Tailoring the Specifications for Pressure Reducing Valves

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Introduction

The authors have noticed that water utilities around the world are experiencing difficulties when it comes to the specification of pressure reducing valves (PRVs). This is of particular concern in complex situations, such as the low pressure systems in Southeast and South Asia or the high pressure differential situations such as in some parts of Europe and South Africa.

This paper will explain the issues around tailoring PRV specifications to specific local conditions. It intends to serve as a discussion platform between the utility engineers, consultants and the sales staff of pressure reducing valve manufacturers.

Building up a specification – the supplier standard specification approach vs. the system requirement approach

The most common manner in which specifications are compiled is through copying data sheets from trustworthy suppliers or combining the key features from a number of such suppliers. It is the authors' belief that even though this method may assist in the prevention of low quality equipment being used, it may lead to situations where the features are different to what would be needed for the specific situation; this due to the fact that the standard specification may fit a general system's requirement that is not representative for the specific application.

PRV types – an Overview

The basic pressure reducing valve structure is very similar for all valve manufacturers and consists of three main parts:

1. A valve body assembly, that incorporates a seat arrangement;
2. An internal trim, which consist of a plug, shaft and actuator (normally diaphragm or piston);
3. A bonnet (or cover) assembly.

The differences between the different valves are in the body shape, actuator & guiding mechanism design and in some few cases – deviation from the above described conventional design.

The first, most common valve to be presented is the diaphragm actuated GLOBE type valve. This valve is characterized by internal trim movement that is perpendicular to the flow direction through the valve.

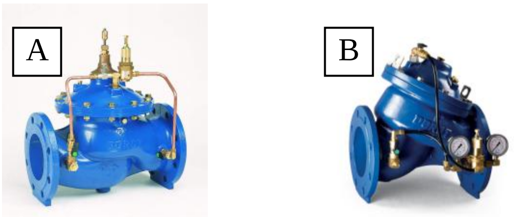

Figure 1: Sample Globe PRV (A) and "Y" pattern PRV (B)

This valve type is relatively simple in design and usually contains no internal sealing. It is easy to maintain even when installed in a valve chamber because the trim can be pulled straight upwards through the manhole. Due to the low-friction trim design, these valves will normally operate under low-pressure differential conditions.

A second, common valve type is often called "Y" Pattern where the internal trim is arranged in a 45-60º angle to the flow direction (patented by Dorot Automatic Controls in the 1970's). This allows for lower turbulence flow through the valve and thus – lower pressure losses for the fully open valve, compared with the Globe design (refer to **Table 1** for further information).

Characteristics of the Globe Type and the Y-pattern Type valve include:

1. Both may have stability problems when regulating pressure under low flow and high pressure differential conditions and in some cases would require use of special devices to assist the low flow regulation ability (see section on "Pressure regulation stability")
2. Both can be supplied in two versions: Standard design and Double-Chamber design. The second is characterized by an additional control chamber, situated below the diaphragm and allows the use of external pressure source below the diaphragm to assist the valve opening in case no sufficient opening force is created by the low line pressure. It is important to emphasize that this unique structure requires internal sealing that may add friction (that increases the required minimal opening pressure) and reduce operation reliability and therefore should only be used in on-off applications and in those very few cases where external high pressure source is available.

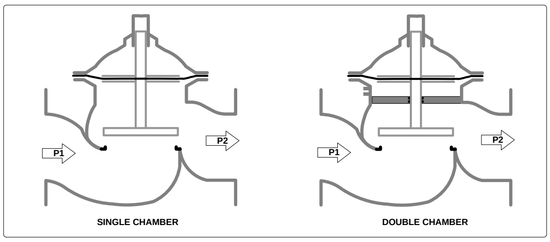

Figure 2: Single and Double Chamber Schematic

3. Both can be piston actuated or diaphragm actuated. Piston actuated globe valves are the original valves, first manufactured over 150 years ago and are still used for extreme high-pressure applications (upstream pressure 40 bar and higher), but suffer from high friction and high ownership costs and are not as common as diaphragm actuators nowadays.

