



Setting the Standard for Automation™

Compressor Modeling and Control

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Standards
Certification
Education & Training
Publishing
Conferences & Exhibits

Presenter

- Gregory K McMillan is a retired Senior Fellow from Solutia/Monsanto and an ISA Fellow. Greg was an adjunct professor in the Washington University Saint Louis Chemical Engineering Department 2001-2004. Greg is currently a principal senior software engineer in Emerson Automation Solutions.
- Greg received the ISA “Kermit Fischer Environmental” Award for pH control in 1991, the Control Magazine “Engineer of the Year” Award for the Process Industry in 1994, was inducted into the Control “Process Automation Hall of Fame” in 2001, was honored by InTech Magazine in 2003 as one of the most influential innovators in automation, and received the ISA Life Achievement Award in 2010. Greg is the author of numerous ISA books on process control, his most recent being *Advances in Reactor Measurement and Control* and *Good Tuning: A Pocket Guide - 4th Edition*. Greg has been the monthly “Control Talk” columnist for *Control* magazine since 2002. Greg is the founder and co-leader with Hunter Vegas of the ISA Mentor Program for users. Greg’s expertise is available on the web sites:
<http://www.controlglobal.com/blogs/controltalkblog/>
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Top Ten Things You Want to Hear from your CEO

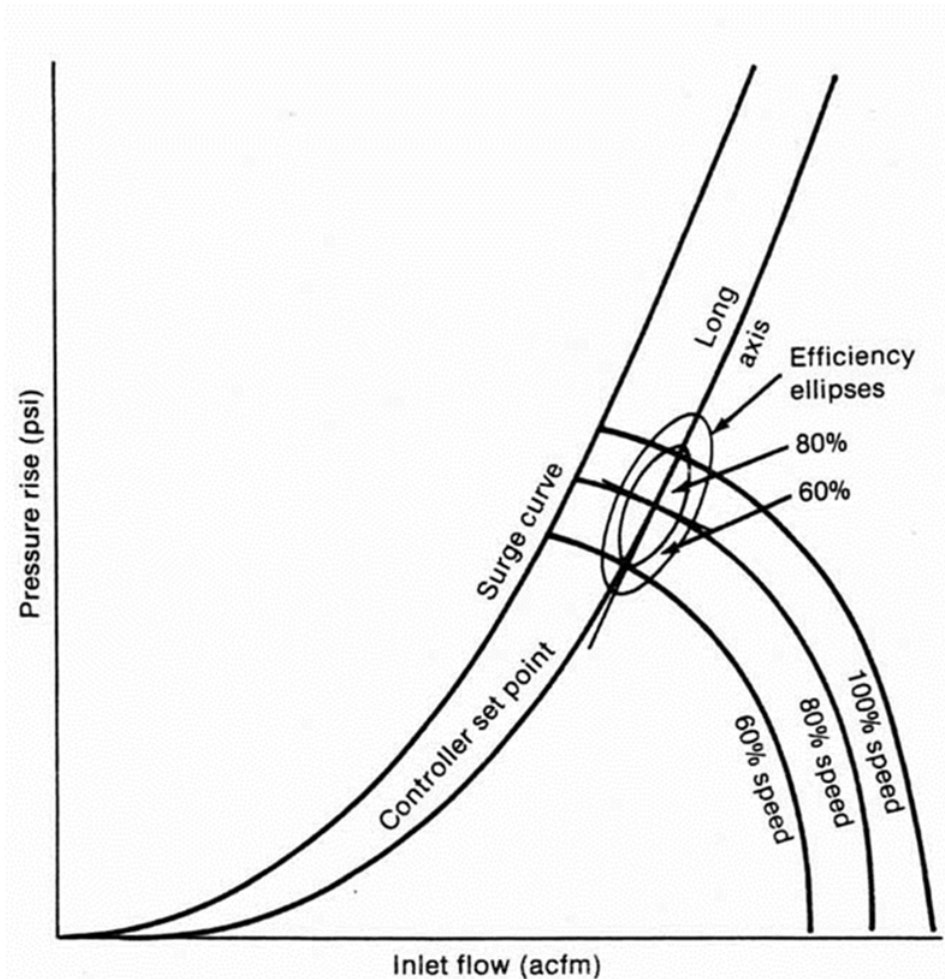


- (10) Sustainable and improvable plant profitability by best automation system is more important than project schedules or costs
- (9) Seek online plant performance metrics with smart time horizons
- (8) Take the time to learn new technologies and exploit Digital Twin
- (7) Read and understand *Good Tuning: Pocket Guide Fourth Edition* and *Process/Industrial Instruments and Controls Handbook Sixth Edition 2019* and apply the knowledge especially best practices
- (6) I have read and understood the Automation Competency Model
- (5) No on-off valves posing as throttling valves - I want “[Valves that don't Compromise Control](#)”
- (4) I want “[What is Truly Important for Measurements and Valves](#)”
- (3) No low bid packaged equipment
- (2) Make innovative process control improvements
- (1) You decide what is best

Topics Covered

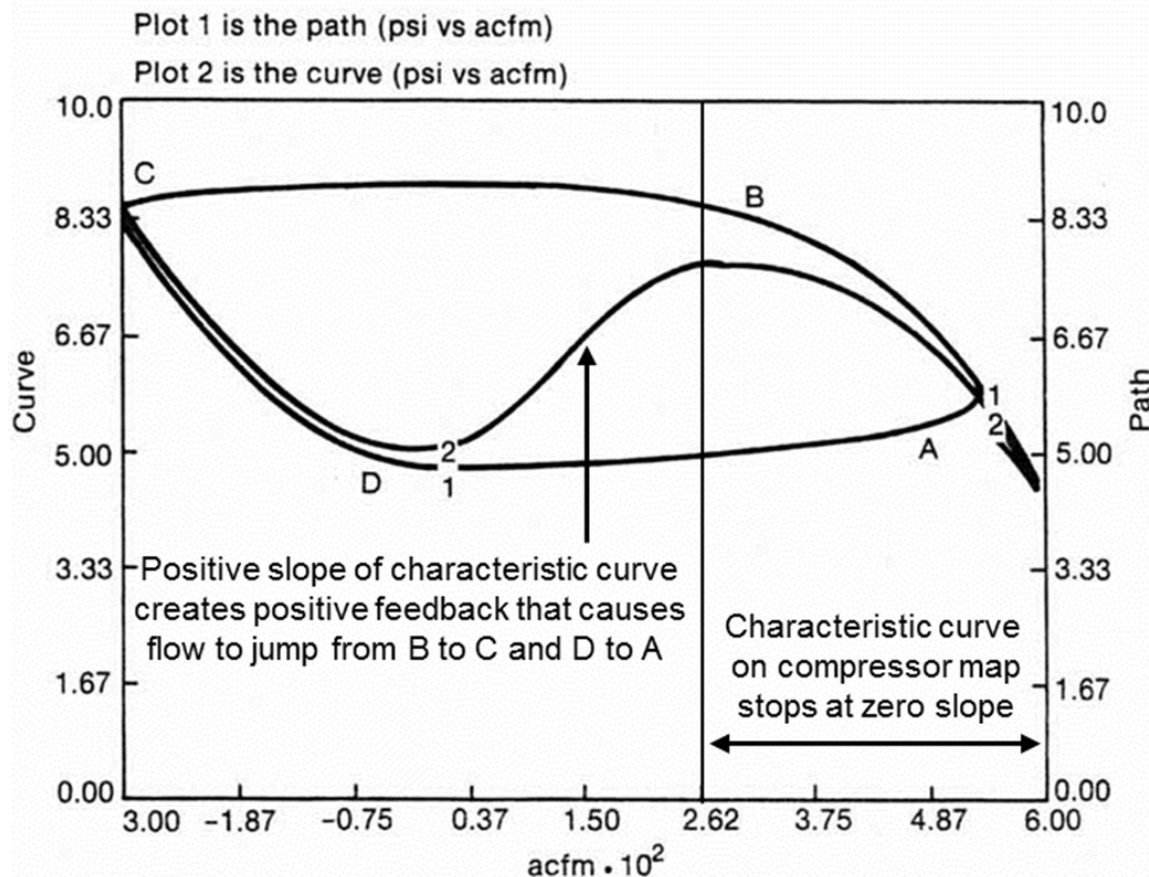
- Compressor Surge Curve and Setpoint
- Compressor Characteristic Curve and Surge Path
- Flow and Pressure Oscillations During Surge
- Compressor Surge Protection & Efficiency Maximization
- Sources of Automation System Dynamics
- How to Make Valve Response Faster
- Valve Alerts
- Digital Twin Use, Improvements Offered, Opportunities, and New Blocks
- Details on Control System Implementation
- Best Practices
- Resources

