Plant design and control valve selection under increasing cost and time pressure - Part I

Following a career spanning three decades, Mr Siemers is well aware of the pitfalls to be avoided when specifying control valves for a range of demanding applications. In his latest paper for Valve World, he looks further into plant design and control valve selection when working under increased time and cost pressure. This article is split into two parts: broadly speaking, part one looks at control valve operating points and provides a case history involving a mismatch. The author then introduces better valve sizing practices and uses this theory to resolve the problems introduced in the case history. Part two (scheduled for the June issue) starts by explaining the trends and definitions of inherent valve characteristics before focusing on „quick and dirty" sizing. The paper then addresses cavitation before concluding with the expert software available to help select the optimum valve characteristic form.

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This publication will continue taking more the aspect of CONTROL QUALITY into account, which can also suffer under the increasing cost and time pressure. The success of the plant - production quality and production quantity - can directly depend on reasonable valve control quality, especially if valves are in "key" functions.

1. Plant design under cost and time pressure

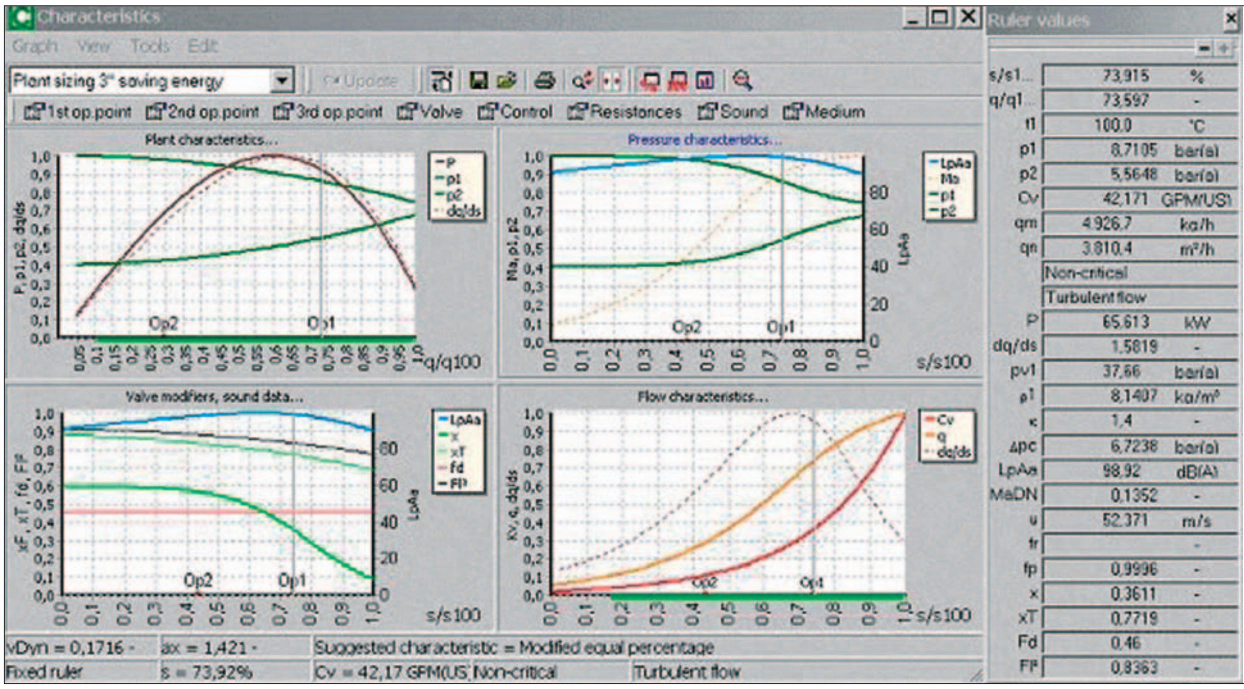
Optimizing the pump start pressure with pressure loss calculation of the pipework is the key to save power and energy in the long/term as well as to reduce wear, noise, and maintenance cost.[1] Accurate calculation sheets for the pipework and the control valve can be printed out within 15 minutes for a plant system shown in Figure1b using the manufacturer-independent CONVAL software for valves, pipes, and pipe devices, generating dynamic graphics of plant and control valve characteristics. See Figure 1a.

