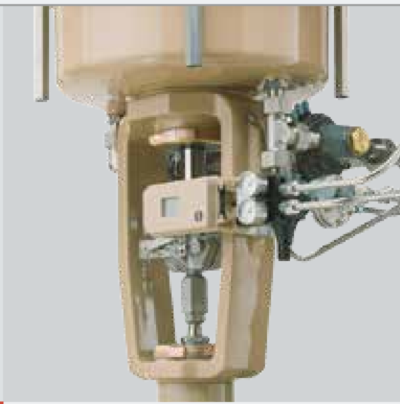
Innovative Control Technology

SPECIAL PRINT

Control Valves with Extremely Fast and Precise Positioning Capabilities



By:
Dr.-Ing. Jörg Kiesbauer
Ulrich Schulz
Uwe Vogel

Special print of German article
published in "Industriearmaturen"
2/2006

SAMSON GROUP

Control Valves with Extremely Fast and Precise Positioning Capabilities

Dr.-Ing. Jörg Kiesbauer, Ulrich Schulz and Uwe Vogel

Industrial processes, such as the Parex™ process in the petrochemical sector or compressor bypass control in the energy sector, place formidable demands on control valves. Valves, some of which fitted with large pneumatic actuators, need to make long strokes very quickly, while they must also be able to handle small stroking movements without overshooting. A new kind of pneumatic valve hook-up with volume boosters and a highly accurate, dynamic digital positioner has been engineered to meet the requirements for these types of processes, providing the valve with excellent control characteristics.

Typical industrial processes

Parex™ process

The Parex™ process [1] is an adsorptive separation method used to recover para-xylene, which is put to use in the production of polyesters or resins, from mixed xylenes. Separating the mixed xylenes by distillation is rather difficult as the xylene isomers boil at almost the same temperature. The Parex™ process developed by UOP simulates a moving adsorbent bed with a continuous counterflow of a liquid feed over the adsorbent, yielding a single-pass recovery rate of over 97 % of para-xylene.

A typical unit consists of 24 adsorbent beds connected to a rotary valve. The rotary valve periodically switches the feed and withdrawal positions. After each switching procedure, two pneumatic control valves regulate the pressure and flow rate of the flows. As the switching processes happen very quickly, it is important that the control valves respond to the changed operating conditions immediately and without overshooting. A good control response of the push-around and pump-around valves is associated directly with an increase in the recovery rate. Apart from the Parex™ process, there are a number of other adsorption processes frequent in petrochemical plants that place similar requirements on control valves.

