SAMSON

Control valve design aspects for critical applications in petrochemical plants

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By:
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Control valve design aspects for critical applications in petrochemical plants – part I

By Dipl. Ing. Holger Siemers, SAMSON AG

With three decades of experience in demanding applications, Mr Siemers has a deep appreciation of developments and trends in sizing control valves. In this paper, he reviews the past, present and future of valve design and sizing, taking all-important issues such as increasing cost pressure and time pressure into account. This paper is presented in two parts: firstly, how to use manufacturer independent software to analyze given or calculated plant parameters in more detail from an overall point of view with a complete power check and optimizing possibilities. Some case studies are also discussed. The second section, scheduled for a future issue, includes information on to design, size and use severe service control valves with good performance for long maintenance intervals. Different philosophies of valve design (plug design), pressure balance systems, stem sealing, actuator sizing, cost philosophies for "high end" applications are discussed.

Control valve design and sizing:

Part I

1. Accurate sizing & software tools
2. Energy saving by plant and valve optimization
3. Debottlenecking: Can the old valve do the new job ?

Part II

4. Predictable troubles with control valve sizing in case of sub-critical flow conditions and in case of flashing.
5. Control valve failures & troubleshooting.
6. The hidden valve enemy: Critical outlet velocities need to take priority

Part III

7. Fugitive emissions philosophies for control valves
8. Actuator sizing philosophies
9. Control valve design and cost philosophies for "high end" applications

The past, present and future of valve design and sizing

Control valves - the workhorses of the control loop - mostly have to convert to 1 to 5 kW heat power (the typical pump power in chemical plants) and, furthermore, in the HPI sector to a range between 5 to 200,000 kW heat power - the typical power range with high performance pumps, flow machines or the total plant power - blocked by flare shut-off valves and control valves. From an economical point of view, these valves often operate more or less successfully under high stress load, characterized by additional expenditure for noise-reducing insulation and devices or maintenance, or should severe problems arise, plant downtime, i.e. low or high cost of ownership.
The following priorities concerning valves are often specified by end users in the HPI sector:
safety and reliability
control quality
environmental aspects
trouble-free life cycles and lowest cost of ownership.
End users increasingly complain about maintenance costs and the amount of spare parts required which are often the highest after-sales cost factors. Nowadays, the contradiction often arises that consultants are under significant pressure to keep costs low and opt for other priorities:
lowest cost of investment
just meeting the specification
Just meeting the warranty time
e-bidding and e-purchasing.

In the oil and gas market sector, many valves are high power [Δp x flow] converters and in combination with fluid corrosion and fluid contamination the valve body and trim may be parts subject to wear. Time is often all-important during the initial phase involving the planning, bidding and ordering of the control valves these days. Unfortunately, this results in valves being selected with a tremendous loss in detail engineering, yet at the same time, the technical responsibility has been shifted to the valve manufacturer.
Typical for urgent projects is that, to avoid penalties, it is taken into account that some control valves are destroyed during the start-up process even in large projects, whereas during a traditional start-up process, a trouble-free commissioning is guaranteed by replacing any critical valves with fittings and flushing the plant beforehand. A tremendous scope of difficulties can influence the project's success if planning mistakes are first detected at this stage because the process condition calculations were too inaccurate or the control valve selection was "quick and dirty." Questions that arise here are: "who is responsible for plant safety?" and "has e-commerce (e.g. e-bidding and e-purchasing) taken place too quickly for severe service control valves or valves with key functions?"The shorter decision time linked to anonymous bidding could mean that key valve features such as plant safe-

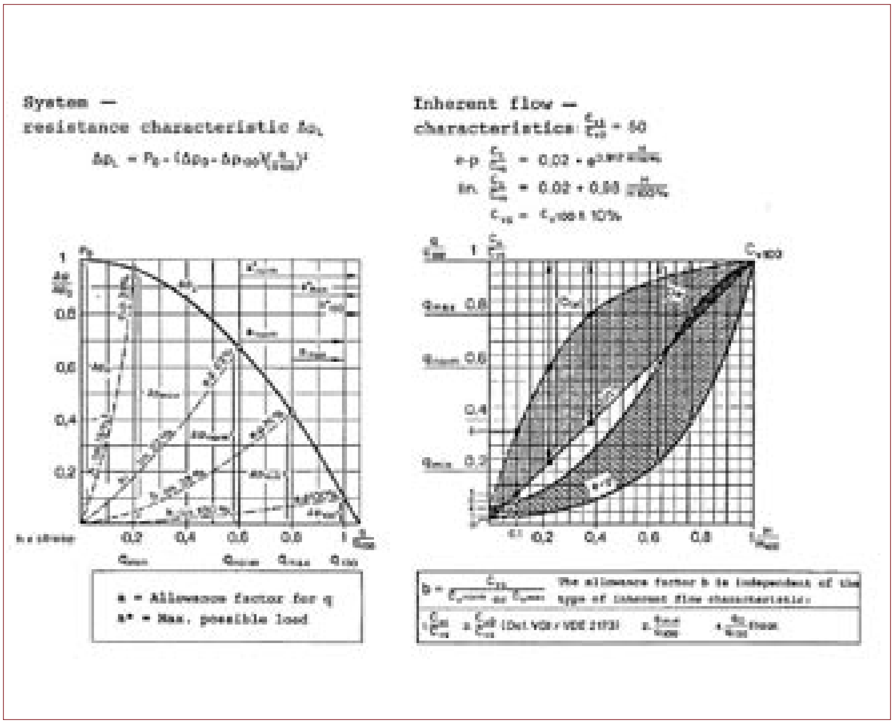


Fig. 1: Calculating installed valve characteristic schemes. Δp versus flow and Flow; Cv versus travel.

ty, control quality and process long-term targets are easily bypassed.
From the valve manufacturer's point of view, the situation is a challenge with regards to fulfilling both aspects concerning competitiveness and reliability. Many well-known company brand names and their valve products are disappearing or have merged to form large conglomerates. The process of the "synergy effect" continues more or less successfully. It should be clear that the chronicle of plant disasters will never cease, but the risk should not be allowed to increase because valves intended for severe service are being sized and selected in a "quick and dirty" fashion without involving time-consuming detail engineering. The question arises: can a happy medium be found to meet the demands of both current and future interests?
From experience gained from the increasing amount of troubleshooting required in petrochemical plants and refineries over past few years, the conclusion that must be drawn is that it is important to make sure that modern lightweight globe and rotary valves are only chosen within their limited range of application. In the recent past, only heavy-duty valves such as high performance cage-guided or top and bottom guided globe valves fitted the total range of applications. For less severe applications these were over-engineered. Pressure to reduce costs meant that this valve generation was replaced in the lower application field by lightweight, inexpensive valves. Low and high performance butterfly valves and other quarter-turn products have been developed for typical market segments.
Rotary plug valves can save costs when they replace globe valves, but there is also a risk if engineering competence for critical applications is missing. Time and effort must be spent measuring new valve products on test rigs before they can be launched onto the market. Operating data limits above test rig possibilities are often detected by troubleshooting experiences or trial-and-error methods. Typical valve characteristics have to be published as stipulated in international standards like the EN IEC 60534. The individual measurements of the actual valve factors or their approximations are stored in in-house software of competent valve companies.
Cavitation and flashing combined with the influence of the valve outlet velocity of pure liquid or liquid/vapor phase can cause severe trouble and, in the worst case, cause plant shutdown. Some experiences in this area are published in Chapter 6.
Most potential problems can be predicted by using highly sophisticated software when the operating limits are known and the load-specific valve characteristics cv, xFz, Fl, xT, Fd are provided by the valve companies. Warning indicators can be activated to indicate a point in a selected system of valves and pipeline where mechanical overload occurs due too high velocities or forces or where the noise level does not comply with the stipulated requirements.

1. Accurate Sizing & Software Tools

The CONVAL® 6 software treats the plant and valve sizing parameters from an overall point of view, issuing dynamic graphics with installed characteristics concerning flow, power, gain and outlet velocity as a function of the valve coefficient cv value and the valve travel. The software is a manufacturer independent optimization tool for pipelines and pipe devices (Figure 2a), including material and property database for more than 1,000 substances including hydrocarbons. Ethylene, propylene, chlorine, natural gas AGA 8 and sixty other industrial fluids are calculated very accurately using equations of state developed by the Ruhr University of Bochum (see www.conval.de for more details).
If operating conditions are given with one, two or three operating points the plant system is defined in the standardized differential pres-

CONVAL®
...by F.I.R.S.T.

Tool for sizing, calculation and optimization of common plant components:

- Control valves
- Steam conditioning valves
- Actuator forces
- Differential pressure flow elements
- Restriction orifice plates
- Safety relief valves
- Tank depressurization
- Pressure loss
- Pressure surge
- **Pipes:**
  - Sizing
  - Pipe compensation
  - Span calculation
  - Pipe wall thickness
- Shell-and –tube heat exchanger
- Condensers
- Pump motor output

Supported by vendor independent device databases (control valves, safety relief valves), fluid property calculation, material databases, …

Fig. 2a: CONVAL Tool description.

