16th STS-AIChE Southwest Process Technology Conference

- Control Valve Performance – Troubleshooting and Understanding Dynamic Performance

- James Beall

- Enero Solutions

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Speaker Bio

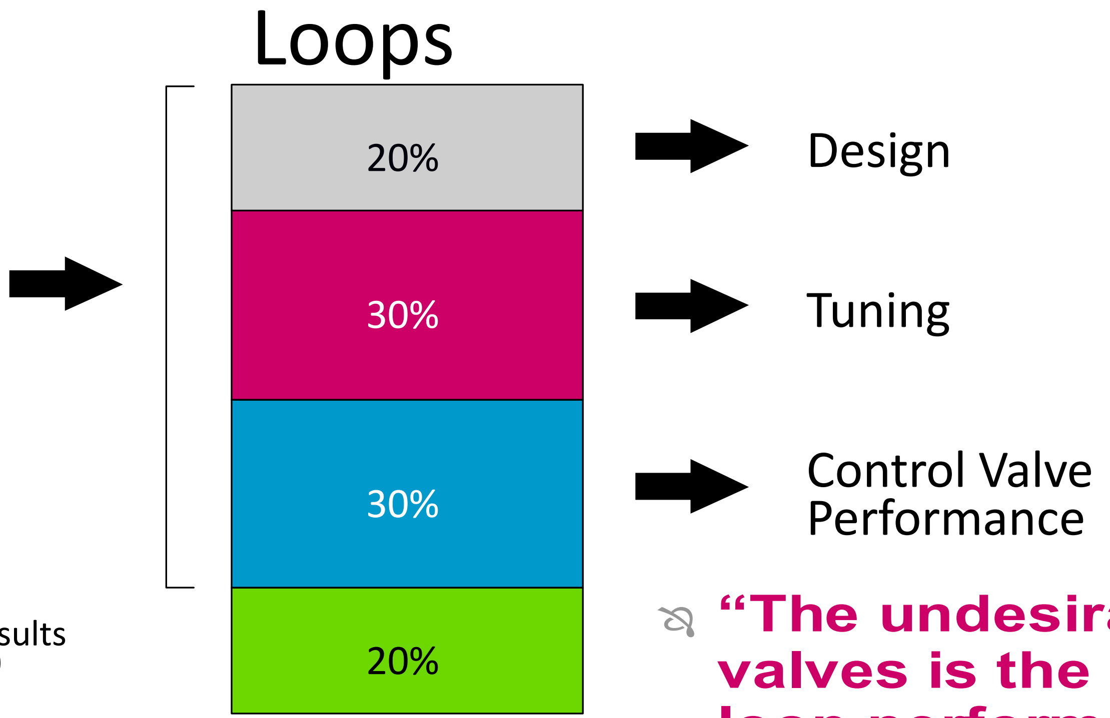
- Principal Process Optimization Consultant, Enero Solutions
- 44 years experience in process automation
  - 3 years Enero Solutions
  - 22 years Emerson Automation Solutions
  - 20 years Eastman Chemical Company
- Advanced Regulatory Control
- Advanced Multivariable Control
- Instructor for process control courses
- Chairman of ISA75.25 subcommittee on control valve performance
- Contributing author to **Process/Industrial Instruments and Controls Handbook**, Sixth Edition.

Control Valve Performance

- You don't know what you don't know!"
- "The undesirable performance of control valves is the biggest contributor to poor loop performance…"
- "0, 25%, 50%, 75%, 100% is no longer good enough!"
- Do you specify maximum lost motion, resolution and step response time on your valve spec sheet?

Control Loops that *Increase* Variability

Increases Variability



Source: EnTech -- - Results from audits of over 5000 loops

1999

"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

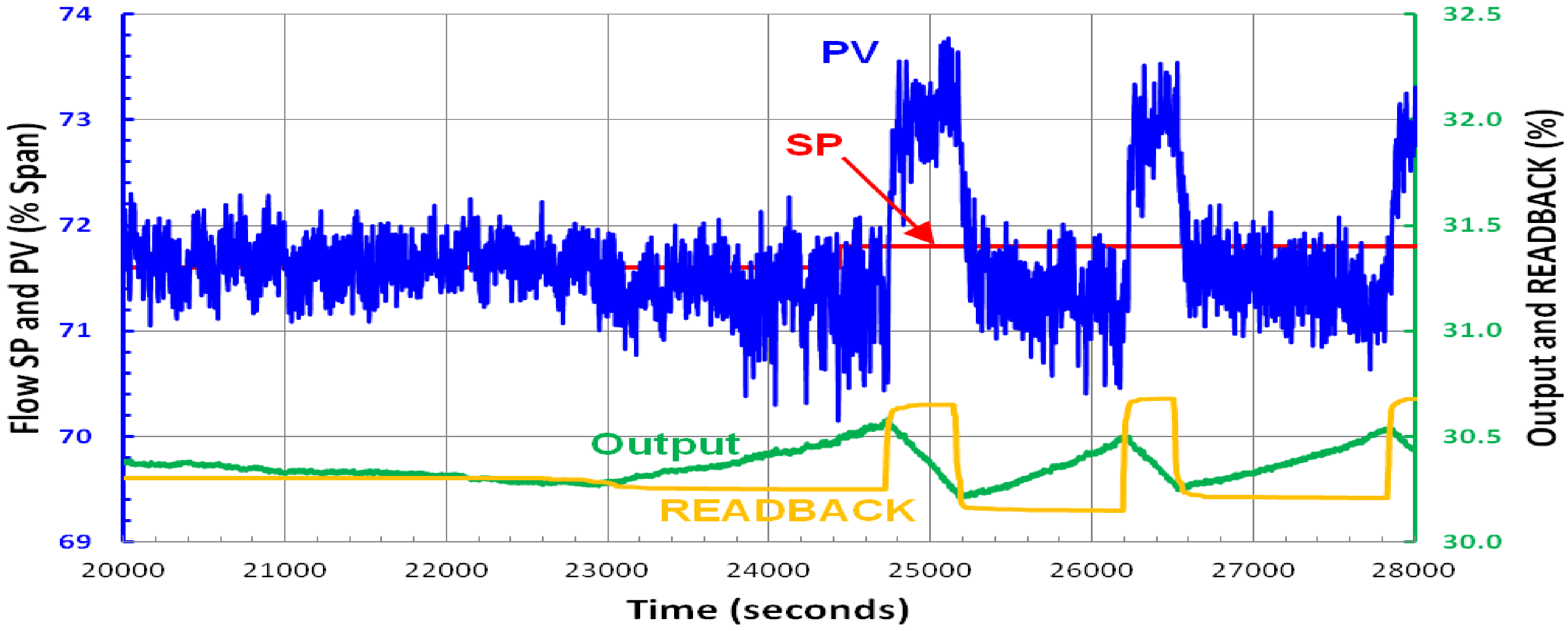
Recent State of Control Valve Performance

- **Refinery in North America**
  - 35% of the loops analyzed had control valves that limit control performance
- **Major Refinery in South America**
  - 45% of the loops analyzed had control valves that limit control performance
- **Chemical Plant in North America**
  - 20% loops had control valves that limit control performance
- **Major LNG Plant in MEA**
  - Can't run plant feed flow loop in Auto due to poor control valve performance

LNG Plant, Feed Gas Flow Control Loop

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 $1million!

