outputs



4 CONTROLLER OPERATION

4.1 Controller Handling



TAG No. (12-digit)

Multifunction key for indications

Control loop displayed (always "1"); changes with „A" in alarm

Analog display controlled variable X

Analog display setpoint W

Analog display controller output Y

Message line (e.g.: transmitter error)

Actual value (controlled variable)

Display can be changed with „Ind": in AM normal W, in MM normal Y

Controller output

Status Indication

Enter key for acknowledgement

Selector for parameter menus

Manual control keys („raise" and „lower")

The values listed below can be displayed by pushing key 

Sxt: Setpoint in %
Err: Control deviation in %
Out: Controller output in %
FT: Differential pressure in mbar
P2: Discharge pressure in bara
YHi: Internal manual control in % (adjustable with  and )
YHe: External manual control signal in %
DPL: Discharge pressure limitation setpoint in %

For further display and operation options please contact the Protronic 550 manual 42/62-55013.

Status indicators:

1: Controller loaded (active)
2: Ramp on
3: Not used
4: Not used
5: Discharge pressure limitation active
6: Gradient supervision active

4.2 Controller Tuning

The following parameters can be tuned on the controller front display:

- Response line breakpoints
- Non-linear output ramp function breakpoints
- Controller parameters

The structure of the controller software does not allow that all parameters can be tuned in the same way. The different procedures are explained below.

4.2.1 The procedure below explains how to tune the values for

- Response line
- Non linear output ramp
- Discharge pressure limitation setpoint
- Discharge pressure limitation gain
- Dynamic intervention gain
- Response line shifting per surge cycle
- Maximum response line shifting
- Opening increment of gradient supervision

These values are tuned in the following way on the controller front:

1. The controller is in normal operating mode; the tag no. is visible in the text display (root menu).
2. Push ESC Menu -> A new indication is visible in the text display.
3. Push ▼ or ▲ repeatedly until "**Parameter**" is visible in the text display.
4. Push Enter -> a) If the password is active, enter the password according instructions in section 4.3.
   b) If the password is inactive, "**LOOP1**" or "**INSTRUMENT**" is visible in the text display.
5. Push ▼ or ▲ if necessary until "**INSTRUMENT**" is visible in the text display.
6. Push Enter -> One of the table values (TAB 1.0 – 4.10) is visible on the display.
7. Push ▼ or ▲ repeatedly until the requested index is visible in the text display.
8. Push Enter -> The LED to the left of the "Enter"-key lights up red and the last digit of the table value starts flashing.
9. Push Ind repeatedly until the digit which has to be tuned is flashing.
10. Push ▼ or ▲ repeatedly until the requested value is reached.
11. Push Enter to accepted the adjusted value.

    Push ESC Menu to cancel the adjustment.

    -> The LED to the left of the "Enter"-key goes off. Proceed to 7 for another adjustment.
12. When finished, push ESC Menu -> "**INSTRUMENT**" is visible in the text display.
13. Push ESC Menu -> "**Parameter**" is visible in the text display.
14. Push ESC Menu -> The tag no. is visible in the text display.

This list indicates all tunable values:

Address	Name	Function	Units
10	TAB1.0	Response line breakpoint 0	EU = %
11	TAB1.1	Response line breakpoint 1	EU = %
12	TAB1.2	Response line breakpoint 2	EU = %
13	TAB1.3	Response line breakpoint 3	EU = %
14	TAB1.4	Response line breakpoint 4	EU = %
15	TAB1.5	Response line breakpoint 5	EU = %
16	TAB1.6	Response line breakpoint 6	EU = %
17	TAB1.7	Response line breakpoint 7	EU = %
18	TAB1.8	Response line breakpoint 8	EU = %
19	TAB1.9	Response line breakpoint 9	EU = %
20	TAB1.10	Response line breakpoint 10	EU = %
50	TAB3.0	Discharge pressure limitation setpoint	EU = %
51	TAB3.1	Discharge pressure limitation gain	EU = %
52	TAB3.2	Dynamic intervention gain	EU = %
53	TAB3.3	Response line shifting per surge cycle	EU = %
54	TAB3.4	Maximum response line shift	EU = %
55	TAB3.5	Opening increment of gradient supervision	EU = %

The addresses 30.. 40 (TAB2.0 – TAB2.10) are not used.
The addresses 57.. 60 (TAB3.7 – TAB3.10) are not used.
The addresses 70.. 80 (TAB4.0 – TAB4.10) are not used.