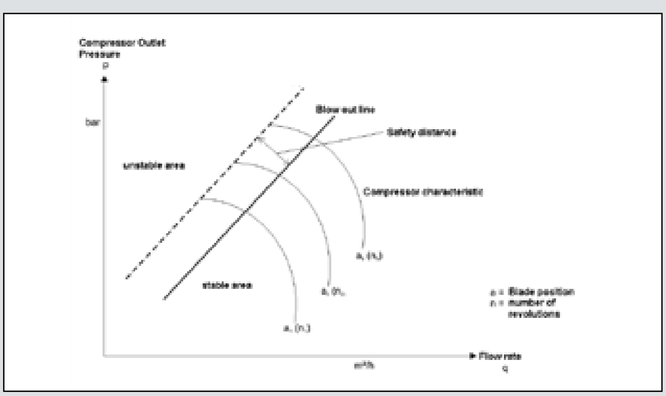


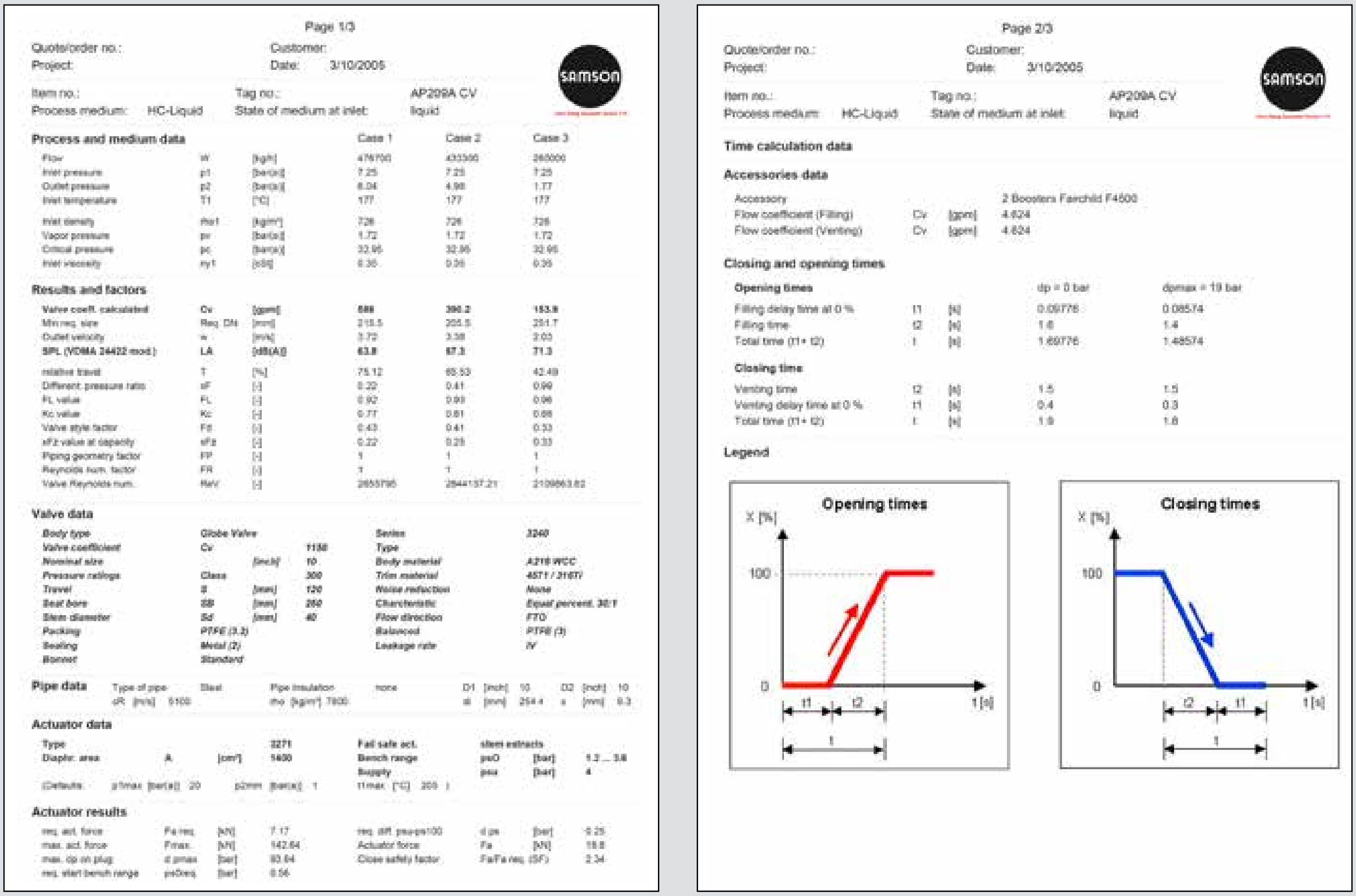
Fig. 1 · Typical pressure-flow rate map of a turbocompressor

Turbine bypass control/surge limit control in turbocompressors

Reducing the feed rate or increasing the feed pressure can cause instable operating conditions in turbocompressors, often referred to as "pumping" (Fig. 1). These conditions become evident as pressure and feed rate fluctuations, which expose the compressor, particularly the blades and bearings, to alternating stress. By using anti-surge valves, a certain volume of the compressed gas is either blown off or fed back to the suction side. For reasons of profitability, operators try to control near the surge margin to minimize losses.