Dead band ≈ 0.6% OUT ≈ 2% PV
Resolution ≈ 0.6% OUT ≈ 2% PV



Control Valve Performance Terminology

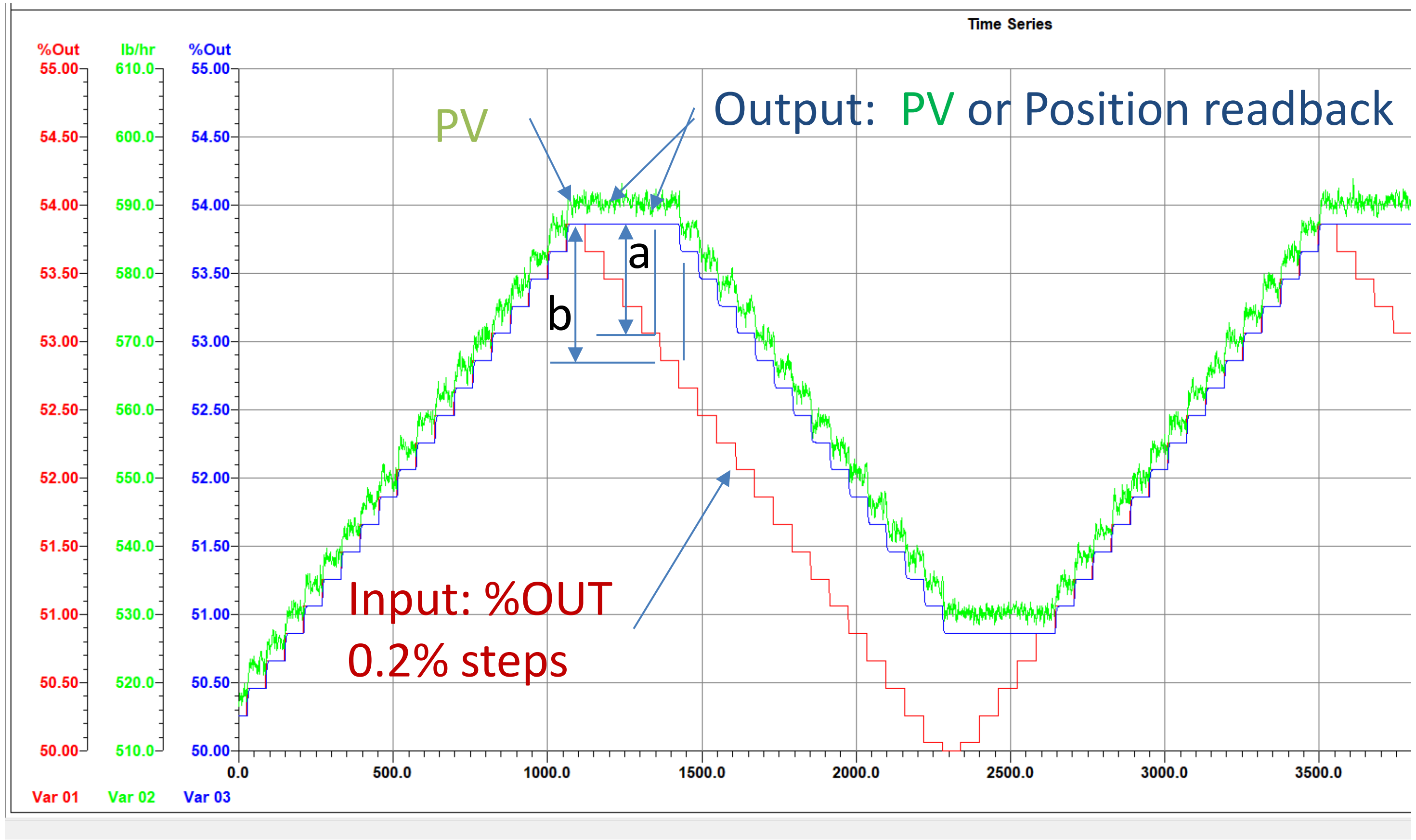
- Per ANSI/ISA-75.25.01-2024 - Test Procedure for Control Valve Response Measurement from Step Inputs and ISA-TR75.25.02 – ISA Technical Report
  - –Dead band
  - –Resolution
  - –Lost motion
  - –Valve Response Gain
  - –Step Response Time
- CVDS30 – "Entech Control Valve Dynamic Specification" – Version 3.0 – Aligned with 75.25

Definitions- ANSI/ISA-75.25.01-2024

- **Dead band** - range through which an input signal may be varied, with *reversal* of direction, without initiating an observable change in output signal [ISA-51.1]. In this document and in the standard ISA 75.25.01, it is defined in percent of input span. Dead band is the sum of the lost motion and resolution. Note that in some other literature this definition is used for dead zone.

  – Deadband is sometimes referred to as "hysteresis", but hysteresis has another meaning. You could think of hysteresis as the change in the deadband at different positions.

Dead band



An ***input*** reversal of amount "a" did not initiate a change in the ***output***, but a larger reversal of "b" did initiate a change in the ***output***. For dead band, the input change **does not** change the output.

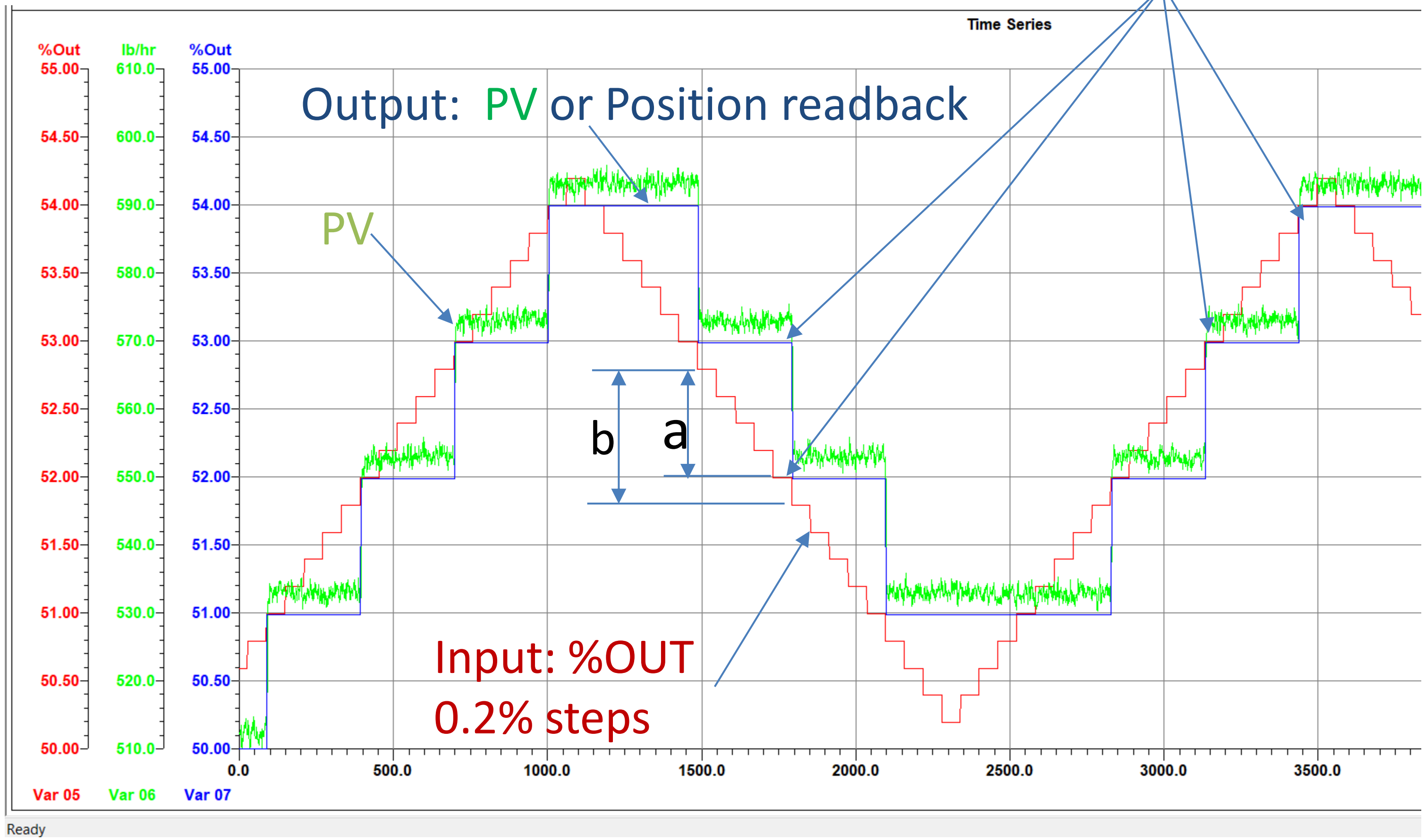
So, a ≤ ***dead band*** < b

Definitions- ANSI/ISA-75.25.01-2024

- **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.
  - Resolution is sometimes referred to as “stiction”, but stiction has a variety of meanings in the industry.

