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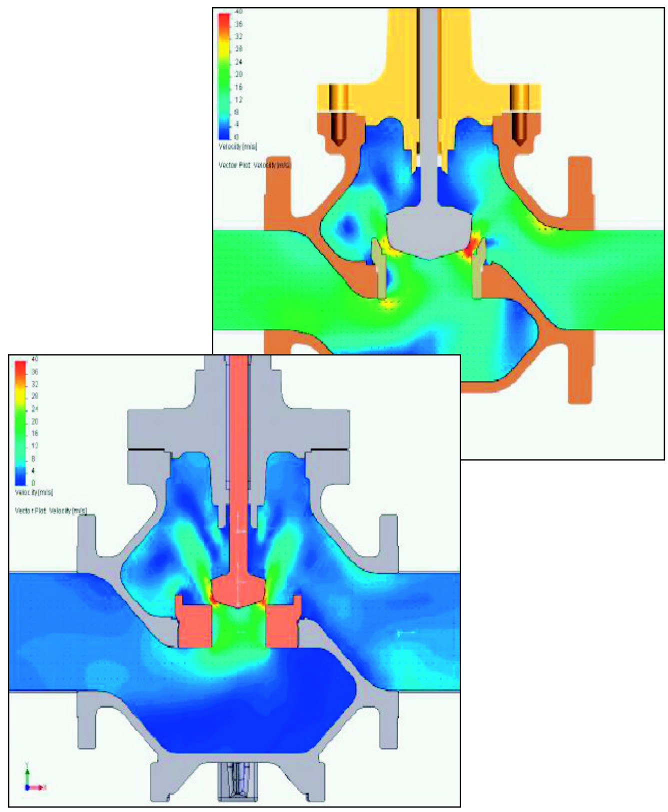
Predicting control valve reliability problems and troubleshooting in petrochemical plants

Critical outlet velocities – The hidden valve enemy



Special print from
Paper 2006 Valve World Conference
November 2006

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Predicting control valve reliability problems and troubleshooting in petrochemical plants Critical outlet velocities - The hidden valve enemy

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Keywords
Standard globe valves and rotary valves · Cost and time pressure change inquiry and quotation process · The hidden valve enemy, critical valve outlet velocities for gas and vapors · Critical trim outlet velocity versus valve body outlet velocity · Stem vibration, a possible reliability problem · Troubleshooting in a German refinery · Coming up with another design other than the current low-noise cage design

Abstract
In the complex area of the prediction control valve reliability, the various aspects of the cost-driven market, which have forced valve manufacturers to develop valves for typical market segments, have to be looked at. In the oil and gas market, a significant portion of valves are severe service valves with high power consumption. A good balance between commercial aspects and necessary safety requirements for the long-term has to be found. This article recommends steps for long-term control valve reliability.

1. Standard globe valves and rotary valves and their differences in general regarding critical applications

Globe control valves are the first choice for general use, covering the largest part of non-critical and critical applications. Driven by increasing pressure of cost, high flow capacity rotary control valves like butterfly, rotary plug or ball designs are mostly used in case of larger sizes in the areas of non-critical applications. These are relatively free of cavitation, flashing and choked flow conditions, within given noise limitations and, if proper control parameters can be achieved.

Table 1 shows the valve size relationship, comparing typical Cv 100 values of rotary plug valves with globe valves. Both valve types have replaceable seats and plugs as well as reduced Cv 100 values for special control tasks. The economic advantage comes with larger sizes where rotary plug valves can be selected up to two sizes smaller than globe valves if just Cv 100 is used as the selection criterion.

Size (DN)	150	200	250	300	400
Cv 100 values for rotary plug valves at 70° opening angle with the largest and smallest seat diameter					
Max Cv 100	795	1100	2223	3110	4872
Min Cv 100	208	279	557	777	1240
Cv 100 values for globe valves at 100 % stroke with the largest and smallest seat and plug					
Max Cv 100	418	731	1116	1740	2900
Min Cv 100	73	186	116	186	418

Table 1

In the past, all standard butterfly and ball valves were designed for on-off service. In order to minimize pressure losses, the majority of such installations were line-sized with the largest Cv 100 value.

Butterfly and ball valves with high flow capacity Cv/DN^2 [$Cv\ 100 \times 100/DN^2$] can achieve Cv 100 values up to four sizes smaller than the required globe valves, not taking the influence of pipe reducers and high outlet velocities into consideration. These high outlet velocities can have a critical damage potential in case of cavitation and flashing.

Globe and rotary plug valves offer a wide range of Cv values to optimize the control parameters to the given plant parameters. Butterfly and ball valves normally need smaller sizes or reduced Cv 100 values (i.e. smaller < 90° opening angle, split-range setting and mechanical travel stop to achieve similar results).

Fig.1a shows the comparison of different valve types. Flow capacity Cv/DN^2 and cavitation sensitivity are presented with the onset of cavitation value x_{Fz}, the key valve factor for cavitation and sound prediction together with the process operating condition. Fig. 1b shows the interaction of flow capacity Cv/DN^2 with the opening angle and valve characteristic and valve design.

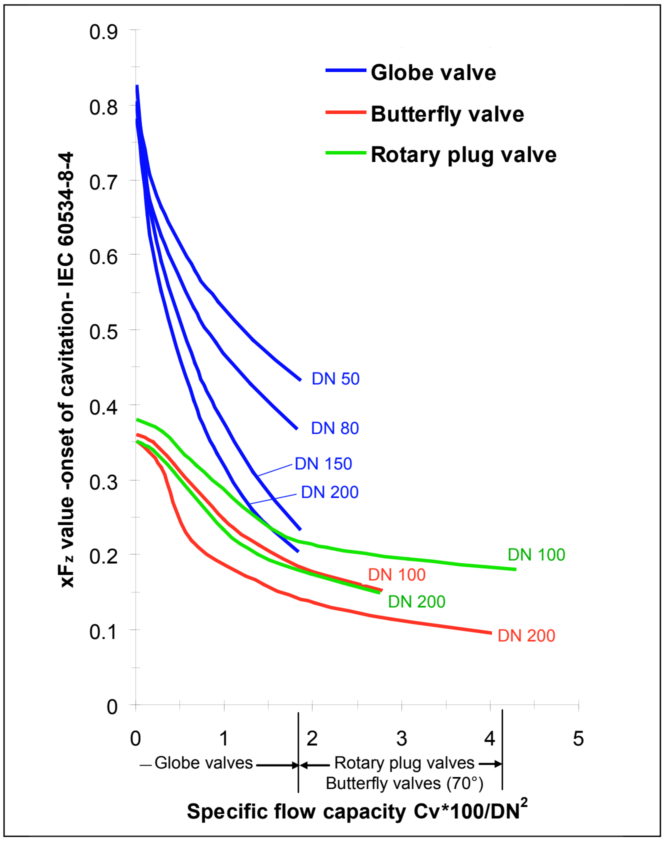


Fig. 1a: Onset of cavitation versus flow capacity

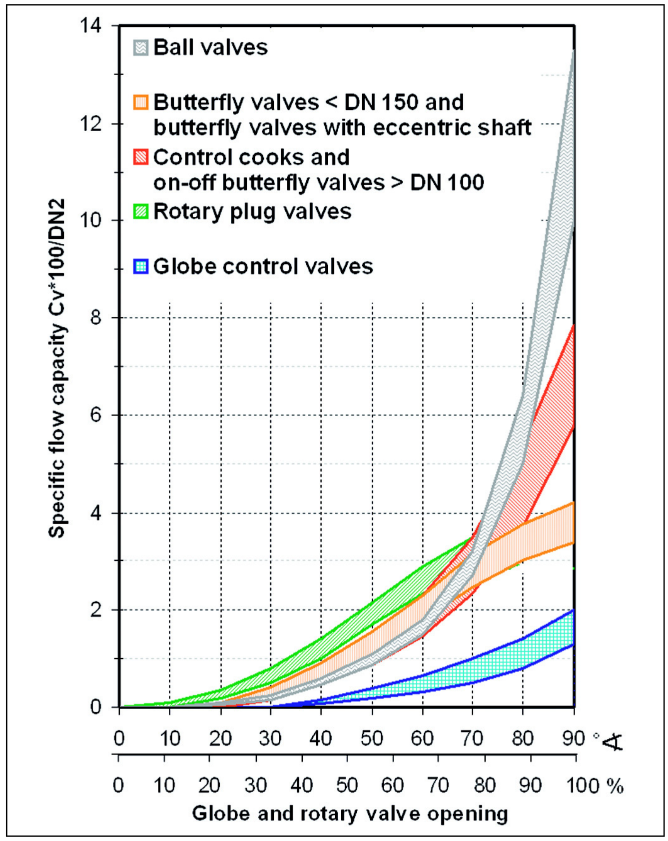


Fig. 1b: Flow capacity versus valve opening

The message of Figs. 1a and 1b is that high flow capacity valves are more prone to cavitation than globe valves at maximum and minimum load. The cavitation intensity is approximately comparable with globe valves at the same value of Cv x $100/DN^2$ at maximum load of the globe valve. But, at smaller loads, globe valve are less sensitive to cavitation than standard rotary valves.