During normal operation, the anti-surge controller has no function and the control valve is closed. It is only in the case of an emergency that the controller needs to intervene immediately because a compressor can reach its surge margin rather quickly. As a result, the typical requirements placed on anti-surge valves include opening times in normal operation of less than three seconds and quick-opening times of under two seconds [2]. The closing times, however, are between 10 and 20 seconds as closing the valve too quickly could cause the compressor to start pumping again.

The dynamic response of the anti-surge valve poses a special challenge, particularly in the case of larger compressors. Due to the large valve sizes and, consequently, large actuators, the air output capacity of the positioners must be increased with volume boosters in the case of high system deviations. This hook-


Page 1/3

Quote/order no.: Customer:
Project: Date: 3/10/2005

Item no.: Tag no.: AP209A CV
Process medium: HC-Liquid State of medium at inlet: liquid

Process and medium data

			Case 1	Case 2	Case 3
Flow	W	[kg/h]	476700	433300	260000
Inlet pressure	p1	[bar(a)]	7.25	7.25	7.25
Outlet pressure	p2	[bar(a)]	6.04	4.98	1.77
Inlet temperature	T1	[°C]	177	177	177
Inlet density	rho1	[kg/m³]	726	726	726
Vapor pressure	pv	[bar(a)]	1.72	1.72	1.72
Critical pressure	pc	[bar(a)]	32.95	32.95	32.95
Inlet viscosity	ny1	[cSt]	0.35	0.35	0.35

Results and factors

Valve coeff. calculated	**Cv**	**[gpm]**	**588**	**390.2**	**153.9**
Min req. size	Req. DN	[mm]	215.5	205.5	201.7
Outlet velocity	w	[m/s]	3.72	3.38	2.03
SPL (VDMA 24422 mod.)	**LA**	**[dB(A)]**	**63.8**	**67.3**	**71.3**
relative travel	T	[%]	75.12	65.53	42.49
Different. pressure ratio	xF	[-]	0.22	0.41	0.99
FL value	FL	[-]	0.92	0.93	0.96
Kc value	Kc	[-]	0.77	0.81	0.88
Valve style factor	Fd	[-]	0.43	0.41	0.33
xFz value at capacity	xFz	[-]	0.22	0.25	0.33
Piping geometry factor	FP	[-]	1	1	1
Reynolds num. factor	FR	[-]	1	1	1
Valve Reynolds num.	ReV	[-]	2655795	2644137.21	2109863.62

Valve data

Body type	*Globe Valve*			*Series*	*3240*
Valve coefficient	*Cv*		*1150*	*Type*	
Nominal size		*[inch]*	*10*	*Body material*	*A216 WCC*
Pressure ratings	*Class*		*300*	*Trim material*	*4571 / 316Ti*
Travel	*S*	*[mm]*	*120*	*Noise reduction*	*None*
Seat bore	*SB*	*[mm]*	*250*	*Characteristic*	*Equal percent. 30:1*
Stem diameter	*Sd*	*[mm]*	*40*	*Flow direction*	*FTO*
Packing	*PTFE (3.2)*			*Balanced*	*PTFE (3)*
Sealing	*Metal (2)*			*Leakage rate*	*IV*
Bonnet	*Standard*				

Pipe data Type of pipe Steel Pipe insulation none D1 [inch] 10 D2 [inch] 10
cR [m/s] 5100 rho [kg/m³] 7800 di [mm] 254.4 s [mm] 9.3

Actuator data

Type			3271	Fail safe act.	stem extracts		
Diaphr. area	A	[cm²]	1400	Bench range	psO	[bar]	1.2 ... 3.8
				Supply	psu	[bar]	4

(Defaults: p1max [bar(a)] 20 p2min [bar(a)] 1 t1max [°C] 205)