4.2.2 Tuning of all other values

1. The controller is in normal operating mode; the tag no. is visible in the text display (root menu).
2. Push  -> A new indication is visible in the text display.
3. Push  or  repeatedly until "**Parameter**" is visible in the text display.
4. Push  -> c) If the password is active, enter the password according instructions in section 4.3.
   d) If the password is inactive, "**LOOP1**" or "**INSTRUMENT**" is visible in the text display.
5. Push  or  if necessary until "**LOOP1**" is visible in the text display.
6. Push  -> One of the tunable values (addresses 1 – 199) is visible on the display.
7. Push  or  repeatedly until the requested index is visible in the text display.
8. Push  -> The LED to the left of the "Enter"-key lights up red and the last digit of the table value starts flashing.
9. Push  repeatedly until the digit which has to be tuned is flashing.
10. Push  or  repeatedly until the requested value is reached.
11. Push  to accepted the adjusted value.

    Push  to cancel the adjustment.

    -> The LED to the left of the "Enter"-key goes off. Proceed to 7 for another adjustment.
12. When finished, push  -> "**LOOP1**" is visible in the text display.
13. Push  -> "**Parameter**" is visible in the text display.
14. Push  -> The tag no. is visible in the text display.

Address	Name	Function	
1	GAIN	Proportional Gain	-
2	RESET TIME	Integral Time	min
67	OUT_MIN	Minimum Controller Output	%
68	OUT_MAX	Maximum Controller Output	%
69	OUT.RAMP +	Asymmetric Output Closing Gradient	%/s
70	OUT.RAMP -	Asymmetric Output Opening Gradient	%/s
77	SP.RAMP +	Ramp increase (LOAD)	EU/s = %/s
79	SP.RAMP -	Ramp decrease (UNLOAD)	EU/s = %/s
91	ALARM1	Margin for response line shifting	EU = %
92	ALARM2	Margin for dynamic intervention	EU = %
93	ALARM3	Margin for gradient supervision	EU = %
94	ALARM4	Gradient limit	EU = %/s

4.3 Password

The default password is "**02004**". The password is required for getting access to the "**INSTRUMENT**" and "**LOOP1**" menus. It remains active for 30 seconds, after leaving from the "**Parameter**" menu to the root menu (tag no. visible). The password can be changed. Please refer to **ABB** operating instructions.

The password has to be entered at the controller front, as soon as the "**Parameter**" menu is called.

1. The controller indicates "**Password: 00000**" in the text display.
   The leftmost digit is flashing.
2. Push 

repeatedly until the digit which has to be adjusted is flashing.
3. Push  or  repeatedly until the requested value is reached.
4. Repeat step 2 and 3 until the correct password is visible in the display.
5. Push 

-> **LOOP1**" or "**INSTRUMENT**" is now visible in the text display.
6. Push 

again to get access to either menu (see sections 4.2.1 step 5 or 4.2.2 step 5)

5 ANTISURGE VALVE

The antisurge valve is equipped with a positioner of proportional action. The positioner compares the incoming setting signal with the travel of the valve spindle and alters its output until correspondence between the setting signal and the valve travel is obtained. The travel is thus rigidly associated with the setting signal, independent of disturbance quantity, such as friction of the valve stuffing box, etc.

The valve actuator is equipped with a solenoid valve. The latter serves for quick opening of the antisurge valve when shutting down the compressor. The solenoid valve receives a signal from the shut-down logic, whereupon it cuts the air delivery to the diaphragm actuator and simultaneously vents the latter to atmosphere so that the antisurge valve opens rapidly.