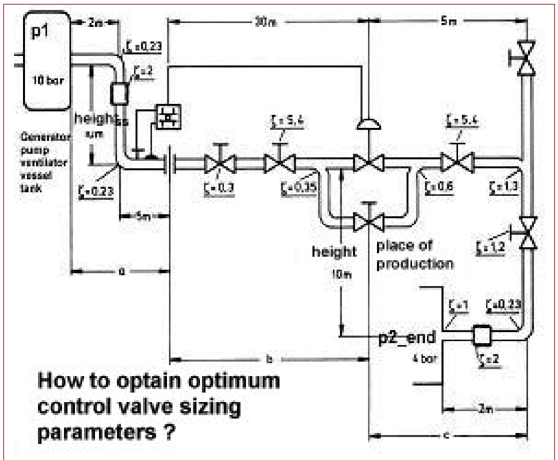


Fig. 3a: Typical plant layout (simplified) in a chemical or petrochemical plant.

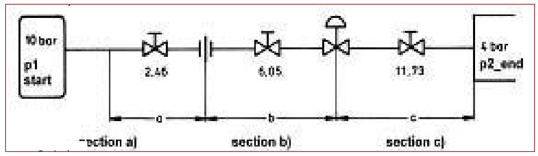


Fig. 3b: Same plant layout, split into three sections to show pressure losses.

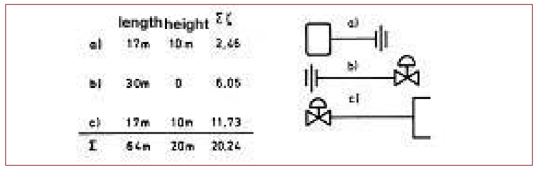


Fig. 3c: Input values of the pressure loss plant system.

Special valve manufacturer software is available and is mainly used for proprietary control valve series and their special demands. Programs can store several thousand pieces of valve data like cv characteristics, noise data and noise correction measurements and related functions of valve recovery factors based on flow lab data. Specific actuator sizing or special sizing methods for mixtures and the flashing outlet conditions are available as well as having links to quotations, pricing, drawing software and to the production units.

Box 1: In-house valve sizing program

sure versus flow diagram at the left-hand side (see Figure 1). The inherent cv-characteristic of any valve as well as all other valve characteristics xFz, Fl, xT, Fd, a.s.o. are stored in a large valve data base in the form of equations or polynomial coefficients. Every valve installed characteristic like flow, gain and valve authority, sound, inlet and outlet velocity, as well as cavitation, flashing, and choke flow areas are presented in graphic form on the right-hand side. A dynamic ruler publishes all results including alarms and hints at any valve travel position. The program combines expert valve sizing with powerful plant optimization and trouble shooting.

The software provides a bi-directional COM link to spreadsheets and CAE systems (Figure 2b) as well as in-house valve sizing programs (Box 1) which companies can use to store valve data e.g. sound measurements, administration of inquiry and quotation systems as well as pricing and drawings.

2) Energy saving by plant and valve optimization

The first case study shows many aspects of plant optimizing and presents methods to obtain the most important parameters for control valve sizing at two or, even better, three operating points. An exceptional amount of over 50 % of power and costs could be saved if plant design, pipes and pipe devices such as control valves were to be sized more rationally.[1]

Lower power consumption of control valves reduces the cost of investment by using standard valve series without noise abatement devices and increases the life cycle because of the reduced amount of wear of the throttling valve parts.

Saving energy means recalculating our figures with a lower start pressure of p0 = 6 bar and optimizing the pipeline and all the pipe devices. The result is, on the one hand, a change

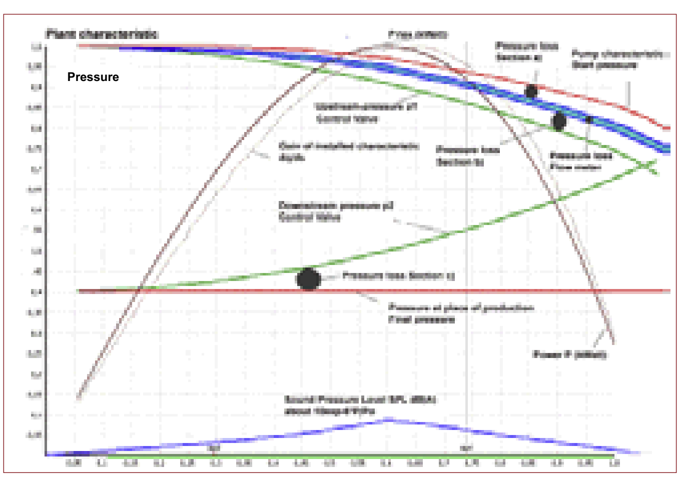


Fig. 4: Case study 1 - pressure/flow diagram with additional data on valve power and gain characteristic.

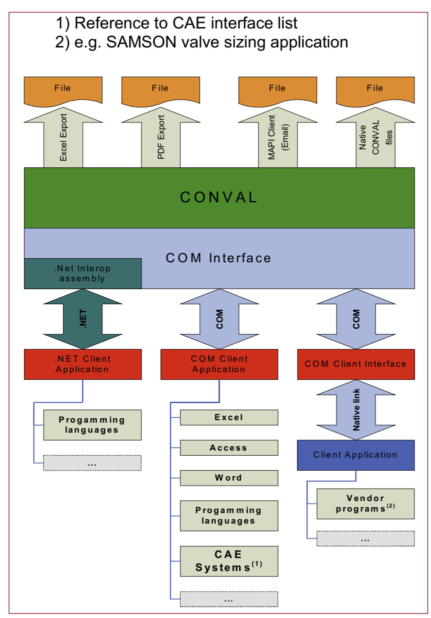


Figure 2b: The following CAE tools provide a bi-directional interface to CONVAL® 6.0:

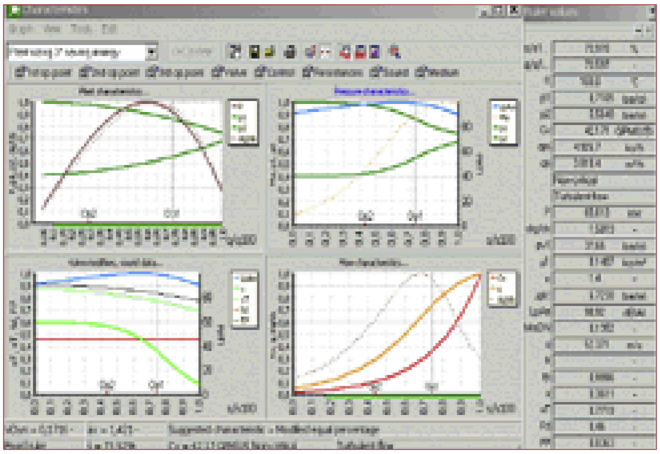


Fig. 5: Valve and control loop optimization with operating conditions from Table 1. Start pressure 10 bar.

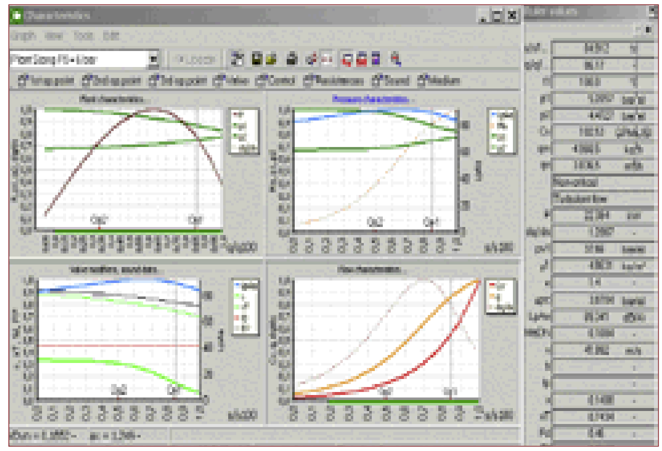


Fig. 6: Valve and control loop optimization with operating conditions from Table 2. Start pressure 6 bar.

from a DN 3" to a DN 4" pipe system including the pipe devices. On the other hand, focusing on the control valve's operating point qmax again, the power consumption is reduced from 60 to 20.3 kW and the total energy cost from USD 69,445 down to USD 31,203. That equates to an annual savings of roughly USD 38,282.*

The noise from the control valve is reduced from 98 dB(A) to 88 dB(A) with the lower power consumption. Therefore the cost for the larger pipes and their devices are compensated for as there is no need for any noise abatement device in the valve and the maintenance costs are significantly reduced as well.

The plant layout is simplified in Figure 3a and split up into three sections in Figure 3b to show the pressure loss of the devices from the start pressure P0=10 bar_abs. For example, in Figure 3b, section a refers to the distance between the tank or pump and the flow meter orifice. The next section, section b, takes into consideration the distance between the flow meter and the control valve. Finally, section c represents the distance downstream of the control valve to the place of production with the plant end pressure of p_end = 4 bar_abs. Figure 3c summarizes all input values of the pressure loss plant system in this case study for a compressible fluid: dry air at a temperature of 100 °C.

After this preparation, the features of CONVAL can work out how to obtain optimum control valve sizing parameters in less than 30 minutes and, moreover, it can optimize control loop parameters as well as power, energy and cost parameters as shown in Figures 5 & 6.

*regional average 1999.

The plant pressure loss calculation of Figure 3 results to the characteristics of up- and downstream pressures; valve power consumption and gain - $\Delta q/\Delta s$ - versus flow shown in Figure 4.