Compressor Surge Curve and Setpoint



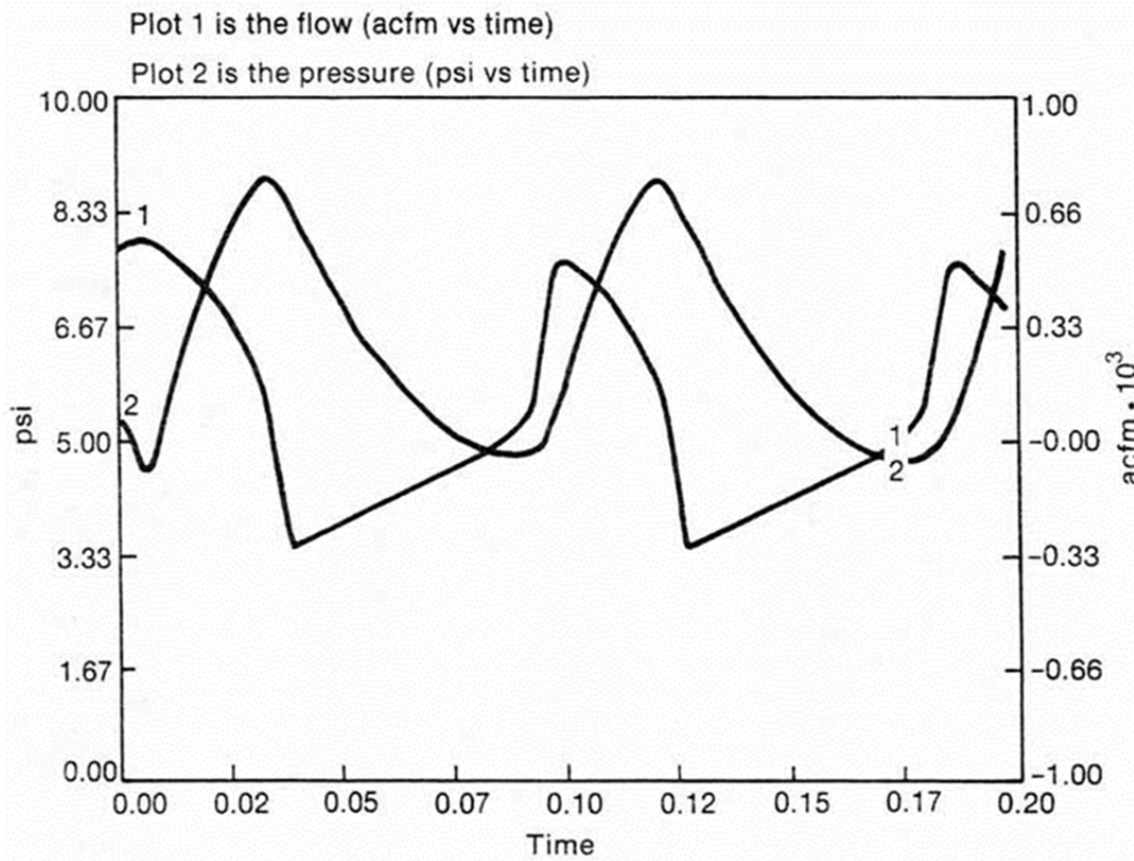
Since the objective is to keep the operating point to the right of the surge curve, why not generate a set point for the surge controller that is parallel to the surge curve? This turns out to be the best control strategy. Not only is surge prevented for all possible positions of the operating point on the compressor map, but energy is saved by less unnecessary recycle or vent flow and higher operating efficiency. Since the long axis of the efficiency ellipses are parallel to the surge curve set point, the operating point moves along the long axis for load changes.