The third valve type to be presented is the direct diaphragm sealing valve, which has a resilient diaphragm used both as the actuator and as the sealing element. This valve has a simple structure and is, therefore, simple to maintain and use. It can regulate low flow rates and is not as sensitive to poor water quality as other valve types. Many of these valve types present exceptionally low pressure losses (high Kv factor) and may be considered as an excellent alternative for low-pressure systems. Water utilities, Consultants and PRV manufacturers are encouraged to explore this option, particularly in the low pressure systems in South and South East Asia.

On the other hand, this valve type may have noisier operation compared with other valve types, may suffer diaphragm aberration at high pressure differential conditions and is rated to max. 16 bar pressure in most cases. Therefore, this valve type should not be used for regulating under high pressure differential applications.

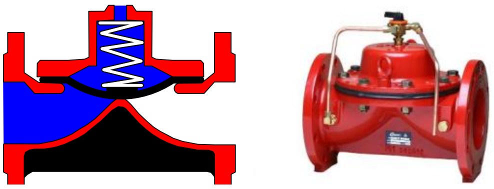

Figure 3: Direct Sealing Diaphragm Valve

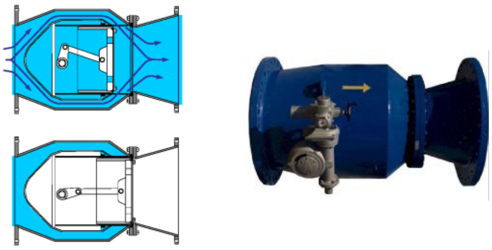

Figure 4: Plunger type Valve

The fourth and last type that is worth mentioning is the plunger type valve that is an inline, piston or electric motor actuated valve, where the plug movement is parallel with the flow direction. These valves would have very high cavitation resistance and good regulation performance but suffer from very high purchasing and operational costs.

Main Parameters to be considered when specifying a PRV

Pressure Loss

Pressure loss is often considered as a key factor in PRV tenders, in many cases, just because Kv/Cv factors are easy to compare. However, one should always keep in mind that the function of a PRV is pressure reduction – i.e. the PRV should create pressure loss!

The only case where pressure loss may become an issue is where the upstream pressure may drop (during peak demand periods) to values that are close to or even lower than the required set value.

If that is the case, it is not only the basic valve Kv/Cv factor that affects the pressure loss but even more so, the type of pilot system used.

Two way versus three way control systems

Hydraulic control systems for pressure reducing valves can be grouped in two main categories: 2-way and 3-way control systems. It is essential for the user to understand the differences between these two types of circuits and the specific applications thereof.

A 2-way control system, is the standard (and in some cases the only) available pilot control loop for hydraulic control systems. This loop consists of two elements: A fixed orifice or needle valve at the upstream side of the control loop and a pilot valve assembled on the downstream side of that system. The pilot valve resistance (open percentage) varies in response to the changing downstream pressure. If the downstream pressure is high, the pilot valve will close, thereby allowing upstream pressure to enter the valve's control chamber and push the actuator in the closing direction. When the downstream pressure is too low, the pilot valve will open which will allow pressure from the main valve's control chamber to be vented to the lower downstream pressure, which will cause the actuator to open.