2. Cost and time pressure change inquiry and quotation process, how to avoid "quick and dirty sizing"

Increasing time and cost pressure have changed the inquiry and quotation process for larger projects. On the one hand, control valve manufacturers are not able to offer some hundred control valves for oil and gas projects with severe service applications within just a few days, without having time to perform detailed engineering.

The result may be a kind of "quick and dirty sizing" with many open questions concerning the long-term reliability objective and the risk of malfunctions.

There is a better way considering the circumstances of insufficient time to select a specific range of valves from different degrees of difficulty and send this limited percentage of 50 to 100 pieces to the client's valve suppliers. In this case, these valves are to be handled with care. Detailed engineering and any open questions can be discussed within the given short period. The final supplier can get the order with a price level guarantee and the project winner can continue the project work. This will not only save resources of all valve manufacturers, but mainly also those of the company's own instrumentation engineering department by avoiding the process of comparing technical quotations and pricing for the entire number of "incorrectly sized" control valves submitted by numerous different suppliers.

On the other hand, cost-saving tasks change the valve ordering process, resulting in single-source contracts, which large end users and consultants have established over the past couple of years after auditing only one valve supplier for a huge project or for general delivery. This also saves a lot of resources on both sides, but there is still a risk concerning selecting the right control valves.

In the early stage of project design, just the pipe diameters are published, which allows the selection of the majority of line-sized on-off valve products. Assuming that on average just 5 % of the total number of valves are for throttling service, while the great majority are on-off valves, this much smaller quantity can only be selected by rule of thumb for selecting the valve size versus the valve type Cv 100 value. Detailed operating conditions are not

published at this early stage and may change tremendously after the pressure loss calculation of the process engineers.
By reducing the specific globe valve size by one up to four times in case of single-source contracts, rotary valves are generally selected because of the unbeatable lower price compared to globe valves.
Severe problems have to be solved later when realistic operating conditions from pressure loss calculations are available. In severe service applications, this data often calls for low-noise devices, proper control parameters and moderate outlet velocities, especially if now the application shifts into the area of severe service with cavitation, flashing and choked flow.
If too small valve sizes are selected, taking only the calculated Cv value into account, then high flow capacity valves ($Cv \times 100/DN^2 > 2$) need to be selected with care in case of critical liquid operating conditions.

3. Critical valve outlet velocities for gas and vapors

If valves are selected for gas or vapors, rules for limited outlet velocities have been established not to operate control valves at outlet velocities $Ma > 0.3$ to avoid long-term reliability problems. This is also of interest for the calculated noise warranty, especially in case of low-noise valves.
Furthermore at $0.3 < Ma <= 0.7$, low-noise devices lose their acoustical benefits in comparison to a standard valve. At $Ma = 0.7$ there is no difference in noise between a low-noise and a standard valve. Valves should operate at $0.3 < Ma < 0.7$ only for short periods. Long-term operation of control valves at $Ma > 0.3$ creates a reliability risk and should be generally avoided for the industrial standard control valve types.

4. The need for limitations of valve outlet velocities

In case of cavitation and flashing which contain wet vapor, missing regulations create a "hidden valve enemy" with negative impact on long-term reliability.
And there is also the experience of increasing damage potential on comparing dry gases with less overheated vapors or saturated vapors like saturated steam. In contrast to the limit of the average velocity $Ma = 1$ combined with more or less severe density shocks at the valve body outlet (Fig. 2a), the downstream pipe expanders choke the flow at $Ma > 1$, which should be avoided as it creates high-frequency sudden density shocks comparable with explosions (Fig. 12). Then extremely sudden forces acting not only downstream but also upstream may damage the valve body and the plug guiding. Such forces can cause plug and stem rupture and a kind of "cold welding" between the trim shaft and the bushing (Fig. 2b).
There are multiple parameters such as the size and pressure rating of the valve and pipe as well as the material, fluid properties, corrosion and dirt potential as well as the specific installation situation, which may call fore more complex rules.
If measures are taken such as optimizing and protecting against corrosion and dirt, it is surprising that sizing control valves at outlet velocities $Ma < 0.3$ in general avoids most long-term difficulties (only for short periods of time $0.5 < Ma < 0.7$).
For liquids, it takes special efforts to find comparable rules for limited outlet velocities in case of cavitation and flashing.
In addition, web research or studying oil and gas companies' and manufacturers' regulations results in some very different recommendations as well as many contradictions. Nothing seems to be established.

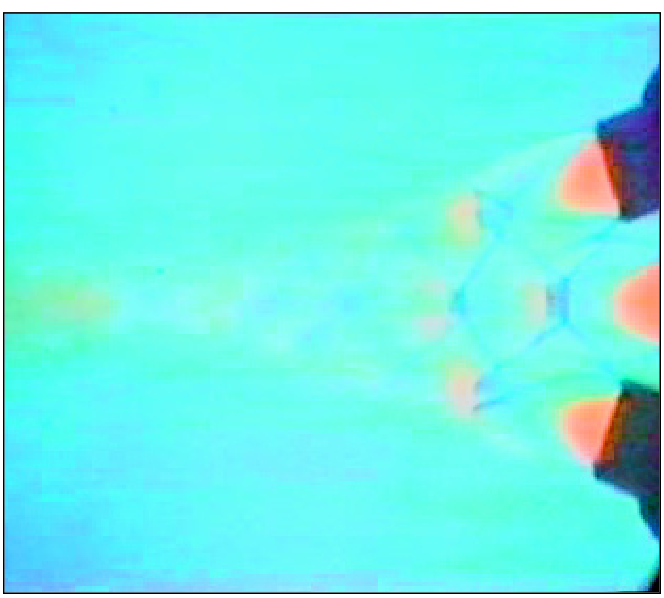


Fig. 2a: Sonic velocity producing shock waves

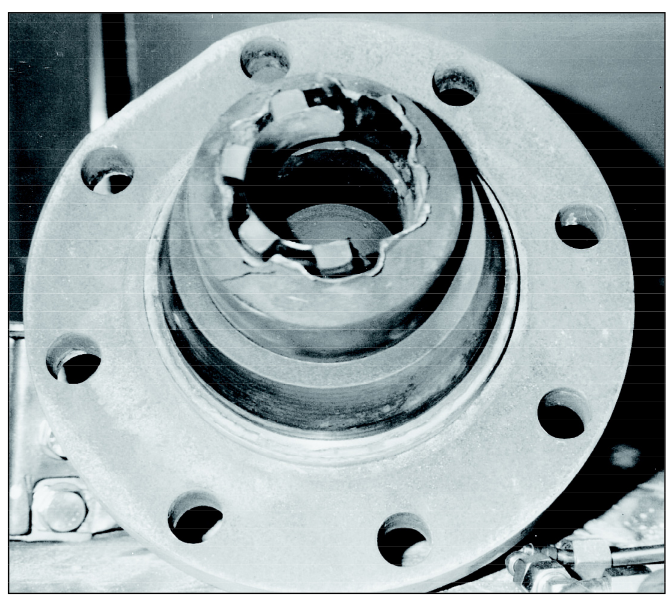


Fig. 2b: Bushing and stem damage (Mach theoretical >1)

Decades of maintenance reports demonstrate that the long-term reliability risk is self-evident even for liquids in case of cavitation and flashing if valve outlet velocities are too high. The fluid nature is wet vapor in the vena contracta (Fig. 3) and if cavitation choke flow ($xF > Fl^2$) or flashing ($p2 < pv$) occurs, also wet vapor exists in the valve and downstream pipe.
There is no doubt that limiting the liquid or wet vapor outlet velocity in the same way as for vapor and gas is important in days where often cost pressure is the decision maker.
Wet steam and wet vapor have a higher damage and pipe vibration potential than saturated vapor because of the higher density and mass weight, which unfortunately is a rarely known fact due to a very low sonic velocity, which can reach values below 100 m/s [328 ft/s].

5. Trim outlet velocity not practical for standard globe and rotary valves

The first Valve Reliability Predicting Conference in Maastricht in December 2005 introduced a velocity model published by CCI [3] called "kinetic energy model": The trim outlet velocity is limited. Further publications from other manufacturers and valve users produced many pros and cons. The company CCI stated very clearly that there is a "hidden valve enemy" in the form of a too high trim outlet velocity.

