ANTI SURGE CONTROL
SYSTEM REQUIREMENTS

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ANTI SURGE CONTROL
SYSTEM REQUIREMENTS

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Control System turbolog DSP

Specification

for Anti-Surge Control Systems

supplied by third parties

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20.11.2001 First Issue
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1. Requirements for puchaser supplied anti-surge control systems

MAN-TURBOis one of the companies with the highest number of patents in the field of surge protection. Based on this experience, MAN-TURBO has developed their turbolog DSP fully digital machinery control and monitoring system which includes anti-surge control. turbolog DSP is characterized by its fast response time. turbolog DSP can respond within 1 millisecond to process upsets.

This enables MAN-TURBO to supply a full compressor system including machines, package and controls and monitoring.

If turbolog DSP is not supplied with the compressor, the purchaser has to take care of the anti-surge control. Certain requirements have to be met in order to provide adequate machine protection.

2. System Specification

2.1 Controller Program Execution Time

Program execution time of digital controller is a system dead time which has to be minimised. The Total Program Execution Time (TPET) from change of input signal to change of output signal must be below 50 ms. If a controller with a TPET of more than 5 milliseconds is used, the safety distance between surge line and control line has to be increased over the standard 10% surge flow value in order to meet the safety requirements. Details will be dis-cussed during detail engineeering phase.

2.2 Control Algorithm

Standard PI-Control is not able to provide adequate anti-surge protection. Derivative action can normally not used as certain noise signals are imposed to the flow signal.

Open loop control action which reponds on rapid changes of the operating point need to be included.

2.3 Manual Operation

Automatic surge protection must always have priority over manual operation. Manual access to the anti-surge control valves must go through the anti-surge controller and must not override anti-surge control in closed valve direction.

2.4 Control law

The compressor surge line is defined as a fixed line in the performance map showing head versus inlet volumetric flow. The control law for anti-surge control has to be based on these data.

-

Following data need to be measured to calculate head and flow

- Flow (delta p)
- Discharge pressure
- Suction pressure (not required on air compressors with ambient suction pressure)
- Suction temperature
- Discharge temperature (only if flow measurement is on discharge side)

2.5 Transmitters

Smart type transmitters are not acceptable as they include a dead time. Transmitters with fast response time like Rosemount 1151 have to be used.

If galvanic isolators need to be supplied, analogue type isolators have to be used in order to avoid system dead times.

2.6 Anti-surge valves

The following remarks apply to systems where stable controlled operation on the control line with partial blow-off is required.

Axial flow compressors need hydraulic operated blow-off valves with a controlled opening of 1 to 2 seconds for full stroke (10% stroke in 0.1 to 0.2 seconds).

All other compressors may be equipped with pneumatic operated valves. The cotrolled stroke time has to be less than 6 seconds for full stroke (10% stroke in less than 0.6 seconds). Solenoid operated opening time has to be less than 2 seconds for full stroke.

Anti-surge valves for axial flow compressors have to be sized for 130% of compressor design flow at compressor design pressure.

Anti-surge control valves for certain centrifugal compressors may be designed smaller than those for axial flow compressors. Please check during detail engineering.

2.7 Piping arrangement of Anti-surge valves

For piping arrangement of anti-surge valve please refer to attached data sheet 10000086431.

Pipe routing has to be selected such that the volume between compressor discharge nozzle, anti-surge valves and compressor discharge check valve are as small as possible. Maximum pipe length are given in data sheet 10000086429.

	Datenblatt Strömungsgünstige Anordnung von Pumpgrenzregelventilen	MAN TURBO

A. Max. zulässige Rohrleitungslängen, bzw. Volumina auf der Kompressordruckseite, bis zur Rückschlagklappe, einschließlich der Zuleitung bis zu den Pumpgrenzregelventilen.

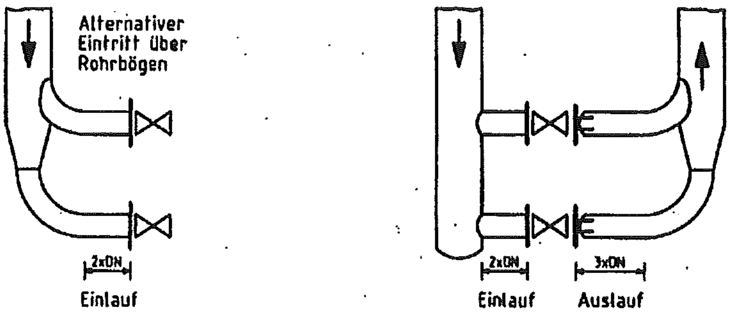
$$Max.Volumen = Auslegungsfördermenge\left[\frac{m^3_{eff}}{s}\right] * Zeit$$