Obtaining optimum control valve parameters

The following seven steps will prove beneficial to obtaining the optimum control valve parameters:

1) Divide the plant pipework into three sections
   a) From pressure source - pump/vessel; start pressure to the flow meter upstream pressure.
   b) From the flow meter downstream pressure to the control valve upstream pressure.
   c) From the control valve downstream pressure to the plant end pressure (place of production)
2) Pressure loss calculation for qmax. qnorm. and qmin. section a)
3) Flow meter optimization with residual pressure losses at qmax. qnorm. and qmin.
4) Pressure loss calculation for qmax. qnorm. and qmin. section b) to start with flow meter downstream pressure. The yields the first result: the valve upstream pressure characteristic at qmax. qnorm. and qmin.

Note: given the amount of detail in some of the graphics in this article, readers might like to note that a high resolution PDF version can be viewed at: www.valve-world.net/magazine/controlvalves.asp.



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 exchangers
- Condensers
- Pump motor output

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

Fig. 1a: Result of proper control valve optimization using program parts: pressure loss; differential pressure flow elements and control valves.

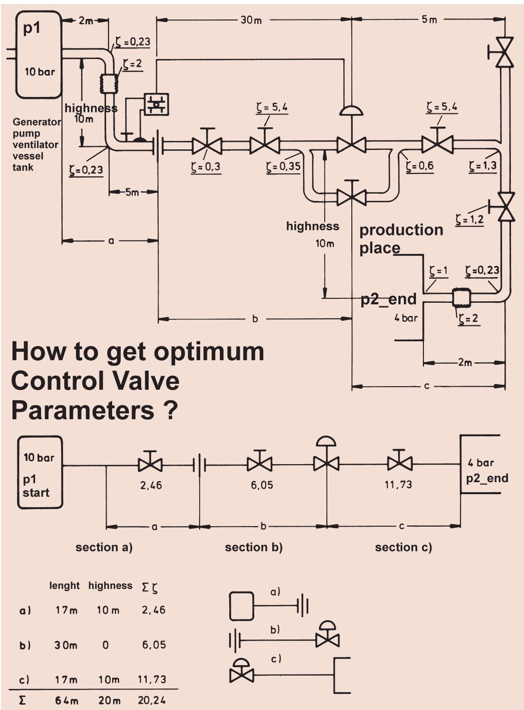


Fig. 1b: Plant system and proper control valve optimization with the CONVAL software.

5) Pressure loss calculation for qmax. qnorm. and qmin. section c) to start with any control valve downstream pressure e.g. p2 = p1 - Δpn (Δpn = 1 bar). Compare the result with the plant end pressure and iteratively correct the valve downstream pressure with the pressure drop deviation until the end pressure is reached. This yields the final result: the valve downstream pressure characteristic at qmax. qnorm. and qmin.

6) Control valve sizing and optimization leads to the selection of the most suitable control valve. Valve parameters to optimize: Cv100 value and the valve inherent characteristic

7) Check the control parameters: control range, $q_{max} < 0.9 x q_{100}$, valve gain $0.5 < gain < 2$ and SPL dB(A) characteristic: The loop gain depends on the control variable Flow q, Level L, Temperature T or Pressure p: $\Delta q / \Delta s$; $\Delta L / \Delta s$; $\Delta T / \Delta s$ or $\Delta p / \Delta s$. p=p1; p2 or Δp. Check the valve max. power consumption and select a valve which withstands its highest stress situation at max. power. For a new plant, more than fifty per cent power savings can beachieved by sizing the plant and valve parameters more accurately. [1, 4]

2. Control valves today are converting links between budgets!

Increasing cost and time pressure have considerably affected plant designers. To explain the change of planning parameters from the past to today, a simple pneumatic control loop (Figure 2a) could help to understand the upcoming problem. The control valve is the connecting link between the CONTROL EQUIPMENT and the CONTROLLED SYSTEM. Control equipment can include signal transmitters, actuators, single controllers or complex DCS systems. The controlled system includes pumps, pipework, and pipe devices like valves. If all signal transfer devices 2) to 5) operate in a strictly linear way the flow meter and the control valve as signal transfer devices 1) to 6) also need to work as linearly as possible to achieve an excellent control quality (Figure 2b).

If different departments are responsible for the control equipment and for the controlled system with their specific budgets the need of the valve pressure differential is quite often forgotten. If the differential pressure ratio is too small, the control valve will lose control authority.

The responsibility for control quality depends on the valve authority, the valve inherent characteristic quality and the characteristic form but also on the selected cv100 value. Mismatching can lead to an uncontrolled process variable and excessive gain fluctuations up to loop hunting. Under the worst-case conditions the investment targets of production may not be met.