In contrast to expensive multi-stage microflow channel trims which can throttle high differential pressures of liquids without any cavitation, the throttling process of standard globe and rotary valves with pressure recovery convert the liquid phase into a wet vapor phase in case of cavitation and flashing. The "critical trim outlet velocity" cannot be detected here at the trim

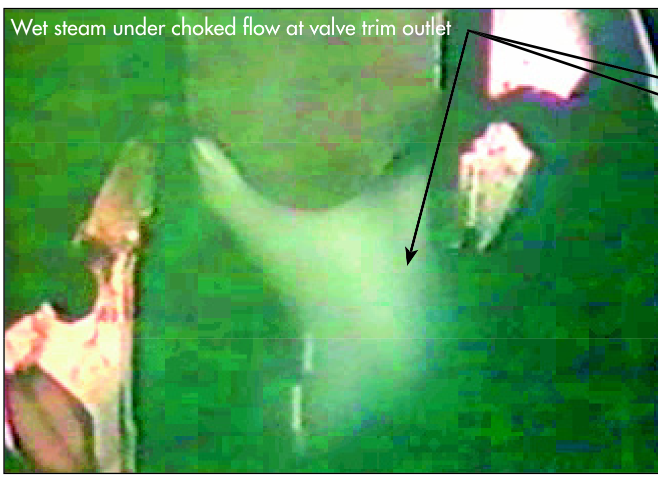


Fig. 3a: Flow measurements: water, 20 °C, 6 to 1 bar FTC

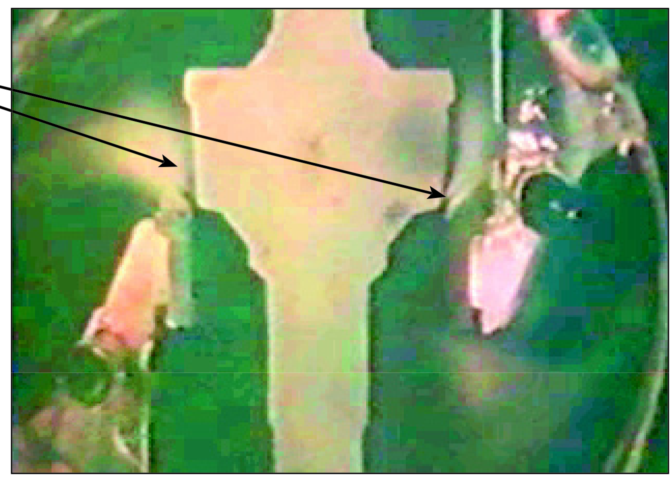


Fig. 3b: Flow measurements: water, 20 °C, 6 to 1 bar FTO

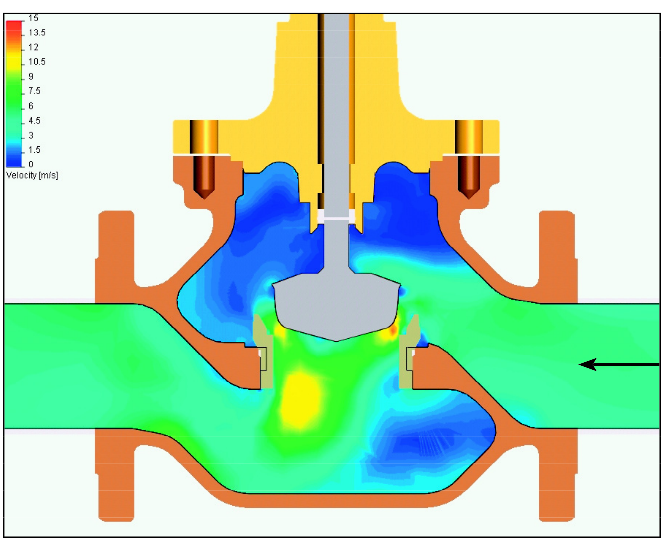


Fig. 4a: CFD flow simulation: liquid, 10 to 9 bar FTC

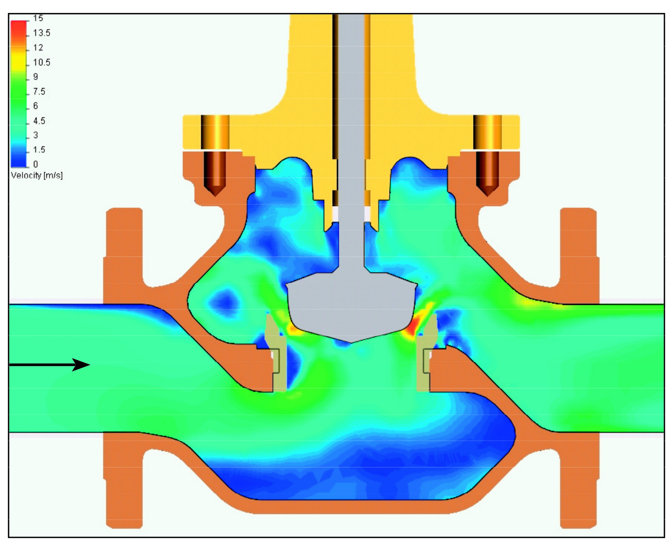


Fig. 4b: CFD flow simulation: liquid, 10 to 9 bar FTO

outlet because the velocity is not a liquid velocity anymore, instead it is converted into the sonic velocity of wet vapor, which is a property value, and causes liquid choked flow if Kc or $Fl^2 < xF$ or generally in case of flashing $p2 < pv$ (Fig. 3).

SAMSON AG publishes critical valve body outlet velocities in case of cavitation and flashing. The wet vapor sonic velocity at valve outlet must be avoided.

In contrast to flashing ($pv > p2$) with a steady wet vapor phase at the valve outlet, the cavitation process ($pv < p2$) can have a wide range of operating data ranging from harmless sound-producing cavitation up to absolutely severe cavitation areas with the highest damage potential. In the same succession, the wet vapor phase may convert into liquid again directly at the trim downstream in the valve body or much later in the downstream pipework as a function of the given operating data xF to the valve liquid recovery factors xFz and Fl (Figs. 6 to 7).

If discussing reliability prediction and standardization, this more or less simple rule opens up a wide field of fine tuning and improvement in the long run.

6. Valves developed to preferred market segments and possible reliability problems of overloaded valves

Another reliability aspect is that under cost pressure, the valve design has changed in the last decades from top and body-guided or cage-guided valves to appropriate valves for chemical, pharmaceutical, food and beverage markets as well as for biofuel applications. In this case, approximately 80 % of all control valves are connected to smaller pumps up to maximum 5 kW. The remaining 20 % consisting of more sophisticated or tailor-made control valves are used in the HPI market at upstream and downstream production places of, amongst others oil, methanol, LNG and gas applications.

The majority of these more expensive valves are supplied by larger, much more powerful pumps or flow machines. There is no doubt that these valves are designed for higher performance. Globe valves with top and bottom-guided plugs or top and seat-guided plugs as well as cage-guided plugs are used here more often combined with highly effective, low-noise devices. As an alternative to globe valves, high-performance rotary valves in butterfly, rotary plug and ball design also updated with low noise features are available nowadays. Here, special process demands concerning control quality, noise reduction, smallest seat leakage, high shut-down pressure and cost comparison open the market for both types of valves.

Oil and gas (HPI) market power consumption of control valves

Crude oil pumps in refineries:	1,000 to 2,000 kW
Anti-surge control valves:	1,000 to 4,000 kW
Flair and start-up valves:	up to 200,000 kW
Gas or steam pressure let down:	3,000 kW
Typical pump power	100 to 1,000 kW

Valves with top-guided parabolic plugs if developed mainly for the mass market must be selected with care and should not be used if excessive power (dp x flow) will overload the valve, resulting in stem vibration, unpredicted sound level and failures.

The CFD simulation software is very effective for optimizing and understanding flow in control valves (Fig. 4). For a simulation at p1 = 10 bar to p2 = 9 bar, the velocity profile becomes asymmetrical.

This effect can lead to stem vibration and unpredictable noise levels especially at $xF > 0.5$ and smaller loads $Cv/Cv\,100 < 0.25$ (Fig. 5).

For seat diameters > 32 mm and $xF > 0.5$, valves with top-guided parabolic plugs should be selected with care if cavitation cannot be avoided [1].

7. CFD flow calculation of the rotary valve and piping system

High-capacity rotary valves, on the one hand, are more prone to cavitation and, on the other hand, can be sized two to three times smaller than globe valves (Fig. 1b), of course, at lower cost. Therefore, the main field of application is non-critical applications where globe valves may not be mandatory and are more expensive.

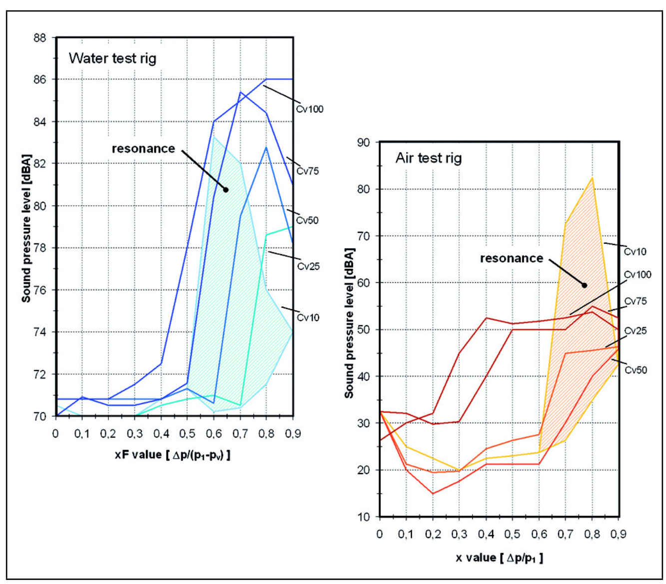


Fig. 5: Top-guided parabolic plug with stem vibration at smaller loads detected in a water and air test rig. The sound pressure level dB(A) can increase by up to 25 dB(A) higher than predicted.

