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.

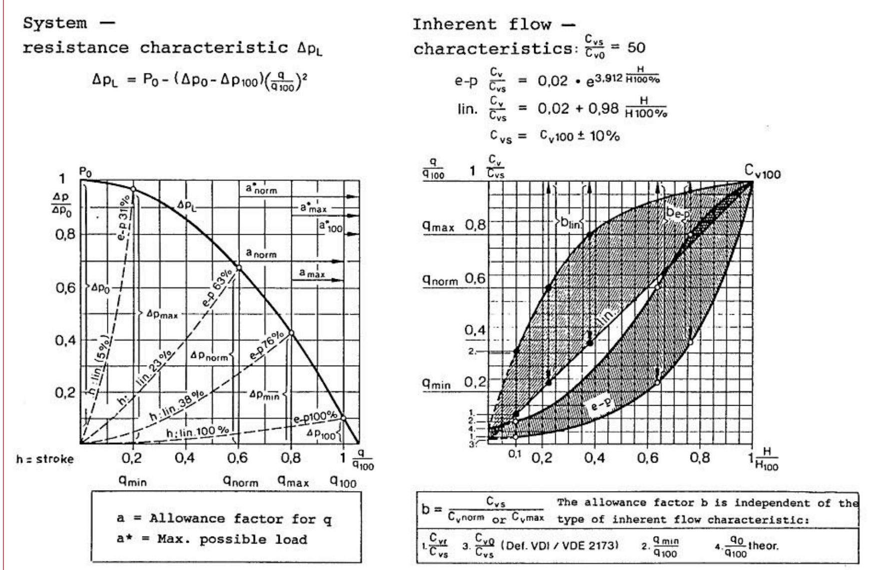
End users increasingly complain about maintenance costs and the amount of spare parts required which are often the highest after-sales cost factors. Nowadays, the contradiction often arises that consultants are under significant pressure to keep costs low and opt for other priorities:

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.

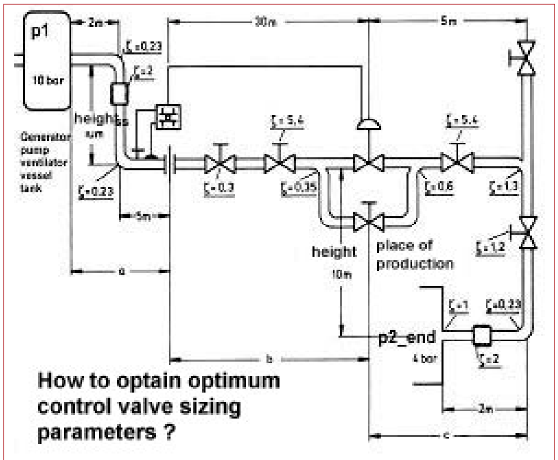


Fig. 3a: Typical plant layout (simplified) in a chemical or petrochemical plant.

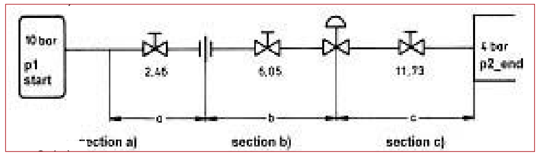


Fig. 3b: Same plant layout, split into three sections to show pressure losses.

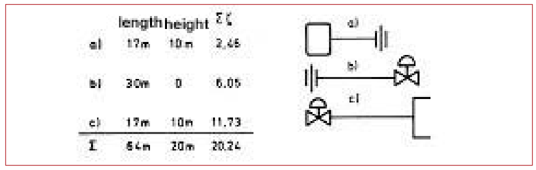
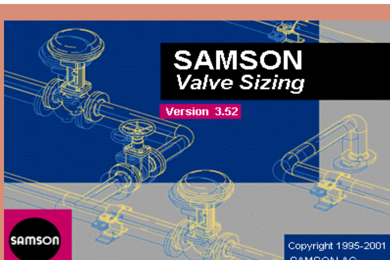


Fig. 3c: Input values of the pressure loss plant system.