Actuator results

req. act. force	Fa req.	[kN]	7.17	req. diff. psu-ps100	d ps	[bar]	0.25
max. act. force	Fmax.	[kN]	142.64	Actuator force	Fa	[kN]	16.8
max. dp on plug	d pmax	[bar]	93.84	Close safety factor	Fa/Fa req. (SF)		2.34
req. start bench range	ps0req.	[bar]	0.56				

Page 2/3

Quote/order no.: Customer:
Project: Date: 3/10/2005

Item no.: Tag no.: AP209A CV
Process medium: HC-Liquid State of medium at inlet: liquid

Time calculation data

Accessories data

Accessory			2 Boosters Fairchild F4500
Flow coefficient (Filling)	Cv	[gpm]	4.624
Flow coefficient (Venting)	Cv	[gpm]	4.624

Closing and opening times

Opening times			dp = 0 bar	dpmax = 19 bar
Filling delay time at 0 %	t1	[s]	0.09776	0.08574
Filling time	t2	[s]	1.6	1.4
Total time (t1+ t2)	t	[s]	1.69776	1.48574
Closing time				
Venting time	t2	[s]	1.5	1.5
Venting delay time at 0 %	t1	[s]	0.4	0.3
Total time (t1+ t2)	t	[s]	1.9	1.8

Legend

Fig. 2 · Control valve sizing sheet including calculation of the opening and closing times

up, however, has the disadvantage that the required positioning times can only be achieved with considerable overshooting. In addition, simple hook-ups with positioner and booster respond poorly to small changes of the set point. As a result, such small changes can only be controlled in an unsatisfactory way.

Control valve sizing and selection

In a first step, control valves for any kind of process need to be sized very carefully using the common methods according to IEC 60534 (Fig. 2a). Concerning the dynamic response, the following criteria need to be fulfilled, for example in a Parex™ process:

- Step-response behavior: The response time including delay for step changes between 5 and 50 % in both directions over the entire positioning range from 0 to 100 % must not exceed two seconds and no overshooting must occur.
- Control response: During normal automatic operation, the control valve is expected to respond even to small changes of the positioner input signal within ten seconds.
- Closing and opening times: The closing and opening times over the control valve's entire opening range must not exceed two seconds.

These requirements can only be met with a special pneumatic hook-up of the positioner and the boosters required in this case, which will be detailed in the following sections. When sizing the valves, it should be possible to select the number of boosters required to achieve the specified times (Fig. 2b).

Control valve engineering and design

The positioner includes a control loop subordinate to the main control loop that is designed to precisely and quickly open the control valve over the entire opening range of 0 to 100 %. The set point for this loop is set by the main loop of the process control system to control process variables, such as pressure, temperature, flow rate, or liquid level.
To control the valve opening, the electropneumatic positioner requires an electric power supply, a set point signal (4 to 20 mA or a bus signal), and an air supply that should be as constant as possible. Depending on the system deviation, the positioner pressurizes or vents the diaphragm chamber of the pneumatic actuator, which is mostly equipped with one or more springs arranged on the opposite side of the diaphragm to provide fail-safe action. The positioning speed changes depending on the positioner's air output capacity.
For larger valve sizes (larger than 4") and, consequently, higher flow forces acting on the valve plug, there is a need to use actuators with larger effective diaphragm areas (e.g. 1400 or 2800 cm^2) and larger rated travels (e.g. 120 mm) as shown in Fig. 3. As a result, the volumes in the actuator to be pressurized or vented are relatively high and the positioning speed is reduced considerably.
To counteract this problem, the positioner is combined with volume boosters (Fig. 4). The positioner increases or reduces the air pressure on the inlet diaphragm of the booster such that the booster pressurizes or vents the actual actuator with larger air passage cross-sections when system deviations occur.
The boosters are usually equipped with an adjustable bypass restriction to stabilize the positioning control loop.
When the bypass restriction is closed, the positioner increases or reduces the air pressure on the diaphragm of the booster, which pressurizes or vents the pneumatic actuator correspondingly. Using the valve position feedback, the positioner changes