In case of cavitation and flashing, the "hidden valve enemy" (too high outlet velocities) is much more evident for standard rotary valves than for globe valves. The pressure reduction process includes the valve and a more or less long section of the downstream pipe system, where long-term trouble like pipe vibration, welding ruptures and abrasion to pipe and body holes are waiting.
The CFD simulation selected here make visible the influence of outlet velocities in the valve and downstream pipe system.
Sophisticated low-noise rotary valves are also available these days. Rotary plug valves and also butterfly and ball valve solutions can be offered with reduced Cv values and reduced diameter of the integrated seat or disc, together with integrated and/or outlet low-noise reducers like baffles. The larger valve size takes care of the critical outlet velocity. The price is higher than for the smaller valve size of a standard rotary valve, but still lower material costs and a smaller actuator size may lead to a competitive offer.

Liquid CFD simulations

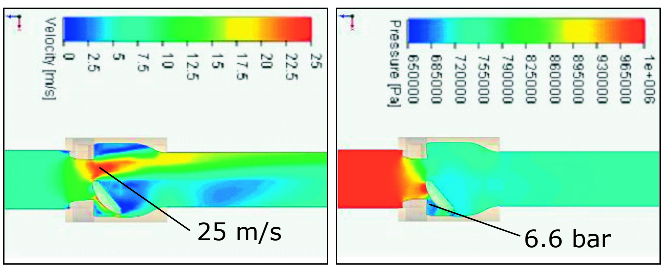


Fig. 6a: Too small size create a critical velocity profile of a rotary plug valve at 50° opening angle. Pressure profile 10 to 7.55 bar with cavitation xF > xFz. The throttling process continued in the downstream pipe.

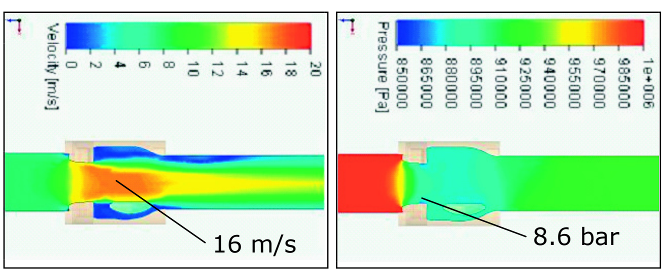


Fig. 6b: Velocity and pressure profile of a rotary plug valve at 90° opening angle, 10 to 9.2 bar

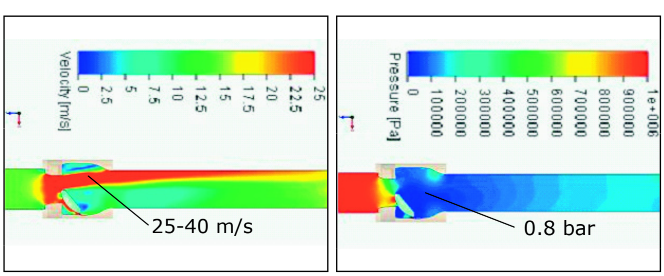


Fig. 7: Critical velocity and pressure profile of a rotary plug valve at 50° opening angle, 10 to 2 bar. The throttling process is not finished at valve outlet. The valve upstream and downstream velocities are too high and cause long-distance interaction with the downstream pipe.

8. Limited outlet velocities to avoid troubleshooting

In case of partial cavitation xF > xFz, engineering rules have been established to limit the liquid outlet velocity to < 5 m/s [16.4 ft/s] and to < 3 m/s [9.8 ft/s] if severe cavitation xF > xFmr occurs.
Some useful approximations if other values are published:
Kc=xFmr onset of choked flow approximately Fl^3
Note: According to ISA-RP75.23, xFz is only approximately equal to $1/\sigma_i$ and Kc is only approximately xFmr= $1/\sigma_{mr}$
In case of flashing conditions, the average outlet velocity has to be calculated for the mixture of liquid and wet steam or wet vapor. Severe pipe vibration and valve damage can be avoided if the valve outlet diameter restricts the outlet velocity below 60 m/s [197 ft/s] (the average of 0.7 Ma sonic velocity of liquid/gas and wet vapor mixture).
These initial basic rules may be modified slightly using more reported values and experiences, meaning for example, if the

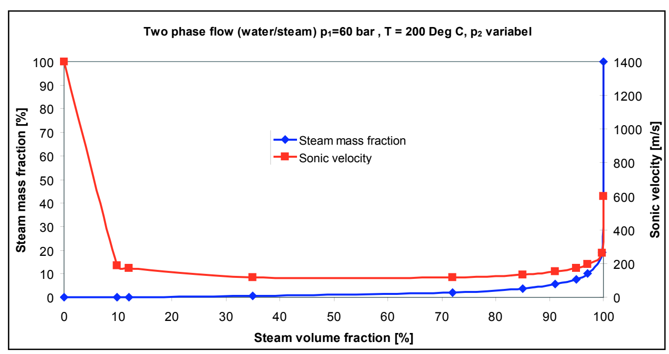


Fig. 8: Case study of sonic velocity areas below 200 m/s [656 ft/sec]

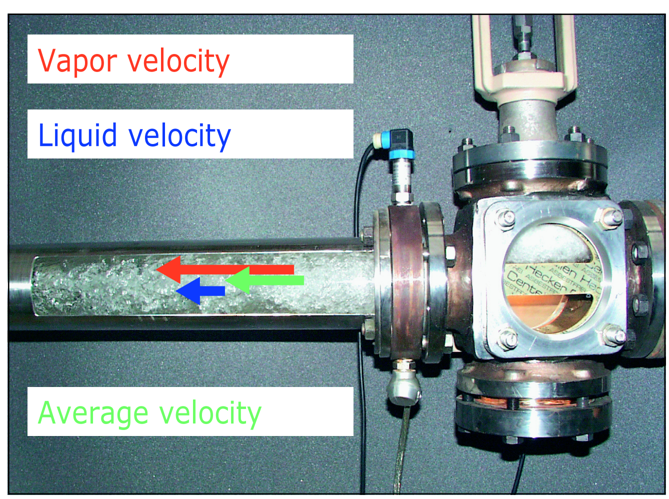


Fig. 9: Flashing research at SAMSON AG

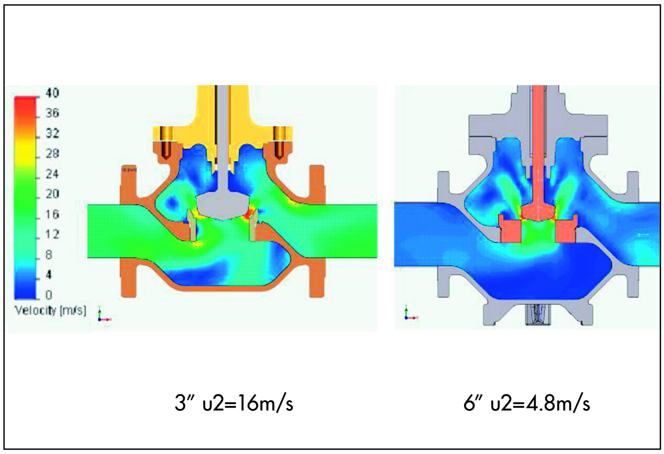


Fig. 10: Different body and piping stress situations due to velocity profiles at similar operating position for 3" and 6" valves (also see Figs. 4)

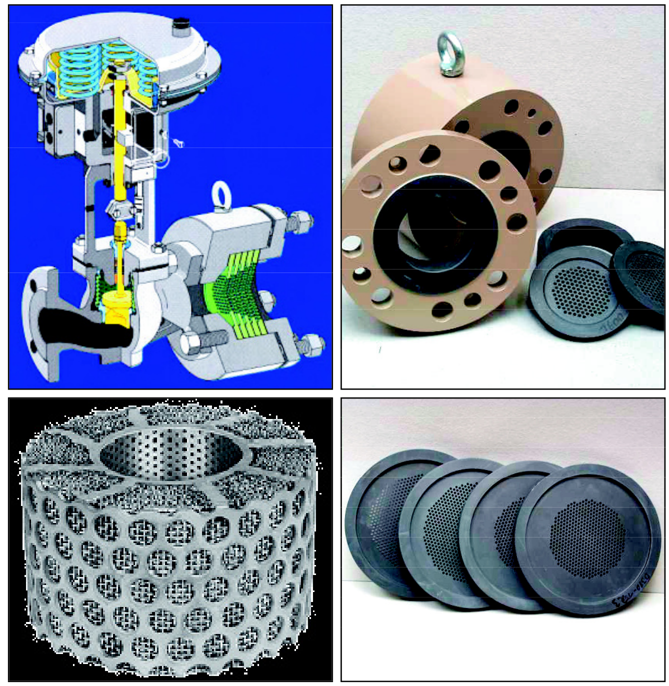


Fig. 11: Low-noise flow divider and outlet silencer to reduce the noise and control outlet Ma numbers.

cavitation intensity is very small xFz < xF < xFz +0.1, the limited outlet velocity could be somewhat higher. If, in addition, dirt, solids or/and corrosive fluids occur together with cavitation, velocity limits should be adhered to more strictly. At least companies offering special designed valves for severe service can apply this long-term fine-tuning process.

