A Technical Discussion Regarding Valve Authority and Pressure Drop Trade Off for the District Cooling Energy Transfer Stations in the JLT projects

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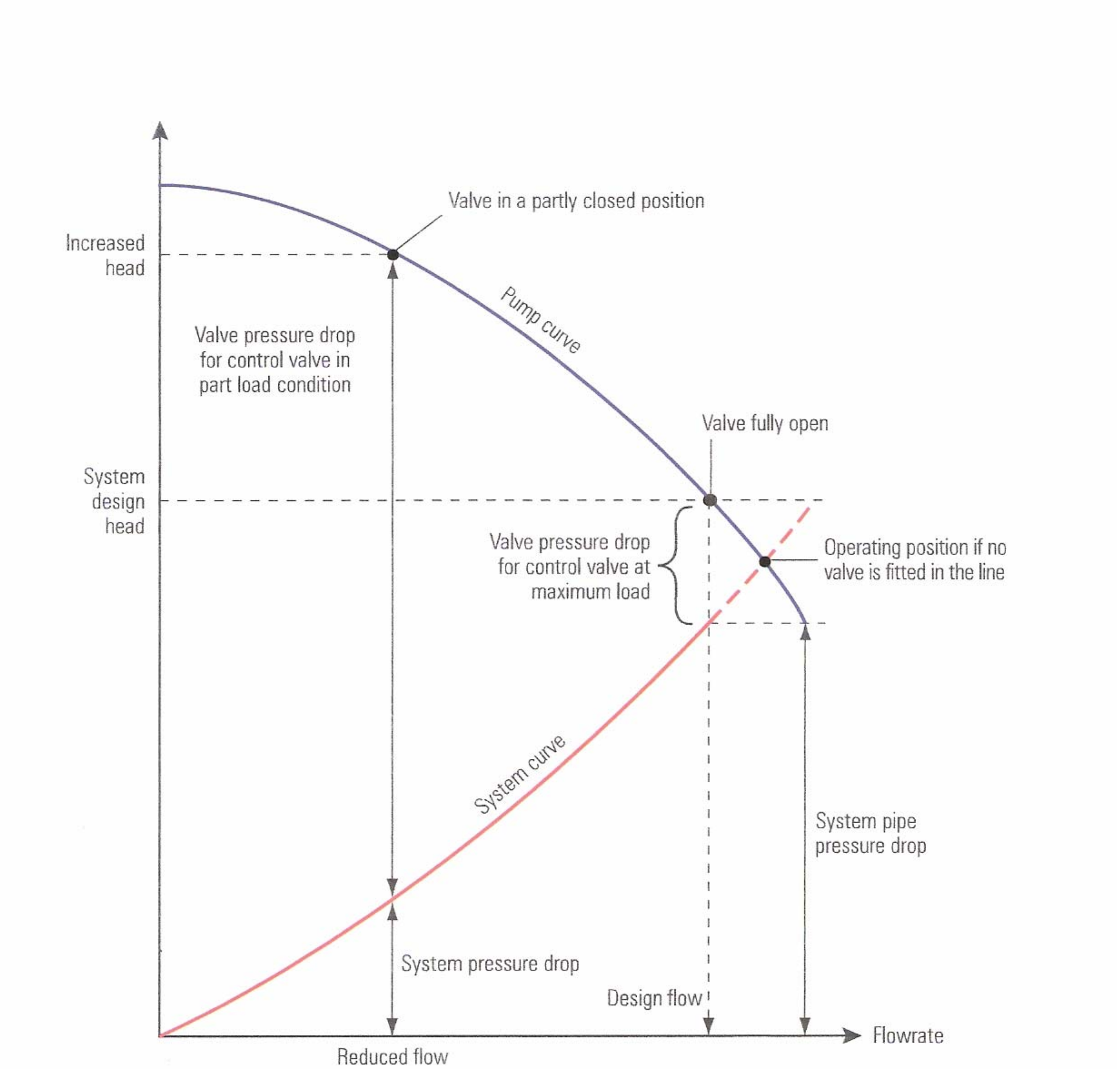
<u>Brief</u>:

- A two-port electrically actuated control valve is requested to control the temperature on the incoming water from the Heat Exchanger
- As the control valve throttles towards its closed position, flow will decrease and the pressure upstream of the valve will increase, hence causing changes in the pump head. As illustrated below:



- Changes in pump head impact the power consumption of the pumps, increasing operating costs on the district cooling plant side.
- Hence a differential pressure "control" valve is required to regulate the *DP* across the motorized control valve in order to offset pressure changes due this latter's throttling actions.
- The introduction of the above dual controlling elements poses two intertwined problems

- Q1: What should be the maximum allowable pressure drop across the aggregate of the heat exchanging loops – i.e. the system curve in the above diagram?
- Q2: What is the required authority of the control valves?

Some Considerations:

When selecting a two-port control valve for an application the following needs to be taken into consideration.

i- **Undersized Valves**

Under-sizing a control valve, in a system, increases the pressure drop of the entire system – meaning the pumps would use a larger amount of energy simply to pass sufficient water through the system and more specifically through the control valve. However, assuming a cost no object scenario, i.e. enough water could be forced through the valve, then the accuracy of the control is at an optimal as the entire travel of the valve may be utilized to achieve the desire control.

ii- **Oversized Valves**:

Over-sizing a control valve, in that same system, would reduce the amount of energy needed to pump the necessary flow into the system and hence reducing power consumption. However, such savings will come at the cost of a decrease in the accuracy of control, as the initial travel from fully open towards the closed position would have no effect on the control medium and therefore on the control variable. In other words, when a valve is over-sized, significant control can only be achieve when the valve is throttling in the neighborhood of its closed position. Hence, only a relatively small fraction of the valve travel is useful for control. As a consequence, small movements of the valve stem are expected to have a relatively large impact on the control medium, yielding erratic control with poor stability and accuracy.

Clearly, a trade off exists between the above two considerations; and proper sizing requires a sustainable equilibrium where a balance between control while reducing energy losses is achieved.

From Authority to Flow Coefficient:

A common concept in the industry that embeds the above two considerations is that of "valve authority" within a given system. Mathematically it is easy to see how, as the authority of a control valve is defined as:

$$N = DP_v / (DP_v + DP_c).$$

Where:

DP_v = Pressure drop across a fully open control valve

DP_c = Pressure drop across the remainder of the circuit.

In other words, the valve authority within a system indicates how much of the system's total pressure drop comes from the control valve. It is a common practice in the industry to consider the range between 0.2 – 0.5 as "acceptable". Hence, and in general, if the authority is too high (above 50%), then the control valve is likely to be undersized and so the system would benefit from a larger size valve in order to reduce losses that are driven by excessive pressure drop. If the value is too low (below 20%), then the valve movements will have a marginal impact relative to the total system and hence the valve is likely to be over-sized, yielding poor control.

In case the maximum flow rate of the circuit / system is given, then it becomes easy to map the required authority to the required flow coefficient – the key sizing variable; as:

$$Cv = V \times (\text{square root } (G/DPv))$$

Where:

- Cv = the flow coefficient
- V = flow rate
- G = specific gravity of the liquid (control medium) – Water = 1.

Hence, determining the required valve authority when the flow rates as well as the maximum allowed system pressure drops - within a system - are known becomes tantamount to determining the required Cv and then sizing the valve accordingly.

<u>The Case of JLT</u>:

Similarly to the above discussion, the flow rates for each plot (system) are exogenously given. The size / characteristics of the pumping stations as well as the distance of individual plots from the plants are determining factors in deriving the upper bound for the allowed pressure drop per plot. In this sense, deciding on the maximum allowed pressure drop across the aggregate of the heat exchanging loops per plot (Q1) lies in the scope of the district cooling plant (PDC). Moreover the district cooling plant may set a maximum allowable pressure drop without even considering issues relating to valve sizing. However, whether this upper bound is feasible needs to be investigated. This matter is further exacerbated by the fact that most of the MEP contractors have already procured several of their respective heat exchange loop components save the control valves. As expected feasibility is a function of the control valves authority, i.e. a function of the answer to be provided for Q2.