Table 1 lists the different pressures for the normal and the more important max. flow rate, often the main operating point of process control. The control valve calculation shows a

	Flow q [kg/h]	Qnorm kg/h 2000		Qmax kg/h 5000	
Pressure loss calculation of pipe		**Case a)**	**Case b)**	**Case a)**	**Case b)**
Section a)	p1 bar_abs	10	6	10	6
	p2 bar_abs	9.937	5.973	9.65	5.866
	Power [kWatt]	0.3664	0.257	5.005	3.253
Optimization of flow meters					
	p1 bar_abs	9.937	5.973	9.65	5.866
	p2 bar_abs	9.894	5.916	9.374	5.479
	Power [kWatt]	0.242	0.541	4.21	9.59
Pressure loss calculation of pipe					
Section b)	p1 bar_abs	9.894	5.916	9.374	5.479
	p2 bar_abs	9.879	5.873	8.668	5.193
	Power [kWatt]	0.584	0.401	10.83	7.436
Examine the pressure differential of the control valve = p2 section b) - p1 section c)					
	p1 bar_abs	4.3	4.09	5.61	4.48
	p2 bar_abs	3.999	4.0	4.02	4
	Power [kWatt]	3.9	1.134	45	15.33
Operation conditions of the control valve:					
	p1 bar_abs	9.879	5.873	8.668	5.193
	p2 bar_abs	4.3	4.09	5.61	4.48
Control valve sizing and optimisation					
	Cv - Value	12.37	24.7	40.6	101.2
	Sound Pressure Level SPL dB(A)	97	90	98	89
	Power [kWatt]	45.4	19.8	59.3	20.3
Total balance of power and energy and yearly consumption cost					
	Power [kWatt]	50.49	22.1	124.34	55.91
	Energy [kWatth] yearly	403,93	177,04	994,77	447,28
*without grade of electrical effectiveness of the flow machine	Yearly consumption cost Approx. 2001	15,850	12,368 USD	69,494 Saving: 38,295 USD/year	31,246 USD

Table 2: Power and energy optimization of a plant Comparison of results with different start-up pressures case a) 10 bar or case b) 6 bar

power consumption of 60 kWatt and a predicted sound pressure level SPL of 98 dB (A).

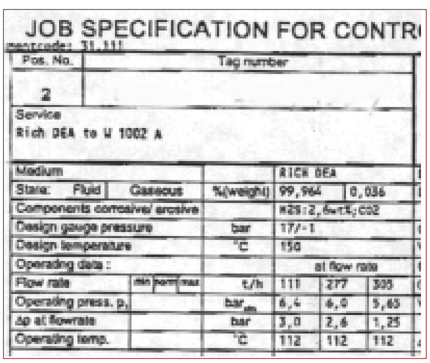
Flow	q kg/h	2000	5000
Pressure	p1 bar_abs	9.879	8.668
Pressure	p2 bar_abs	4.3	5.61

Table 1: Control valve optimization from an overall point of view.

3. Debottle-necking: can the old valve do the new job?

When looking to increase the productivity of an existing plant, engineers have to take control valves into account. This second case study for an existing application to control a liquid medium flow presents the troubleshooting measures to increase a plant's productivity to meet current market demands.

This example looks at an existing 8" cage valve (Figures 7 and 8) optimized for 85 dB (A) with an additional multi-hole baffle (Figure 12) and provides an easy method to obtain new valve parameters without having to start a new time-consuming total plant pressure loss cal-


JOB SPECIFICATION FOR CONTR

Pos. No.	Tag number				
2					
Service	Rich DEA to W 1002 A				
Medium			RICH DEA		
State: Fluid / Gaseous	%(weight)		99,964	0,036	
Components corrosive/ erosive			H2S:2,6wt%;CO2		
Design gauge pressure	bar		17/-1		
Design temperature	°C		150		
Operating data :			at flow rate		
Flow rate	t/h		111	277	305
Operating press. p1	bar		6,4	6,0	5,83
Δp at flowrate	bar		3,0	2,6	1,25
Operating temp.	°C		112	112	112

Fig. 7: Case study 2: The old specification data.

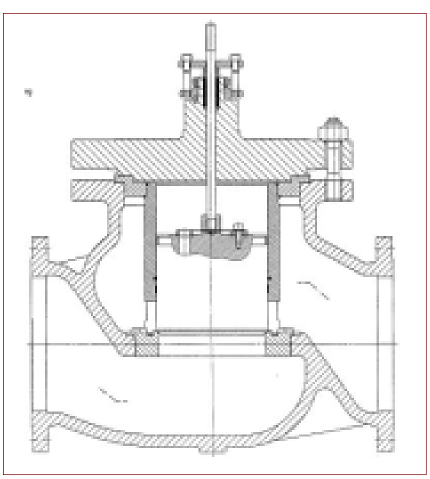


Fig. 8: Case study 2: The old 8" cage pressure-balanced control valve.

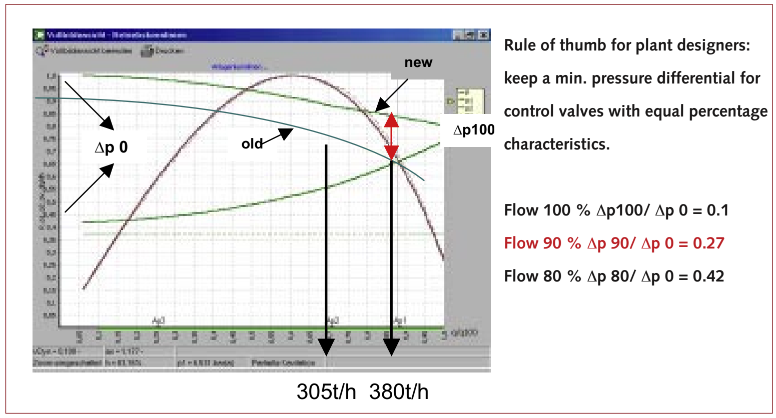


Fig. 9: Case study 2: Old and new upstream pressure line to increase the flow.

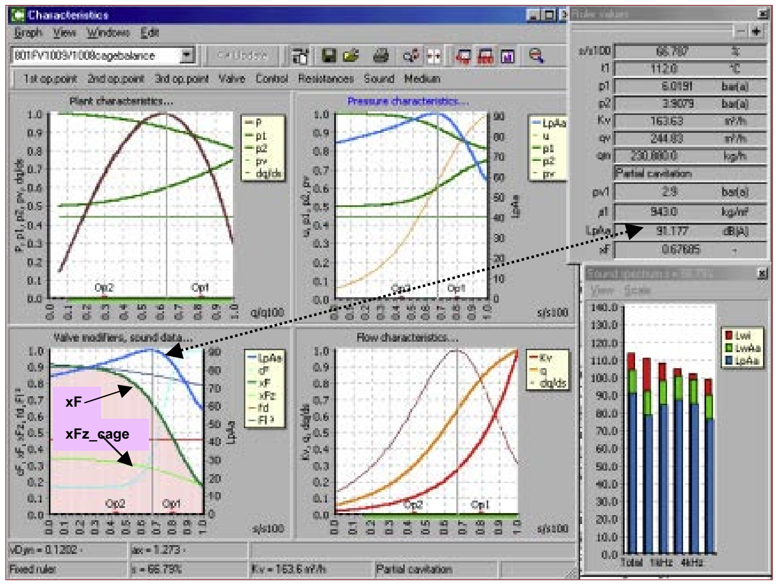


Fig. 10: Case study 2: Calculation of the cage retained seat valve with max. SPL [LpAa] > 91 dB(A).

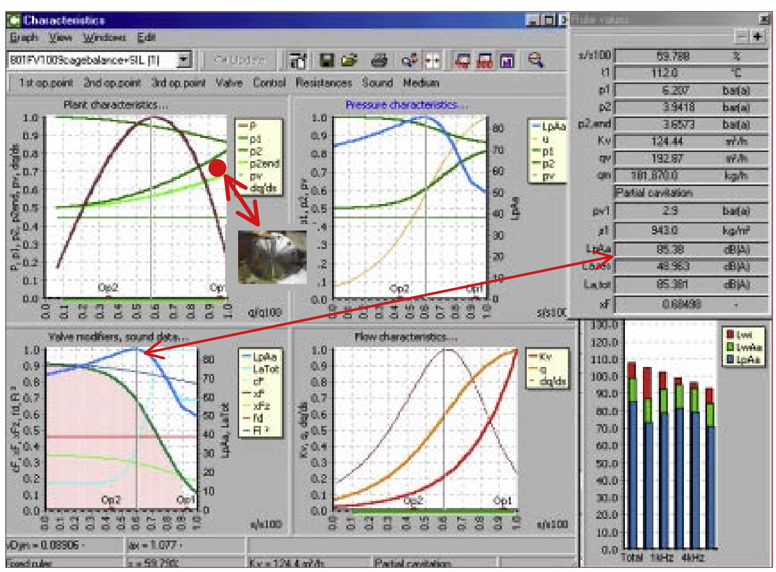


Fig. 11: Case study 2: Sizing of the existing cage valve with multi-hole baffle to reduce the noise from 91 to 85 dB(A).