9. CFD flow calculation the globe valve and piping systems with expansion pieces

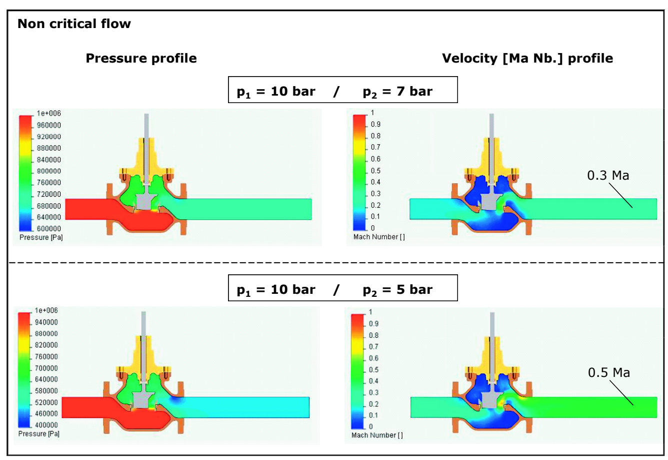
Fig. 10 shows a CFD comparison in case of cavitation: The large impact of the valve body stress situation compared under the same operating conditions with non-critical and critical outlet velocities u2 [2].

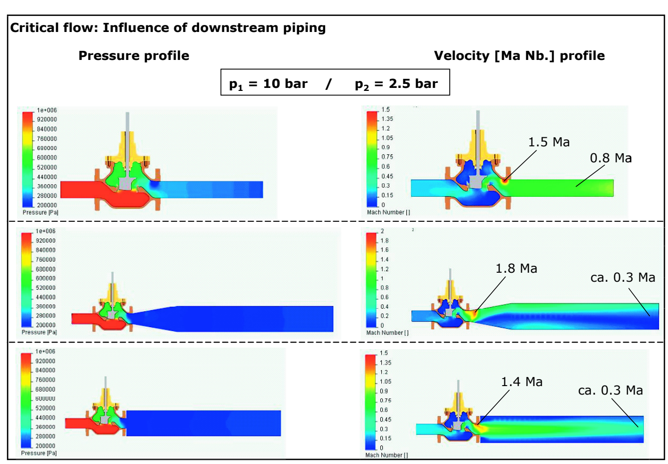
Critical pressure reduction with gas and vapor (steam) need higher valve sizes because of the critical density expansion to avoid excessive outlet Ma numbers. CFD simulations very clearly show that conical expansion pieces can create a long-term reliability risk if the valve outlet Ma becomes > 0.7.

Also the lower velocity profile near the pipe wall of a sudden expansion shows acoustical benefits in comparison to conical expansion pieces. The given plant downstream pressure takes place directly downstream of the valve and creates high Ma numbers with dangerous density shocks (Fig. 12).

Larger valve sizes with reduced seat diameters can keep Ma numbers lower and avoid the risk of damage. Apart from other benefits, downstream silencers combine a more economic smaller valve size with the optimum expansion outlet size for Ma < 0.3 as well. Additional benefits are the further sound reduction of the silencer baffles, shifting about 70 % of the total power from the moving valve trim parts to the very sturdy perforated orifice plates (baffles). In brief: just an expansion of the pipe diameter at valve downstream is not enough. The "enemy" is still evident when the outlet valve flange is sized too small.

CFD simulations with gas





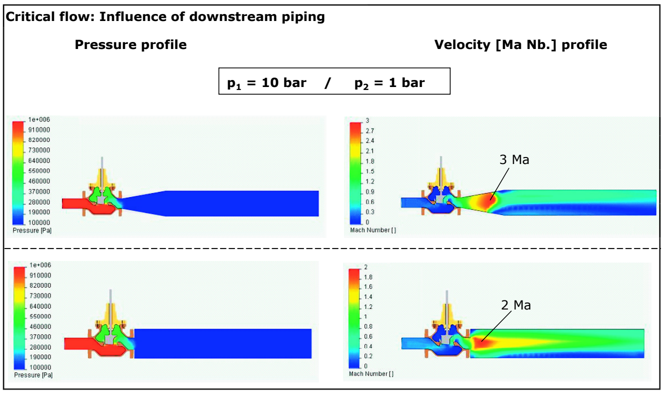


Fig. 12: Influence of downstream piping in case of gas pressure reduction [2] Ma numbers > 1 are values in the expander area and will combine sonic and supersonic velocities with density shocks at downstream pipe.

10. Troubleshooting in case of cavitation and flashing in a German refinery

Three examples (presented at the Valve World valve reliability seminar in Maastricht, December 2005) underline the importance of limited outlet velocities.

1) Severe cavitation damage
2) Severe flashing damage
3) Severe cavitation pipe vibration

The examples here are taken from the TOTAL refinery in Spergau formerly Leuna 2000 (Fig. 13), one of the biggest investment in Europe costing about two billion Euros. Its actual capacity is 11 million tonnes of crude oil coming from Russia. Around 1300 control valves contracted by LURGI and TECHNIP are installed in the refinery.

Fig. 13: TOTAL refinery in Spergau

Example 1

Troubleshooting with replacement of an 8″ rotary plug valve with a 12″ globe valve and anti-cavitation trim in 2002

The offer of an alternative of a larger rotary valve with 20 dB(A) noise reduction was not accepted in this case. Valve damage and sound reduction from >100 dB(A) to 85 dB(A). Too high outlet velocity or too small valve size lead to unpredicted plant shutdown.

Operating data:	306 °C
Vapor pressure:	0.1 bar (a)
Density:	796 kg/m³
Wrong sound calculation	< 85 dB(A)
Measurements:	>100 dB(A)

	Flow	qmin	qnorm	qmax
Flow	t/hr	202	505.5	607
p1	bar a	14.3	14.3	14.3
p2	bar a	1.3	6.0	8.3

Table 2

Cavitation damage occurred in a rotary plug valve as a result of “quick and dirty” sizing (Fig. 14).

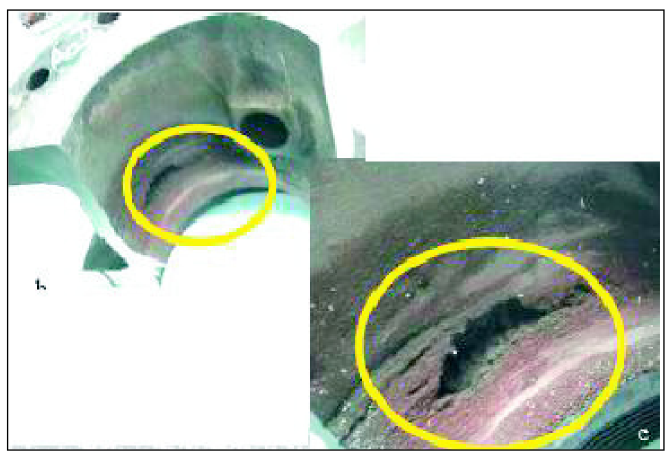


Fig. 14: First blowout and unpredicted plant shutdown

The delivered spare rotary plug valve needed control of wall thickness with thermographic measurements and the use of a downstream baffle to change the plug position in order to prolong the service life by two months for the regular plant shutdown (Fig. 15).

CONVAL™, a manufacturer-independent software for plant optimization pinpoints partial, severe and maximum cavitation with choked flow and warns against too high outlet velocities. (CONVAL™ trademark of F.I.R.S.T GmbH).

Fig. 15: Spare rotary valve under operation before replacement with 12" globe valve (just before the second blowout)

Also a 12" rotary valve may handle this application. But 85 dB(A) noise reduction is a challenge for this type of valve.

Cavitation-free operation with AC trim system (Fig. 17), but more space (and budget) is necessary to replace an 8" rotary valve with a 12" globe valve for long-term troublefree operation (Fig. 18).