Resolution

With resolution, the motion "*catches back up*" to the change in input signal when the input signal change is > the resolution



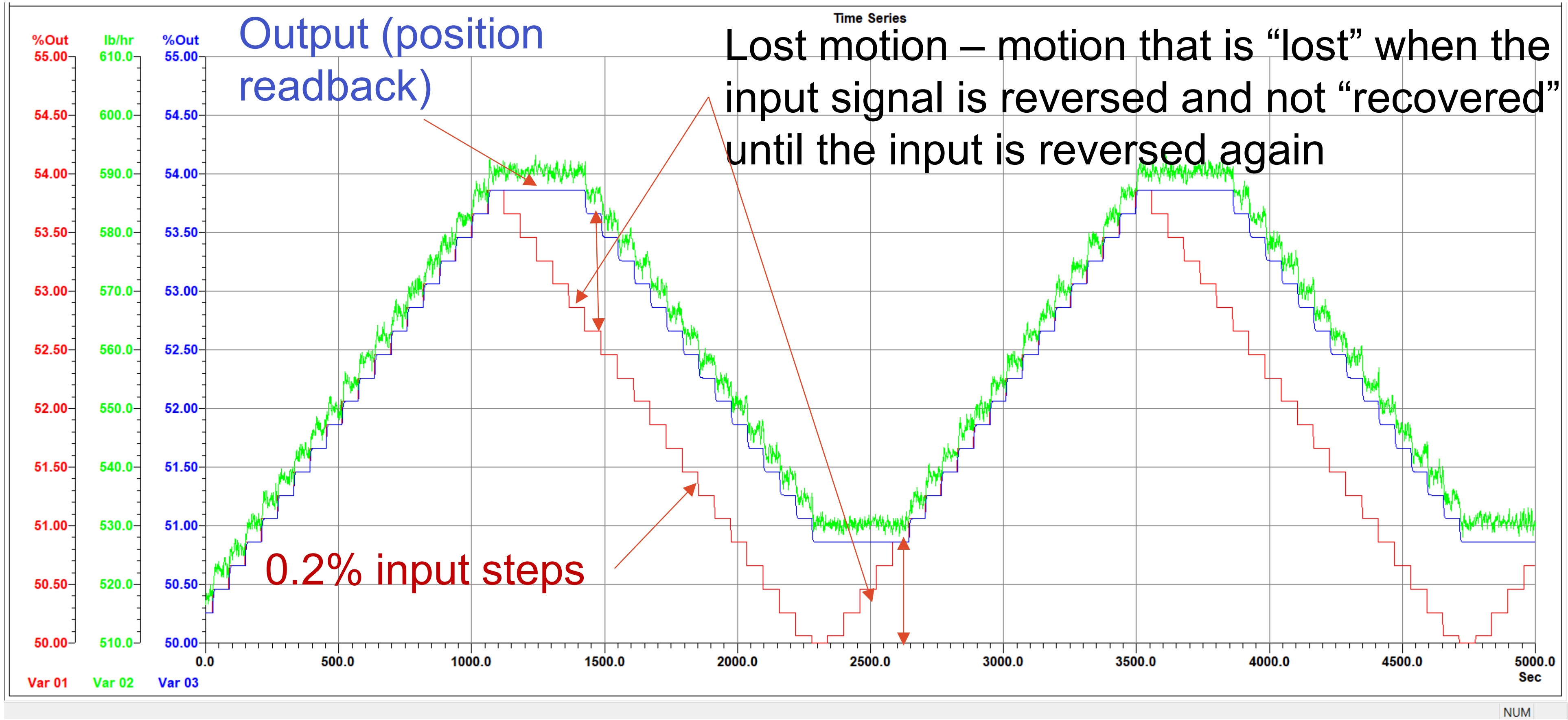
An ***input*** change in the same direction of amount "a" **did not** initiate a change in the ***output***, but a larger reversal of "b" **did** initiate a change in the ***output***. For **resolution,** the input change **does** change the output.

So, a < ***resolution*** ≤ b

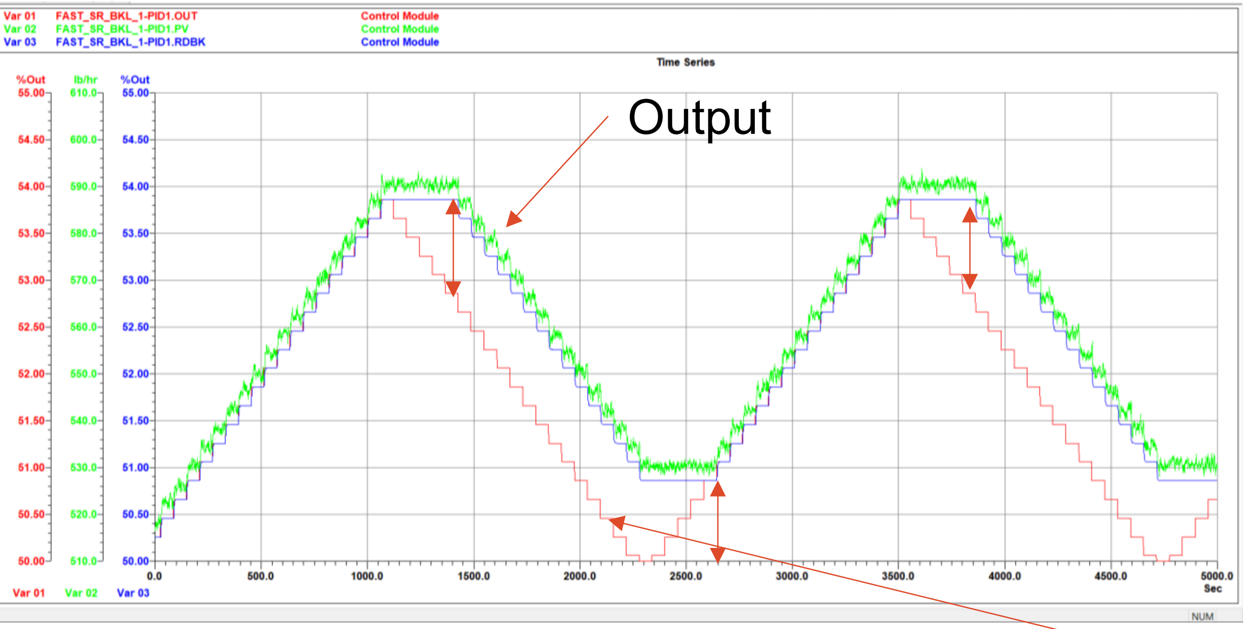
Definitions- ANSI/ISA-75.25.01-2024

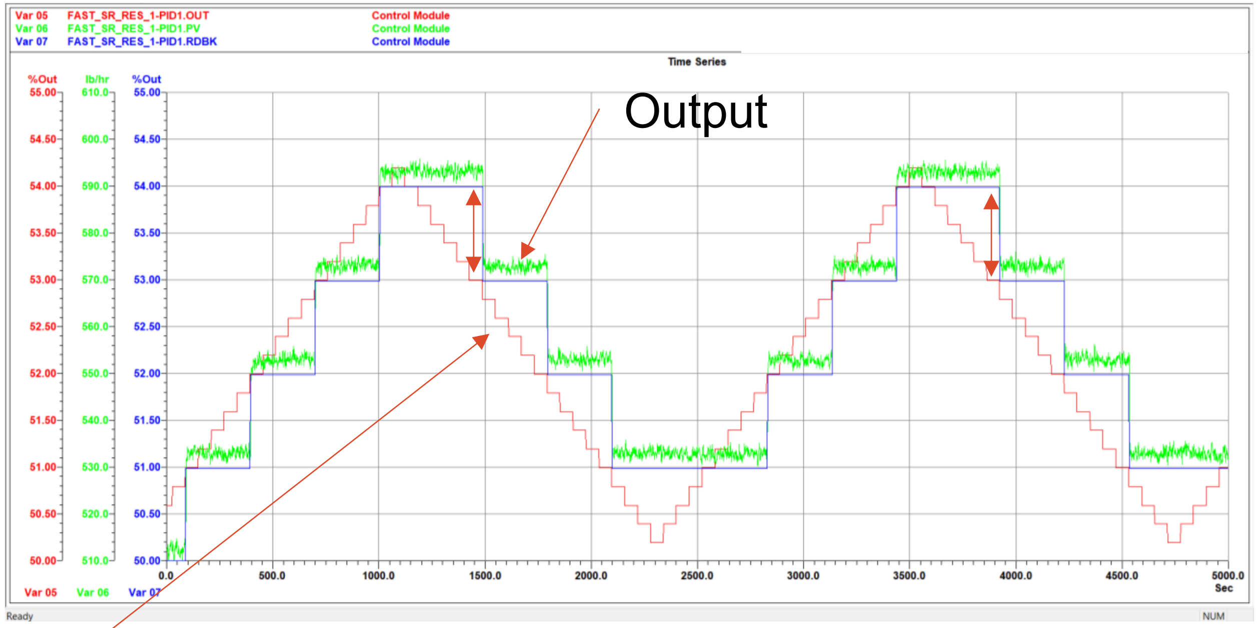
- **lost motion** - absolute value of the change in the offset between the input and output of a system when the input signal is reversed, both expressed as %span. If the input is stepped, this measurement is made when the output first responds to the reversed signal. Note that lost motion creates dead band and can be created by several sources such as backlash, shaft windup, and friction forces in the control valve system.
  - Lost motion is sometimes referred to as “backlash”, but backlash is only one source of lost motion. Other sources of lost motion include (friction forces/positioning gain), rotary valve shaft windup (twist), internal positioner settings, etc.

