How to Get the Most Out of Control Valve

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Top Ten Things You don’t Want to Hear from your Valve Supplier

• (10) I went out for bids and found the cheapest possible valves
• (9) These valves have been extensively used in packaged equipment
• (8) These valves have such a tight shutoff, I dare you to try and open them
• (7) You can standardize on these valves for isolation and sequences
• (6) You get all the flow you need when the valve is just 10% open
• (5) Why do you want to know the valve response time? We have quick opening trim
• (4) Thanks to my 1969 Guidelines based on Nyquist Plots, I was able to omit positioners
• (3) We don’t need to know the piping system
• (2) All I need is the available pressure drop at the design flow
• (1) What do you mean by installed flow characteristic?
Alerts

- **Common mistakes**
  - Minimizing leakage
  - Maximizing capacity
  - Minimizing valve to system pressure drop ratio
  - Minimizing cost

- **Watch outs**
  - Actuators sized for loose packing at room temperature
  - Resolution and deadband tests done at positions > 40%
  - Response time tests done for steps > 1%
  - Shaft windup and backlash not measured
  - Error between feedback stem and closure member is huge
  - Positioner is being lied to
  - Booster used instead of positioner
  - Integral action in positioner turned on
Sliding Stem versus Rotary Valves

• Sliding Stem Valves
  – No translation of motion (no backlash and stem feedback error)
  – Less seating friction
  – More choices of flow characteristics
  – Less change of oversizing

• Rotary Valves
  – Lower cost (cost savings increases with square of size)
  – More capacity
  – Less abrasion and plugging from solids
  – Less coating of stem from sticky fluids
  – Less stagnation by elimination of crevices
    – Critical for sanitary operation (beverage, food and pharmaceutical)
    – Critical to prevent polymerization (Hydrogen Cyanide & Acrolien)
Limit Cycle Amplitude and Period from Resolution and Deadband

Limit cycle from stiction (resolution) for 1 or more integrators in system:

\[ A_o = S_v \times K_o \]

\[ T_o = 4 \times T_i \times \left[ 1 / (K_o \times K_c) \right] \]

Limit cycle from backlash (deadband) for 2 or more integrators in system:

\[ A_o = B_v / K_c \]

\[ T_o = 5 \times T_i \times \left[ 1 + 2 / (K_c^{0.5}) \right] \]

- \( A_o \) = amplitude of limit cycle (%)
- \( B_v \) = backlash (deadband) of valve (%)
- \( K_c \) = controller gain (dimensionless)
- \( K_o \) = open loop self-regulating process gain (dimensionless)
- \( S_v \) = stiction (resolution) of valve (%)
- \( T_i \) = integral (reset) time (sec)
- \( T_o \) = period of limit cycle (sec)
Good Versus Poor Valve Design Performance for Throttling

Maintenance test of 25% or 50% steps will not detect Backlash & Stiction. All valves look good except for stroking time for 10% or larger steps!
Rotary Valves Actuator Connections with Poor Resolution and Excessive Backlash
Sliding Stem (globe) valves generally have the least backlash and stiction and a wider throttling range but may not be suitable for large sizes or slurries.
Diaphragm actuators generally have a resolution of 0.1% versus 1% for pistons. New hi pressure actuator increases valve size and max process pressure handled.
Roller Diaphragm Valve

Extremely precise sanitary low flow control valve (laminar flow to 3rd power of stem position)
Signal characterization advisable for nonlinearity
Splined Short Shaft Connection for Minimal Windup & Backlash in Rotary Valves

Dramatically less windup and backlash than pinned or keyed connections
Segmented V-Notch Ball Valve

Segmented V-Notch ball reduces torque (reduces friction) and improves flow characteristic at low flow. Splined shaft reduces backlash.
Lo Torque Lo Noise Butterfly Valve

Contoured disk reduces torque (reduces friction) and improves flow characteristic at low flow. Splined shaft reduces backlash. Teeth reduce noise.
Dead Band from Backlash at all Positions and Stiction at Closure

Backlash varies from 0.2% - 20%
Hysteresis from Energy Dissipation in Actuator (Exaggerated to Show Effect)

Usually Hysteresis < 0.1%
Resolution Limit from Stiction and Actuator Sensitivity Limit

Resolution varies from 0.1% - 10%
To Make Valve Fast, put Booster with Bypass on Output of Positioner

Despite age old guidelines, never replace positioner with volume booster! Potentially unsafe!

Please turn off integral that has been enabled as default by supplier!

The air supply line from the air header to booster air set must be short and large and dedicated to booster. This air supply should not be shared with positioner and other users of air to ensure no dip and restriction in booster air flow.

Please use Ultra Low Friction (ULF) packing!

Open bypass just enough to ensure a non-oscillatory fast response.

Must be functionally tested before commissioning!
Volume Booster with Integrated Adjustable Bypass Needle Valve

Air Supply from Filter-Regulator

Signal from Positioner

Adjustable Bypass Needle Valve

Air Loading to Actuator
Flow Open Loop 0.2% Step Response for 2% Shaft Backlash (Lost Motion)
Flow Closed Loop 10% Load Response
0,10% Backlash 0.2,0.05 PID Gain

Lower PID Gain causes delayed slower recovery
Level Closed Loop 10% Load Response
10% Backlash: 4.4, 8.8, 0.88 PID Gain

Higher PID Gain reduces amplitude & period
Level Closed Loop 10% Load Response
10% Backlash: 4.4, 8.8 PID Gain & ER Off => On

Higher PID Gain & External Reset Feedback help
Flow Open Loop 0.2% Step Response for 1% Shaft Stiction
Flow Closed Loop 10% Load Response
6% Stiction: 0.2, 0.05 PID Gain & ER Off => On