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

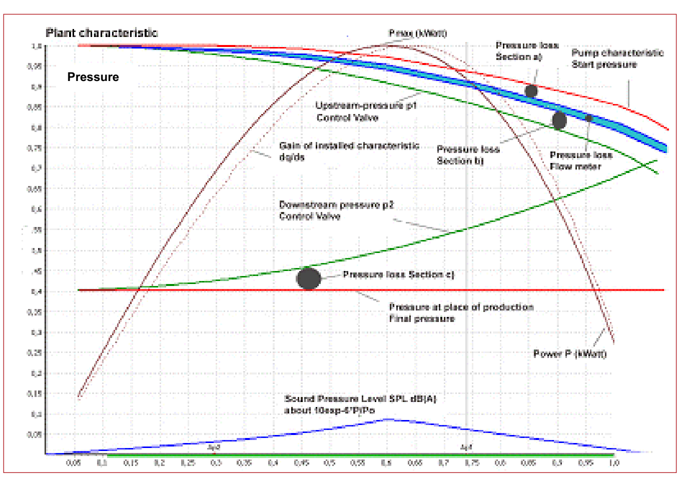
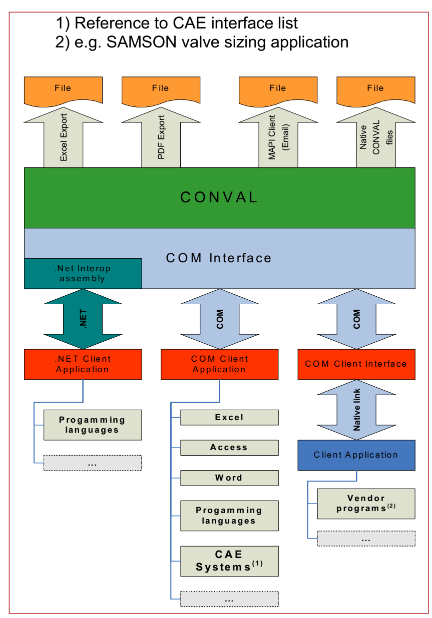


Fig. 4: Case study 1 - pressure/flow diagram with additional data on valve power and gain characteristic.

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



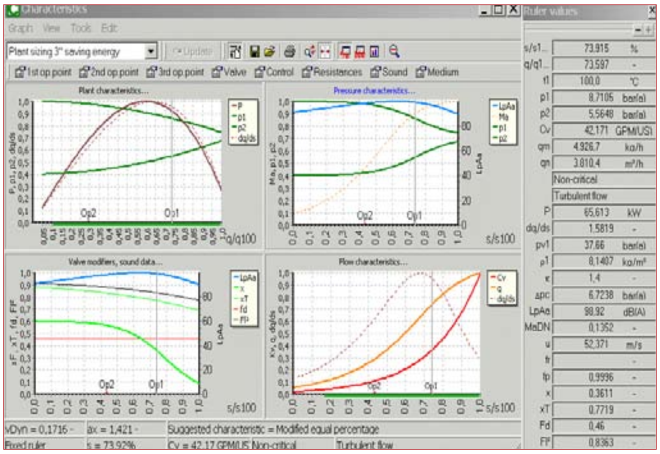


Fig. 5: Valve and control loop optimization with operating conditions from Table 1. Start pressure 10 bar.