Case study: Good stroking, bad control

In many cases the traditional engineering practice does not fit the needs of today. Additional engineering rules should be added to, or even used to replace, the traditional engineering practice which only

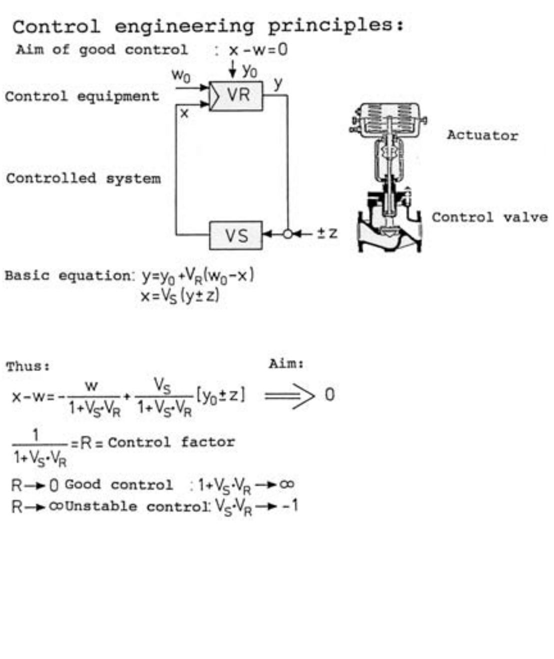


Fig. 2a: Control valve: the converting link between control equipment and controlled system.

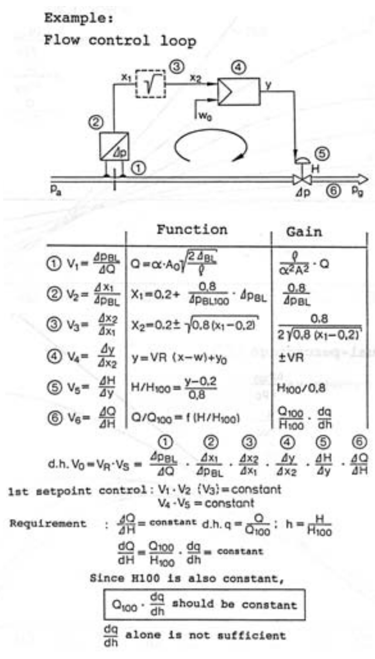


Fig. 2b: Importance of valve gain fluctuations to control quality.

takes the relationship "valve stroke versus flow" into account.

Quick selecting only looks at the traditional "stroke versus flow" requirements for the given operating point qmax. But the stroke $s < 0.8$ is not of interest here. Stroking to $s=1$ will increase the flow only by about 1.7 %. Here it is not the valve manufacturer's responsibility but rather the plant designer's problem to get the production under control and to increase valve authority at qmax., for example with more pump power.

Planning mistakes often occur as a result of too small budgets and missing control competence.

Figure 3 (bottom right) shows that the operating point qmax is situated at "good" < 0.8 s/s100 stroke but not controllable at 98.3 % flow. See also warning alarm in the top left chart. The plant target to get a reasonable control of qmax. (means production quality as well as production quantity) cannot be achieved.

Sources of planning mistakes

Planning mistakes can result from a number of situations, including: excessive pressure loss due to pipe and pipe devices, insufficient pump power; not enough expenditure on plant design; failure to take the need for necessary differential pressure ratio for control valves into account;