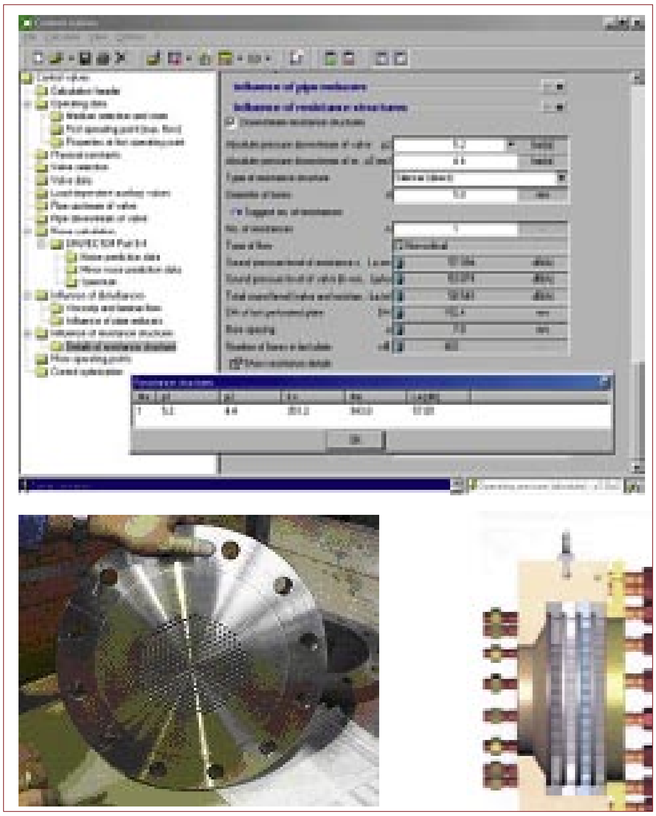


Fig. 12: Case study 2: Calculation and construction of downstream resistance structures like single and multi-baffles.

Fig. 13: Case study 2: CFD optimization of anti-cavitation trim design - computer flow simulation. Shown is SAMSON's AC Trim I System Parabolic plug top and seat guided. Seat and plug CFD optimized.

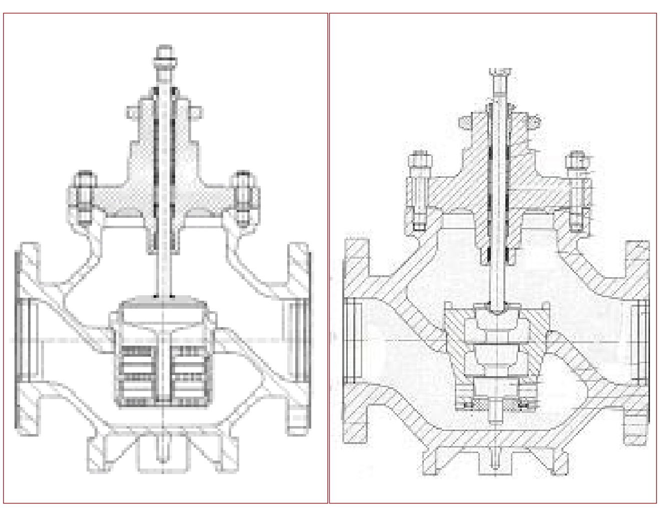


Fig. 14: Case Study 2: AC Trim System. The result of flow research (patent pending) Natural low noise, dirt and vibration insensitive. Top and seat guided low noise parabolic trim, no risk of stroke blocking.

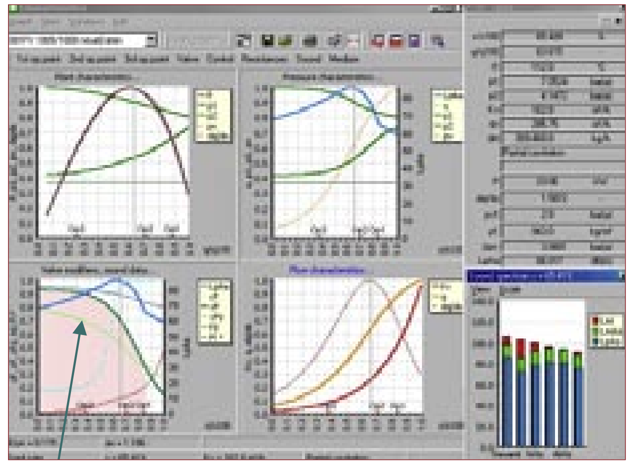


Fig. 15: Case Study 2: Sound optimisation for < 85 dB(A) noise limit with the unique AC Trim System and highest xFz characteristic of control valves today.

culation. At least with just one more powerful pump the new operating point can be kept controllable. However, severe cavitation increases the noise to 96 dB (A) with the existing control valve. The unique new development of an anti-cavitation trim "AC Trim System" can solve cavitation problems and reduce the sound < 85 dB (A) within the entire control range (see Chapter 5).

The software provides the user with new calculation methods including graphic supports to help check the control valve performance as well as leading to the most economic solution to reduce noise (Figures 9, 10 and 11).

The question arises: can the existing control valve be updated taking noise limitation of 85 dB(A) into account ?

The case study is based on a real situation where the productivity had to be increased, while keeping the noise level (SPL) within the existing regulations. If the old DN 8" valve just fulfilled the noise requirements of 85 dB(A) by using a baffle or silencer, then the solution for the revised valve presents a real challenge.

The cage retained seat valve has been operating for some five years without complaints, but cannot be used after debottle-necking to control 30% more flow because of increasing sound-pressure-level > 95 dB(A). The new pump-impeller increases the power to such a level that there is no economic solution available with the old valve. Fortunately the development and research program of SAMSON AG has presented the unique anti-cavitation AC Trim System. This fulfils the 85 dB(A) requirement and replaces the existing cage trim design (Figures 13 and 14).

Successful debottle-necking after increasing the pump power (Figure 15)

The new pump impeller increases the plant upstream pressure and the power and noise as well. The old cage valve now generates 96 dB(A). There is no chance to keep the low noise level with the existing valve. The new valve with AC Trim System shows no cavitation at the operating point 380t/h 65 dB(A) and less cavitation < 85 dB(A) in the entire range of control. ■

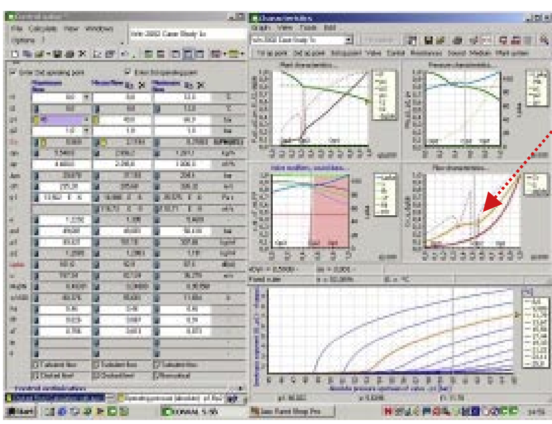
Control valve design aspects for critical applications in petrochemical plants – part II

By Dipl. Ing. Holger Siemers, SAMSON AG

This second section of Mr Holger Siemers article on control valve design and sizing continues on from part I, which can be found in the June 2004 issue of Valve World. This section presents information on design, size and use of severe service control valves, the kind of troubles that can be predicted with control valve sizing as well as suggestions for troubleshooting control valve failures. The final section, part III, will be ready and waiting in the upcoming October issue.

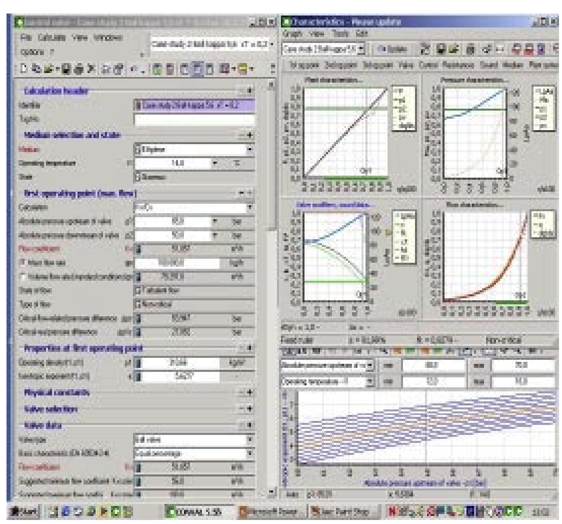
4) Predictable troubles with control valve sizing in case of sub-critical flow conditions

It is well-known that sensitive valve sizing areas exist with supercritical gases and slightly sub-cooled or non-sub-cooled liquids (flashing). Vapors and gases are calculated with the isentropic exponent k as one of the property values. Some hydrocarbons, e.g. ethylene, are near or above the "critical points t_ crit. and p_crit." during the process.



Critical flow

Predictable control instability, if application data are near the critical point because of sudden change of density and isentropic exponent.



Not critical flow

Incorrect result:
Cv calc = 81
xT = 0.2
at operating point
wrong κ=1.2

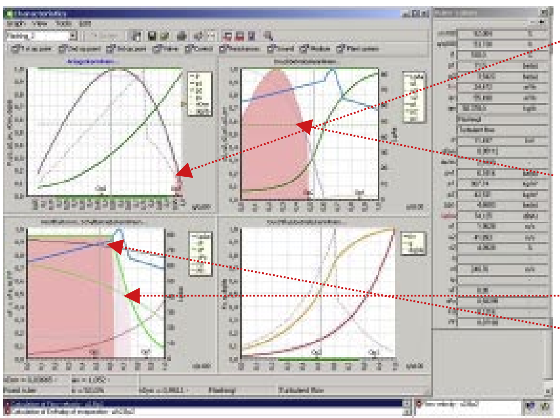
Correct result:
Cv calc= 59
with
κ = 5.6 !