Für die unterschiedlichen Maschinen sind bauartbedingt folgenden Zeiten einzusetzen:

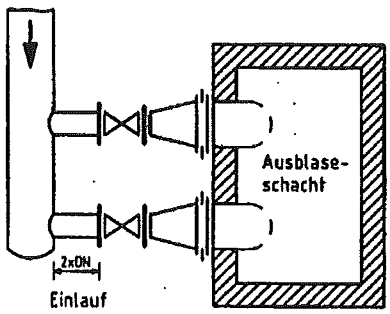
- Axialverdichter 0,5 Sekunden
- Radialverdichter (Deutschland) 1 Sekunde
- Radialverdichter (Schweiz) 2 Sekunden

Falls in Sonderfällen die geforderten Volumina aus zwingenden baulichen Gründen nicht realisierbar sind, ist MTM zu konsultieren.

B. Ventilanordnung bei großer Entfernung zum Abblasekamin



C. Ventilanordnung unmittelbar vor Ausblaseschacht



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	Data sheet Aerodynamically favourable arrangement of surge control valves	MAN TURBO

A. Max. permissible lengths and volumes on compressor discharge side up to check valve, incl. branch to upstream the surge control valve.

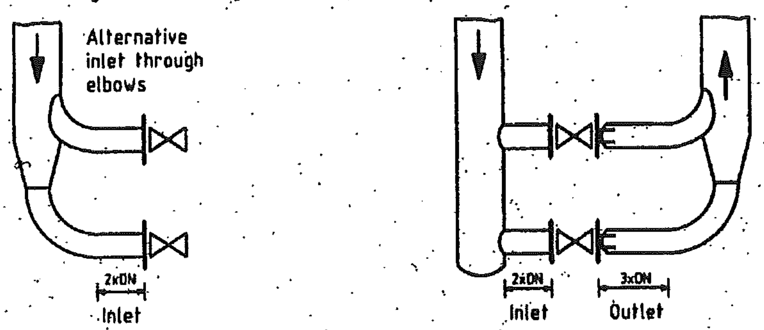
$$Max.Volume = Rated\_Comressorflow\left[\frac{m_{eff}^{3}}{s}\right] * Time$$

For the different types of compressors the following times have to be used:

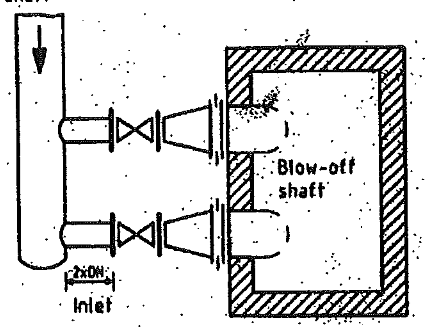
- Axial compressors 0,5 Seconds
- Radial compressors (Germany) 1 Second
- Radial compressors (Swiss) 2 Seconds

Deviations have to be announced to MTM.

B. Valve arrangement with large distance from blow-off stack.



C. Valve arrangement immediately upstream blow-off shaft



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	Datenblatt **Auslegung von Pumpgrenzregelventilen**	MAN TURBO

Auslegungskriterien für Pumpgrenzregelventilen	
Auslegungsmenge	130 % Auslegungsmenge (bei Auslegungsdruck)
Kennlinie	Linear (max. 2 % Linearitätsabweichungen)
Handbetätigung	keine (Maschinenschutz)
Zulässige Leckmenge bei max. Vordruck	Einsitzventile 0,01 % Kvs Doppelsitzventile 0,5% Kvs
Sicherheitsstellung	Feder öffnet, Medium schließt
Stellungsregler	pneumatisch / hydraulisch
Limitierung des Schalldruckpegels	< 112 dB(A) aus mechanischen Gründen

Stellzeiten	**Radialkompressor**	**Axialkompressor**
	Abblaseventile mit pneumatischem Antrieb	Abblaseventile mit hydraulischem Antrieb
geregelte Öffnung	≤ 3 Sekunden (voller Hub)	≤ 1,5 Sekunden (voller Hub)
Schnellöffnung	< 2 Sekunden (voller Hub)	≤ 1 Sekunde (voller Hub)
Schließen	10 ... 20 Sekunden	10 ... 20 Sekunden

<u>**WICHTIG**</u>: Die Lage der Widerstandslinie der Pumpgrenzregelventile im Kennfeld des Kompressors muß auch im Bereich niedriger Drehzahlen unterhalb der Abblaselinie liegen. Um Rotating Stall zu vermeiden, muß der Axialverdichter bei niedrigem Gegendruck angefahren werden. Desweiteren müssen das Abblaseventil und der Abblaseschalldämpfer überdimensioniert werden, damit eine niedrige Widerstandskurve erreicht wird. Bei der Betrachtung der Widerstandslinie müssen alle dem Ventil nachgeschalteten Widerstände (z.B. Rohrleitungen, Schalldämpfer, Diffusoren, etc.) beachtet werden.