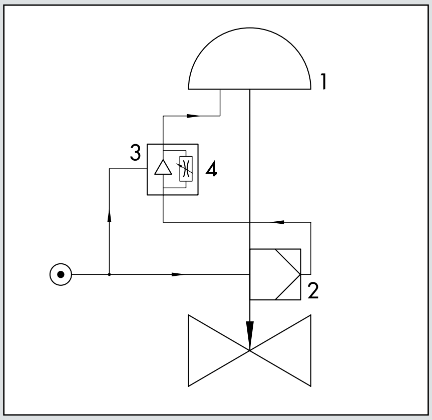


Fig. 4 · Control valve with booster
1 Valve with actuator
2 Positioner
3 Booster
4 Bypass restriction

Fig. 5 · Valve shown in Fig. 3 as installed in the plant (new pneumatic hook-up visible in the foreground)

Fig. 3 · Control valve with large pneumatic actuator and digital positioner (SAMSON Type 3730-3 Expert+) for Parex™ process applications

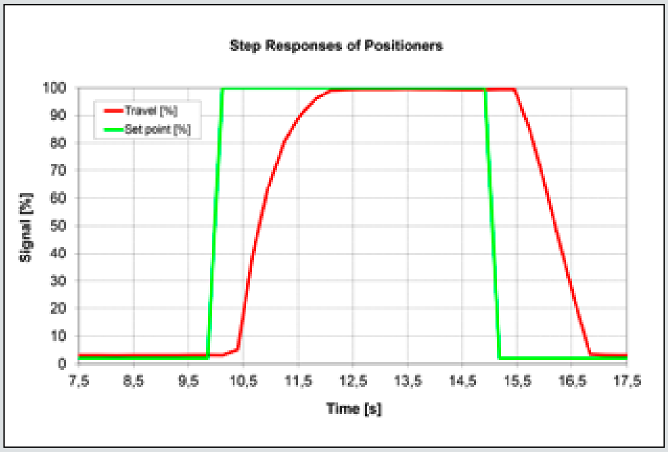


Fig. 6 · Opening and closing behavior with times of approx. 2 s

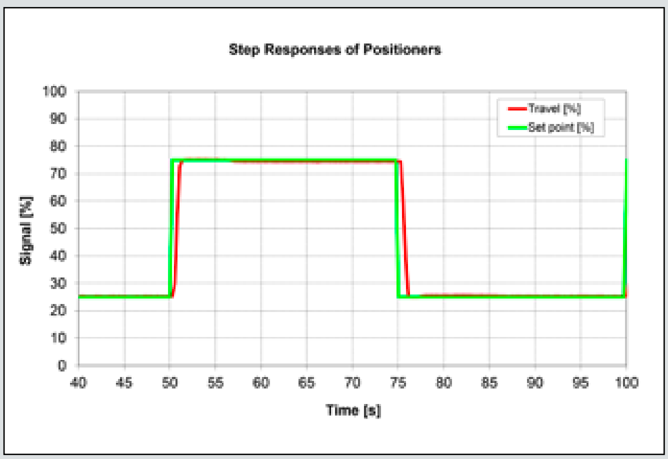


Fig. 7 · Response to 50 % step changes (response time < 2 s)