Range of κ from p1 = 60 to 70 bar and t1 from 12 to 16 °C

Fig. 16: Sensitive sizing areas in case of supercritical flow "isentropic exponent above the critical point" > 2

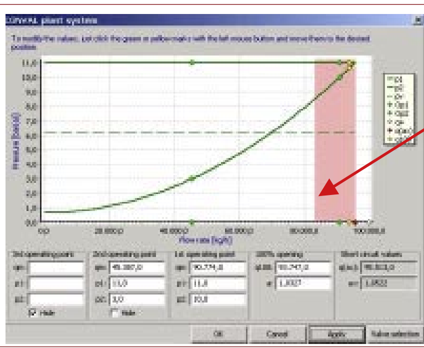
The sizing standard IEC 60534 2-1 includes an information table with typical isentropic exponents used for steam and gas sizing. The total range $1 < k < 2$ is well-known for all compressible fluids. However, it is less-well-known that values $2 < k < 20$ exist with supercritical fluids near and above the property critical point.

We would like to introduce this matter with the help of latest development in precise property calculation, published at the Ruhr University of Bochum for more than 60 industrial gases and integrated into the CONVAL“ software.
The third case study shows tremendous sizing differences in flow calculation for an ethylene application at the critical point of properties by using the real isentropic exponent >> 2. This can have a negative influence on plant safety valves and other devices. In the past, devices for supercritical flows were oversized because the wrong isentropic exponents and “choked flow limits” were used. We are interested to start an open discussion on how to define and handle this phenomenon and on how to validate it with measurements.



1)*Red area: Planning error: Loss of control quality at operating point qmax, see Fig. 18
Valve authority too small to control qmax related to: SHELL DEP 32.36.01.17.-GEN
2)*Red area: Selection error
Flashing with outlet velocities > 60 m/s, risk of mechanical damage, pipe vibration. Larger DN is recommended, if control < Op2
3)Light red area: cavitation start if xF > xFz
4)Red area: choked flow, max. cavitation or flashing start, if xF >Fl²

Fig. 17: Example of warning indicators in a hot water application to indicate the onset of cavitation and flashing at smaller loads. If not controlled below Op2 no risk, if often control smaller loads < Op2, valve DN too small.



*Red area: Planning error leads to reduced control quality at operating point qmax
Valve authority Vdyn too small to control qmax: CONVAL red area alarm if:
$V_{dyn} = \Delta p\_q90 / \Delta p\_0 < 0{,}27$;
$qmax > 0{,}9q\_100$

Input of one to three operating points. Illogical characteristics can be corrected by picking up an operating point and shifting the point to the logical place. This helps to avoid time-consuming plant system pressure loss calculations.
The red area shows here that Op. 1 is near the max. plant system flow –short circuit performance- and the valve pressure drop

Fig. 18: Dynamic plant system: – pressure versus flow-
***Red area: Planning error: Loss of control quality at operating point qmax. Valve authority too small to control qmax. Optimised, following: SHELL DEP 32.36.01.17.-GEN (Design and Engineering Practise)**

1-Butene	Diethylether	Isohexan	Pentane	R125
Air	Diisopropyl	Isopentan	Phenol	R134a
Ammonia	Dipropylether	Krypton	Propane	R141b
Argon	Ethane	Methane	Propylbenzol	R142b
Benzene	Ethylbenzol	Methanol	Propylene	R143a
Butane	Ethylene	Natural gas	SF6	R152a
Carbon	Fluorine	(AGA8)	Toluene	R218
monoxide	Helium	Neon	Water	R22
Carbon dioxide	Heptane	Neopentan	Xenon	R23
Chlorine	Hexane	Nitrogen	R11	R32
Cyclohexane	Hydrogen	Nitrous oxide	R113	R41
Cyclopentan	Hydrogensulphi	Nonane	R12	
Cyclopropan	de	Octane	R123	
Decane	Isobutane	Oxygen	R124	

Table 3: Available substances calculated with thermodynamic equations

Fig. 19: Typical damage due to cavitation if pressure differential > 20 bar. Feedwater control valve mismatched for start-up 70 to 1 bar.

Fig. 20: Damage due to flashing if p2 << pv and v2 >> 60 m/s.

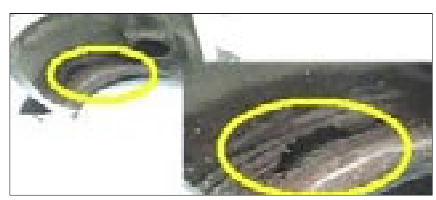


Fig. 21: Damage due to a rotary plug body due to cavitation v2 >> 5 m/s.

Fig. 22: Damage due to steam pressure letdown Ma >> 1.

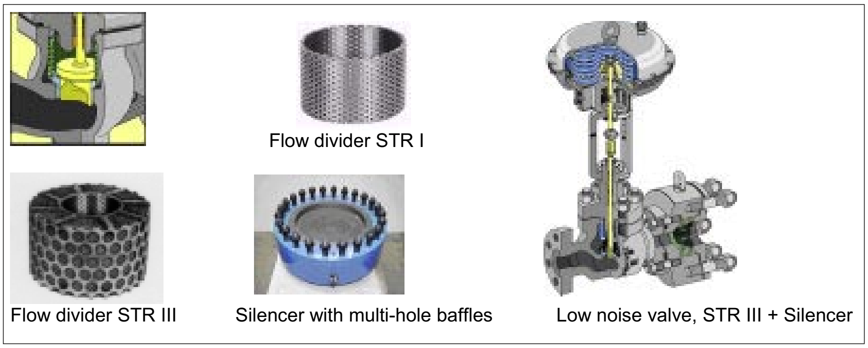


Fig. 23: The simplified noise abatement system used for compressible fluids.

Predictable troubles with control valve sizing in case of flashing as well as installation cost saving which results in poor planning parameters

Figure 17 shows an example of warning indicators in a hot water application to indicate the onset of cavitation and flashing at smaller loads. If not controlled below Op2 no risk, if often control smaller loads <Op2, valve DN too small.

Fig. 24: AC Trim I System.

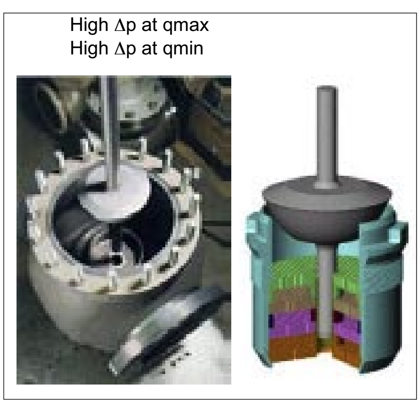


Fig. 25: AC Trim II System

CONVAL calculates real thermodynamic flashing conditions with about sixty hydrocarbons [see Table 3] and recommends the minimum valve DN to avoid critical outlet velocities. The calculations resemble steam table mathematics. This is based on a reliable source, the "Lehrstuhl für Thermodynamik Fakultät für Maschinenbau der Ruhr-Universität Bochum"

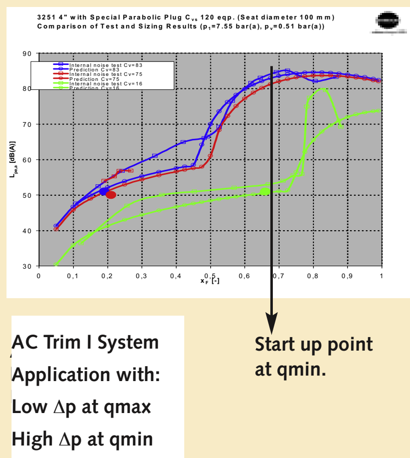
www.ruhr-uni-bochum.de/themo/index-eng.htm

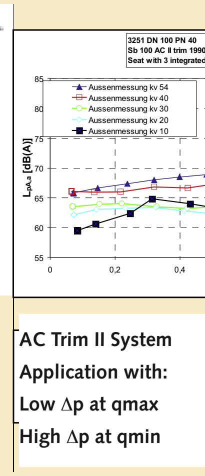
Installation cost saving which results to poor planning parameters

Detecting planning mistakes: qmax > 0.9 q100, Δp at qmax too small. See Figure 18.

5) Control valve failure and troubleshooting.

Ranging from seat guided V-port to CFD optimized trims and their applications. There are different solutions to avoid critical sound and mechanical valve failure (see Figures 19 through 22). This section introduces anti-cavitation valve trim designs [2] and noise attenua-





p1 [bar]	11	11	11
p2 [bar]	4	4	4
pv [bar]	0.01	0.01	0.01
Q [m^3/h]	30	108	144
rho [kg/m^3]	835	835	835
kv ges [m^3/h]	10.36	37.3	49.73
Lp [dB(A)]	< 70	< 70	< 70
xF	0.64	0.64	0.64

Fig. 26: Case history: application with low Δp at qmax and high Δp at qmin. Troubleshooting for an acetic acid plant, replaciong a noisy cage valve >> 85 dB(A) at a petrochemical plant in Hull (UK) with an AC Trim I System. The requirements were to avoid cavitation in the range of control in case of corrosive fluids. XFz > 0.75 at critical min. flow.

Fig 27: Case history: application with high Δp at qmax and high Δp at qmin. Troubleshooting for a gasoline loading station at a refinery in Hamburg (Germany) with AC Trim II System and the requirement to reduce SPL > 90 dB(A) to < 70 dB(A) in the entire range of control. XFz > 0.75 in the total range of control.

Globe valve type	X_{Fz} for valve 75% load	X_{Fz} for valve << 75% load	Resistance to contamination	Vibration behavior
Parabolic plug	0.25 to 0.35	clearly up to 0.8	high	poor for single-guided plugs
Piston-balanced plug with cage	0.25 to 0.35	up to 0.5	low	good
V-port plug	0.25 to 0.35	up to 0.5	high	excellent
Perforated plug	0.25 to 0.35	0.25 to 0.35	low	good
AC Trim System	0.35 to 0.5	clearly up to 0.85	high	good

Table 4: Different trim designs and their advantages and disadvantages in severe service applications.

tion devices and discuss their advantages and disadvantages as well as their application limits. Note that too high velocities at the valve moving parts and at valve outlet are mainly responsible for valve failure especially where corrosive fluids are handled.

