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

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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.

Part I

1. Plant design under cost and time pressure
2. Control valves today are converting links between budgets!
3. From traditional to modern Development and Engineering Practice (DEP) for plant designers
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Part II

5. Trends and definitions of inherent valve characteristics for globe and rotary valves.
6. Detail engineering-sources for plant and valve designers have dried out!
7. Noise reduction and getting the plant power under control.
8. Selecting the optimum valve characteristic form
9. Using software to increase control quality, reduce cost and save time for creativity

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.
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, qmax < 0.9xq100, 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: ∆q/∆s; ∆L/∆s; ∆T/∆s or ∆p/∆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 be achieved 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 uncontrollable 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
CONTROL VALVES

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 \( q_{\text{max}} \). 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 \( q_{\text{max}} \), 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 \( q_{\text{max}} \) is situated at “good” < 0.8 s/s\(_{100}\) 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 \( q_{\text{max}} \) (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; 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.
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 \( \Delta p_{100} / \Delta p_0 = 0.1 \) 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:

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

Plant designers’ responsibility (Figure 5a)
The process design flow \( q_{\text{max}} \), shall stay \( \leq 0.9 \times q_{100} \). \( q_{100} \) as a function of the selected \( cv_{100} \) value can be replaced with a valve manufacturer independent relationship: the max system flow : \( 0.9 \times q_{100} \) can also defined to 0.85 \( q^* \) as the distance to the max. system flow. \( q^* = q_{90} \times q_s = \) short circuit performance without control valve).

At \( q_{\text{max}} = 0.9 \times q_{100} = 0.85 \times q_s \) the valve authority shall design \( \Delta p_{90} / \Delta p_0 \geq 0.27 \). \( q_s = q^*/q_{90} \) can be calculated for gas and liquid as a function of \( p_1 \) and \( \Delta p \) and minimum selection between \( q_{s_1}; q_{s_2}; q_{s_3} \):

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**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: \[ q_{v,1} = \frac{q}{q_0} = \frac{1}{1 + \frac{P_{c1} - P_c}{\Delta P}} \]

Gas; Steam: \[ q_{v,2} = \frac{q}{q_0} = \frac{1}{1 + \frac{P_{c2} - P_c}{\Delta P}} \]

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

Liquid; gas; steam: \[ q_{v,3} = \frac{q}{q_0} = \frac{1}{1 + \frac{\Delta P}{\Delta P_{0}}} \]

(e.g., if \( \Delta P_{90} / \Delta P_0 = 0.27 \), this results to the valve independent rule for plant designers \( q_{90} = 1 / 1.17 \times q^* = 0.85 \times q^* \))

**Valve manufacturers’ responsibility (Figure 5b)**

The valve cv100 value shall keep the total valve authority \( \Delta P_{100} / \Delta P_0 \geq 0.1 \). If \( \Delta P_{100} / \Delta P_0 = 0.1 \) 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 \( \Delta P_{100} / \Delta P_0 = 0.1 \) 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.

<table>
<thead>
<tr>
<th>Flow ( q/q_{100} )</th>
<th>Valve authority ( V = \Delta P / \Delta P_0 )</th>
<th>Stroke, Travel ( s/s_{100} ) eq. char.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>0.9</td>
<td>0.27</td>
<td>0.85</td>
</tr>
<tr>
<td>0.8</td>
<td>0.42</td>
<td>0.77</td>
</tr>
</tbody>
</table>

**Fig 5a:** Plant designers’ responsibility.

**Fig. 5b:** Valve manufacturers’ responsibility.

**Fig. 5c:** Valve authority \( V_{dy} = 0.27 \) at \( q_{max} = 0.9 \times q_{100} \) 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 \( p_1 \) at \( q_{\text{max}} \) from 6 to 7.5 bar abs and at \( q_{\text{min}} \) 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 \( \text{SPL} < 80 \text{ dB(A)} \). (See Figure 6a.)

The installed flow characteristic gain variation stays within the engineering practice rule: \( 0.5 < \frac{\Delta q}{\Delta s} < 2 \) in the entire range of control. From \( q_{\text{min}} \) up to \( q_{100} \) 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 \( cv_{100} \) 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: \( 0.5 < \frac{\Delta q}{\Delta s} < 2 \) between the operating points \( q_{\text{max}} \) and \( q_{\text{min}} \) shown with the bottom green line in the top left and bottom right graphs. The sound pressure level can exceed \( > 85 \text{ dB(A)} \). 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 \( cv_{100} \) 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.