Lost Motion


Time Series
Output (position readback)
Lost motion – motion that is "lost" when the input signal is reversed and not "recovered" until the input is reversed again
0.2% input steps
%Out
lb/hr
%Out
55.00
610.0
55.00
54.50
600.0
54.50
54.00
590.0
54.00
53.50
580.0
53.50
53.00
570.0
53.00
52.50
560.0
52.50
52.00
550.0
52.00
51.50
540.0
51.50
51.00
530.0
51.00
50.50
520.0
50.50
50.00
510.0
50.00
Var 01
Var 02
Var 03
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
Sec
NUM

Both Valves Have ~1% Dead band, but…





~1% Lost motion, 0% Resolution

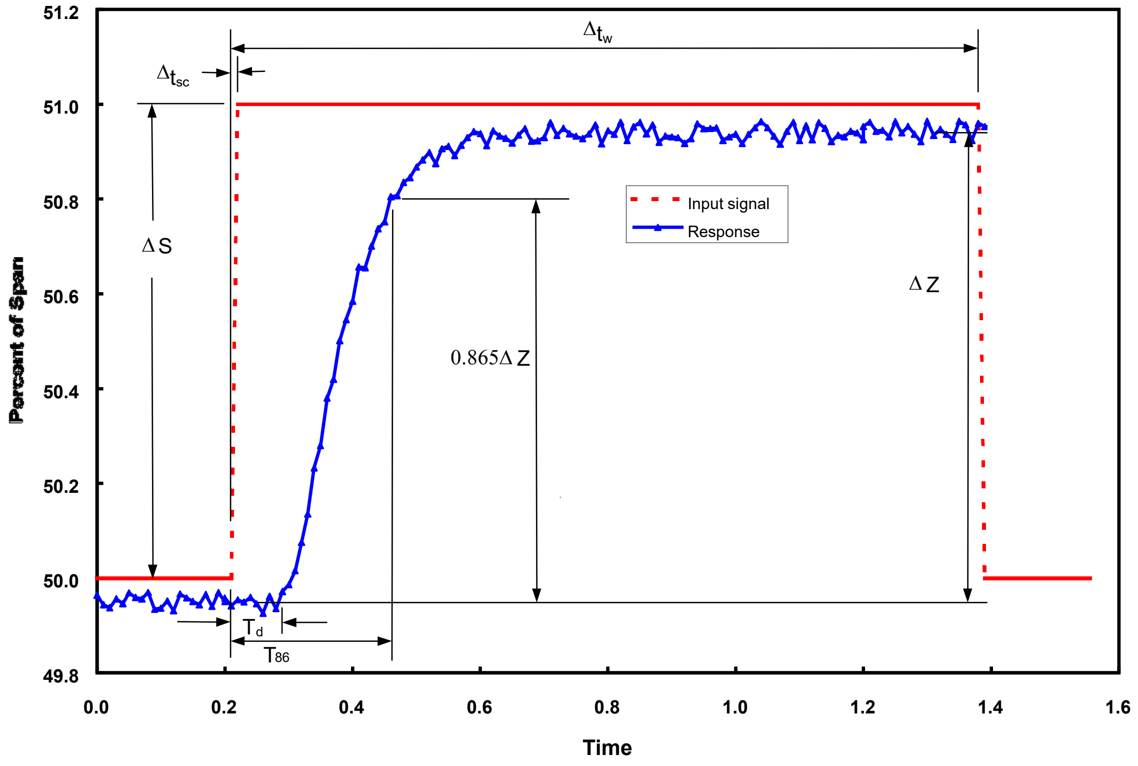
0.2% input steps

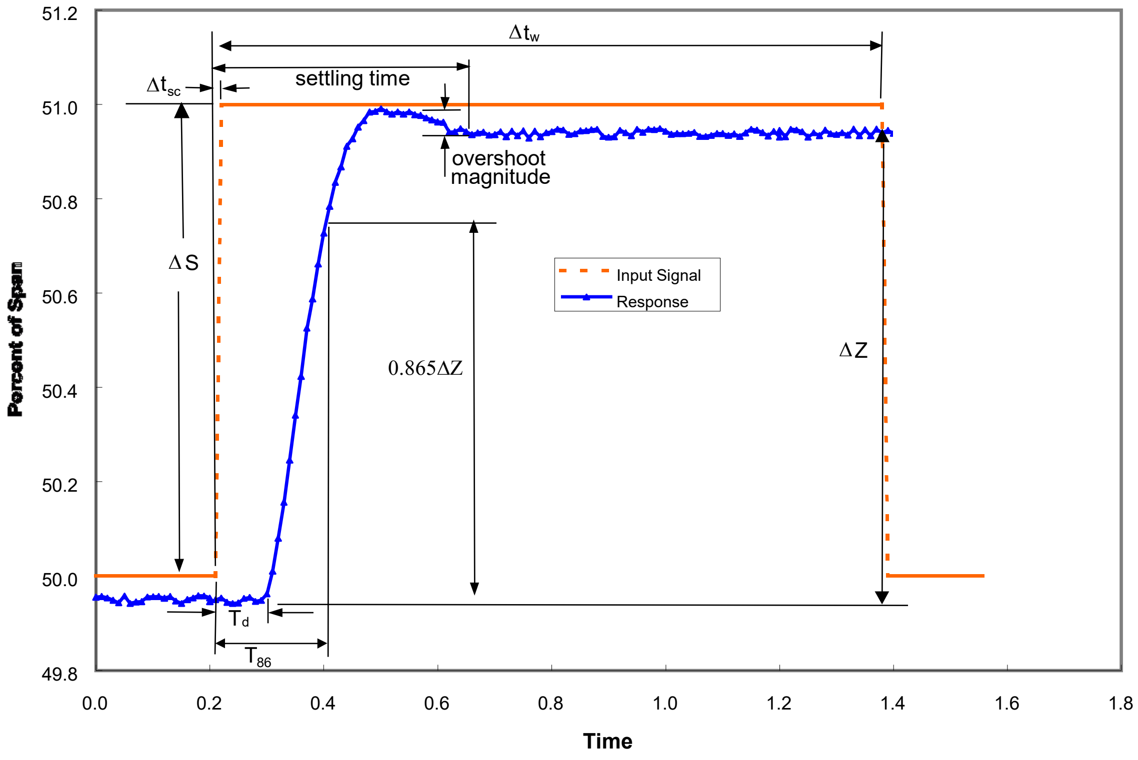
0% Lost motion, ~1% Resolution

Definitions- ANSI/ISA-75.25.01-2024

- **Step response time -** 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.
  - Note that the step response time includes deadtime.
  - Recall that a first order self-regulating system reaches 86.5% of its full steady state value after 2 * Time Constant. The use of the 86.5% of final value was to think of ½ of the response time (that includes dead time) as an "approximate time constant" for use in comparison to the process time constant(s) and the Lambda of the loop (if Lambda tuning is used).