its pneumatic output signal until the system deviation approaches zero. As in all other control loops, the high air output capacity of the booster can destabilize the control loop.
As a result, the bypass restriction is usually open. Small system deviations cause the positioner to work with very small air outputs and the generated air bypasses the booster, which, due to its natural hysteresis, does not respond. The actuator is directly pressurized or vented by the positioner until a new state of equilibrium has been reached. The position of the bypass restriction determines the set point changing range that the booster does not operate in. Within this range, the response times to changes of the set point can be too long. Another disadvantage is that the opening speeds for large set point changes (e.g. from 0 to 100 %) are reduced when the bypass restriction is opened too far.
Problems may arise here since it can be rather difficult in practice to determine the optimum setting, weighing instability against sufficiently small system deviations that even out quickly.
The new pneumatic hook-up (Fig. 5), together with a digital positioner, considerably improves the dynamic control response.
The hook-up uses a pilot booster and a main booster for larger signal changes near the set point. All boosters are equipped with a bypass restriction.
The air output capacity of the pilot booster is considerably higher than that of the positioner, yet also considerably smaller than that of the main booster. As a result, the positioner and pilot booster cause the main booster to respond much quicker when

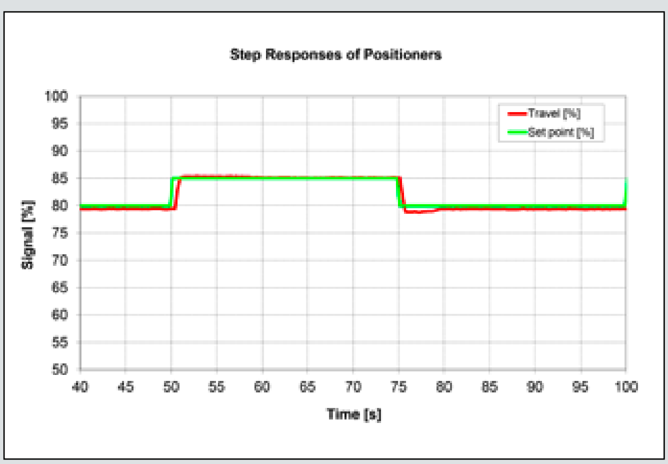


Fig. 8 · Response to 5 % step changes (response time < 2 s)

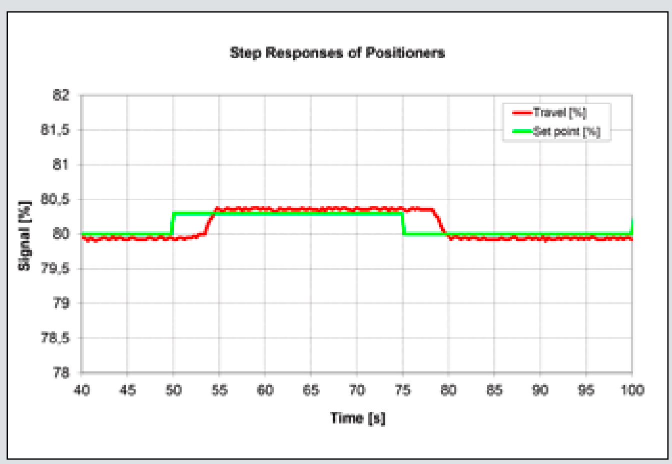


Fig. 9 · Response to 0.3 % step changes (response time < 5 s)

pressurizing or venting the actuator. Consequently, the bypass restrictions can be opened further, which leads to better stability and control accuracy in the control loop, without causing marked overshooting.
Nevertheless, this hook-up reaches the limits for response speed when handling very small signal changes below ±2 %. A solution to this is to install an additional bypass booster connected in parallel with the main loop. The boosters in the main loop do not respond to small signal changes. Rather, the positioner together with the bypass booster control on their own.
The new hook-up with digital positioner, bypass booster as well as pilot and main boosters helps achieve a control behavior in valves with large pneumatic actuators that is characterized by a very dynamic response with short response times as well as a high control accuracy, even with small set point changes (Figs. 6 to 9).