Lower PID Gain increase limit cycle period
External Reset Feedback stops cycle with offset
Level Closed Loop 10% Load Response
6% Stiction: 4.4, 8.8, 0.88 PID Gain

Higher PID Gain reduces amplitude and period
Flow Open Loop 0.1% Step Response for Poor Positioner Design
Flow Closed Loop 10% Load Response
Poor Positioner: 0.2 PID Gain

Irregular cycling due to variable dead time
Flow Closed Loop 10% Load Response
Poor Positioner: 0.4 PID Gain & 30 sec Reset

Higher PID gain & larger Reset time stops cycles
Flow Closed Loop 10% Load Response
Poor Positioner: 0.8 PID Gain & ER On
Flow Open Loop 20% Step Response for Large Actuator
Flow Closed Loop 20% Load Response
Large Actuator: 0.2 PID Gain & ER Off => On

External Reset Feedback can stop cycles
Level Closed Loop 20% Load Response
Large Actuator: 4.4 PID Gain & ER Off => On

External Reset Feedback can stop cycles
Most valve rangeability statements are erroneous because they do not account for installed characteristic and effect of backlash and stiction (greatest near seat-seal).

$\Delta P_R = 0.0625$ corresponds to valve drop at max flow being 6.25% of system drop which is close to 5% drop cited to minimize energy use in attempt to discourage replacement of valves with VFDs, which have their own problems due to effect of static head, I/O card resolution, and the deadband and rate limiting in VFD setup.

Valve pressure drop ratio ($\Delta P_R$) for installed characteristic:

- Characteristic 1: $\Delta P_R = 0.5$
- Characteristic 2: $\Delta P_R = 0.25$
- Characteristic 3: $\Delta P_R = 0.125$
- Characteristic 4: $\Delta P_R = 0.0625$
Most valve rangeability statements are erroneous because they do not account for installed characteristic and effect of backlash and stiction (greatest near seat-seal).

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Loss in Rangeability due to flat slope (flow not going to zero until valve closes)
Valve Resolution Amplified by High Process Gain

Oscillations could be due to non-ideal mixing, valve stiction and backlash, or pressure fluctuations.
Conventional PID
Fine and Coarse Valve Control

ZC speed of response must be slow and tuning is difficult, (notch or nonlinear gain helps).

Must add feedforward for fast and large influent disturbance.
**Advanced MPC**

**Fine and Coarse Valve Control**

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<td>Small (Fine) Reagent Valve SP</td>
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<tr>
<td>controlled variable</td>
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<tr>
<td>controlled variable</td>
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Model Predictive Controller (MPC) setup for rapid simultaneous throttling of a fine and coarse control valve that addresses interaction, rangeability and resolution issues. Coarse valve penalty on move (move suppression) is increased (manipulated variable) and fine valve position penalty on error is decreased (controlled variable) to reduce unnecessary movement of coarse valve. Disturbance variables can be readily and accurately added.
Explore, Experiment, Discover and Learn by Virtual Plant

• Virtual plant has been my key to deeper knowledge
• New objects enable seeing realistic valve response
  – Variable Backlash and Stiction
  – Variable Deadtime
  – Variable Time Constant
  – Variable Velocity Limit
Concluding Remarks

- Counterintuitive increase in PID gain helpful in most cases
- Backlash and stiction increase dead time as PID gain is decreased
- If oscillation is not decaying & period decreases as PID gain decreases, the oscillation is mostly likely a limit cycle from backlash or stiction
- Turning on true external reset feedback may stop oscillations if the readback of actual ball, disk or plug position is fast and precise
- A dramatic increase in PID reset time helpful for poor positioner case
- Both backlash and stiction show up as square wave in unfiltered flow
- Low noise, high rangeability flow measurement extremely useful
  - Reveals & deals with backlash, poor positioner, lying valve & nonlinear valve gain
- Backlash will not cause limit cycle in just a flow loop (single integrator) but response for low PID gain has delayed slower oscillatory recovery
- Oversized valve may increase PV amplitude of limit cycle from higher stiction by operation closer to seat or seal and greater valve gain
- Not discussed was benefit of kicker, step size low limit & lead-lag
Please, let's not go Backwards & Instead Realize Value of Technological Advances!

- Use on-off & isolation valves for sequences and Safety Instrumented Systems (SIS) and use Low stiction & Low backlash throttling valves with smart positioners for loops. Many loops require both types of valves.
- If size and process conditions permit, preferably use sliding stem (globe) valves with diaphragm actuators and ultra low friction (ULF) packing.
- Make sure valve drop is at least 25% of max system drop.
- Make sure actuator is sized for 150% max torque & thrust.
- Please add following requirements to Control Valve Specs:
  - Resolution plus deadband < 0.2% to 1.0% at minimum flow position.
  - Stem position feedback (readback) error < resolution.
  - Small Step (e.g., Resolution + 0.1%) 86% Response Time = 1 to 10 sec.
  - Large Step (e.g., 20%) 86% Response Time = 1 to 20 sec.
  - Valve Gain (installed flow characteristic slope) = 0.5 to 2.0 % flow / % stroke.
  - Minimum flow valve position > 5%.
  - Positioner tuning overdamped but aggressive (high gain no integral action).
    - “Travel Control” rather than “Pressure Control” in Digital Valve Controller (DVC).
Take Advantage of 21st Century Advances in Measurements & Valves

Essentials of Modern Measurements and Final Elements in the Process Industry

A guide to design, configuration, installation, and maintenance

By Gregory K. McMillan

Setting the Standard for Automation™
Valve Response: Truth or Consequences
Control Magazine April 2016


ISA-75.25.01 Test Procedure for Control Valve Response Measurement from Step Inputs
ISA-TR75.25.02 Control Valve Response Measurement from Step Inputs (Technical Report)
Questions?