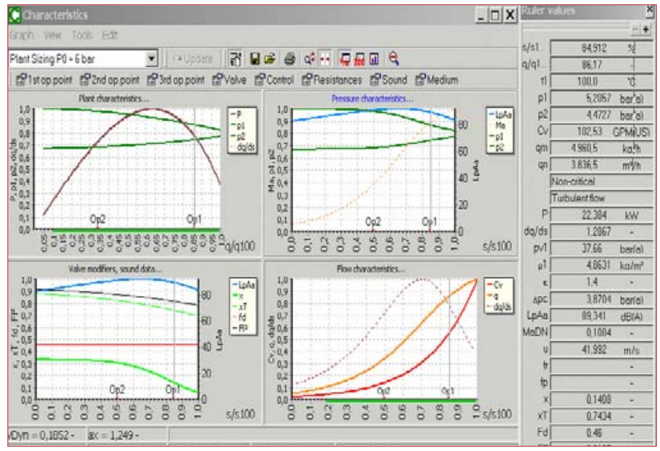


Fig. 6: Valve and control loop optimization with operating conditions from Table 2. Start pressure 6 bar.

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).

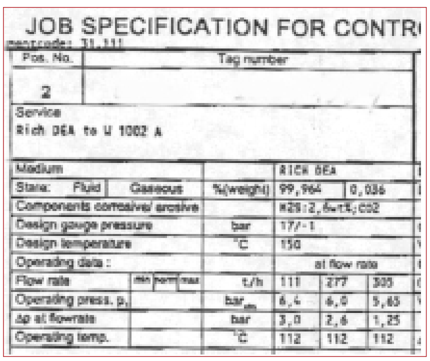
Flow	q kg/h	2000	5000
Pressure	p1 bar_abs	9.879	8.668
Pressure	p2 bar_abs	4.3	5.61

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. 2	Tag number				
Service: Rich DEA to U 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 (min / norm / max)	t/h		111	277	305
Operating press. p_1	bar_{abs}		6,4	6,0	5,65
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.

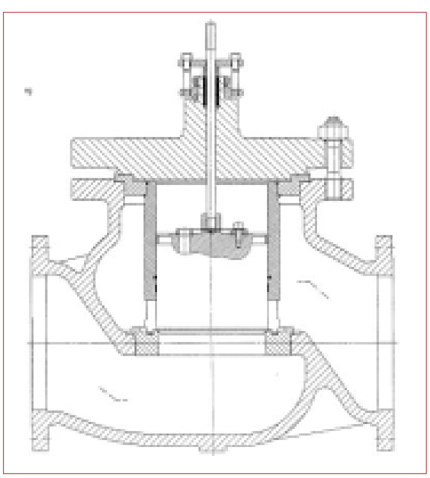
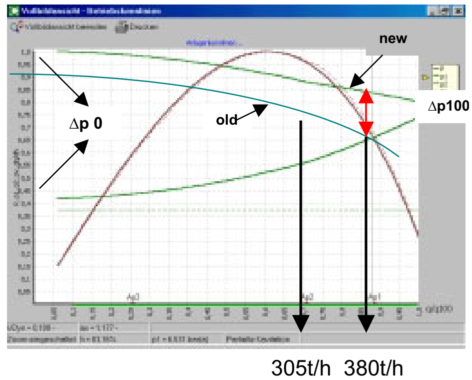


Fig. 8: Case study 2: The old 8" cage pressure-balanced control valve.



Rule of thumb for plant designers: keep a min. pressure differential for control valves with equal percentage characteristics.