Step Response Time T_{86}

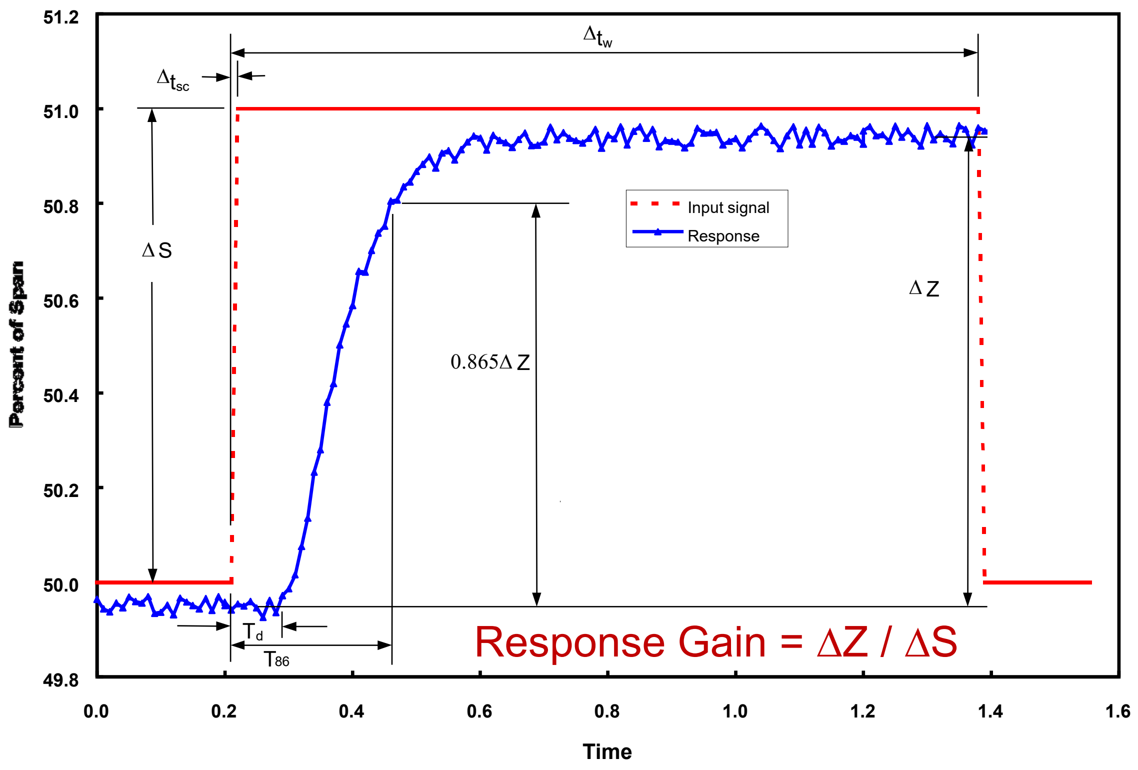


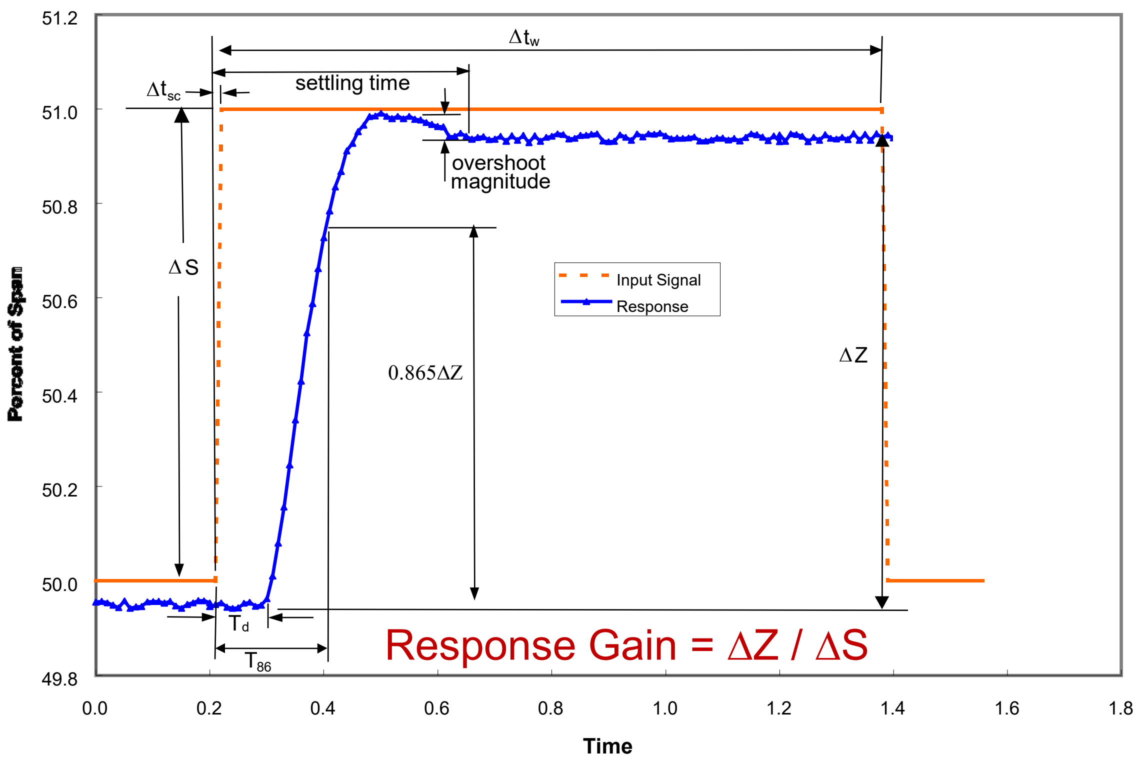


Definitions- ANSI/ISA-75.25.01-2024

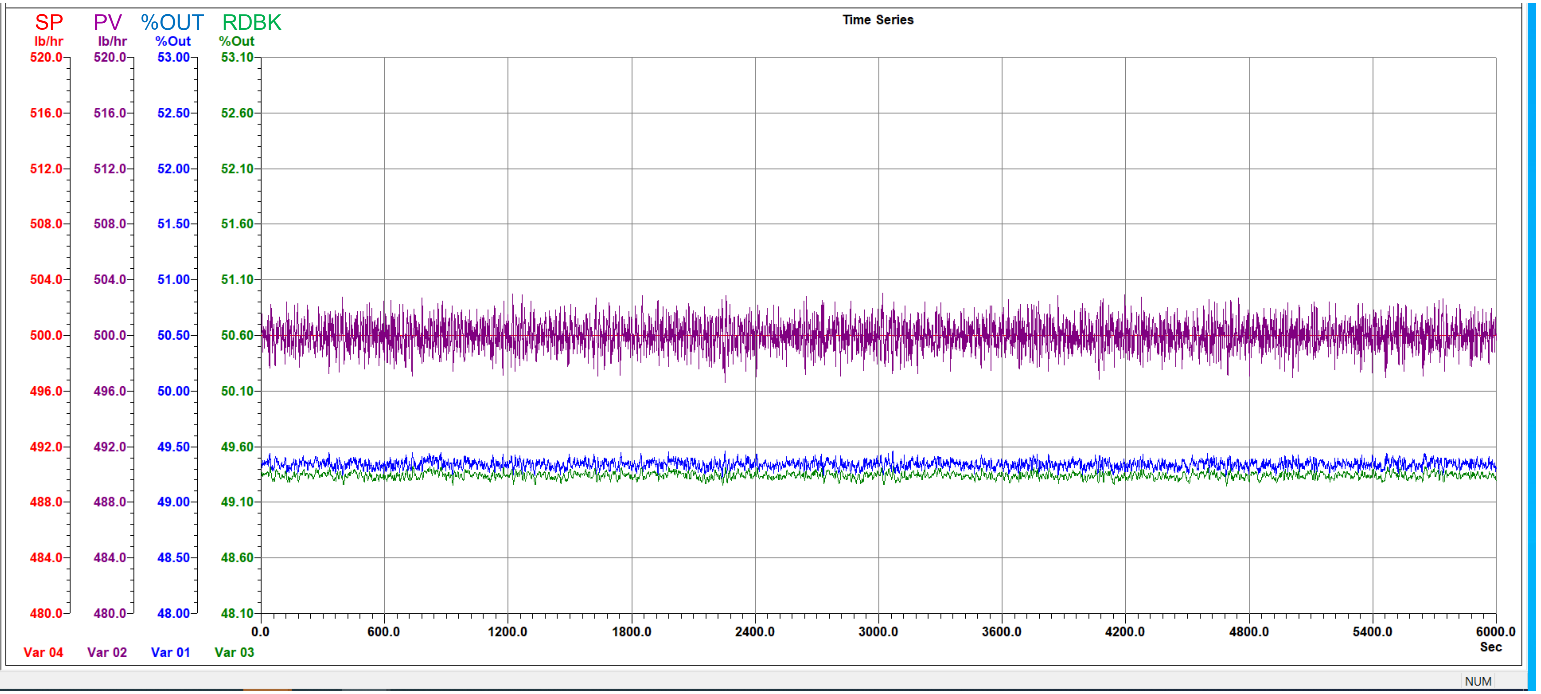
- **Response Gain -** ratio of the steady state magnitude of the process change ΔZ divided by the signal step Δs that caused the change. One special reference response gain is defined as that calculated from the 2 percent step size response time test. This is designated as GZ02, which is used as the nominal response gain at a specific input signal. This can be used to compare the response gain for different sizes of step inputs at the same nominal position.
  - The “process”, Z, can be the stem position or any other process variable that reflects the change of the valve’s flow coefficient. A flow rate through the valve provides the most information as it includes all aspects of the valve’s response. Note that the changes in the differential pressure across the valve can impact the gain but can be taken into account. See the “**response flow coefficient**”. Using the actual process variable for the control loop would represent be a measure of the loop process gain.