SAMSON AG offers under strong limitations of valve outlet velocities and other parameters the high performance V-port trim for general service; flow dividers I and III and downstream low noise devices for gas and steam pressure letdown. See Figure 23.
If the V-port trim sound pressure level (SPL) is not acceptable for liquid applications or cavitation and corrosion must be avoided in general, the unique AC Trim System is recommended (see Figures 24 and 25) with top and seat guided plug; it is vibration-free and dirt-insensitive. The max. pressure differential 25 to 40 bar depends on the fluid properties. For case histories of troubleshooting with the AC Trim system , please see Figures 26 and 27. Further, Table 4 gives an overview of the advantages and disadvantages of different trim designs.


Fig. 28: AC Trim III System.

AC Trim III system multistage design

The AC Trim III System is ideal for liquid application to avoid cavitaion, wear and noise (see Figuire 28). Features include top and seat guided plug, vibration free and dirt-insensitive, with/without pressure balance, pressure dfferential 25 up to 120 bar; AC Trim V System-5 stages-120 bar $< \Delta p <$200 bar. Three and five stages in the cv range from Cv =1 (3 stages) to Cv=116 from DN 1 to DN 6 inch in globe and angle type valves are used in case of severe cavitation problems e.g. high Δp together with a larger control range qmin to qmax. Typical applications are feed-water start-up valves, refinery valves, snow gun valves, injection valves, boiler applications, high pressure letdown service, etc.

6) The hidden valve enemy: Critical outlet velocities need to take priority

Beating "quick and dirty" sizing philosophies, if selecting too small valve DN taking only the calculated Cv value into account. High flow capacity valves (Cv/DN^2) need to be selected with care when critical operation conditions are involved. Rule of thumb to avoid mix phase flow: in case of pv equal or near to p1 avoid 20xDN any pipe restriction at valve upstream, no elbows, no manual valves, no pipe reducers.
Sensitive sizing areas special valve DN selection by giving priority to the outlet velocity condition of cavitation and flashing in liquid application and gas and steam pressure letdown, taking important piping parameters into account.
In case of flashing conditions, the average outlet velocity has to be calculated for the mixture of liquid and wet steam or vapour. Severe pipe vibration and valve damage can be avoided if the valve outlet diameter restricts the outlet velocity to less than 60 m/s (average of 0.7 Ma of mixture sonic speed). SAMSON has developed equations of state for flashing outlet velocities used in CONVAL for all fluids in Table 3. ■

To be continued.

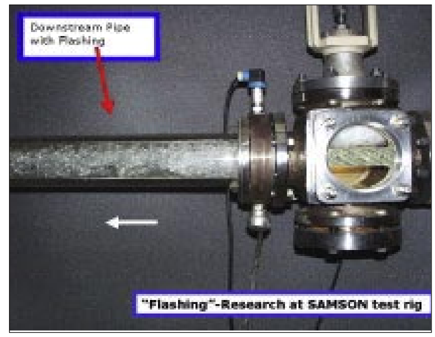


Fig. 29: Flashing Photo SAMSON AG test rig [2]

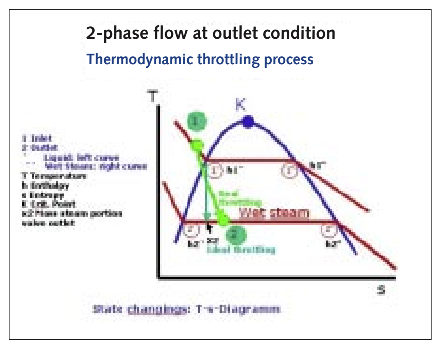


Fig. 30: The thermodynamic flashing process. T = temperature; s = entropy; K = critical point.


Fig. 31: Plant shutdown due to "quick and dirty" sizing with 8 inch rotary plug valve and too small DN.
Non-subcooled naphtha p1 = pv.
The application requires a 12 inch valve to avoid the risk of sonic speed "choked flow" at the valve outlet.

Valve design	K_C	$\Delta p_{crit,cav}$ [bar]
Single-stage globe valves with stellited or hardened valve plug and seat	0.7	25
Single-stage globe valves with standard materials	0.7	15
Rotary plug valves (with eccentric spherical disk)	0.4	10
Butterfly and ball valves	0.2-0.3	5

Table 5: Recommendations to reduce cavitation erosion [2]. Using table 5 for non-corrosive liquids with cavitation: $X_F > X_{Fz}$
- **Outlet velocity should not exceed 2m/s to max 5m/s depends on valve design**
- **Low vibration valve plug design like seat, cage or top and bottom guided plugs.**
- **Low cavitation erosion: $\Delta p < K_C \cdot (p1-pv)$ or $\Delta p < \Delta pcrit,cav$, if $\Delta p > K_C \cdot (p1-pv)$!**
- **Cavitation erosion: $\Delta p > K_C \cdot (p1-pv)$ and $\Delta p > 25$ bar -> multistage globe valves (like AC Trim III System)**

Control valve design aspects for critical applications in petrochemical plants – part III

By Dipl. Ing. Holger Siemers, SAMSON AG

7) Fugitive emissions philosophies for control valves

It is interesting to compare the use of the bellows seal design versus low emission packing material. The bellows seal design seems to have been forgotten in international discussions and published papers, but it is still unbeatable as regards its life cycle and tightness quality. In the “world of valves” under the requirements of fugitive emissions approximately 5% are control valves.

This means about 95% valves are on-off devices like gate, cock or ball valves. Most often, they remain static in the open or closed position. Only a very small percentage are cycled or part of a dynamic process. For the majority of on-off valves that are equipped with bellows seal, the bellows are designed only for some thousands cycles.

Control valves can be components of high dynamic processes with most valves controlling to a set point. Hence they move around the operating point, with the valve stroke moving

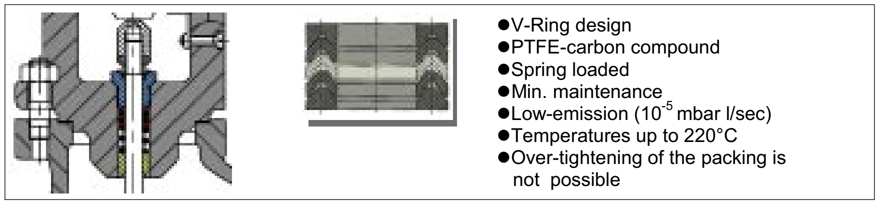


Fig. 32: Standard stuffing box design

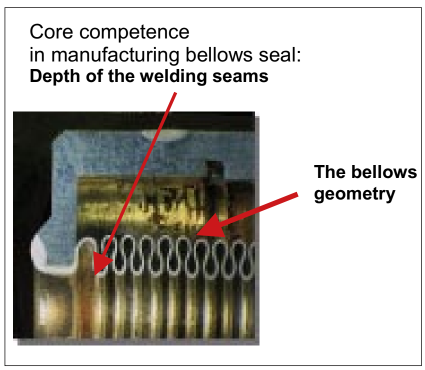


Fig. 33: Precise production of the bellows geometry seams is assured by testing macro sections.

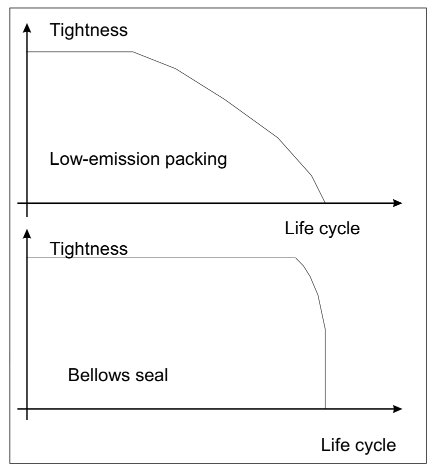
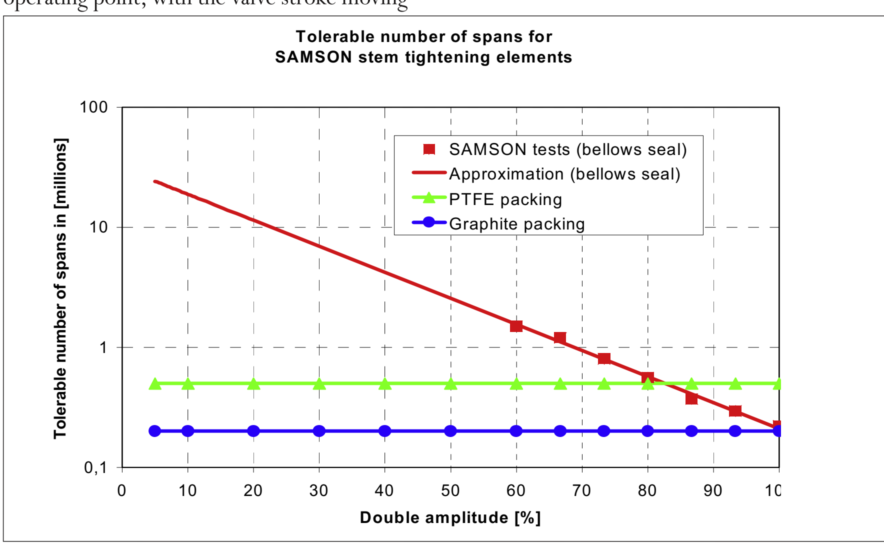


Fig. 34: Life cycle comparison



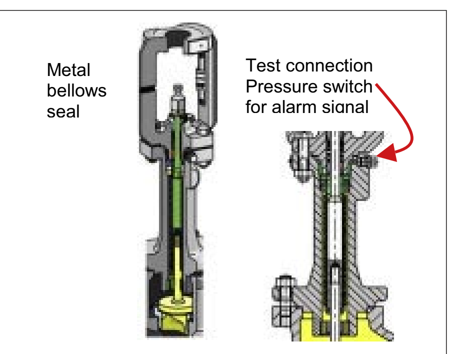


Fig. 35: Life cycle comparison in chemical plants with PTFE/graphite packing and bellows seal

within less than twenty per cent of the total travel. Very occasionally they “sleep”.

