Impact of Control Valve Performance on Control Performance
Introduction

• Importance of Valve Performance
• Standards and References
• Dead Band and Resolution
• Response Time
• Loop Gain
• Comments on Valve Troubleshooting
• Summary
• Speaker Info
“The undesirable behavior of control valves is the biggest contributor to poor loop performance and the destabilization of product uniformity”.

W. L. Bialkowski, President
EnTech Control Engineering
LNG Plant, Main Gas Feed Flow Loop

High Process Gain amplifies valve non-linearities!

Cycle caused by nonlinearity in control valve and aggravated by high process gain – The loop had to stay in Manual- for a valve that cost $1 million!

Dead band ≈ 0.6% OUT
Resolution ≈ 0.6% OUT
Vitamin plant—Steam Valve

Batch time reduced 27% and steam consumption reduced
Chemical Plant – Steam Valve

Flow cycles in automatic

Flow cycles in automatic

1% Output Steps

Valve Readback

5 min.

Step test: Valve had a 30 – 90 second Response Time! – Root cause of cycle!
Control Valve Performance

- ANSI/ISA–S75.25 (Standard) - *Test Procedure for Control Valve Response Measurement from Step Inputs*
  - Defines metrics and test procedure
  - Does NOT provide guidance to specify valve performance requirements

- ANSI/ISA–TR75.25 (Technical Report) - *Control Valve Response Measurement from Step Inputs*

- EnTech Control Valve Dynamic Specification V3.0
  - V2.0 update to V3.0 to align with ANSI/ISA–75.25
  - DOES provide guidance to specify valve performance requirements
Definitions from ANSI/ISA-S75.25

- **Dead band**: the range through which an input signal may be varied, with reversal of direction, without initiating an observable change in output signal [ANSI/ISA-S51.1-1979 (R1993)]. In this standard and ISA-TR75.25.02-2000, it is defined in percent of input span. Note that in some other literature this definition is used for dead zone.
Definitions from ANSI/ISA-S75.25

- **Resolution**: smallest step increment of input signal in one direction for which movement of the output is observed. Resolution is expressed as percentage of input span. The term in this document means: the tendency of a control valve to move in finite steps in responding to step changes in input signal applied in the same direction. An example of this is when the valve is driven by a stepper motor or an AC motor or when the pneumatically actuated control valve sticks in place, having stopped moving after the previous step change.
Resolution

INPUT TO VALVE

SMALLEST INPUT CHANGE IN THE SAME DIRECTION TO GET A RESPONSE

S<RESOLUTION<2S

VALVE POSITION

NO RESPONSE

FULL 2S RESPONSE

NO RESPONSE
Resolution

0.2%< Resolution < 0.4%

40 seconds

0.2% PID OUT steps (input to valve)

Flow PV
Dead Band

INPUT TO VALVE
Step Size = S

Valve Position

Partial Response

Partial

Full

No Response

Full Response

Input Reversal
Change to Get a Response

S < Dead Band < 2S
Dead Band

0.2% < Dead Band < 0.4%

40 seconds
Dead Band and Resolution Cause Limit Cycles

Controller Output

Controller PV – Flow
Definitions from ANSI/ISA-S75.25

- **step response time (T86):** the interval of time between initiation of an input signal step change and the moment that the response of a dynamic reaches 86.5% of its full steady state value. The step response time includes the dead time before the dynamic response.
Step Response Time ($T_{86}$)

$T_{86}$ – Includes Dead Time
Step Response Time VS. Step Size

The graph illustrates the step response time versus step size for different valve positions. The x-axis represents the step size (%), and the y-axis represents the step response time (sec). The graph shows data for multiple valve positions and indicates how response time changes with different step sizes.
From ANSI/ISA–TR75.25

• **Region 1** is defined as small input steps which result in no measurable movement of the closure member within the specified wait time.
  – Comment: This is in the region of dead band and resolution.

• **Region 2** is defined as input step changes which are large enough to result in some control valve response with each input signal change, but the response does not satisfy the requirements of the specified time and linearity.
Region 3 is defined as step changes which are large enough to result in flow coefficient changes which satisfy both the specified maximum response time and the specified maximum linearity.

- Comment: This is the range of “typical” control moves

Region 4 is defined as input steps larger than in region 3 where the specified magnitude response linearity is satisfied but the specified response time is exceeded.

- Comment: This is typically caused by velocity limited operation.

EnTech Control Valve Dynamic Specification V3.0 is similar, using A, B, C, D instead of 1, 2, 3, 4.
Step Response Time VS. Step Size

For valve B, positioner E T86 required ~2 seconds.