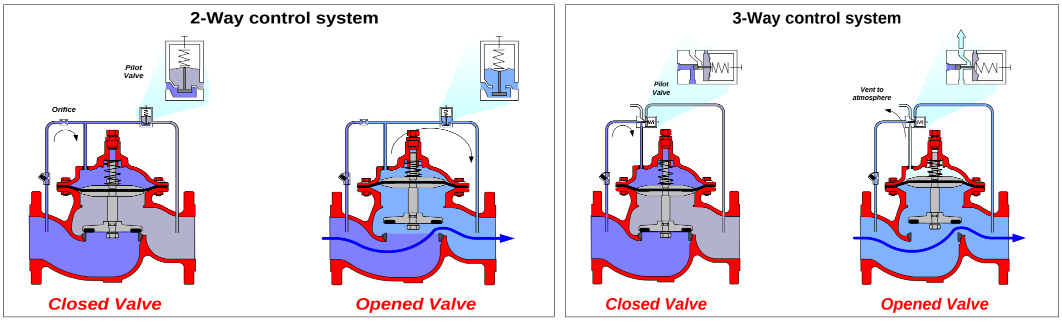

Figure 5: Two-way and Three-way Control System Schematics

Note that the Kv/Cv factors and pressure loss charts published by most valve manufacturers relate to a fully open valve with control chamber completely vented. However, when using the 2-way control system, the main valve's control chamber in the "Open" mode, is still pressurized by the downstream pressure. Therefore the valve will not open fully and a minimal pressure loss is induced by the valve, even if the flow through it is low.

This is of utmost importance when specifying PRVs for low(est) pressure systems.

Three way control pilot valves are basically 3-position selector valves that:

- In case of high downstream pressure connect the upstream pressure port to the main valve control chamber to close it.
- When the downstream pressure matches the set pressure (plus-minus a fixed dead-band), the pilot valve will block all ports and thus keeping the volume inside the control chamber and valve position fixed.
- In case of low downstream pressure, connects the control chamber port to the vent port and allows complete discharge of the control chamber pressure and full opening of the valve.

A 3-way control system will therefore allow the valve to reach its published pressure-loss in case the supply pressure will drop, while the commonly used 2-way control system will make the pressure loss much bigger than the published data.

At 3 m/sec (10 ft/sec) flow velocity, the 2-way control system (pink curve) looses some 3 meters of pressure more than the same valve controlled by a 3-way system (blue curve).

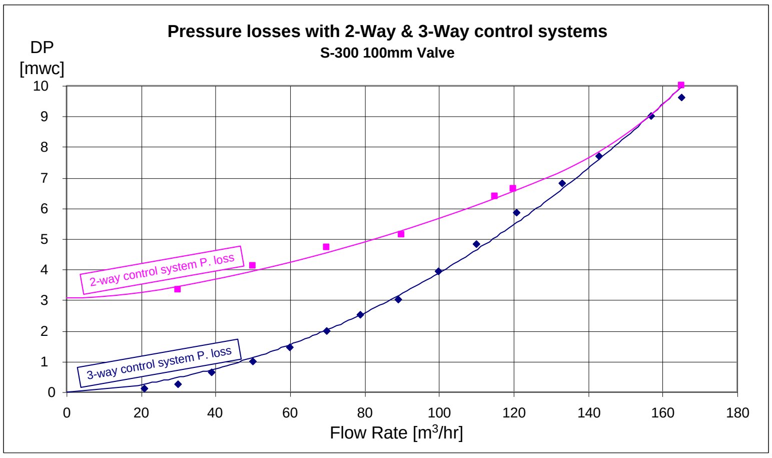

Figure 6: Pressure Losses in accordance with the type of control system

The effect of valve design – Kv/Cv consideration

The flow coefficient *Kv* is defined as the flow *Q* in m3/h with a pressure drop of 1 bar (=9.81 m).

$$Q = Kv \cdot \sqrt{\Delta P}$$

Or

$$\Delta P = \left(\frac{Q}{Kv}\right)^2$$

Once the Kv is known, the amount of flow at a given pressure drop can be found, or, conversely, the pressure drop can be determined for a specific flow.

The Cv coefficient is the same in US units were the flow is measured in gallons per minute (gpm) and the pressure drop in pounds per square inch (psi).

As mentioned earlier, the valve design and Kv/Cv data is often specified as an important and easily compared factor between different valve brands. Some manufacturers even highlight this parameter as a key advantage over others. However, actual comparison between different products in the market show negligible difference in the actual pressure loss for normal flow rates of up to 3m/sec.