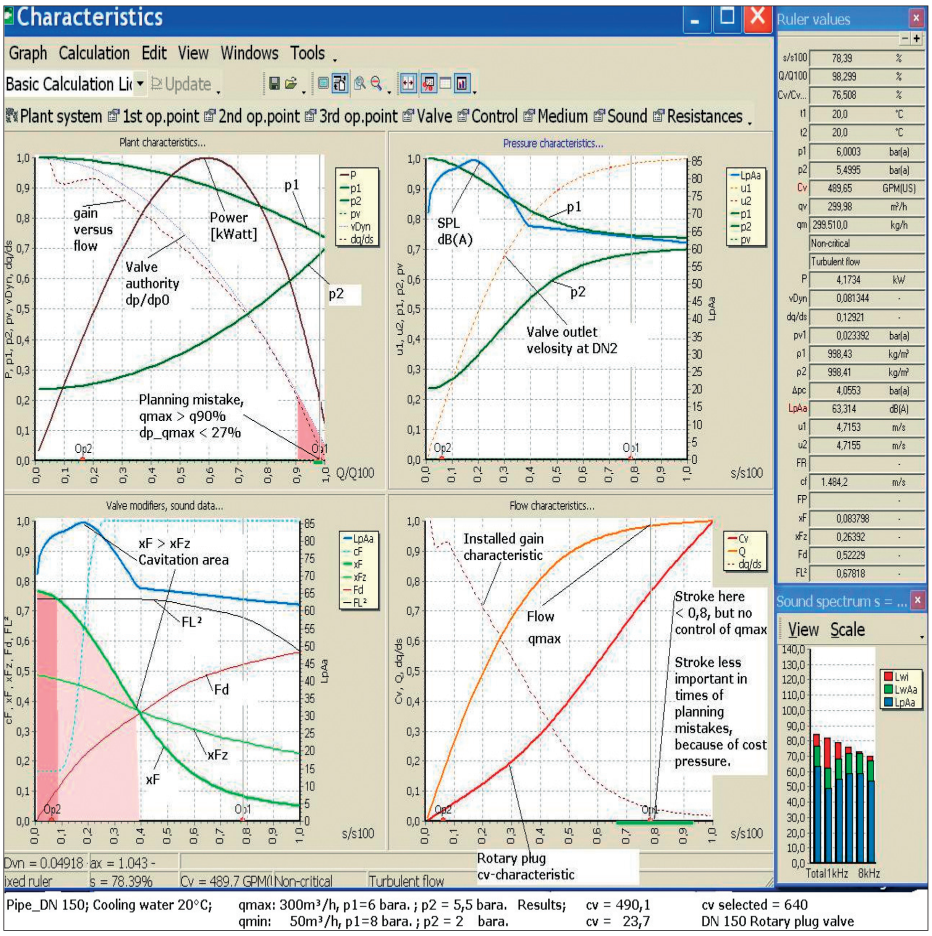


Fig. 3: Typical results of time and cost pressure: no control of production target qmax.

no accurate pressure loss calculation with too many assumed parameters. To de-bottleneck, if neither changing the pipe DN nor saving pressure loss is possible then one troubleshooting option includes increasing the pump power with new pump or pump impeller (see Figure 5).

3. From traditional to modern Development and Engineering Practice (DEP) for plant designers

The history of traditional "valve stroke versus flow" requirements dates back to earlier times (Figure 4a) when heavy-duty top-guided and bottom-guided or cage-guided valves were oversized and over-engineered in stroke and body weight for the standard applications of today. At that time, only linear or equal percentage valve characteristics were known. In the time of plant pioneers, new processes were installed for the first time on a lower scale production volume. Valve trims were reduced several times to double the production regarding increasing market demands. In the same way pumps and pipe devices were installed with flow reserve.

Today plant parameters are well known. From an economic point of view globe valves often selected with the largest seat. If designed with too small a residual pressure differential globe valves need to be ▶

replaced with high flow capacity rotary valves. CONVAL's graphical support can show and self-explain advantages and disadvantages and the risk of over-sizing.
In general engineering practice, the control valves at system end (short circuit performance) should not be oversized.
The standardized plant system with total valve authority $\Delta p100 / \Delta p0 = 0.1$ shows the impact of an ideal equal percentage and linear inherent valve characteristic. Figure 4b compares good control parameters with an equal percentage and bad control parameters with a linear characteristic.
To calculate the control rangeability from 5 to 100 % stroke and gain fluctuation:

The gain fluctuations $\Delta q / \Delta s$ versus flow as a function of the total valve authority [$v = \Delta p100 / \Delta p0$] (see Figures 4c and 4d). Following the SHELL development and engineering practice (DEP) 32.36.01.17 GEN control valve selection, sizing and specification in principle recommends plant designers follow the plant design rules indicated below for pump, pipework, and pipe device design. Important is for the "split responsibilities" to work together. One recommendation is to replace the "operating point versus stroke" requirements under the responsibility of plant designers and valve manufacturers to avoid considerable loss of control quality.