Region 1
Region 2
Region 3
Region 4

Response slows for larger steps.
Slow response of control valve, due to slow response of valve positioner, causes cycling of PV. Solution – retune the digital positioner!
Slowness of control valve, due to slow response of valve positioner, causes cycling of PV. Solution – replace the pneumatic positioner with a high performance digital positioner!
Summary: Step Response Time

- **Region 1 and 2** are bad for control performance.
- **Region 3** performance provides the most linear operation of the valve and hence the best control performance.
- **Region 4** performance (large step, slow or velocity limited) is typically inconsequential to control performance except in special cases like anti-surge control.
- So, **minimize** the size of **Region 1 and 2**, **maximize** the size of **Region 3**.
“Gain”

- **General:** change in output divided by the change in input

  \[
  \text{Gain} = \frac{\Delta\text{Output}}{\Delta\text{Input}}
  \]

- **Process control:**

  \[
  \text{Process Gain} = \frac{\Delta\text{Controller PV (\% of span)}}{\Delta\text{Controller Output (\% of span)}}
  \]
Loop Gain

Total Loop Gain = (Controller Gain) \times (\text{Valve Flow Gain}) \times (\text{Process Gain}) \times (\text{Transmitter Gain})

Valve flow gain magnitude and consistency are important!
Control Valve Flow Characteristics (Inherent)

Control Valve Inherent Flow Characteristics:

The relationship of flow through the valve VS. valve position at constant process conditions and pressure drop.

\[ \text{Flow} = \text{Cv} \sqrt{\Delta P / SG} \]

\( \text{Cv} \) = valve flow coefficient (a function of valve position)
*Thus, at constant \( \Delta P \) and SG, \%Flow = \% Rated Cv
Total Loop Gain & Installed Valve Gain

• Recall: Valve gain magnitude and consistency are important!

• Valve Flow Gain as Installed

\[
\text{ValveFlowGain} = \frac{\Delta \text{Flowrate}(\%)}{\Delta \text{StemPosition}(\%)}
\]

\[
\text{Flowrate} = Cv \sqrt{\Delta P / SG}
\]

• Thus, the Valve Flow Gain as installed, depends on inherent valve flow characteristics AND the actual $\Delta P$ across the valve
Valve Trim Selection Example:

Matching Valve Characteristic to Process Behavior

- Process Characteristic
  - Input = Cv
  - Output = Flow

- Ideal Combined Characteristic

- Valve Characteristic
  - Input = Stem Position
  - Output = Cv
Installed Gain – Goals and Selection

From a “% of flow span* perspective”…

Gain ≥ 0.5 (to reach 100% PV)

Gain ≤ 2.0 (to avoid amplification of valve non-linearities)

Gain as close to 1 as possible and as constant as possible

* Could be span of flow controller, or maximum valve flow or maximum desired flow
Installed Characteristics and Process Gain

Installed characteristics

Installed gains
Process Gain increases as controller output decreases, causing loop instability.
Gain Characterizer

• A signal (gain) characterizer on the output of the controller, or in a smart valve positioner, can help linearize the total process and/or valve flow gain
  – Note that the use of this technique can cause confusion. The actual output to the valve, should be displayed to the operator.
  – An alternate method is to adjust the controller tuning based on the valve position (controller output)
• However, note that the characterizer DOES NOT reduce the PROCESS non-linearities due to valve non-linearities
  – If the characterizer REDUCES the process gain, it correspondingly INCREASES the effective valve non-linearity (e.g. dead band) resulting in the same effective PROCESS non-linearity!
Specifying Valve Performance

• Process or Valve Gain – close to 1 %PV/%OUTPUT and “constant as possible”
  • “Span” could be span of flow controller if applicable, or maximum valve flow or maximum specified flow (latter two choices assume 0 min. flow)

• Key Valve Tracking Performance Parameters
  • Valve Dead Band
    • Note Process Dead Band = Process Gain * (Valve Dead Band)
    • Thus, required Valve Dead Band = Allowable Process Dead Band / Process Gain
  • Resolution
    • Note Process Resolution = Process Gain * (Valve Resolution)
    • Thus, required Valve Resolution = Allowable Process Resolution / Process Gain
Specifying Valve Performance

• Response Time Parameters
  • Response Time ($T_{86}$) - < 1/3 of process time constant
  • Size of Region 1 - (~=dead band/resolution) - bad, minimize
  • Size of Region 2 – bad, minimize
  • Size of Region 3 – wide as possible but over 10% typically not required
  • Size of Region 4 – not of great consequence to control

• *EnTech Control Valve Dynamic Specification V3.0* helps SPECIFY control valve performance
Summary

• Many operational problems can be prevented, and process control significantly improved, by proper selection of the control valve
  – Consider control loop stability and performance during valve procurement!
  – Valve gain, dead band, resolution, response time regions are clearly defined parameters
  – Severe control valve nonlinearities cannot be corrected by the process controller

• Applies across all process industries
Presenter – James Beall

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  - 14 Years Emerson Process Management
  - 19 Years Eastman Chemical Company
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