Table 1: Pressure Loss Comparison

100mm 3-Way controlled valves at a 3 m/sec flow speed (24 lit/sec)							
	Valve A-1	**Valve A-2**	**Valve A-3**	**Valve B (Flat-Disc)**	**Valve B (U-Port)**	**Valve C (Flat Disc)**	**Median Value**
Type	**Globe**	**Weir**	**"Y" pattern**	**"Y" pattern**	**"Y" pattern**	**Globe**	
Kv [m3/h]	167	220	175	200	170	173	184
P. Loss [mwc]	2.6	1.5	2.4	1.8	2.5	2.4	2.1
Difference from median	+0.4	-0.6	+0.3	-0.3	+0.4	+0.3	-

* Kv data taken from the original manufacturers catalogs

If the pressure loss values in **Figure** are compared to the pressure loss values in **Table 1** (between different types of valves all with 3-way systems) it be seen that pressure loss is much more sensitive to the type of control system than to the type of control valve used.

Minimal opening pressure

Minimal operating pressure should only be considered in those cases where the supply pressure may drop to extremely low values – as low as just 10 meters or less. This is a very rare case in developed countries, but a common case in developing countries and primarily in South-East Asia.

The hydraulic control valve is opened by the force applied by the line pressure on the bottom part of the valve's internal trim. Counter to this force act (i) the friction, (ii) the weight of the trim and (iii) the spring force. The only force that is uncontrolled and that resists the movement of the valve internal trim, both to open and to close, is the friction. The larger the friction, the bigger the minimal operating pressure required to overcome it. Therefore, low friction mechanisms are essential for low operating pressure systems.

The main friction causing element that is used in some of the PRV models is the use of internal O-ring, dynamic seals (see **Figure 9**). These are pressed tight around the valve shaft and will generate large friction forces that will make the minimal operating pressure larger in comparison to a similar valve that has no such internal seals. With time, the continuous aberration will cause these seals to break and leak internally, which can cause even higher friction. In some cases this may even lead to complete valve seizure both at low as well as in high pressure conditions.

It is therefore recommended to avoid using valves that incorporates internal dynamic sealing in their structure when minimal operating pressure (and minimal operating pressure differential) is a critical factor to be considered.

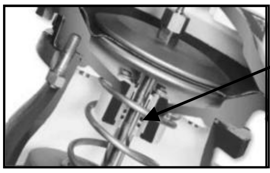

Figure 2: Internal O-ring seals in a PRV

Cavitation index

Cavitation phenomena can arise in hydrodynamic flows when the pressure drops. Due to a local pressure drop in the vena-contracta (the narrow passage between the valve's plug and seat), vapor cavities are formed and carried with the flow to the downstream side of the valve, where the vapor bubbles collapse due to the higher pressure. In the final phase of bubble implosion, high pressure peaks are generated inside the bubbles and in their immediate surroundings. These pressure peaks lead to mechanical vibrations, noise and material erosion of surfaces in walled areas.

The risk of cavitation damage can be calculated as follows if the cavitation index of the PRV (X_{fi}) is available:

$$x_f = \frac{P_1 - P_v}{P_1 - P_2}$$

P1 = Upstream pressure
P2 = Downstream pressure
Pv = Vapor pressure (the pressure at which water boils at ambient temperature)

If $X_f \leq X_{fi}$ there is a potential danger for cavitation damage in the valve

It should be noted that it is difficult to accurately determine the cavitation index of a valve. It requires sophisticated laboratory equipment which most valve manufactures do not have in their own testing facilities. The cavitation index should ideally be determined by an independent laboratory that has the expertise and the required equipment for testing cavitation.

The risk of cavitation should normally be considered if the upstream pressure is high and if the expected upstream to downstream pressure ratio is significant (applicable thumb rule may be over 3:1). If the upstream pressure is less than 25 meters the risk of cavitation damage will usually be insignificant.

Pressure regulation stability

Pressure fluctuations are often found to be one of the main causes of high frequencies of new leaks.