Es ist möglich, einen Teil des gesamten Druckgefälles (bis ca. 50%) in eine nachgeschaltete, feste Drossel in Form einer Lochscheibe oder eines Lochkäfigs zu verlagern.

Drosselklappen als Stellorgane für Pumpgrenzregelungen kommen wegen der Nachteile gegenüber Ventilen nur für Enddrücke < 1 barg oder für Radialkompressoren kleinerer Fördermengen in Betracht. Im Vergleich zur streng linearen Charakteristik von Ventilen besitzen Drosselklappen eine mehr oder weniger s-förmige Charakteristik. Deswegen sind Klappen bei kleinen Durchflüssen nicht regelbar. Der sichere Regelbereich reicht von 20° bis 65°-Klappenwinkel. Ferner bildet sich auf der Rückseite des Klappenblattes aufgrund der intensiven Verwirbelung eine hohe Schallenergie aus.

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	Data sheet Design requirements for anti-surge valves	MAN TURBO

Design criteria for anti-surge valves	
Design flowrate	130 % of compressor design flow (at design pressure)
Performance charactericstics	Linear (max. 2 % linearity deviations)
Manual operation	None (machine protection)
Admissible leakage rate with max. supply pressure	Single-seat valves 0.01 % Kvs Double-seat valves 0.5% Kvs
Safety position	Spring opens, Air / Oil closes
Position controller	Pneumatic / Hydraulic
Limitation of sound pressure level	< 112 dB(A) for mechanical reasons

Setting time requirements	Radial-flow compressor	Axial-flow compressor
	Blow-off valves with pneumatic drive	Blow-off valves with hydraulic actuator
Controlled opening	≤ 3 seconds (full stroke)	≤ 1.5 seconds (full stroke)
Quick opening	< 2 seconds (full stroke)	≤ 1 second (full stroke)
Closing	10 ... 20 seconds	10 ... 20 seconds

IMPORTANT: The position of the resistance curve of the anti-surge control valves in the performance characteristics of the compressor has to be below the blow-off line, also in the low-speed range. To avoid rotating stall the axial-flow compressor needs to be started at low discharge pressure. For a low resistance curve the capacity of the blow-off valve and silencer has to be oversized. For the calculation of the resistance curve all downstream resistances (e.g. Piping, Silencers, etc.) have to be taken in account.

It is possible to shift a portion of the total pressure drop (max. 50%) to a firmly installed throttle device arranged downstream of the valve and which has the form of a perforated plate or low-noise cage.

Because of their disadvantages compared to control valves butterfly valves are only considered for use as control units for discharge pressures < 1 barg or for radial-flow compressors of smaller size. Compared to the strictly linear characteristics of control valves butterfly valves have a s-shaped characteristic. Butterfly valves can control a flow in an opening range between 20° up to 65°. Therefore, they do not allow controlled compressor operation at the anti-surge control line. Moreover, a high sound energy develops on the rear side of the disc due to intensive turbulence.

Sheet 1: German / Sheet 2: English

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Control System turbolog DSP

Using DCS Systems

for Compressor Anti-Surge Control

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1. Introduction

Almost every modern process is controlled and monitored by a DCS system. These systems have become more and more powerful in the last years. They provide excellent monitoring functions, include data storage features as well as free programmable control functions. For high-speed control applications, fast response control modules are available which sample the input data 10 times per second.

It is hard to believe that these DCS systems should not be able to protect compressors from surge. The anti-surge control valves have typically stroke times of 2 seconds for a full stroke and process parameter changes are generally very slow.

This article deals with the special requirements of compressor (and turbine) protection systems and how modern DCS system can deal with these requirements.

2. Thousands of compressors are protected by DCS systems and have never been damaged

Statement: Thousands of compressors all over the world are protected by anti-surge control loops as part of the DCS. Most of them have never been damaged or even exposed to a compressor surge. This should prove that DCS anti-surge controls are fully adequate for process gas compressor anti-surge control.

The first part of the statement is surely correct, the second is wrong.