Response Gain



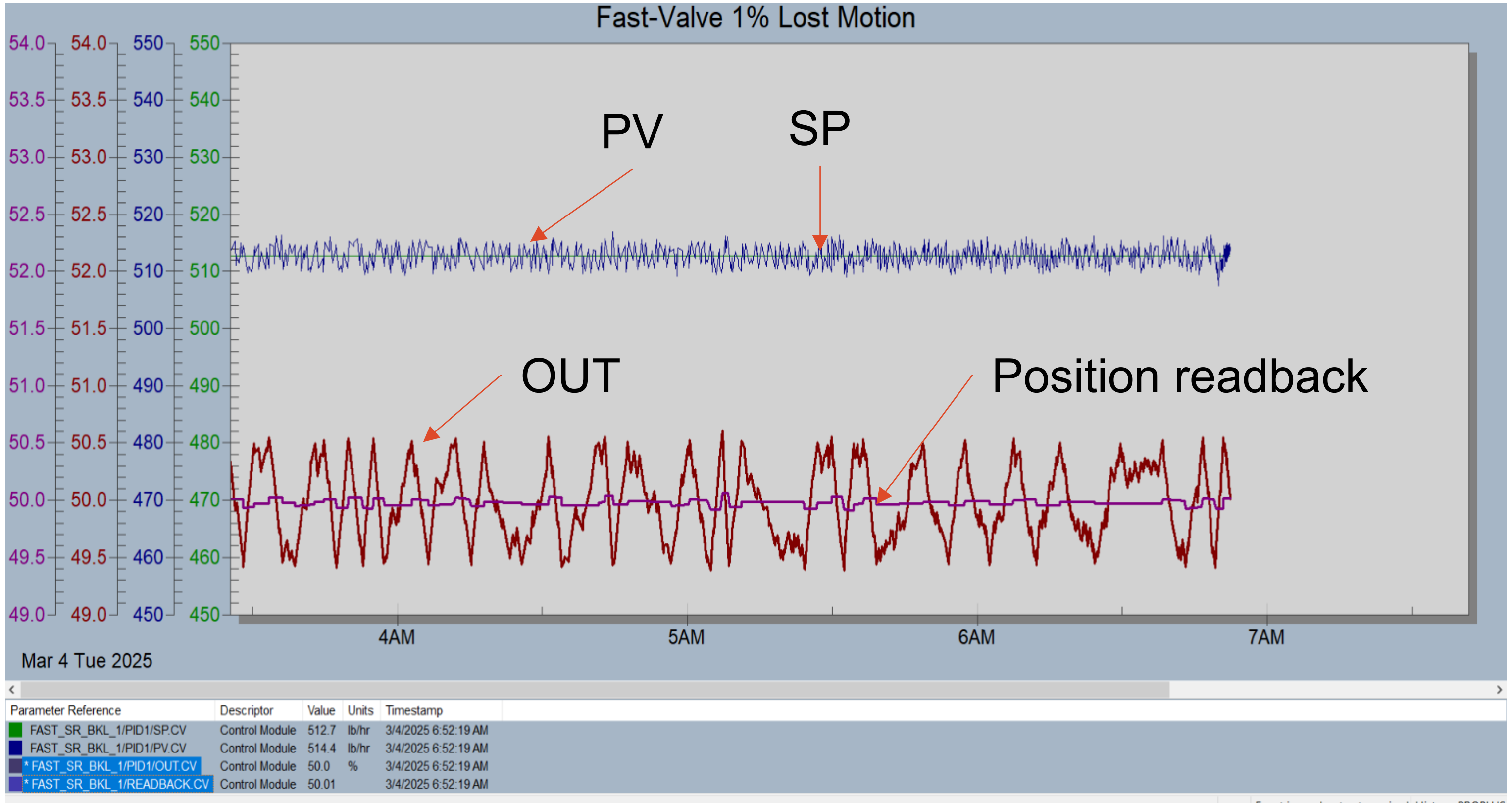


Base Case- Good Valve, Fast SR Process



- Loop – Fast, self-regulating, 0-1000 lb/hr PV scale
- Symptom – Limit cycle
  - PV – ~0.2% P-P (noise)
  - OP – ~0.2% P-P
  - Position readback- ~0.2% P-P

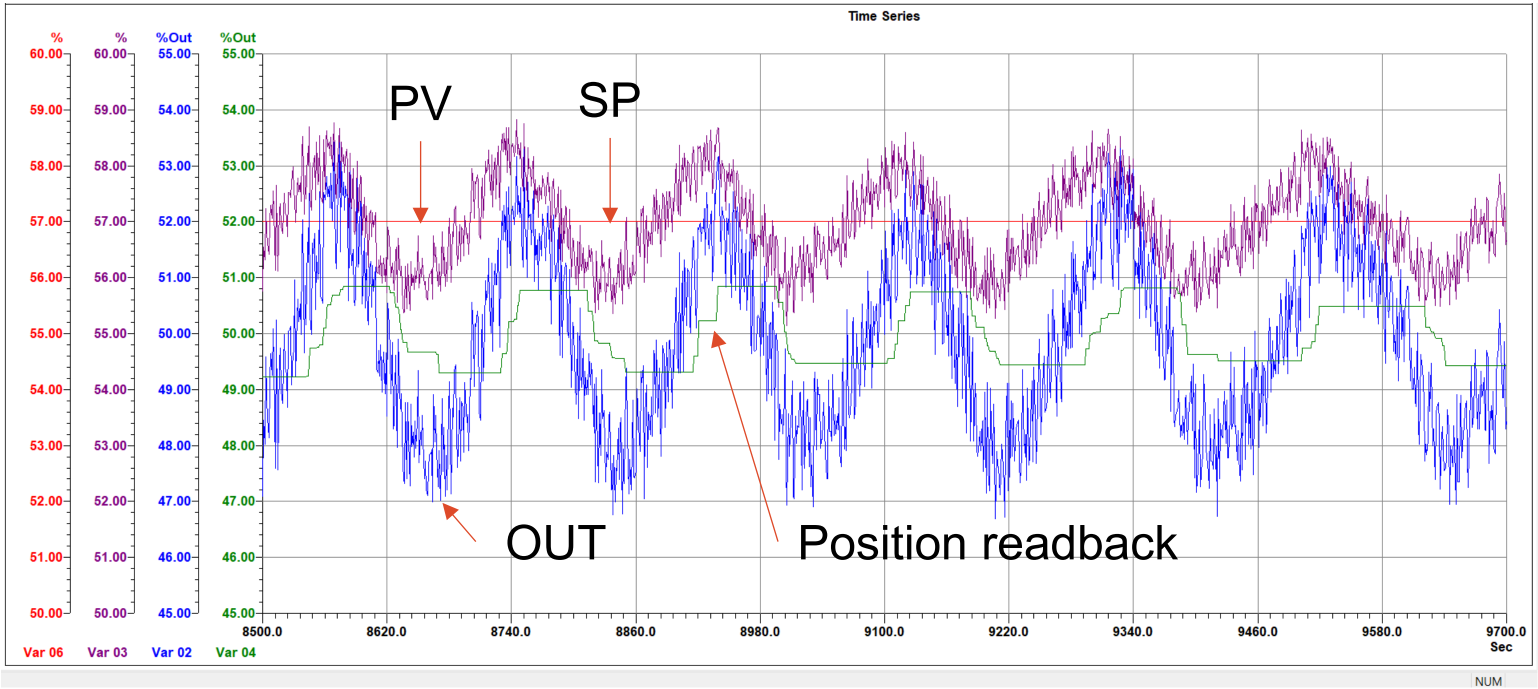
Case 2 - ~1% lost motion – Fast Self-Regulating Process



- Loop – Fast, self-regulating, 0-1000 lb/hr PV scale
- Symptom – No continuous limit cycle of PV
  - PV – ~0.3% P-P
  - OP – ~1% P-P
  - Position readback- ~0.2% P-P

Lost motion in the presence of fewer that 2 integrating elements **will not** limit cycle the process. The OUT may cycle due to PV noise and/or load changes.