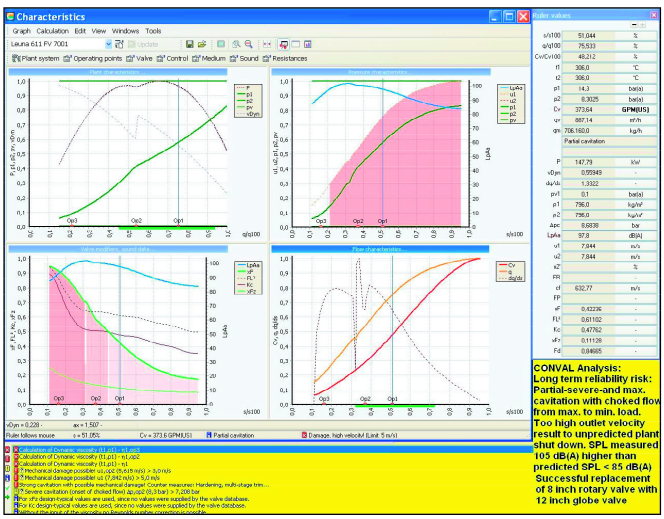


Fig. 16: Calculation of the 8" rotary plug valve. The software pinpoints partial, severe and max. cavitation with choked flow and warns against too high outlet velocities. Replacement with a low-noise 12" globe valve.

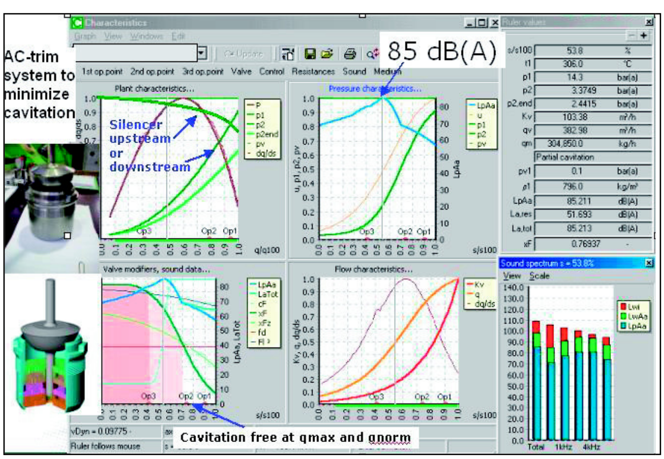


Fig. 17: Calculation and optimization of the 12" low-noise globe valve

Fig. 18: Installation problems solved

Example 2

Severe flashing and pipe choked flow with too small rotary valve and troubleshooting with the help of proper flashing calculation and an optimum valve outlet size.

Most critical:
Flashing with boiling liquid p1 = pv
Operating data: 45 °C
Vapor pressure: 25 bar (a)
Density: 670 kg/m³

	Flow	qmin	qnorm	qmax
Flow	t/hr	50.46	144.2	158.6
p1	bar a	25.1	25.1	25.1
p2	bar a	11.3	11.3	11.3

Table 3

Fig. 19: First shutdown due to corrosive fluid and incorrectly selected material combined with flashing and too high outlet velocities

Recommendations and regulations for control valve reliability in case of flashing conditions:
Keep valve outlet velocity below sonic velocity of wet vapor.
Recommendation u2 < 60 m/s (< 192 ft/s).
In case of boiling liquids (non-undercooled) p1 = pv: Valves should be selected line-sized with no reducers, elbows or block valves and should be 20 times DN at valve upstream to avoid mixed flow at valve inlet.
For mixed hydrocarbons and liquid mixtures, new property specifications have to be reported in the valve specification sheet from process engineers.

a) % Mass-portion of wet vapor at downstream condition
b) Density of wet vapor at downstream condition

The software can calculate flashing and liquid/vapor mixtures with graphic support of installed characteristic, if wet vapor mass part and density at p2 conditions are given.
On the first occasion, a 4" globe valve failed because of corrosion and flashing with too high outlet velocity (after 1½ years, body leak and unpredicted plant shutdown Fig. 19). The second time, a 4" rotary plug valve in Hastelloy™ failed and caused severe pipe vibration and damage. In case of corrosive fluids, cavitation should be avoided, if possible, and the valve guidance tolerance system should be protected in the long term with the lowest velocity profile.
Proper material selection is important if flashing occurs with corrosive fluids as well as making sure that the critical outlet velocity is not exceeded.

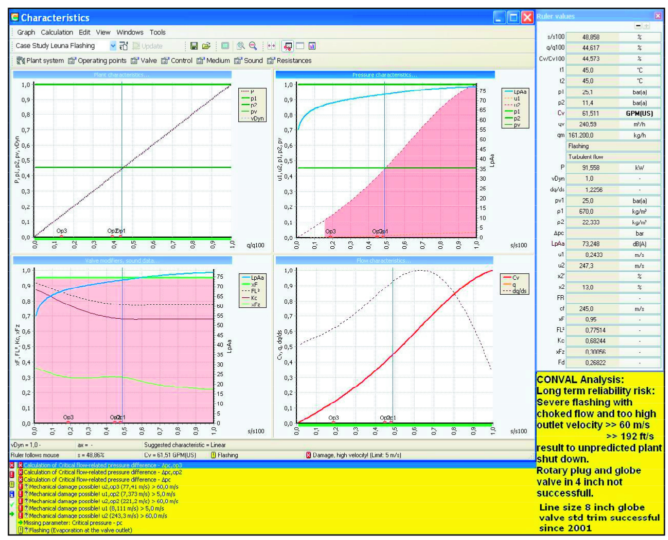
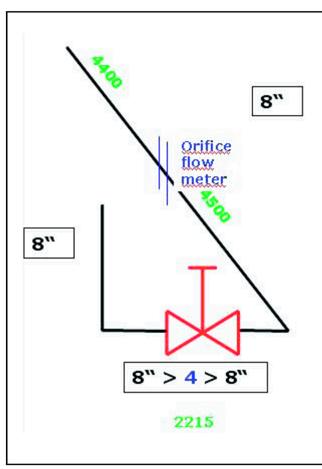


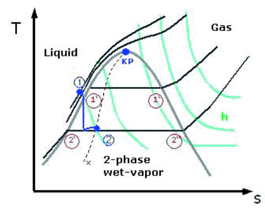
Fig. 20: Flashing calculation and warning system. Calculation of severe flashing conditions (p1 = pv) with 4" rotary plug valve in 8" pipe system. Critical outlet velocity u2 = 247 m/s Ma (theoretical) > 1



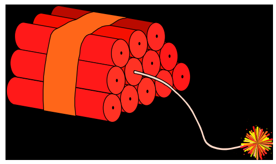
Multiple failures in installation and valve sizing cause:

- Rotary valve body erosion and corrosion
- Pipe wear (elbows)
- Possible vaporization at valve inlet, strong flashing
- Wear in the orifice flow meter
- Tremendous costs for spare parts, maintenance and plant shutdown

T Temperature
h Enthalpy
s Entropy
KP Critical point
x2 Mass steam portion valve outlet
x1 Mass steam portion valve inlet



Outlet velocity (4″ valve)
-> Mass portion of flashing 13 %
251 m/s! Mach (theoretical) > 1
if average sonic velocity is assumed between 120 to 60 m/s



2-phase flow at outlet condition

Density and velocity changes

$$x_2 = \frac{h_1' - h_2'}{h_2'' - h_2'} + x_1 \bullet \frac{h_1'' - h_1'}{h_2'' - h_2'}$$

$$\rho_2 = \frac{1}{\frac{x_2}{\rho_D} + \frac{1 - x_2}{\rho_F}}$$

$$u_2 = \frac{W}{\frac{\pi}{4} \bullet \rho_2 \bullet D_N^2}$$

Result of wet vapor velocity calculation at downstream condition p2 for a 4″ valve

$$x_2 = \frac{h_1' - h_2'}{h_2'' - h_2'} + x_1 \bullet \frac{h_1'' - h_1'}{h_2'' - h_2'} = \frac{108.2 - 49.34}{518 - 49.34} = 13\% \quad (x_1 \approx 0)$$

$$\rho_2 = \frac{1}{\frac{x_2}{\rho_D} + \frac{1 - x_2}{\rho_F}} = \frac{1}{\frac{0.13}{2.99} + \frac{1 - 0.13}{670}} = 22.3 \text{ kg m}^3$$

$$u_2 = \frac{W}{\frac{\pi}{4} \bullet \rho_2 \bullet D_N^2} = \frac{158600/3600}{22.3 \bullet \frac{\pi}{4} \bullet 0.1^2} = 251 \, m/s$$

Fig. 21: Analysis of the valve malfunction.
The complete mathematics is integrated in the SAMSON sizing software as well as in the CONVAL™ plant optimization software.

The calculation shown below was performed with the software to size an 8″ globe valve with standard seat-guided contoured plug. The globe valve is successfully in operation since 2001 (Fig. 22).

Also a 8″ rotary plug valve with decreased Cv value (seat diameter) if designed for flashing and carefully selected pipework may handle this application.