Plant designers' responsibility (Figure 5a)
The process design flow qmax. shall stay ≤ 0.9 x q100. q100 as a function of the selected cv100 value can be replaced with a valve manufacturer independent relationship: - the max system flow : 0.9 x q100 can also defined to 0,85 q* as the distance to the max. system flow. (q* = q_90 x qs = short circuit performance without control valve).
At qmax. = 0.9 x q100 =0,85 x qs the valve authority shall design $\Delta p90 / \Delta p0 \geq 0.27$. qs=q*/q_90 can be calculated for gas and liquid as a function of p1 and Δp and minimum selection between qs_1; qs_2; qs_3:

Characteristic eq. : 1 : 15; $0.5 < \Delta q / \Delta s < 2$ ok
Characteristic lin. : 1 : 5; $0.5 < \Delta q / \Delta s < 2$ not ok

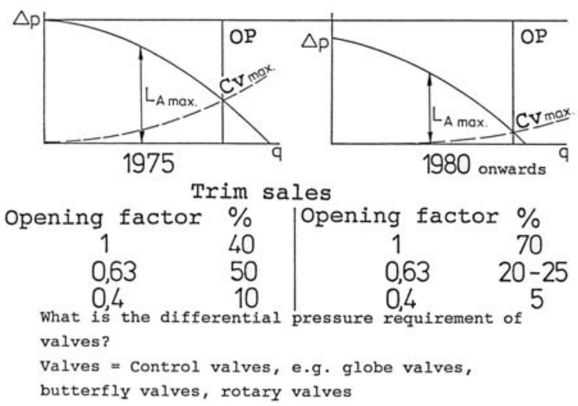


Fig. 4a

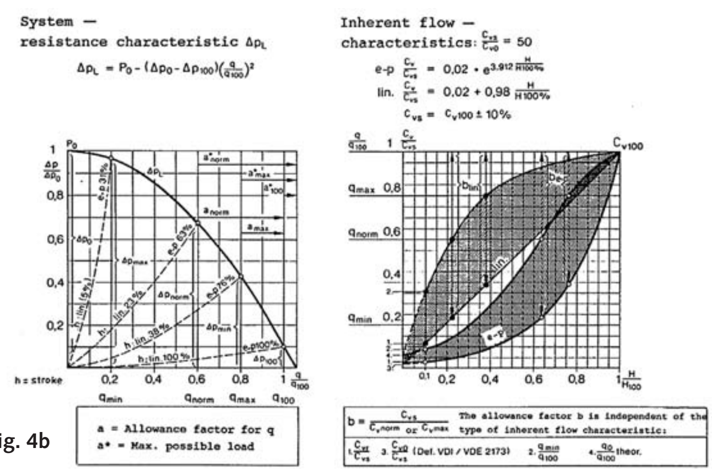


Fig. 4b

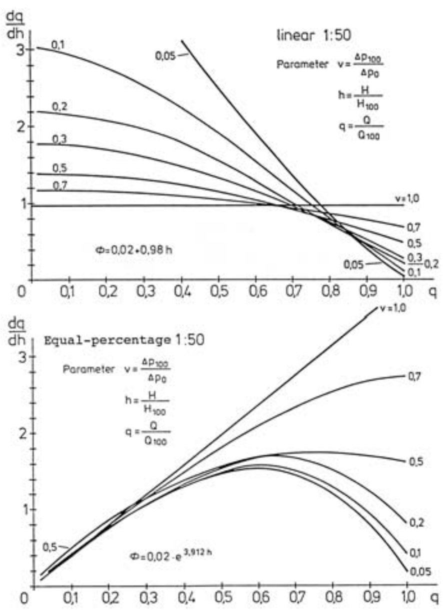


Fig. 4c: Signal proportional q.

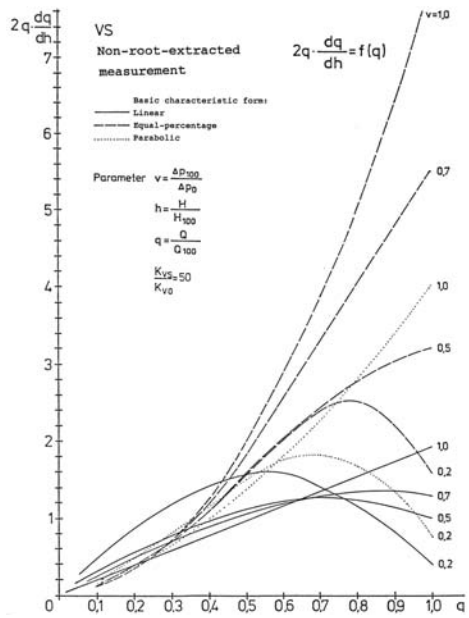


Fig. 4d: Signal proportional q^2.

Figs. 4a to 4d: Plant system trends and how to keep gain fluctuations (control quality) under control.