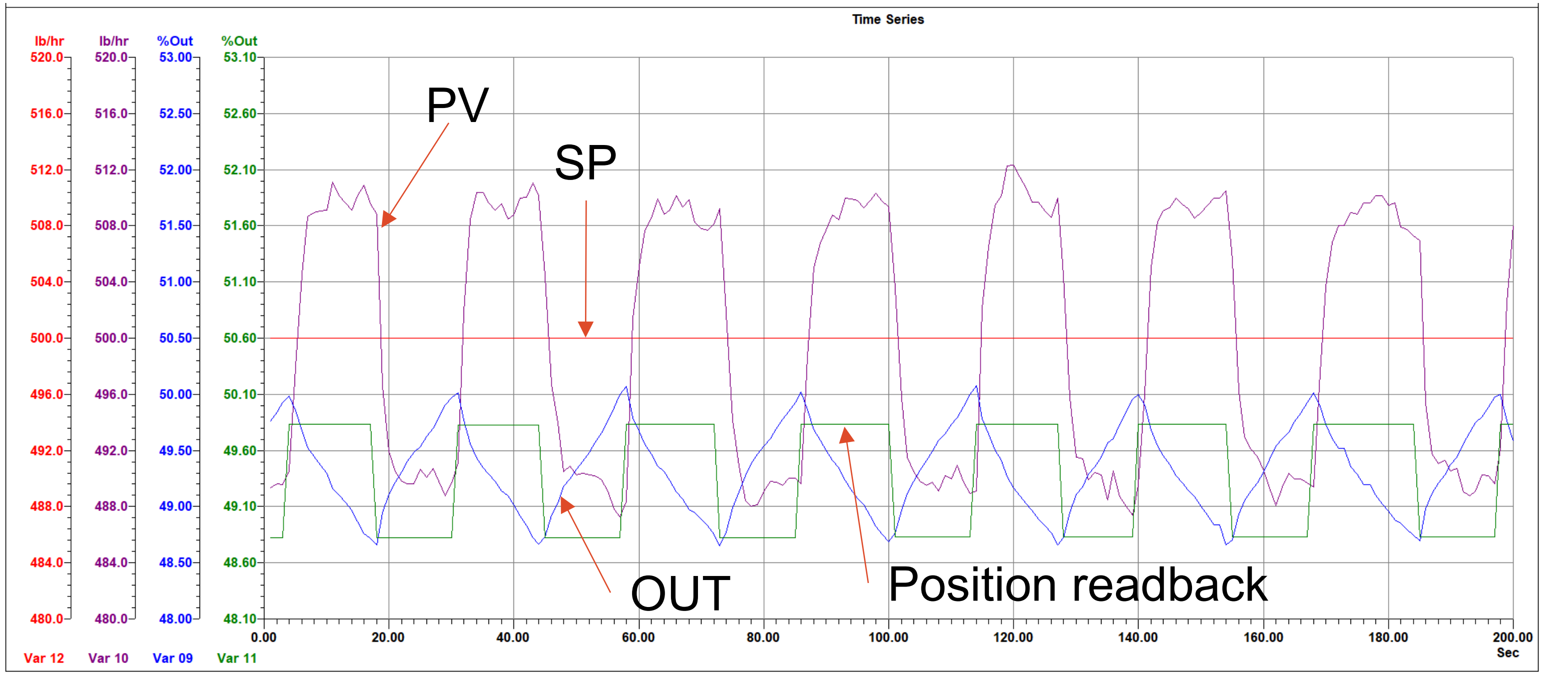
Case 3 - ~ 1% lost motion - Integrating process



- Loop – Integrating response, 0-100% PV scale
- Symptom – Limit cycle
  - PV – ~3% P-P
  - OP – ~3% P-P
  - Position readback- ~1.3% P-P

Lost motion in the presence of 2 or more integrating elements **will** limit cycle.

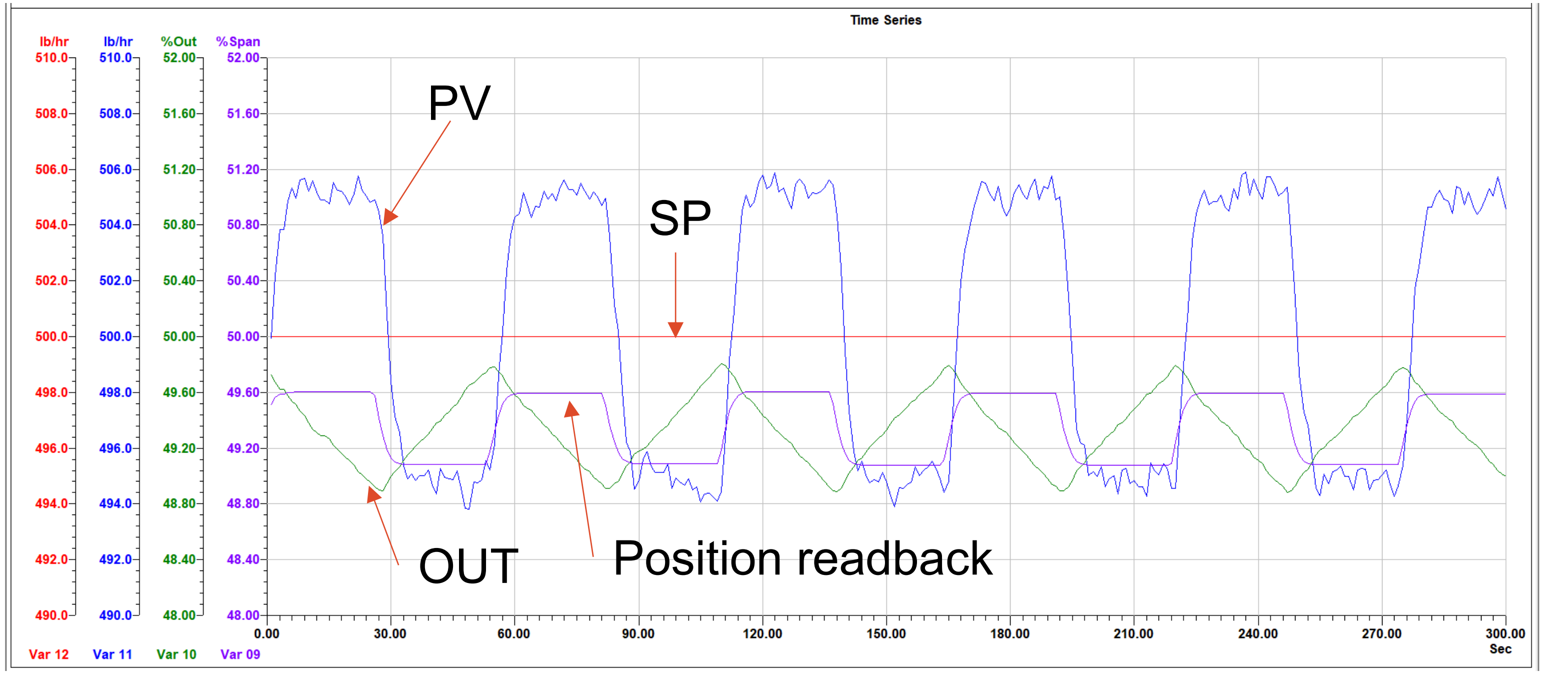
Case 4 - ~ 1% resolution – Fast Self-Regulating Process



- Loop – Fast, self-regulating, 0-1000 lb/hr PV scale
- Symptom – Limit cycle
  - PV – ~2% P-P
  - OP – ~1% P-P
  - Position readback- ~1.3% P-P

Resolution in the presence of 1 or more integrating elements will limit cycle.