Flow 100 % Δp100/ Δp 0 = 0.1

Flow 90 % Δp 90/ Δp 0 = 0.27

Flow 80 % Δp 80/ Δp 0 = 0.42

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

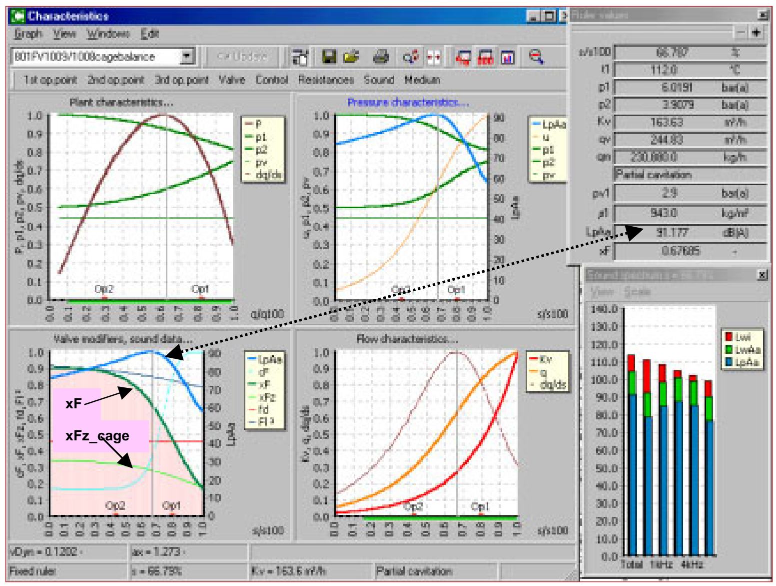


Fig. 10: Case study 2: Calculation of the cage retained seat valve with max. SPL [LpAa] > 91 dB(A).

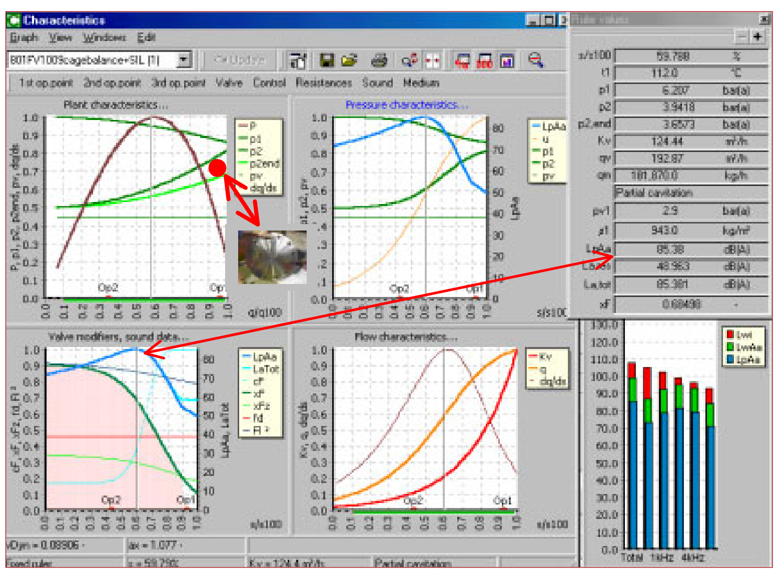


Fig. 11: Case study 2: Sizing of the existing cage valve with multi-hole baffle to reduce the noise from 91 to 85 dB(A).