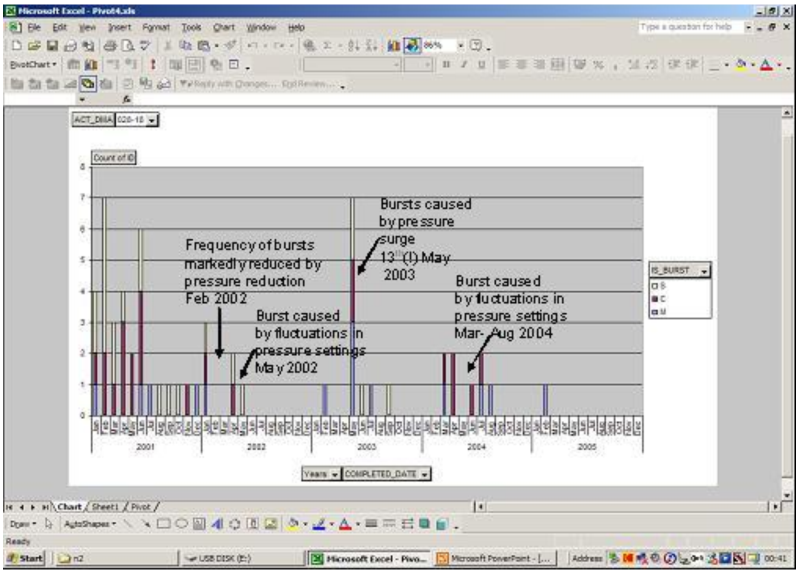

Figure 3: Burst Frequency and Pressure Fluctuations (Source: David Pearson)

These pressure fluctuations are usually related to transients (water-hammer/surge) and to changing zone pressure due to changing demands. However, high amplitude and frequency fluctuations can be also a result of low flow instability, typical to globe and "Y" pattern valves.

The cause for this low-flow instability is a large valve gain. Valve gain is the flow rate change with respect to valve travel. Under static test conditions of constant pressure drop, a curve showing steady-state flow, plotted as a function of valve travel, would be called an “inherent valve characteristic”. Another way of demonstrating the gain is looking at the change of Kv values as a factor of the valve travel. It represents how a particular valve operates when it’s subjected to specific pressure drop and flow conditions.

The three inherent valve characteristics are quick opening, linear and equal percentage, were values with quick openings have high gain at the lower travels, with each travel increment producing large increases in flow. If the valve opening increases, the gain decreases proportionately. Flat-disc, globe and "Y pattern" valves are typical quick opening type and therefore have large gain under low flow and high pressure differential conditions (when the plug is near the seat = low travel). This would mean those valve may suffer instability under high pressure-differentials and low flow conditions.

As shown in the early stages of developing the IWA methodology, in many cases, a large percentage of the night flow can be attributed to leakage. Viewing this, it is clear that the result of reducing physical losses will therefore cause a further reduction in minimum night flow. This leads to a clear conclusion that a PRV used in municipal networks may need to regulate under extreme low-flow conditions.

Achieving this with globe and "Y" pattern valves is partially enabled by the following three often-used solutions:

a. Cage design (often called V or U port) which change the valve characteristics to logarithmic type but on the other hand creates additional head-loss to the fully open valve due to the cage vanes blocking large section of the internal water passage. This cage design may also present instability in extreme low-flow conditions due to the relatively large water passages between the cage and the seat arrangement.

b. Small by-pass PRV installed in parallel to the large main PRV. This by-pass valve will be set to a higher pressure that the required set-point of the main valve, so that when the flow decreases the downstream pressure increases some, the main valve closes and the low flow is regulated by the by-pass valve. It is important to note that in such a case the system's pressure will increase when the demand flow is low – thus causing an increase of the leakage rate! It is the authors recommendation to avoid this solution with non-modulating PRVs.

c. A Reduced-Port valve is another common way of improving low-flow stability. This is a valve with a plug-seat arrangement that is downsized compared with the nominal valve size (end-connections size). The gain is same as a smaller sized valve (i.e. better stability at lower flow rate, though would be limited at near zero flow rates just as the smaller valve). A drawback here would be similar to the cage solutions – higher pressure losses at high flow rates and limited regulation stability at extreme low-flow conditions.

d. A fourth and last solution to be presented here is the linear throttling plug (LTP®) valve design that allows very small gain (=equal percentage) at low valve travel and at linear gain change at higher travel. Thus, without affecting the headloss of the valve.