Excellent dynamic control response in the running process

Of course, the main task of the digital positioner is to position quickly and precisely according to the requirements as well as to optimally and automatically set the proper control parameters in combination with the complex new pneumatic hook-up including volume boosters. In the examined processes, the digital positioner introduced in publication [3] was used. This positioner has a very favorable combination of digital and analog components for signal processing, acting as the preliminary stage to the internal volume booster. The positioner has a control loop performance tuner on board, so to speak, and, unlike devices from other manufacturers, does not require an external software to optimally adapt itself to the pneumatic system. This allows service personnel to start up plants quickly and smoothly after completing service or maintenance work.
Moreover, customers use the extended on-board and online diagnostic functions that the positioner can additionally perform during operation [3].
Important information could be gathered from the histograms of the valve position (operating range, Fig. 10) and the steady-state error (Fig. 11) saved in the positioner. The results demonstrated that the error averaged out at very good values between 0.2 and 0.5 %.

The permanent online data logger in the positioner was used to document and analyze the excellent dynamic control response during the process (Figs. 12a and b). The unparalleled control response also in plant operation becomes obvious.
In offline mode, the positioner can even record its step-change response (Figs. 6 to 9).

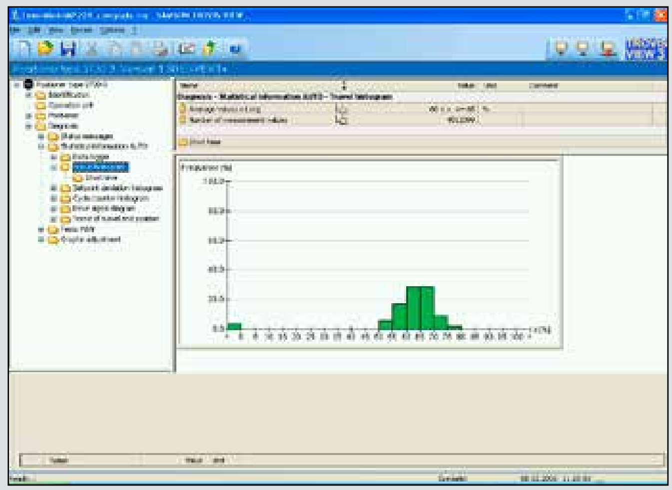


Fig. 10 · Long-term operating range data of the control valve between 50 and 80 % (on-board diagnostics provided by digital positioner)

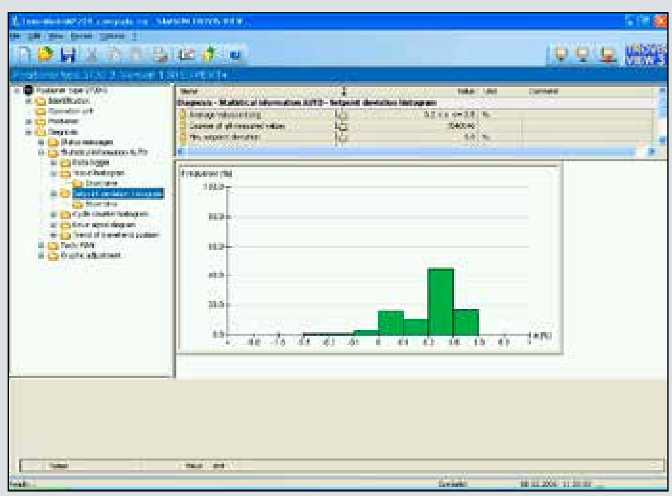


Fig. 11 · Long-term control accuracy data with typical values between 0.2 and 0.5 % (on-board diagnostics provided by digital positioner)