The short circuit performance of system upstream pressure characteristic [2] is given by:

Liquid: $$qs\_1 = \frac{q^*}{q_{90}} = \frac{1}{\sqrt{1-\frac{p_{1\_90}-p_v}{p_{1\_0}-p_v}}}$$

Gas; Steam; $$qs\_2 = \frac{q^*}{q_{90}} = \frac{1}{\sqrt{1-\frac{p_{1\_90}}{p_{1\_0}}}}$$

The short circuit performance of system pressure differential characteristic [2] is given by:

Liquid; gas; steam: $$qs\_3 = \frac{q^*}{q_{90}} = \frac{1}{\sqrt{1-\frac{\Delta p_{90}}{\Delta p_0}}}$$

(e.g. if Δp90 / Δp0 = 0.27 $qs\_3 = \frac{q^*}{q_{90}} = 1{,}17$ this results to the valve independent rule for plant designers q_90 = 1/1,17x q* = 0,85 x q*)

Valve manufacturers' responsibility (Figure 5b)
The valve cv100 value shall keep the total valve authority Δp100 / Δp0 ≥ 0.1. If Δp100 / Δp0 = 0.1 the valve characteristic shall be chosen as equal percentage as possible. Figure 4b shows the relationship for any other "flow versus pressure drop" relationship for the plant parameter total valve authority Δp100 / Δp0 = 0.1 only if an ideal equal characteristic is selected. Consequently following the new suggested regulations the mismatched plant system as shown in Figure 3 can be optimized in the early stage of planning.

Flow q/q100	Valve authority V = Δp / Δp0	Stroke, Travel s/s100 eq. char.
1	0.1	1
0.9	0.27	0.85
0.8	0.42	0.77

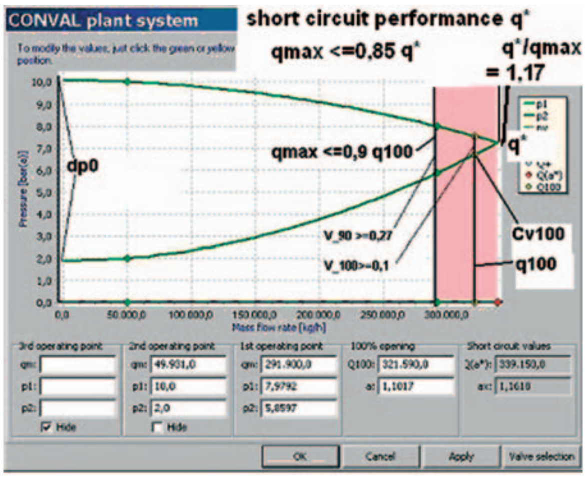


Fig 5a: Plant designers' responsibility.

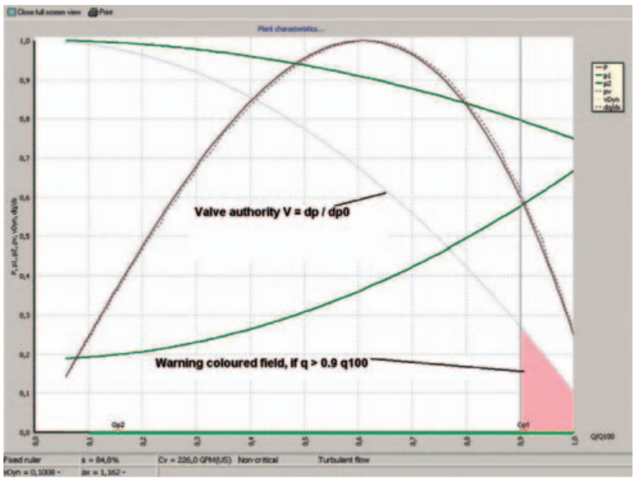


Fig. 5b: Valve manufacturers' responsibility.