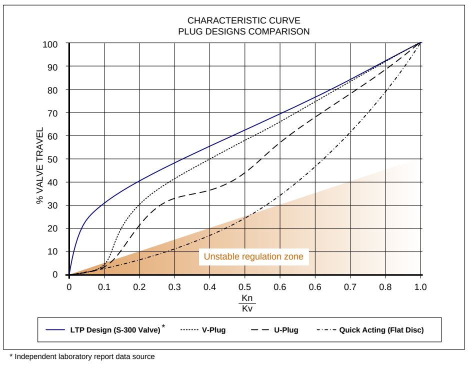

Figure 4: Plug design – performance comparison,
(Source: *Dorot Automatic Control Valves hydraulic lab.)*

To summarize this section – One purpose of using Pressure Reducing Valves in water networks is the reduction of NRW. Reducing background and burst leakage is one of the key benefits of using PRVs. Low flow stability is a key parameter in NRW projects where such conditions are expected. The parameter that defines low flow stability is the valve gain. Small gain allows better stability and can be checked by the rate of Kv change per valve travel.

Therefore it is suggested to request in the tender specification that the Kv change in the first 5% of the valve travel will not be more than 3% of the Kv value of the fully open valve.

Cost of ownership: PRV maintenance issues

The cost of the PRV is almost always a major issue when comparing two similar products. In today's market, the actual cost difference between different products complying with the same technical tender specification can reach a few hundred US$ at most (normally much less) per unit. However, in most cases the issue of maintenance, labor and spare parts, referred herby as 'ownership costs' are ignored.

PRVs are not maintenance free. If a water utility decides to install a large number of PRVs the maintenance cost and labor efforts can become substantial. Maintenance costs can be divided to two main subsections: spare parts costs and labor costs.

As the design of most PRVs is similar, so will be the need for spare parts. The parts that are the most subjected to wear and tear are dynamic internal sealing – such as static O-ring seals that are in touch with a moving valve shaft. Wear and tear of those seals may cause internal leakage and even valve trim seizure and will require sending a maintenance team to the valve chamber, stopping the water flow through the valve and complete disassembly of the valve mechanism in order to replace the worn seal. One can see that even a small and low-cost part such as an O-ring seal may cause periodical costs that are in times much higher than the cost differences between different valve brands.

Another labor consuming element is the control system's filter. All control systems should be fitted with a filter that assures clean water through the narrow ports in the PRV's control system (nozzles, needle valves and pilot valve's ports). The most common filter used is a small external filter that can get clogged with dirt if not cleaned periodically. The intervals between one filter flushing and the other are a factor of the flow through the control system and the water quality and may be anything between once per week to once every few months. Reducing the labor cost associated with filters' flushing can be achieved by two options:

a. Using a large volume filter, where the flushing intervals are longer;

b. Using a self-flushing, inline filter arrangement. This filter is a skeleton with external strainer installed within the main valve water passage, so that some of the water is filtered and can reach to the control system, while the rest of the flow flowing through the valve will wash dirt particles of the strainer.

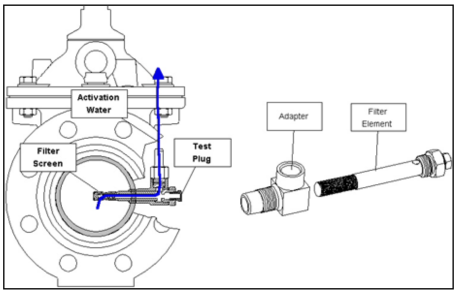

Figure 5: Self Flushing Inline Control Filter

Another issue to be considered is the ease of maintenance work (primarily assembly and disassembly of the valve internals) when the valve is installed in a narrow chamber below ground. Due to that, it is the authors' opinion that globe valves that allow vertical lifting of the bonnet and trim, should be preferred over "Y" pattern valves that are difficult to handle in such cases and consume more labor and special tooling.