Process gas compressors are tailor made to the process requirements. They are normally designed such that all operating points are located outside the surge area. If the process operates as specified, a compressor will never operate under surge danger. Even no automatic anti-surge control at all will provide the same degree of protection!

Anti-surge control is only required for those applications or those events, where the process does not perform as designed or expected. There are only very few applications where the compressors are designed for operation under partly recycle flow. In all other application, the anti-surge control loop serves as an insurance contract. As long as no event occurs, the insurance with the lowest costs is the best.

The quality of an insurance contract can only be checked under a severe event. The same applies to anti-surge controls.
Not before the compressor has been exposed to the most severe upset, the anti-surge control may be considered adequate.

3. Slow or fast upsets

3.1 Influence of Compressor Performance Map

The performance curves of process gas compressors are often very flat in the vicinity of surge. A typical slope is 10% in the area between anti-surge control line and surge line. A typical diagram is shown in Fig. 1. In some applications, the slope is even flatter.

API asks for a 6% minimum headrise to surge. This means that the compressor head at the surge line must be 6% above the design head. But note that the slope of the performance curve goes flatter and flatter the more the surge line is approached.

The anti-surge control line is typically located 10% to the right of the surge line. This distance is normally referred to the surge flow. As the surge line is typically located between 40% and 80% of full range flow, the safety distance is typically 4% to 8% of full range flow.

In the following considerations, an average surge line location at 60% of full range flow shall be assumed. This means that the safety distance counts to 6% of full range flow.

With a 10% slope, 6% in flow correspond to 0.6% in pressure.

<u>First Thesis:</u> A 0.6% change in pressure will move the compressor operating point from the control line to the surge line.

3.2 What can make the compressor pressure to change by 0.6%

As a first approach, the compressor head and thus the pressure ratio can be considered to be proportional to the square of the speed of rotation.

<u>Second Thesis:</u> A speed reduction of 1.2% brings the compressor operating point from the control line into surge.

The speed range for a compressor is normally limited to the range from 70% to 105 % which is a third of the full range speed.

If the speed raise/lower commands are limited to allow to change the speed within 60 seconds from minimum to maximum or vice versa,
180 seconds are required for a 100% speed change. A change of 1.2% requires only 2.16 seconds.

<u>Third Thesis:</u> Pushing the speed lower button for more than 2.2 seconds drives the compressor operating point from the control line into surge.

The same applies to compressors with variable geometry.

A similar upset may be caused by a compressor operating in series or in parallel with another.

Changing the performance of a series compressor by 0.6% may force the other compressor into surge.

If two compressors are operated in parallel, a slight pressure drop at the discharge of one compressor may force its check valve to close. A full flow drop of 60% of full range flow within 1.5 seconds may follow.

4. Anti-Surge Controller Performance

Anti-Surge controller are used to avoid the compressor from going into surge. To understand the way they work, following explanations should be given.

Typically, anti-surge controller contain a combination of closed loop and open loop control.

The output of the anti-surge controller acts on a recycle or blow-off valve which vents discharge gas to the suction side or to the atmosphere.

Anti-surge control valves have a typical stroke time for a full stroke of 6 seconds under closed loop control and 2 seconds under open loop control. They are typically designed for 70% to 130% of design flow.

Open loop control only acts on special upset conditions. A speed change of 1.2% should not be considered as an upset condition. Thus, only closed loop control has to match this upset.

The normal closed loop anti-surge control algorithm is PI-mode. Derivative action is normally prohibited as the flow signal is always slightly noisy (due to flow turbulence).

The controller output of a PI-Controller is determined by the formula

$$y = KP \cdot xd \left| 1 + \frac{1}{T_N} \quad dt \right|$$

where y is the controller output, KP is the controller Gain, xd is the control error (difference between surge flow and actual flow) and TN isis the resetres is the reset (integral) time constant. TN is typically set to 10 seconds, fast response controller allow to select a Gain KP = 2 to 3.5. For the influence of the controller program execution time (TPET) on the Gain see chapter 5.

With a control error of 6% (distance between control line and surge flow) and a gain of 3, the integral action will change the controller output by 1.8% per second. For fast transient upsets, this integral action has almost no effect. The only protection can be provided by the proportional action.

The proportional action changes the controller output signal and thus the anti-surge control valve position proportional to the Gain KP and the control error xd. In our example, a gain of 2 will open the valve by 12%, when the surge line is reached. If the gain can be increased to 4, the valve opens 24% during the same event.

<u>Fourth Thesis:</u> The response of a controller during fast upsets is proportional to the controller Gain and to the distance between surge line and control line.