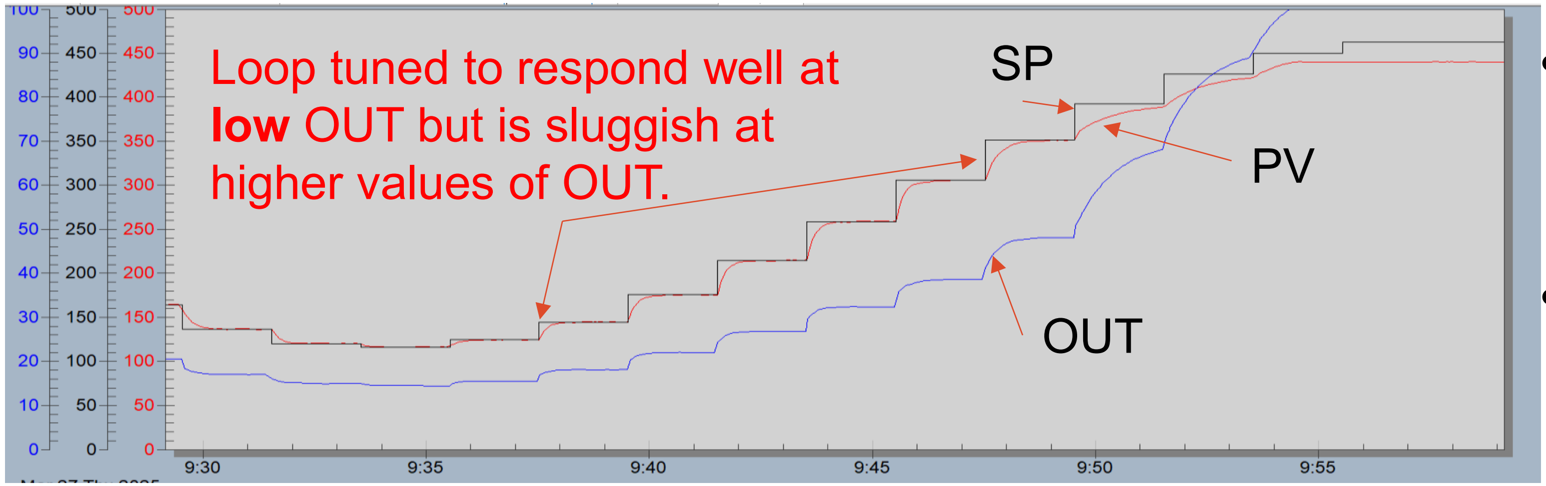
Case 5 Step response time variation – Fast Self-Regulating Process

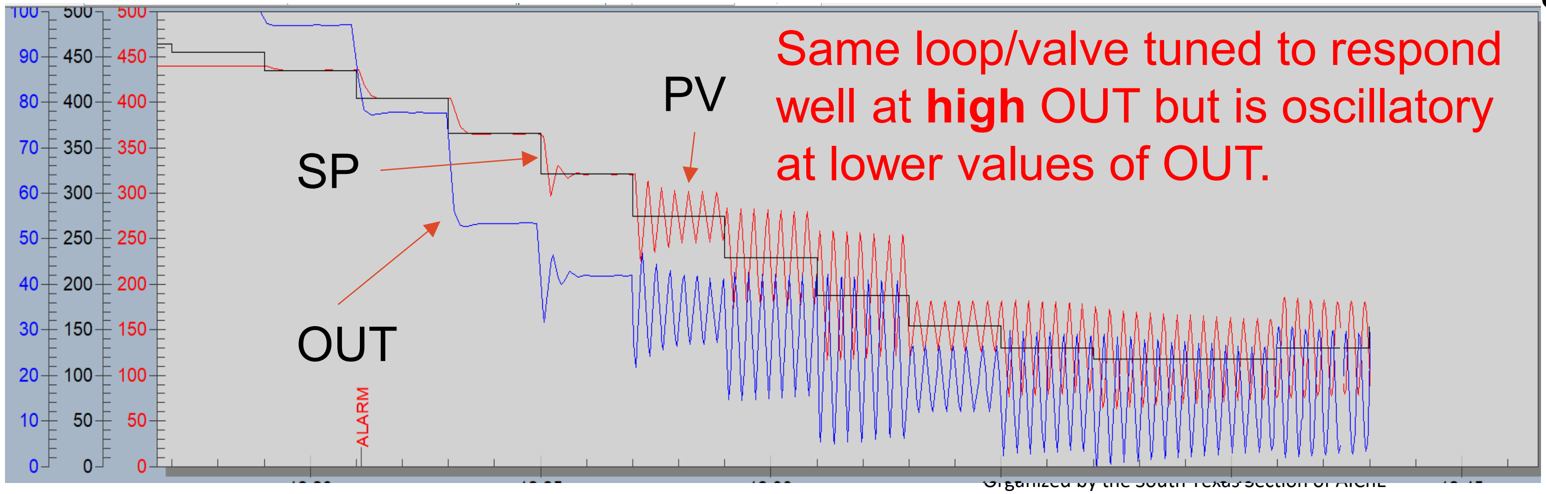


- Loop – Fast, self-regulating, 0-1000 lb/hr PV scale
- Symptom – Limit cycle
  - PV – ~1% P-P
  - OP – ~0.8% P-P
  - Position readback- ~0.5% P-P

If the valve step response time is a significant portion of the loop dynamics, and it becomes large for small input reversals, then 1 or more integrating elements in the loop **will** cause limit cycle. Note that this cycle is very similar to that caused by resolution on a fast, self-regulating process!

Case 6 Valve response gain – Fast Self-Regulating Process





- Loop – Fast, self-regulating, 0-500 lb/hr PV scale
- Valve – Valve response gain is higher at lower value of OUT.
- Symptom – closed loop response time changes at the valve response gain changes the loop gain.

Summary of Symptoms

- **Lost motion** in the presence of fewer that 2 integrating elements will not limit cycle the process. The OUT may cycle due to PV noise and/or load changes.
- **Lost motion** in the presence of 2 or more integrating elements will limit cycle.
- **Resolution** in the presence of 1 or more integrating elements will limit cycle.

Summary of Symptoms

- If the **valve step response time** is a significant portion of the loop dynamics, **and** it becomes large for small input reversals, **and** there is 1 or more integrating elements in the loop, it will cause a limit cycle. Note that this cycle is very similar to that caused by resolution on a fast, self-regulating process!
- A significant variation in overall loop gain due to the **valve response gain** will change the closed loop response time of loop. This can result sluggish response at some positions of the valve and aggressive at other positions.

Troubleshooting

- Put the loop in manual and observe a change in the pattern
- Determine process type and dynamics (e.g. self-regulating or integrating, deadtime, time constant(s), etc.
- Check and improve PID tuning
- If poor performance continues, perform the valve performance tests

Troubleshooting

- "Smart" digital positioners and I/O communication can provide key variables to diagnose valve issues
  - "Valve" position at the point being measured
    - Usually the "actuator" position
    - Accuracy of measurement varies
    - Valve type impacts correlation of position to actual closure member position
  - Output (pressure(s), electric power, hydraulic) is very helpful
  - Speed of communication of variables varies

Comments

- Valve non-linearities are non-linear! They will vary for each test, different valve position, different process conditions, etc.
- Different actuators, valve types, positioners, positioner tuning are susceptible different non-linearities
- Though integral action (without a dead zone) in a positioner can eliminate dead band, it can result in self induced limit cycle (with the PID controller in manual!)

Summary

- Good control valve performance is required for good process control performance
- Poor control valve performance continues to be a prevalent issue, even with “smart” positioners
- Control valve specifications should include performance specifications
- Control valve and control performance improvements have the highest ROI of all control improvement activities!