It is advisable to verify that:

- the valve internal trim can be approached without having to remove the valve body;
- the valve can be disassembled without special tools and with as little personnel as possible;
- The valve bonnet and trim weight is low enough to be lifted by hand or by simple lifting winch, with no need for heavy-duty crane trucks;
- that manual isolation valves (gate or butterfly) are installed, both sides of the PRV system to allow disassembly without having to drain the whole system;
- that a manual by-pass system is designed so that the water supply can be continued into the system during maintenance activities. .

Sample commonly used specification demands and their relevancy to sample system's requirements

This chapter will present most common specification requests and evaluate their relevancy different situations (A=Required, B=May be considered, C=contradicting).

Table 2: Common Specification Requests

Common Specification	Low Press.	Standard Pressure	High Press.	Remarks
The Pressure Reducing Valve shall maintain a constant downstream pressure regardless of changing flow rate and/or inlet pressure	A	A	A	
The valve shall be hydraulically operated, single diaphragm-actuated, globe or angle pattern.	B	A	A	Can consider other types for low-pressure systems
The valve shall be hydraulically operated, single diaphragm-actuated, "Y" pattern.	B	B	B	Cost of ownership issues
The valve shall consist of three major components: the body; the cover; and the internal trim assembly.	A	A	A	
The actuator assembly shall be double chambered with an inherent separation partition.	C	C	B	Cost of ownership issues and high head-losses.
No separate chambers shall be allowed between the main valve cover and body	A	A	B	
Packing glands and/or stuffing boxes are not permitted and there shall be no pistons operating the main valve or pilot controls.	A	A	B	
The diaphragm assembly shall be fully guided at both ends by a bearing in the valve cover and in the valve seat	B	A	A	Direct sealing diaphragm valves may be considered in low-pressure systems (no bearings)
The main valve shall be center guided…	C	C	C	Maintenance and stability issues. Usually associated with internal sealing
The entire actuator assembly (seal disc to top cover) shall be removable from the main line as an integral unit	B	B	B	The weight of the actuator may be excessive.
All valve components shall be accessible and serviceable without removing the valve from the pipeline	A	A	A	
The control system shall consist of a 2-way adjustable pilot valve	C	B	A	In case P1 may be low – prefer 3-way system

Note: many parts of the specifications published by the manufacturers define specific designs and methods used by the valve producer and that can be built in other (sometimes more efficient) ways. It is advisable to put into the tender the actual system requirements rather than limiting the supply to a specific valve design. Only designs that affect the valve performance or current\future cost should be specified.

Below some specification criteria that have relevancy and that are rarely added to tender specification:

Table 3: Uncommon but Important Specification Requirements

Specification	Remarks
The PRV should regulate in a stable accurate manner even if the flow velocity drops below 0.3 m/sec. This without having to adopt additional throttling	Refer to section on "Pressure regulation stability"

device and without having to install an additional smaller low-flow by-pass PRV.	
The pressure losses inflicted by the above mentioned fully opened PRV should not exceed 0.3 bar at nominal flow speed of 3 m/sec.	Relevant only to low-pressure systems or to "standard" pressure systems were the upstream pressure may drop to values near the required downstream set-point.
The Kv loss factor of the standard valve throttled to 5% opening should be less than 3% of the Kv factor of the fully open valve. This data should be backed by a hydraulic test report.	Refer to section on "Pressure regulation stability"
The minimal opening pressure of the valve should be lower than X	Relevant to low-pressure systems only. X should be the actual minimal supply pressure value available.
The minimal pressure differential for reliable operation should be 2 mwc or less	This is relevant for low-pressure systems only. Note that some valve types would require higher operating pressure differentials. Note the difference between this specification and the previous one…
The critical cavitation coefficient of the valve will be of value X or lower (calculated: (P1-Pv)/DP). This data should be backed by an independent laboratory report.	X should be defined according to actual system requirements. Refer to "Cavitation index" section. A practical no. for most cases will be 1.5.
The water passage through the valve shall be not less than 15% of the nominal specified standard valve diameter (full bore valve).	Important primarily in low-pressure systems where pressure loss is an issue.
The valve shall be designed in a way that enables disassembly of the bonnet and trim vertically up from the top of a narrow pit.	Refer to "Cost of ownership" section
The typical weight of a 6" (150mm) control chambers and trim assembled as a complete unit shall not exceed the permitted lifting weight for a single person as defined in the regulations.	Refer to "Cost of ownership" section
The valve shall include a low friction trim. No O-ring sealing is permitted on the valve stem.	
The valve should require low maintenance. No set periodic packing or parts replacement should be required.	
The valve's pilot control loop should include a low maintenance "self-cleaning" filter.	