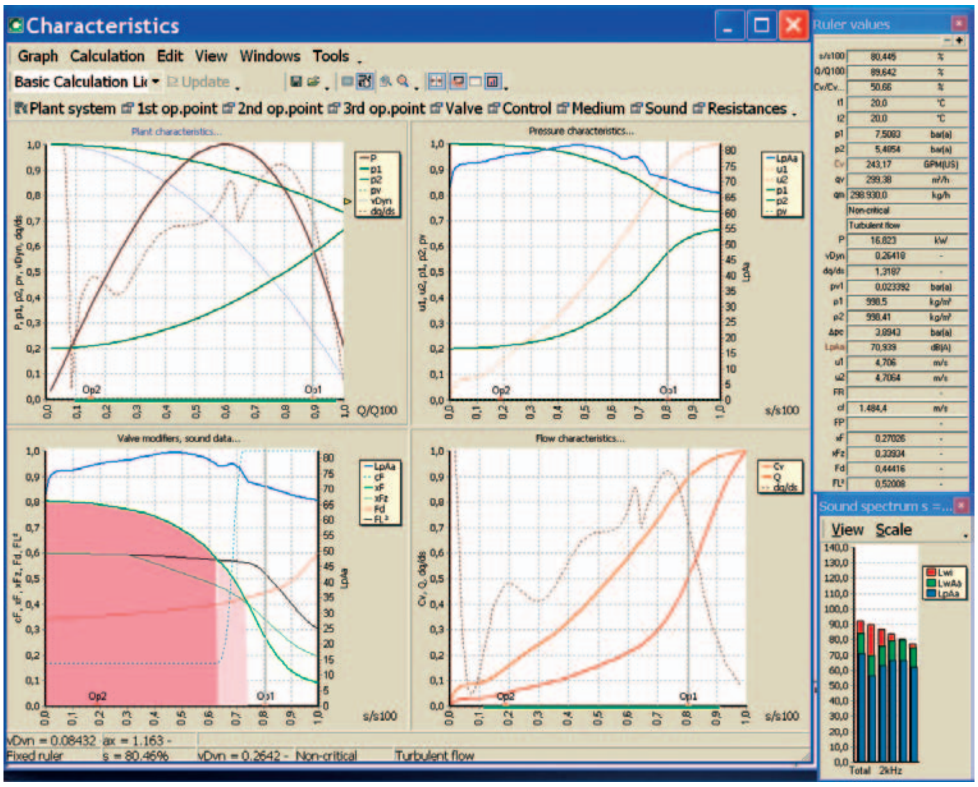


Fig. 5c: Valve authority Vdyn = 0.27 at q_max = 0.9 q100 for a low noise cage ball valve ™ (PiBiViesse, Italy), 6 inch.

Figs. 5a, b, c: How to avoid loss of control quality using proper plant parameters and valve sizing.

4. The new DEP for trouble shooting the mismatched case study from section 2

Figures 6a and 6b show a new upstream pressure characteristic increase p1 at qmax from 6 to 7.5 bar abs and at qmin. from 8 to 9.5 bar abs with installing higher pump power. A DN 150 globe valve with AC low noise trim could be the choice for SPL < 80 dB(A). (See Figure 6a.)

The installed flow characteristic gain variation stays within the engineering practice rule: 0.5 < Δq / Δs < 2 in the entire range of control. From qmin up to q100 presented this reasonable gain borders with the bottom green line in the top left and bottom right graphs in Figures 6a and 6b. If replacing the globe valve with a rotary plug valve of the same cv100 value the installed flow characteristic drifts in on-off direction (Figure 6b). The installed flow characteristic's higher gain fluctuations still stay within the engineering practice rules: 0.5 < Δq / Δs < 2 between the operating points qmax and qmin: shown with the bottom green line in the top left and bottom right graphs. The sound pressure level can exceed > 85 dB(A). The software further indicates choked flow up to 30% travel and min. flow control at small opening 5%. This can easily be further optimized with a smaller cv100 value by reduced seat technology and adding integrated low-noise devices. In case of higher DN, high shut down pressure, exotic materials, and within the given sound requirements a rotary plug valve could be a reasonably priced alternative to globe valves. ■

Don't miss the second and concluding section of this paper in the June issue of Valve World.

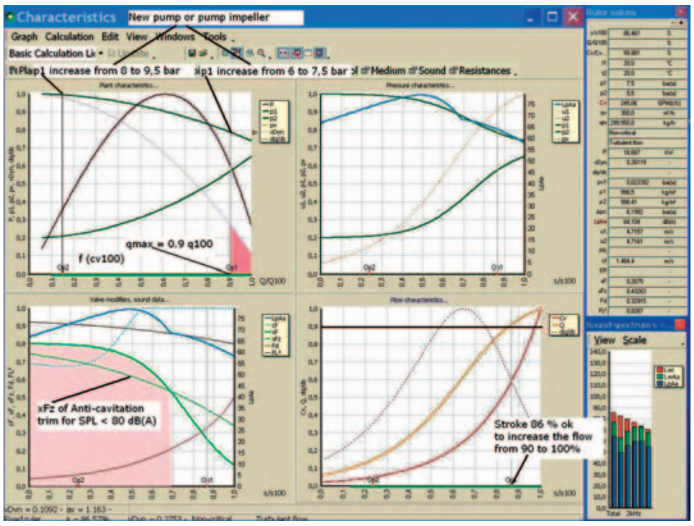


Fig. 6a: Correction of planning mistakes from Figure 3 with more pump power selecting a globe valve.