Here, certified fugitive emission packing material and design is sophisticated, but because

of the small production volume, expensive. Furthermore, the material loses its predicted life cycle time in hazardous environments, i.e. its sealing quality.
Attacks from within the valve, e.g. fluids that contain glue or have diffusing qualities, and from the outside of the valve such as heavy dust or sand, are risks which are much less critical when a bellows seal is used.

8) Actuator sizing philosophies

The key discussion in this chapter centres around the "strong actuator force" versus "low actuator force pressure balance" sizing philosophy. This chapter also takes into account the ranking of friction sources with globe valves and considers how to reduce wear, dirt sensitivity as well as how to balance the initial cost and the cost of ownership.

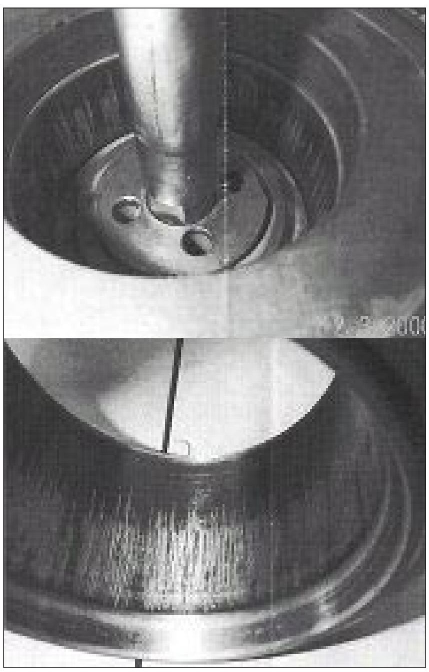


Fig. 36 Damage on pressure balance cage retained seat globe valve.

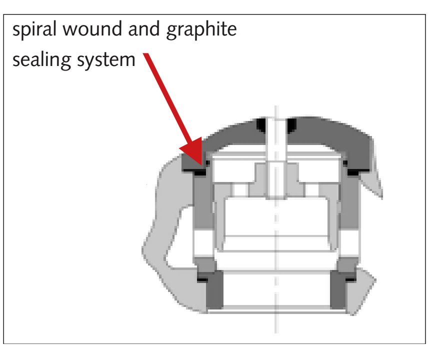


Fig. 37: Cage retained seat pressure balance trim (4 seal design).

Figure 36 shows a pressure balance cage retained seat globe valve that was destroyed by lack of precautionary measures taken against dirt or lack of predictive maintenance. The pipeline not flushed enough prior to start-up and the system lacked dirt filters. Maintenance failed after the first body leakage due to the top flange force being increased and the total set of seals not being replaced. The retainer will hit the piston if the expansion due to any temperature differences cannot be balanced out by the spiral wound and graphite sealing system (see Figure 37).
Smart positioners with additional sensors can take care of "operation friction" by functioning as a watchdog.

Sources of high friction and "stick-slip" effects in globe control valves:
Pressure balance trim design (except double-seated valves)
Piston actuators

Sources of lower friction and "stick-slip" effects in globe control valves:
Stem sealing: graphite packing
Stem sealing: fugitive emission packing system
Stem sealing: bellows seal packing + PTFE packing
Stem sealing: PTFE packing

Sources of lowest friction effects in globe control valves:
Unbalanced trim design
Pneumatic diaphragm actuators

Reliability and safety first

The "lowest cost of ownership" philosophy looks for strong actuator sizing without pressure balance. Believing the process medium is clean is often wishful thinking. Proper installation, including pipe-cleaning before the control valves are installed does not guarantee that the closed pipe system will be free of dirt and solids on start-up.
As a precaution against dirt the following is recommended: use and maintain steam traps in proper function, temporary dirt filters during commissioning are recommended until max. load for the operating process is reached. Extend the time period for pipeline flushing. High water volume and velocities are needed for proper dirt cleaning prior to the start-up process.
Expensive circumference guided trims as well as dirt-sensitive low-noise trims should be installed after the flushing process. For this purpose, the upstream pipeline should have a special "dead" t-bend for gathering dirt and particles at the lowest point.
The philosophy of the lowest cost of ownership, which takes control quality and reliability into account, results in the use of a pressure-balanced design on condition that the strongest actuator is not available or does not fit in the place of installation because of space problems (see Figures 38 and 39).

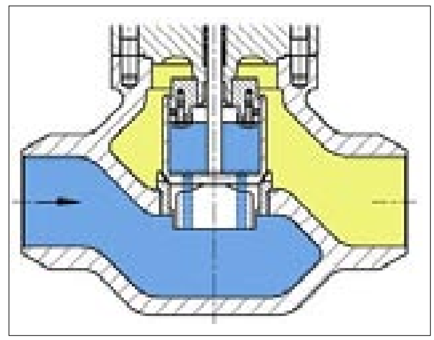


Fig 38:A less dirt-sensitive pressure-balanced plug design, with a rigid, sturdy, one-seal design and screwed-in seat.

Fig. 39: Pneumatic diaphragm actuators, up to an effective diaphragm area of 5600 cm2, can offer a maximum initial spring force of 120 KN. Photo shows also the author of this paper.

9) Control valve design and cost philosophies for "high end" applications

In the past decades, upstream oil and gas exploring processes and downstream hydrocarbon processing projects, involving refineries, methanol plants, LNG storage, and transport etc., have been expanding to provide higher flow capacities. The increasing demand for de-bottle-necking of existing plants and for doubling productivity of new plants are challenging plant and design engineers to look for economical solutions. The objective is to recycle and save–and not to double– energy consumption, in order to meet more stringent environmental regulations. Further objectives are to considerably reduce interior and exterior leak rates, sound emission, as well as operating cost and cost incurred by unpredictable shutdowns. This calls for larger control valves, which should have lowest seat leak rates without higher sensitiveness against dirt.

Traditional cage-balanced globe valves operate properly if the fluid does not contain any dirt or solids and if temperature fluctuations as well as piping forces do not attack the sophisticated tolerance system of the balanced design. But in larger nominal sizes they can lead to extreme initial and operating cost. Failures like poor control from increasing friction parameters as well as jamming and blocking can result if dirt filters, steam traps, pipe force compensation devices, etc, are not installed or improperly commissioned. Maintenance can develop into an important cost factor.

Rotary plug valves, butterfly control valves and ball control valves in valve sizes up to DN 3000 and pressure ratings up to Class 2500 equipped with standardized connections for the largest actuator and designed for the highest shutdown pressures are a good opportunity to save money in those "high end" applications.

Today, demand for very low leak rates met by Class V acc. to IEC 534 Part 4 (metal-to-metal seating) are continuously increasing in comparison with the traditional leak rate met by Class IV which is defined to be less than 0.01% of the nominal Cv 100 coefficient. To achieve Class V sealing effectiveness using standard globe valves is a challenge for any valve manufacturer, to achieve this leak class using a pressure-balanced design is even a greater challenge and to achieve this leak class for pressure-balanced valves at temperatures greater than 200 °C will increase the cost of ownership and the risk of failures. The new considerably lower leak rates of Class V require the fine tuning of the tolerance system, increasing the sensitivity to dirt and temperature fluctuations.

Today end users are becoming aware that larger cage-style valves require a high number of expensive spare parts. For example, when assuming an 8 inch globe flare valve with cv=775, Class IV trim = 0.01% Cv, hydrocarbon fluid as process medium, 362 psig, 392 °F, and shutdown to atmosphere, the leak rate amounts to 32.16 kg/hr = 772kg/day = 278 ton/year. If the product cost amounts to USD 1.20/kg, for example, the loss would be about USD 300,000/year.

The cage-retained seat design was developed many decades ago at a very early stage in the development of the oil and gas exploring and refining industries. As this traditional design has remained largely unchanged, it is unable to meet the economical and technical requirements placed on modern valves today (see Figure 40). Some traditional cage-style valve manufacturers are launching new products with screwed-in seats, but a proven sizing and sales philosophy remains paramount in ensuring an optimized balance between initial cost and cost of ownership.

Pressure-balanced, axial flow valve
This perforated trim design is not suitable for the existing process conditions.

Fig 41: Insufficient commissioning and poor cleaning and flushing of the pipeline.

In contrast to larger cage-balanced globe valves, which pose cost problems when used in high-end applications, rotary plug valves, high-performance double eccentric butterfly valves and triple eccentric butterfly valves used in severe service applications, as well as ball valves also available in a low-noise design are economical and reliable solutions without loss of performance.

In the past decades, these butterfly valves have developed from a single to a double eccentric design in order to improve control quality by reducing the breakaway torque. Though the sealing elements became highly sophisticated, they could not achieve Class V sealing effectiveness on a long-term basis under severe operating conditions e.g. high temperature fluctuations.