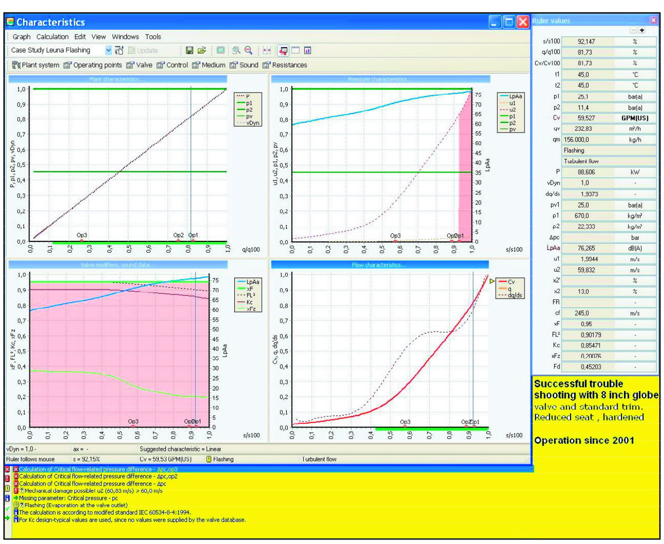


Fig. 22: Selecting the valve 8″ to avoid critical outlet velocity u2 > 60 m/s [197 ft/s]

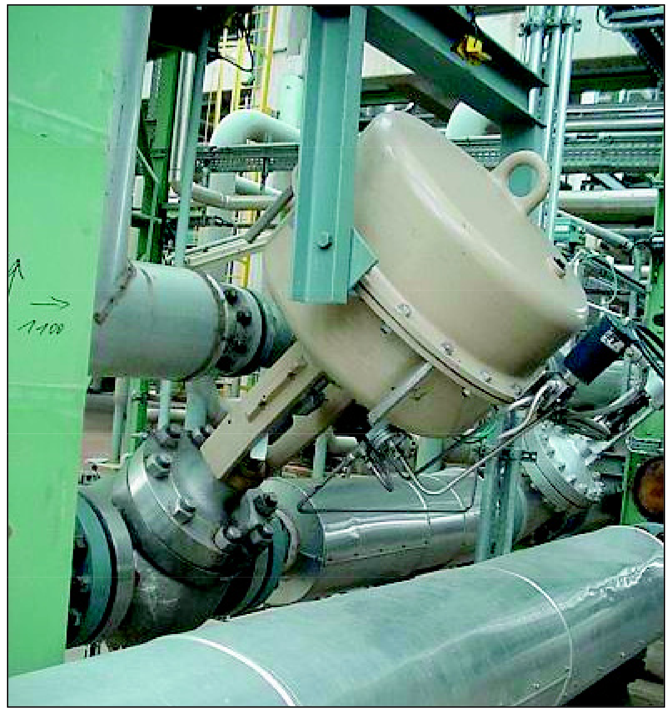


Fig. 23: 8″ standard globe valve delivered to German TOTAL refinery in Spergau, replacing a 4″ rotary plug valve to avoid plant shutdown.

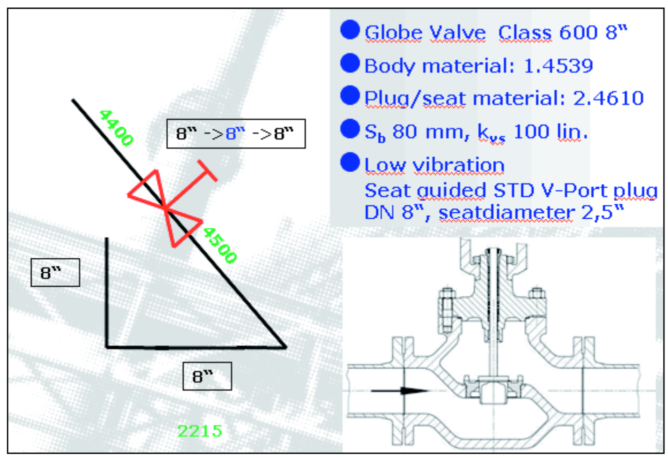


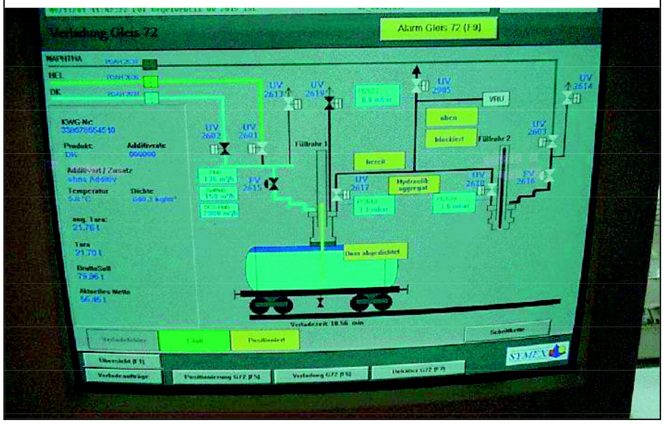
Fig. 24: Flashing: proper material and pipework as well giving the wet vapor space is all that's needed.

In case of flashing (p2 < pv), expensive multi-stage trims do not provide any advantages. It is better to use standard trims, hardened material and to keep valve outlet velocity below sonic velocity of wet vapor (< 60 m/s) as well as to ensure proper pipe installation.

Example 3

Severe dangerous pipe vibration of too small petrol loading valves and successful troubleshooting

Severe pipe vibration (risk of piping/weld seam rupture) with these rotary plug valves



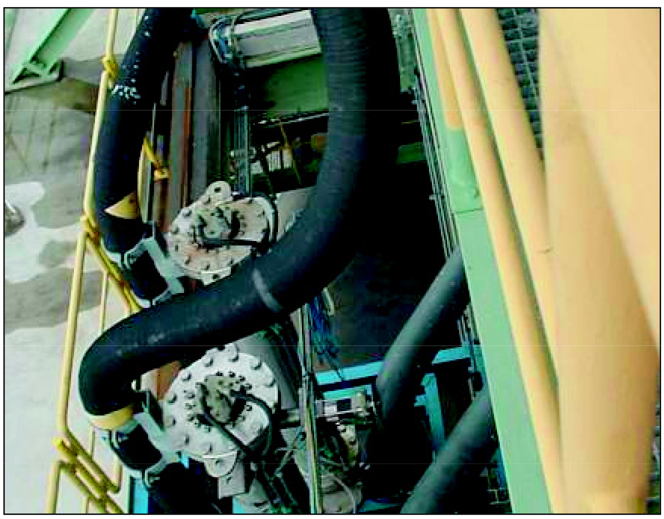
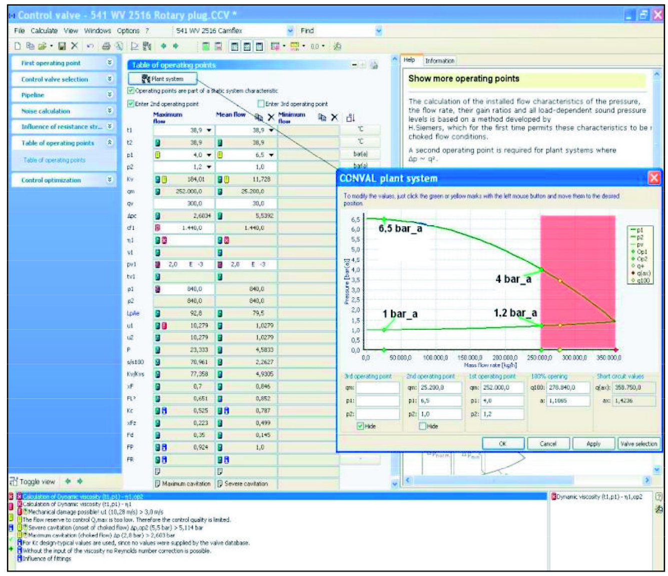


Fig. 25: Petrol loading station: Too small sizes of rotary valves on first floor cause noise and severe dangerous pipe vibration



High noise and pipe vibration with rotary plug valve.

Better pipe dancing on the ground floor

Fig. 26: Operating data show severe cavitation for standard type of rotary valve which increase noise to 96 dB(A) and cause severe vibration of the pipework

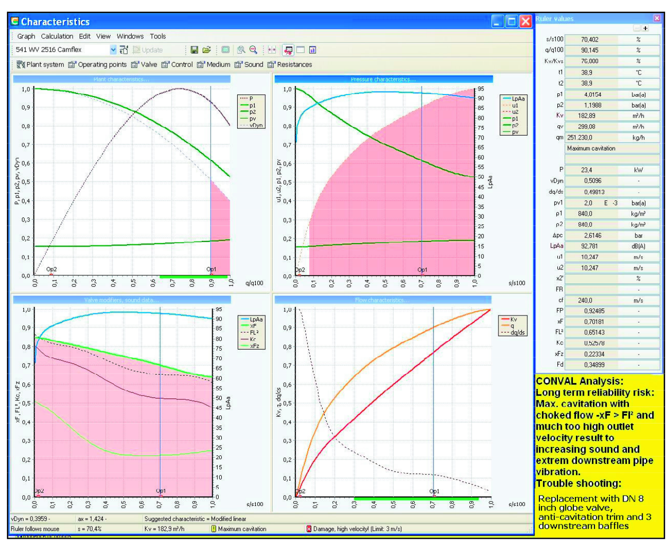


Fig. 27: Graphic support with root malfunction analysis of the wrong sized valve – Calculation with 4" rotary plug valve, critical outlet velocity u2 = 10.42 m/s (33.72 ft/s) installed in 8" pipe. Warning of too high valve outlet velocity as root failure source.

