Differential Pressure Control

Hydronic College by IMI Hydronic Engineering Inc.
Why differential pressure control?

- Control valves work with improved authority, therefore their performance is improved.
- Reducing pump head and keep high controllability in the system.
- Control valves are pressure relieved, so low force (= lower cost) actuators can be used.
- Noise in control valves is reduced or removed completely.
- Based on stabilized differential pressure across the circuit, the flow is limited.
- Circuits is a pressure independent modules. Which means:
  - That the changes in other parts of the system do not affect the circuit.
  - Large plants can be balanced module by module independently.
  - New modules can be added to the system without rebalancing.
Differential pressure variations

Dallas

Thermal plant load [%]

% of heating season below this load
58%

% of cooling season below this load
68%

Heating

Cooling

Power

Flow

Dp piping

At constant supply water temperature

Pressure drops are reduced to 4% of their design value.

\[ \Delta P \propto q^2 \]
Control loop

\[ x = U - x_0 - 10 \text{ volts} \]

\[ 0-100\% \]

\[ 0-100\% \]

\[ 0-100\% \]

Sensor

Controller

Actuator

Valve

Terminal

Power output

Room

Set value U

\[ \Delta x = U - x \]

Signal

Lift

Flow

Power output

\[ x = \text{controlled value} \]

Terminal unit characteristic

Control valve characteristic

Flow in%

Power output %

Lift h in %
Control valve authority

The authority ($\beta$) formulates how much the differential pressure builds up on the control orifice of a control valve when it is closing.

$$\beta = \frac{\Delta P_{\text{Control valve fully open and design flow}}}{\Delta P_{\text{Control valve fully shut}}}$$

Its value indicates how effectively the control valve can reduce the flow while it is closing.
2-way control valve authority (variable flow)

Variable, depends on flows in the piping,
thus also on the opening of all the other control valves.

\[ \beta = \frac{\Delta P_{\text{control valve fully open and design flow}}}{\Delta P_{\text{control valve fully shut}}} \]

Constant as soon as the valve Cv is chosen (\(\Delta p_V\)).

In a variable flow distribution, the authority of a control valve is variable.
Distortion of valve characteristic

The lower the authority, the larger the $\Delta p$ variations on the control valve, the larger distortion of the valve characteristic.

Control valve with Equal-percentage characteristic (EQM)
Variable authority of 2-way control valves

Authority in design conditions:
\[ \beta \approx \frac{5}{5+7} = 0.42 \]

Authority at half-load:
\[ \beta = \frac{5}{5+7+0.96 \times 21} = 0.15! \]

Low flow (half-load):
0.96*21 ft + 0.96*7 ft \(\approx\) 26.9 ft in excess in the valve at half-load

5 ft in the valve
7 ft in the circuit

VSP does not allow to compensate for all local Dp variations in the plant

H: 33 ft
Max. flow (design conditions) \(\Delta p_{Pipe}: 21 \text{ @ design flow}\)
H: 33 ft
Pump head
Control valve oversizing

Control valves are commercially available with Cv values increasing according to the Reynard series:

\[
\begin{array}{ccccccc}
Cv: & 2.0 & 3.0 & 4.0 & 5.0 & 10 & 20 & 30 \\
\end{array}
\]

Flow to a FCU of 29 gpm, \(\Delta p\) 5 psi and 2 psi in connecting pipes. the commercially available control valves create a design \(\Delta pV\) of:

<table>
<thead>
<tr>
<th>Cv</th>
<th>(\Delta pV) [psi]</th>
<th>(\beta_{\text{design}})</th>
<th>(\Delta H) [psi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>7</td>
<td>0.5</td>
<td>14</td>
</tr>
<tr>
<td>20</td>
<td>2.0</td>
<td>0.0</td>
<td>9.0</td>
</tr>
<tr>
<td>10</td>
<td>8.4</td>
<td>0.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>23</td>
<td>49</td>
</tr>
</tbody>
</table>

Conclusion:
Control valves are generally **oversized**.
Effect of $\Delta p$ variations on controlled heat output

$\Delta p$ variations distort the characteristic of the control valve
$\Rightarrow$ the nonlinear characteristic of the terminal unit is no longer compensated

Valve characteristic:
$EQM = 0.33 \quad R = 25$

Rangeability
area of the control valve
**Noise**

**Rule of Thumb:**
Static pressure at the inlet of the valve should be at least twice the pressure drop in the valve.

A cavitating valve is shown in the diagram, along with a graph of sound pressure level [dB].
Closing of control valves

According to its design, each valve has a required actuation close-off force or torque that depends on:
- Tension of the return spring, if any,
- Friction with o-rings and seals,
- Differential pressure applied on the plug.

Each control valve/actuator combination has a certain close-off differential pressure