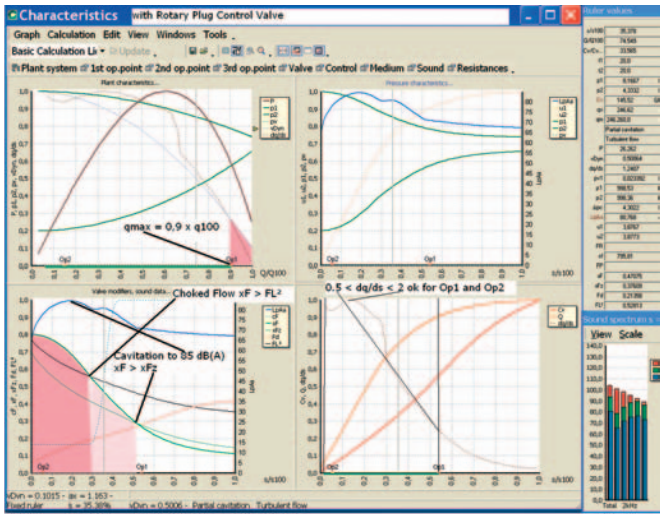


Fig. 6b: Correction of planning mistakes from Figure 3 with more pump power selecting a rotary plug valve.

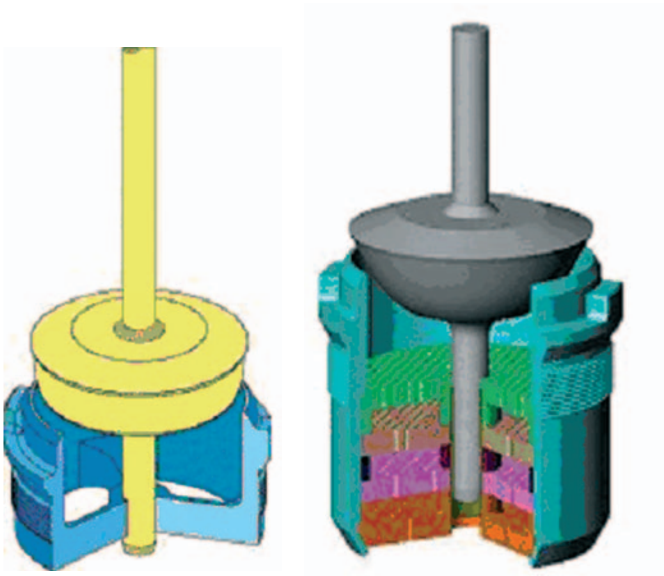


Fig. 6c: The SAMSON AG AC-Trim system can solve upcoming cavitation problems after de-bottlenecking.[3]

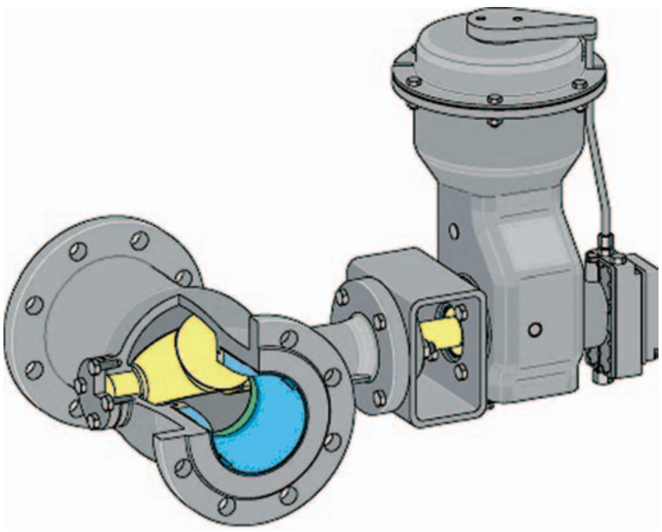


Fig. 6d: The VETEC rotary plug valve in specific areas is a reasonably priced alternative to the globe valve.