5. Controller Gain and Program Execution Time (TPET)

The maximum possible controller gain is determined by the entire anti-surge control loop stability. Dead times need to be avoided. The control valve must be as fast as possible and the valve actuator should respond to any command signal without deadtime and oscillations.

Extended studies have been performed by MAN TURBO in the field of anti-surge controller stability. Both, theoretical calculations as well as simulation studies and field tests have been performed and showed very good consistency. For details please refer to "Ein Beitrag zur digitalen Pumpschutzregelung" from Wilfried Blotenberg.

The faster the controller response, the higher the possible Gain. Analogue or quasi-analogue controller with Total Program Execution Times (TPET) of less than 5 milliseconds allow gains of up to 4. If a TPET of 40 millisecond is used, the maximum gain has to be reduced by 60%. If a controller with 125 milliseconds is used, the maximum gain is limited to 14% of that which could be tuned in immediate response controller. The possible anti-surge controller Gain thus ranges from 0.28 to 0.56.

Let us come back to our example from chapter 4. Even with the highest possible Gain (which can not be used in many applications due to system constraints), the closed loop anti-surge controller within a DCS system will open the anti-surge valve by not more than 3.4% before surge occurs!

Fifth Thesis: A DCS closed loop controller is not able to prevent a compressor surge under transient conditions.

6. DCS systems and open loop control

If closed loop control is not able to prevent a compressor surge, open loop control should be able.

All digital control systems operate in sequence. The input data are sampled, after that, the CPU calculates a new controller output signal as per the control algorithm and after that the valve command signal is updated.

DCS systems typically need 1 second for such a cycle. For all process controls, this is fast enough. For high speed applications, DCS systems allow the program execution time to be reduced to 250 or even 125 milliseconds.

It takes at least one program cycle till the controller responds to a process upset. Under worst conditions, it may take even two cycles.

If the anti-surge valve opens full stroke of up to 130% of design flow in 2 seconds, one program cycle of 125 milliseconds corresponds to 8% in design flow. Two cycles of a 250 millisecond DCS result in 25% of valve stroke or 33% of design flow.
Note: An immediate fast response anti-surge controller has already opened the anti-surge control valve by 33% of design flow, before a DCS system starts to open the valve.

7. When can open loop control be activated

Open loop control improves the performance of fast response controller drastically. With slow response controller like DCS, open loop control must be handled with care.
Within 250 milliseconds, a 2 seconds stroke valve travels 12.5% of its stroke. Please note that this upset could trip many processes.

Open loop control may only be activated after the control line has been crossed more than 3 to 4% of full range flow as flow turbulences may impose a noise level of 2 to 3% to the flow signal.

This allows only a 1 to 2% margin for open loop protection before the compressor goes into surge (Note, the safety distance between surge line and control line is typically 10% in surge flow which correspond to app. 5% full range flow).

As per chapter 3, it takes 0.36 seconds to reduce the flow by 1%. With flatter performance curves, it may take less than 300 milliseconds.

To avoid spurious actions of the open loop control, the open loop control should not just respond to one input variable but should be based on dynamic data. If the compressor is able to surge within 1 to 3 program cycles after having reached the dangerous area, no margin is left for any system response in time.

It should be noted in addition that typically 4 to 5 transmitters are included in an anti-surge control loop and that these transmitters have tolerances and may drift. This has to be considered when selecting the open loop algorithm and the cut-in point.

8. Summary

DCS systems are ideal systems for process control purposes. For high-speed machinery protection systems, they can in no way provide adequate control response. Special controller hardware and special control algorithms are required for these loops.

If a compressor anti-surge control is realized with a DCS system, the safety distance between surge line and control line need to be increased drastically. With a safety distance of more than 30% of surge flow , a DCS system may be able to protect a compressor in case of slow process upsets. But note that this will reduce the compressor part load efficiency by a similar amount. Please note as well that in many applications fast upsets could not at all be avoided.

The best approach for anti-surge control is to use a proven fast response anti-surge control like turbolog DSP.

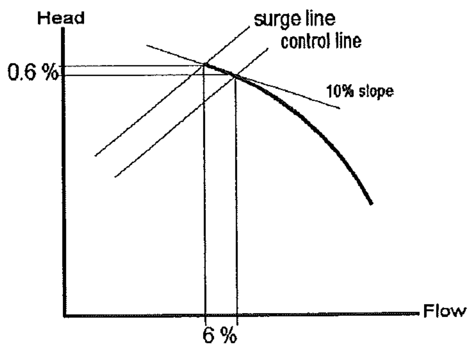

Figure 1 Performance curve