<table>
<thead>
<tr>
<th>Type</th>
<th>Conn. DN in.</th>
<th>Kv (mbar⁻¹)</th>
<th>Cv (m³/h/psi)</th>
<th>MZ18L / 18A / 18B 136 N (30 lb) Max. ΔPc kPa psi</th>
<th>MZ10T 96 N (22 lb) Max. ΔPc kPa psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>VZ22</td>
<td>15 ½&quot;</td>
<td>0.16</td>
<td>0.19</td>
<td>1600 232</td>
<td>600 87</td>
</tr>
<tr>
<td>VZ22</td>
<td>15 ¾&quot;</td>
<td>0.25</td>
<td>0.29</td>
<td>1600 232</td>
<td>600 87</td>
</tr>
<tr>
<td>VZ22</td>
<td>15 ½&quot;</td>
<td>0.40</td>
<td>0.47</td>
<td>1600 232</td>
<td>600 87</td>
</tr>
<tr>
<td>VZ22</td>
<td>15 ¾&quot;</td>
<td>0.63</td>
<td>0.74</td>
<td>1600 232</td>
<td>600 87</td>
</tr>
<tr>
<td>VZ22</td>
<td>15 ½&quot;</td>
<td>1.00</td>
<td>1.17</td>
<td>1200 174</td>
<td>180 26</td>
</tr>
<tr>
<td>VZ22</td>
<td>15 ¾&quot;</td>
<td>1.6</td>
<td>1.9</td>
<td>1200 174</td>
<td>180 26</td>
</tr>
<tr>
<td>VZ22</td>
<td>20 ¾&quot;</td>
<td>2.5</td>
<td>2.9</td>
<td>400 58</td>
<td>50 7.3</td>
</tr>
<tr>
<td>VZ22</td>
<td>20 ½&quot;</td>
<td>4.0</td>
<td>4.7</td>
<td>400 58</td>
<td>50 7.3</td>
</tr>
<tr>
<td></td>
<td>A-AB:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VZ32</td>
<td>15 ½&quot;</td>
<td>0.25</td>
<td>0.29</td>
<td>800 116</td>
<td>500 73</td>
</tr>
<tr>
<td>VZ32</td>
<td>15 ¾&quot;</td>
<td>0.40</td>
<td>0.47</td>
<td>800 116</td>
<td>500 73</td>
</tr>
</tbody>
</table>
The differential pressure across control valves must not vary too much.
Control valve authority

To achieve good control it’s recommended to fulfill two rules on authority:
1. Size the control valve with a Cv with
   \[ \beta_{\text{design}} \geq 0.5 \]
2. Ensure that \( \beta_{\text{min}} \geq 0.25 \)

\[
\Delta p_V \geq \Delta p_C + \Delta p_{\text{pipe}} + \Delta p_{\text{STAD}}
\quad \text{or} \quad \Delta p_V \geq 0.5 \times \Delta H
\]

\[
\beta_{\text{design}} \geq 0.5
\]

\[
\Delta p_V \geq (\Delta p_{\text{piping}} + \Delta p_C)/3
\quad \text{or} \quad \Delta p_V \geq 0.25 \times H
\]

\[
\beta_{\text{min}} \geq 0.25
\]
Improved control by correct control valve sizing

**IDEA**

Ensure design authority of at least 0.5 and minimum on 0.25 in all control valves in the worst conditions.

\[ \beta_{\text{design}} = \frac{\Delta P_{\text{Control valve fully open and design flow}}}{\Delta H} \]

\[ \beta_{\text{min}} = \frac{\Delta P_{\text{Control valve fully open and design flow}}}{H} \]

**Rule no 1:**
For obtaining a design authority of 0.5:

\( \Delta p \) in control valve must be \( \geq 0.5 \times \Delta H \)

Since \( \Delta p \) circuit = 7 ft,
\( \Delta p \) in control valve must be \( \geq 7 \) ft

**Final pump head** = 40 + 7 = 47 ft

\( \beta_{\text{design}} = \frac{7}{14} = 0.5 \) but
\( \beta_{\text{min}} = \frac{7}{47} = 0.15 \)

**Rule no 2:**
For obtaining a minimum authority of 0.25:

\( \Delta p \) in control valve must be \( \geq 0.25 \times H \)

Since \( \Delta p \) piping + circuit = 33 + 7 = 40 ft,
\( \Delta p \) in control valve must be \( \geq 13.3 \) ft \((40/3)\)

**Final pump head** = 40 + 13.3 = 53.3 ft

\( \beta_{\text{design}} = \frac{13.3}{20.3} = 0.66 \) and
\( \beta_{\text{min}} = \frac{13.3}{53.3} = 0.25 \)
Improved control with reduced pumping energy

Control valve sizing with $Dp$ control:
For obtaining a design authority of 0.5 and min of 0.25:

$\Delta p$ in control valve must be $\geq 0.5 \times \Delta H$ and $\geq 0.25$ of stabilized $\Delta p$.

Since $\Delta p$ piping + $\Delta p$ circuit = 7 ft,
$\Delta p$ in control valve must be $\geq 7$ ft

Final stabilized $\Delta p = 7 + 7 + 2 = 16$ ft
$\beta_{\text{design}} = 0.50$ and $\beta_{\text{min}} = 0.44$

Final pump head = 31 + min $\Delta p$ of $DpC$ (2 ft) + 2 + 7 + 7 = 49 ft
Simulation
Dp controller position

Depending on project structure, Dp control will be applied:

On risers,

On branches,

On control valves.
Bigger plant with different Dp control configurations
Find the best Dp control solution…

First, decompose the plant into modules
Case Studies

The savings are real!!
Hong-Kong PolyTech University

- Renovation of 2 University buildings with a total of 106000 ft² (9840 m²)
- Installed cooling capacity:
  - Building 1: 1452 tons refrig.
  - Building 2: 1730 tons refrig.
Local University campus **building 1** – chiller saving

- Variable secondary flow with differential pressure bypass
- Dp controllers at on-off control FCU groups and PAU/AHUs and re-balanced
- Annualized 22% chiller energy saving

**Chiller Power Input vs. Cooling Load**

- **Power input [kW]**
  - 500
  - 450
  - 400
  - 350
  - 300
  - 250
  - 200
  - 150
  - 100
  - 50
  - 0

- **Cooling load [ton refriger]**
  - 341
  - 284
  - 227
  - 170
  - 113
  - 56
  - 2009
  - 2010

**Cooling load [ton refriger]**
Local University campus building 2 – chiller saving

Variable flow primary-secondary system

Addition of Dp controllers at FCU groups zones and pressure independent control valves for PAU/AHU and re-balanced

Annualized 16.5% chiller energy saving
Questions?