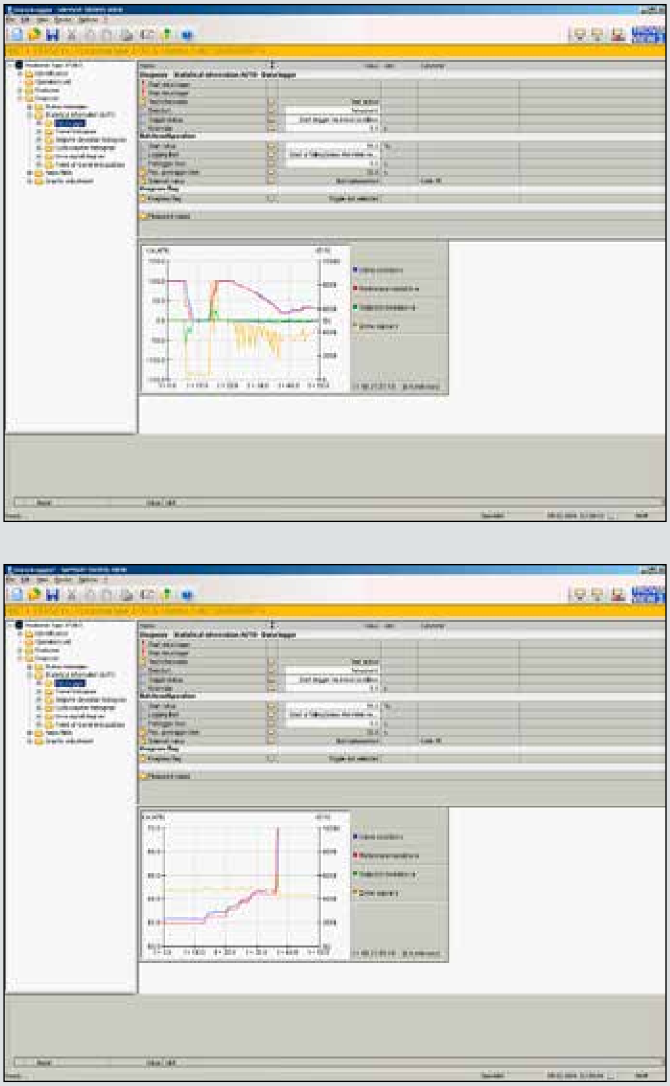


Fig. 12 · Data recorded by the permanent data logger

Conclusion and outlook

Thanks to the pneumatic hook-up comprising a highly precise and quick digital positioner as well as the innovative arrangement of various volume boosters, control valves in demanding control applications, such as Parex™ processes or compressor bypass control, can control with high precision both with large and small signal changes. One operator, Mr. Wolfgang Brans at SASOL Moers, Germany, equipped two valves already installed in a plant with a hook-up as described above. After restarting the plant, Mr. Brans remarked how the restart of the Olex™ process went very smoothly and worked at first go, just like he had imagined. According to him, the new hook-up even reduced the initial differential pressure of the adsorbents by 0.5 bar, i.e. from 3.5 bar gauge (which was problematic) to 3.0 bar gauge.

Reference

[1] UOP Parex™ Process: http://www.uop.com, Process Technology and Equipment. UOP 4217-9

[2] Breckner, K.: Schäden vermeiden durch Pumpgrenzregelung bei Turboverdichtern. Chemie Anlagen und Verfahren cav 2/97

[3] Kiesbauer, J.: New integrated diagnostics strategy for digital positioners.

Dr. Jörg Kiesbauer
Director, R&D Technology and Logistics
SAMSON AG, Frankfurt am Main
Phone: +49 69 4009-1464
drjkiesbauer@samson.de

Ulrich Schulz
R&D, Pneumatics
SAMSON AG, Frankfurt am Main
Phone: +49 69 4009-1663
uschulz@samson.de

Uwe Vogel
Product Management, Control Valves and Pneumatics
SAMSON AG, Frankfurt am Main
Phone: +49 69 4009-1223
uvogel@samson.de

Where Innovation is Tradition

SAMSON AG · MESS- UND REGELTECHNIK · Weismüllerstraße 3 · 60314 Frankfurt am Main, Germany
Phone: +49 69 4009-0 · Fax: +49 69 4009-1507 · E-mail: samson@samson.de · Internet: www.samson.de
SAMSON GROUP · www.samsongroup.net

2014-07 HD · WA 173 EN