Recall that there are two controlling elements in a typical heat exchange loop (several loops form a complete system): the motorized control valve for controlling the temperature and the pressure differential control valve for controlling the resultant pressure. Per the above discussion, there is little sense in under-sizing or over-sizing controlling elements. Moreover, over-sizing the one may not be compensated by under-sizing the other, meaning that both valves must have similar sizes – to the extent possible. To understand this point, the reader should think of every controlling element as a separate entity and apply the conclusion discussed in the previous sections.

Hence, both the motorized valve and the pressure differential valve must have similar Cv's, which is a function of the maximum allowed pressure – as determined by PDC – the heat exchanger design – as given by the building consultant – the non controlling components on individual control loops, e.g. heat exchangers etc and finally the desired authority – as specified by PDC.

Yet, as mentioned above, the prescribed authority has a direct bearing on the total pressure drop across the system. Moreover, both constraints must allow for a feasible solution. To illustrate this point, the reader may consider the example where the authority for the control valve is set at 50% (as was originally specified). As demonstrated above the differential pressure control valve should have a similar Cv and hence a similar internal cross-pressure drop at full flow. In this case then, 100% of the total pressure drop in the system will be from the two controlling elements; leaving no room for any pressure that would naturally result from the heat exchanger as well as the remaining components within the loop.

In fact, reversing the question may give an indication of the range of feasible solutions. By assuming a pressure drop across the heat exchanger of 0.3 – 0.5 bar, and by assuming that the pressure drop which results from all other components (outside of the control valves) ranges between 0.3 – 0.4 then we begin to get an idea of the expected *DP*c, which would then range between 0.6 – 0.9 bar.

For example, by setting the average total allowed pressure drop, per control loop, at 1.6 bar. Then the range of "feasible" authorities would vary over:

A min = 1.6 - 0.9 = 0.7 bar of a combined pressure drop across both controlling elements. Hence, approximately 0.35 (35%) would be allowed for the motorized valve and 0.35 (35%) for the pressure differential control valve. Yielding an authority of: 0.35 / 1.6 = 0.218 or 21.8%

A max = 1.6 - 0.6 = 1 bar of a combined pressure drop across both controlling elements; i.e., approximately 0.5 (50%) for the motorized valve and 0.5 (50%) for the pressure differential control valve. Yielding an authority of: 0.5 / 1.6 = 0.312 or 31.2%

Therefore, under the above assumptions, the range of "feasible" authorities for the control valve map over the interval [0.218 – 0.312]; thereby, setting a feasible range for the required Cv for both the motorized control valve and the differential pressure control valve. However, a couple of remarks must be mentioned.

1- The calculation of the pressure drop across the loop should be done under the worse case condition, i.e. under maximum flow and with both of the control valves in a fully open position. It should also be noted that the stem travel in the motorized valve and the stem travel in the pressure differential control valve do not operate in a way where one mirrors the other, i.e. they do not map onto each other in a linear fashion, making the pressure drop calculation at less than maximum flow extremely difficult to guess.

2- It should also be noted that the 1.6 bar mentioned above is given only as an example for an indicative average. It is not a recommendation made in this paper. Solely PDC (and its appointed consultants) is in a position to determine such a value as well as allowing and authorizing deviations and variances.

Conclusion:

It is clear that the maximum allowed pressure drop across individual loops within plots of land is a function of the:

1. pump size
2. distance of the plot from the cooling plants
3. loop design within the plot, i.e. number of loops, pipe size, heat exchanger size
4. control valves.

Every plot of land must be looked upon individually by PDC in order to determine an acceptable aggregate. Since in most cases, point 1, 2 and 3 are predetermined the only remaining variable is the control valves. Hence, a required Cv must be determined at the individual heat exchanger loop level in order to best accommodate the above constraints. In this process, it is important to note that both the control valve and differential pressure control valve must have similar Cv values in order to achieve an optimal performance across the system.

References:

1- Spirax Sarco, SC-GCM CM Issue 1, Block B, Module 6.3: Control Valve Sizing for Water System, 2005.

2- The Engineering Tool Box, Valve Authority, http://www.engineeringtoolbox.com/control-valve-authority-d_1066.html