Compressor Characteristic Curve and Surge Path



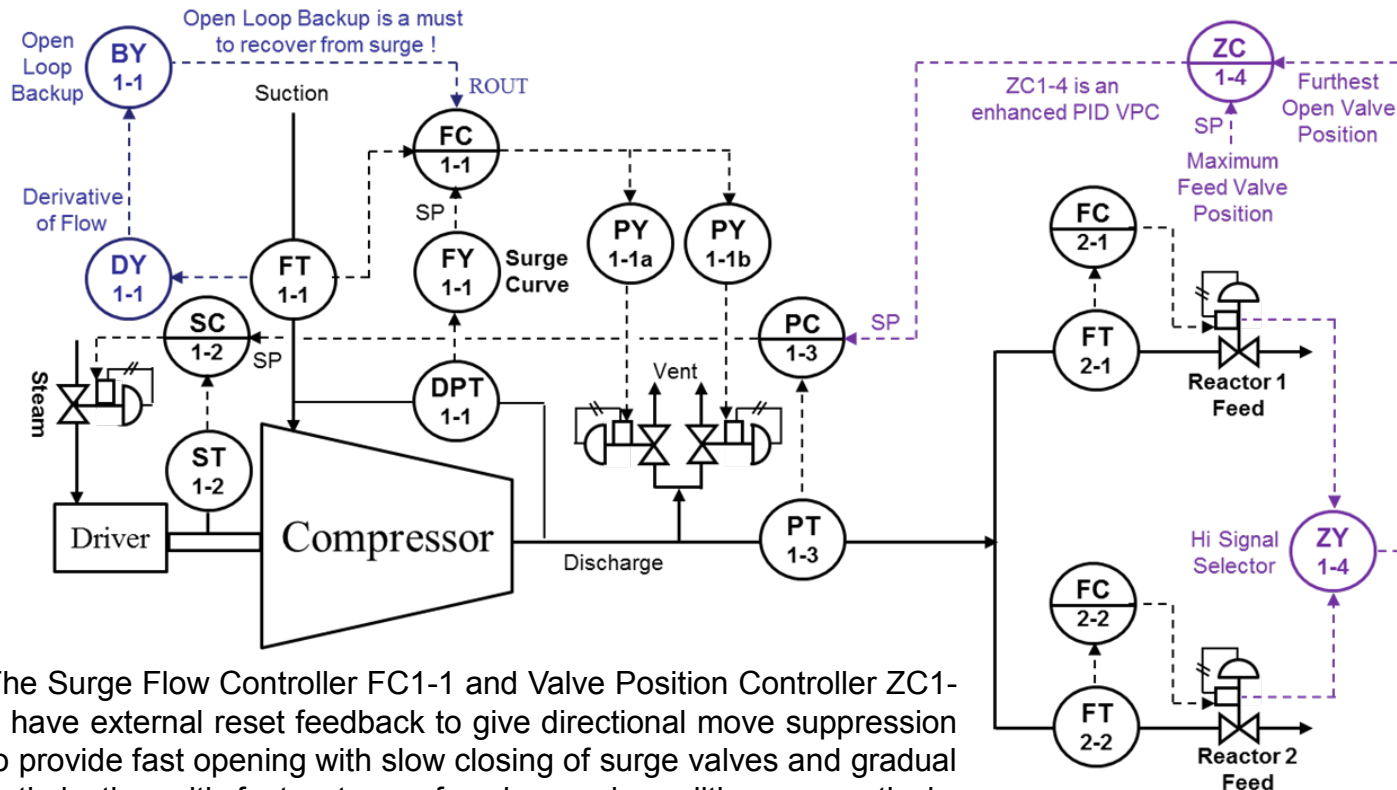
When the operating point reaches point B, which is where the compressor characteristic curve slope is zero, the operating point jumps to point C. This jump corresponds to the precipitous drop in flow that signals the start of the surge cycle and the subsequent reversal of flow (negative acfm). After this jump to point C, the operating point follows the compressor curve from point C to point D as the plenum volume is emptied due to reverse flow. When the operating point reaches point D, which is where the compressor characteristic slope is zero again, the operating point jumps to point A.

Flow and Pressure Oscillations During Surge



The operating point follows the negative sloped portion of compressor curve during the peaks and valleys of the surge flow oscillations. The jumps on the compressor map correspond to the rapid transition between the peaks and valleys.