Fig. 40: To believe that the fluid is clean is often wishful thinking.

SAMSON AG and its associated companies VETEC, PFEIFFER, and LEUSCH offer advanced technologies with unique design features for various severe requirements: e.g. abrasive and contaminated fluids, high shutdown pressures, lowest interior and exterior leak rates, quick-action, on-off, and control functions, as well as expensive alloys like Monel, Hastelloy, titanium, zirconium, duplex, etc. On option, the triple eccentric design of LTR 43 series, is available with an increased rangeability of 1 to 100 and in a low-noise and anti-cavitation version. (See Figures 44 and 45.) The triple eccentric butterfly valve series offers exchangeable seat elements, laminated and full metal rings optimized for low break-away torques and is able to achieve the sealing effectiveness class V (metal-to-metal seating) on a long-term basis. In case of seat damage, both seat elements can be easily replaced.

Principle of triple eccentric seat design (cone/cone).

In case of temperature fluctuations, the disk balances the material expansion by moving slightly to a new sealing line. (See Figure 42.) Acquiring the expertise necessary to manufacture a highly sophisticated triple eccentric valve takes many years

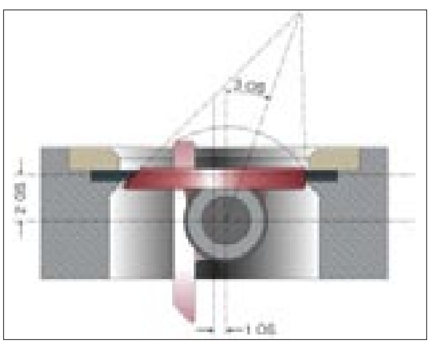


Fig. 42: LTR 43 triple eccentric design (cone/cone)

Fig. 43 LTR 43 triple eccentric seat ring manufactured by LEUSCH to achieve a rangeability of 1 to 100.

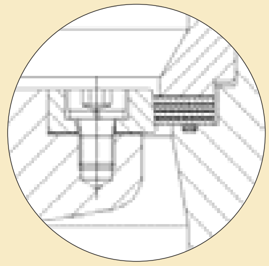


Fig A: Option: the two exchangeable sealing elements are available as spare parts.

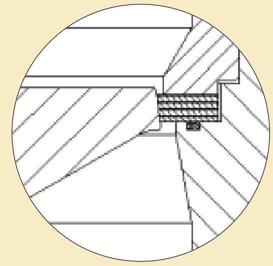


Fig B: Exchangeable sealing element at valve body In case of seat damage the disk has to be changed.

Fig. C: Special baffle ring used to increase the rangeability > 1:100

Fig. D: Low-noise butterfly valve versions can reduce the sound pressure level by about 15 dB(A)

Fig. 44: LTR 43 options for special demands

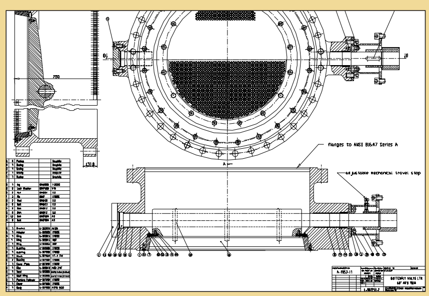


Fig. A: Low-noise versions: Single multi-hole disk for sound reduction by 5 -7 dB(A) at qmax (set point control).

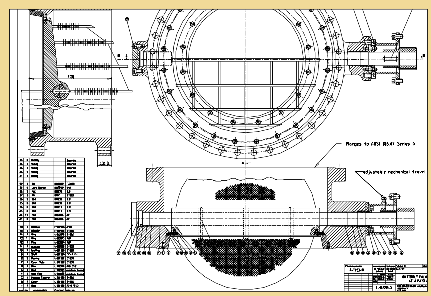


Fig. B: Five-stage multi-hole inline silencer for sound reduction by 7-10 dB(A) at qmax (set point control).

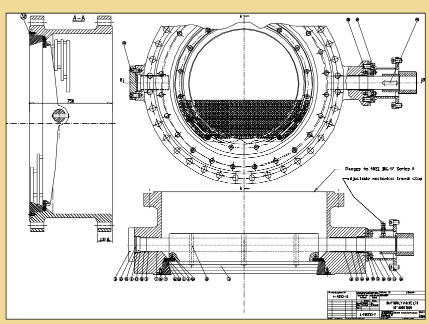


Fig. C: Multi-stage multi-hole inline silencer for sound reduction by 10 –15 dB(A) at qmin (start up).

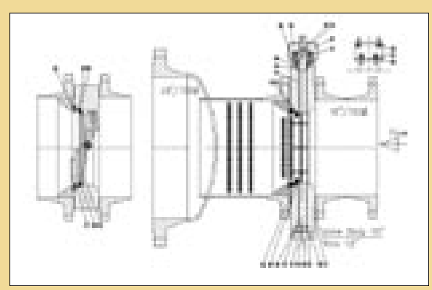


Fig. D: Three-stage multi-hole inline silencer for sound reduction by 10 –15 dB(A) at qmin (start up) and downstream silencer for sound reduction at qmax..

Fig. 45: LTR 43 low-noise versions for liquid applications. The design illustrated in Figure C combined with a downstream silencer in Figure D improves the anti-cavitation characteristic in the entire control range. Economical Class V and low noise solution, if no suitable globe valve is available.

Low-noise ball valves can be used if no economical globe valve solution is available and sound reduction > 15 dB(A) to 25 dB(A) is required (see Figures 46 and 47). Typical applications include:

Flow control for loading arms in terminals
Pump discharge or start up system
Partial throttling, transmission line and by-pass
Anti-surge; surge relief
Depressurization, equalization, venting, blow down switching
Cavity (Taverne) loading and unloading
Demand of double flow direction e.g. offshore platform shipping; low noise pressure swinging application PSA.

Non-pressure-balanced globe control valves are the first choice to ensure plant reliability in most applications. The low-noise features of globe valves are unbeatable in term of sound reduction by up to 40 dB(A) in comparison with low-noise rotary valves, which only achieve a sound reduction by up to 25 dB(A).
From a cost-saving point of view (investment and maintenance costs) globe valve solutions of large DN can easily lead to a cost explosion. High-capacity rotary valves are more cost effective if smaller valve sizes are chosen within an acceptable range of non-critical outlet velocities.
Rotary valves must be selected carefully and engineered expertly for critical applications, such as cavitation and flashing, taking the influence of reducers and lower limits of critical outlet velocities into account.
The new triple eccentric butterfly valve technology and low-noise cage-ball™ valve design can meet customer needs even in "high end" applications where no globe valve solutions are available.
Triple eccentric control butterfly valves are available in sizes up to DN 3000 and in pressure ratings up to Class 2500. Using powerful quarter-turn actuators, high shutdown pressures can be achieved within Class V in a wide temperature range.
In contrast to the traditional cage globe valves, the new high-performance butterfly/ball valve program is a promising solution to cutting cost for projects in the HPI market. ■

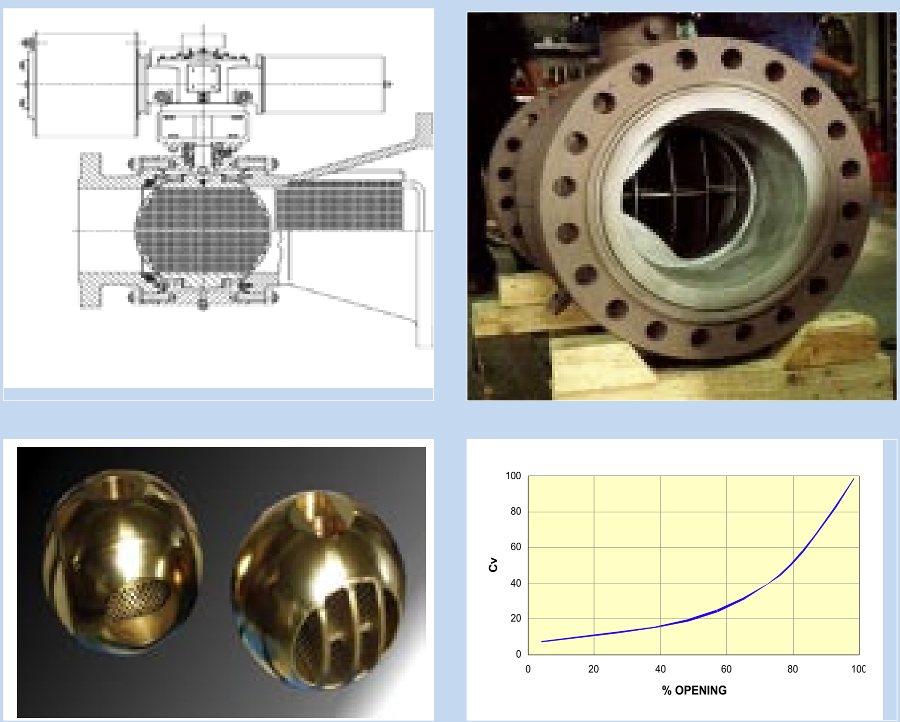


Fig. 46: Low-noise ball valves, ball titanium and titanium oxide coated


Fig. 47: Cage ball™ valve design for sound pressure reduction by up to 25 dB(A). Features include low noise anti-surge control ball valve with downstream silencer; Cv > 1000; Leak class V (metal-to-metal seating); stroking time opening < 1 second; sound reduction up to 25 dB(A).

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