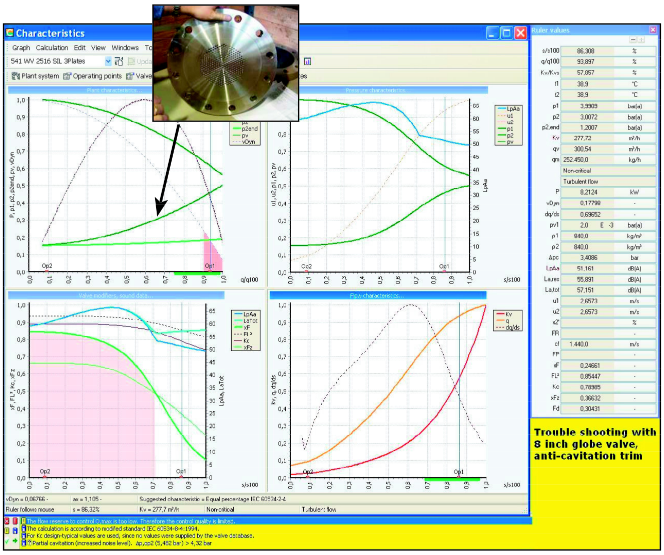
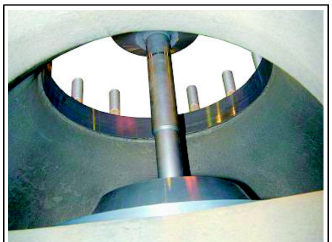
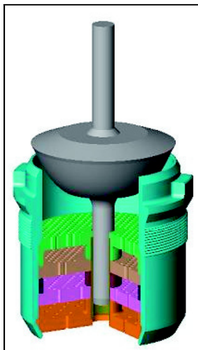


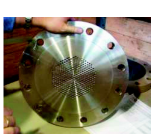
Fig. 28: Troubleshooting with 8″ globe valve and anti-cavitation trim and downstream baffles – Calculation of 8″ globe valve with anti-cavitation device and 3 downstream baffles. Replacement in 2001 with 8″ globe valve u2 < 3 m. Also a low noise rotary plug anti-cavitation design at larger valve size may handle this application.

Anti-cavitation trim with up to four baffles





Top and bottom seat-guided parabolic plug with integrated upstream baffles or downstream baffles (silencer)



Cutaway model operates in the SAMSON test rig for cavitation and flashing research.

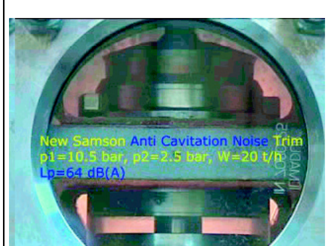


Fig. 29: AC trim system (anti-cavitation design)

11. Coming up with another design other than the current low-noise cage design

Finally, the author has followed growing market demands to present a new alternative to an expensive pressure-balanced cage globe valve design. Metal-to-metal leakage rate Class V is required combined with higher shutdown pressure, which called for a pressure-balanced design. Cage valves are more dirt-sensitive and can have a higher rate of failure, which increases the total cost of ownership (TCO). Today, often there is no time for proper commissioning with a traditional long-term flushing process, dirt filters, replacing cage valves with spool pieces etc.

It is often wishful thinking to believe that the process fluid is clean.

Five special low-noise triple-eccentric butterfly valves operate in a large petrochemical complex in Nanhai, China in critical applications, handling the fire-fighting water (Fig. 32c) and cooling water system (Fig. 32b) at a considerably lower price than a cage globe valve.

This latest development in high-performance butterfly technology offers unique opportunities to reduce cost because this type of rotary valve can be delivered to sizes of up to 100″ and also for high-pressure applications up to Class 2500. The butterfly valve comply with leakage class V with metal-to-metal sealing and even reach class VI bubble-tight requirements similar to soft-seated seats. Combined with a powerful rotary actuator, high shutdown pressures are possible and open up very economic possibilities to replace very expensive pressure-balanced, dirt-sensitive cage globe valves, even when the application calls for noise reduction in a limited area.

Sixteen Type LTR 43 Butterfly Valves in size 60″ work in the Nanhai petrochemical complex [4] as start-up devices of enormous water pumps for the plant cooling water supply.

Fig. 30a shows a unique picture of a dynamic test directly after the successful static leak test for leakage class V at conditions of 8 to 1 bar. The approximately 20-m-high water fountain produced with the small pump shows the main construction parameters of the triple-eccentric design.

In the Nanhai petrochemical complex, a unique challenge was to reduce cavitation noise by about 15 dB(A) to < 90 dB(A) warranty; seat leakage class V, with high cv 100 value > 2000. A pressure-balanced design is not recommended due to possible dirt.

In the design phase, special care was taken to handle the limits of critical outlet velocities (Fig. 32a).

These valves were successfully commissioned and could be offered at a significant lower price than a complicated pressure-balanced low-noise cage globe valve [4].

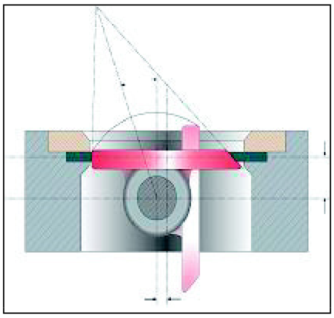


Fig. 30b: Triple-eccentric butterfly design

Fig. 30a: Final inspection at LEUSCH (member of the SAMSON AG Group)

12. Conclusion

The author, who has been active in the control valve business for more than 35 years, has noticed that troubleshooting has increased in all fields and occupies a significant part of his time.

Time and cost pressure from his point of view can affect plant reliability objectives.

The following priorities concerning valves are often specified by end users in the HPI sector:

- Safety and reliability
- Control quality
- Environmentally aspects, trouble-free life cycles and lowest cost of ownership.

Nowadays, the contradiction often arises as consultants are under significant pressure to keep costs low and opt for other priorities:

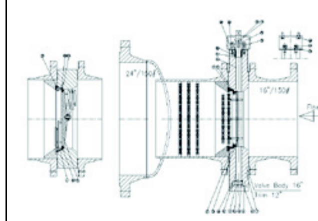
- Lowest initial cost
- Just meeting the specification
- Just meeting the warranty time
- e-bidding and e-purchasing

Valve sizing standards and regulations as well as safety regulations seem to be complete but there are gaps with the potential for unpredicted plant shutdown and disasters.

Noise prediction methods were developed in the early 1980s. This was only possible because competitors worked together with an open mind and a common goal. The same should be possible today concerning the reliability objectives of control valves.

Fig. 31: A different design than the common low-noise cage design

Fig. 32a: Design draft of fire-fighting water, low-noise valve. DN 1 = 16", DN 2 = 12", DN 3 = 24" for outlet velocity < 5 m/s at max. flow



DN 3 = 24"----DN 2 = 12"----DN 1 = 16"

Commis-sioning the cooling water valves

Fig 32b: Cooling water supply valve

Commis-sioning the fire-fighting valves

Fig 32c: Fire-fighting water pump-around valve

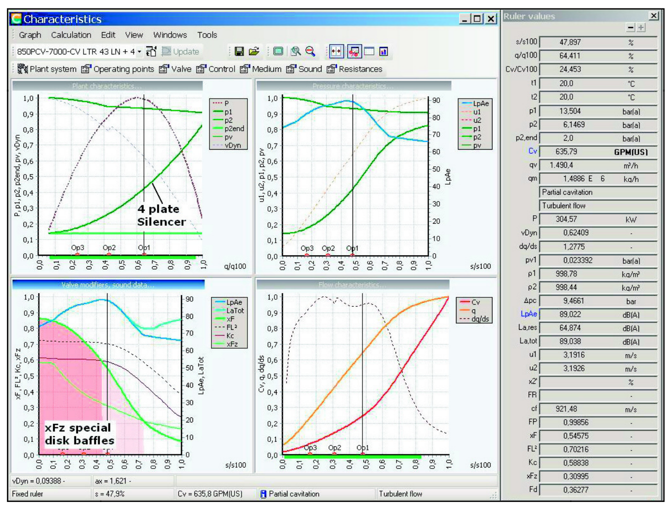


Fig. 33: Calculation of the pump around fire-fighting water control valve (Fig. 32c) with critical pressure letdown 13.5 bar (a) to 2 bar (a) and low-noise devices.

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[3] Sizing for Severe Service "Kinetic Energy Model" L. Stratton CCI 2005 Valve World CVRP Seminar

[4] "Nanhai revisited" Valve World Interview with Teun Hooftman Shell Petrochemicals Company Ltd. Valve World Edition February 2006

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2007-11 DR · WA 183 EN