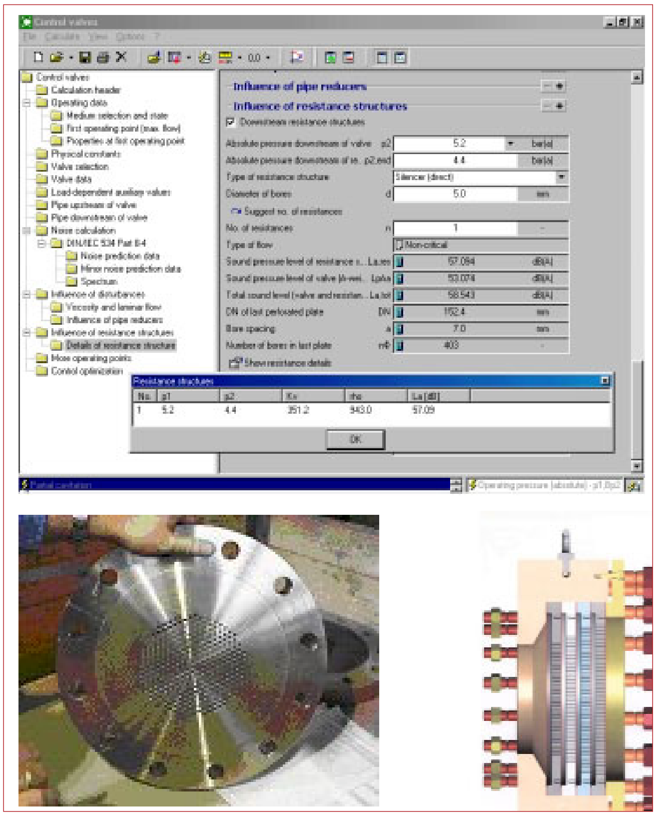


Fig. 12: Case study 2: Calculation and construction of downstream resistance structures like single and multi-baffles.

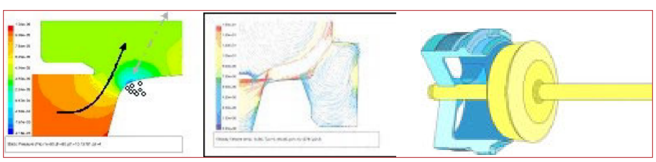


Fig. 13: Case study 2: CFD optimization of anti-cavitation trim design - computer flow simulation. Shown is SAMSON's AC Trim I System Parabolic plug top and seat guided. Seat and plug CFD optimized.

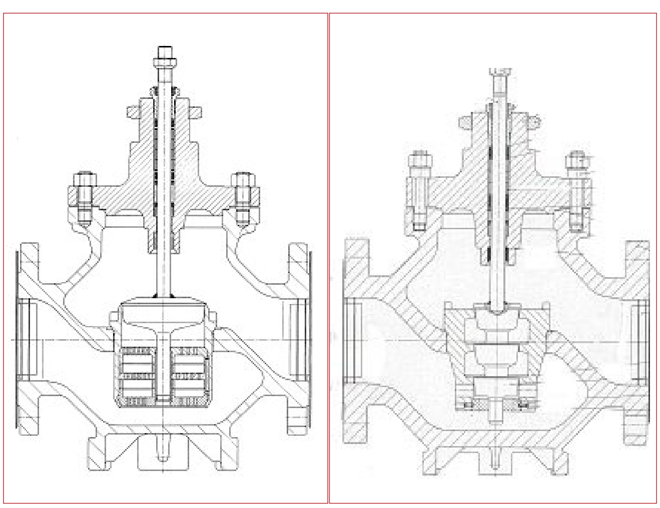


Fig. 14: Case Study 2: AC Trim System. The result of flow research (patent pending) Natural low noise, dirt and vibration insensitive. Top and seat guided low noise parabolic trim, no risk of stroke blocking.

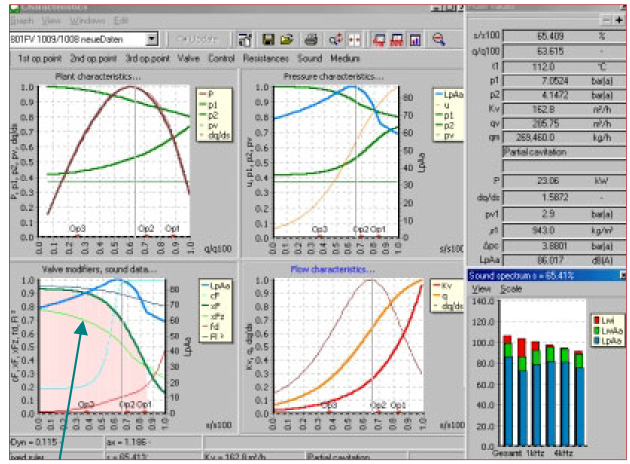


Fig. 15: Case Study 2: Sound optimisation for < 85 dB(A) noise limit with the unique AC Trim System and highest xFz characteristic of control valves today.

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. ■