Critical elements in PRV specifications – the PRV specification checklist

Procurement regulations of the international funding institutions and many countries request fair and competitive open tenders. The following list provides ideas for key elements that should be included in such specification so that the water utility gets an appropriate product – whichever bidder wins:

Basic remark:

- ☑ All of the below requirements should be fulfilled for the supplied valve with the control system and all additional devices assembled and functioning. Note – this requirement is important to prevent a case where, for example, the standard basic valve can meet a specification requirement but adding a specific pilot system to it changes that.

Performance:

- ☑ The valve should regulate to a steady, pre-set downstream pressure, regardless of flow or supply pressure variations. The gain of the valve in low travel should be so that the Kn/Kv < Tn/To (Kn is the Kv at travel Tn. To is the complete valve travel).
- ☑ The downstream pressure in steady-state conditions should have an accuracy of $\pm$0.5 m pressure (0.05 bar) of the set-value at high, as well as near-zero demand flow rates.

  Note: for low pressure systems, this should be a key issue as the percentage change out of low set-value is greater.
- ☑ The pressure drop of the valve with the suggested control system installed (2-way or 3-way) should not be greater than X at a maximal flow rate of Y Suggested values: 3 m pressure at flow speed of 3 m/sec.

  Note: should be an issue only in case the supply pressure may drop to values near or below the requested set downstream pressure value. X and Y should be actual system's values in such case.
- ☑ The critical cavitation coefficient of the valve will be of value X or lower (calculated: (P1-Pv)/DP).
  Suggested value: Less than 1.5.

  Notes: relevant only if the ratio between upstream pressure and the set downstream pressure is greater than 3:1 for long durations (normally not an issue at low and standard pressure systems). This is an important parameter at high-pressure systems.

  X should be calculated from the actual system requirements
- ☑ The minimal upstream opening pressure should be at least X Suggested: 5 m pressure
- ☑ The minimal pressure differential for valve closure should be less than X Suggested: 2 m pressure

Cost of ownership

- ☑ The valve shall be designed in a way that enables disassembly of the bonnet and trim vertically up from the top of a narrow underground chamber. Note: "Y" pattern valves are not a good option in that respect. – This is relevant only to cases where the valve is to be installed in a confined underground chamber.
- ☑ The valve shall include a low friction trim. No O-ring sealing is permitted on the valve stem.

- ☑ The valve's pilot control loop should include a low maintenance "self-cleaning" filter.
- ☑ All valve components shall be accessible and serviceable without removing the valve from the pipeline
  Note: Inline valves are not a good option in that respect.
- ☑ It should of course also be a standard provision to specify stainless steel nuts and bolts etc. for corrosion protection.

Conclusions

Pressure management is becoming increasingly important around the world. The authors observe a trend from plain pressure reduction – done mainly in situation were very high pressures had to be reduced to acceptable levels – to sophisticated pressure management, where marginal pressure reductions and the avoidance of pressure fluctuations are the main objectives.

This trend is relatively new and therefore there is substantial lack of understanding in water utilities around the world. The authors intend to clarify the issues and provide a first guidance. This paper, if well received, may serve as a basis for a future guidance document of the Water Loss Task Force.

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