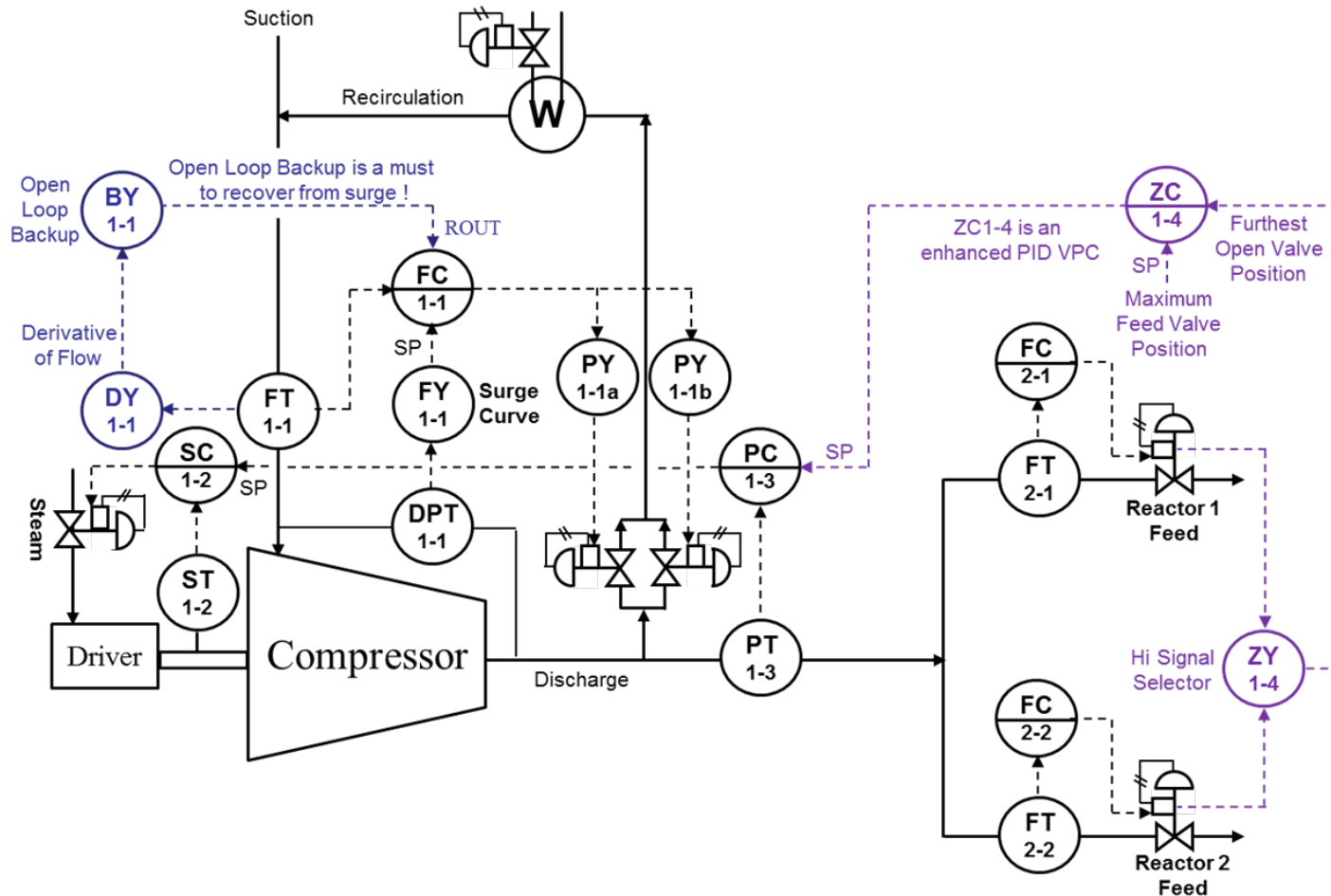
Compressor Surge Protection and Efficiency Maximization (Vent Valves)



The Surge Flow Controller FC1-1 and Valve Position Controller ZC1-4 have external reset feedback to give directional move suppression to provide fast opening with slow closing of surge valves and gradual optimization with fast getaway for abnormal condition, respectively. The derivative of the suction flow computed by DY1-1 uses a deadtime block to provide immediate updates with a good signal to noise ratio. This derivative can be multiplied by the deadtime and added to the current suction flow to give a predicted flow one deadtime into the future. This plus reactor feed valve position can be used to provide a feedforward signal to help surge control deal with user (e.g., reactor) shutdown.

Not shown is decoupling signal between stages or compressors in series or a feedforward of reactor feed flows to preemptively position the surge valves to minimize the pressure upset and to minimize the approach to surge curve for major changes in reactor production rates and reactor startup and shutdown. For users of intermittent stages or compressors, the feedforward would apply to the right stage.

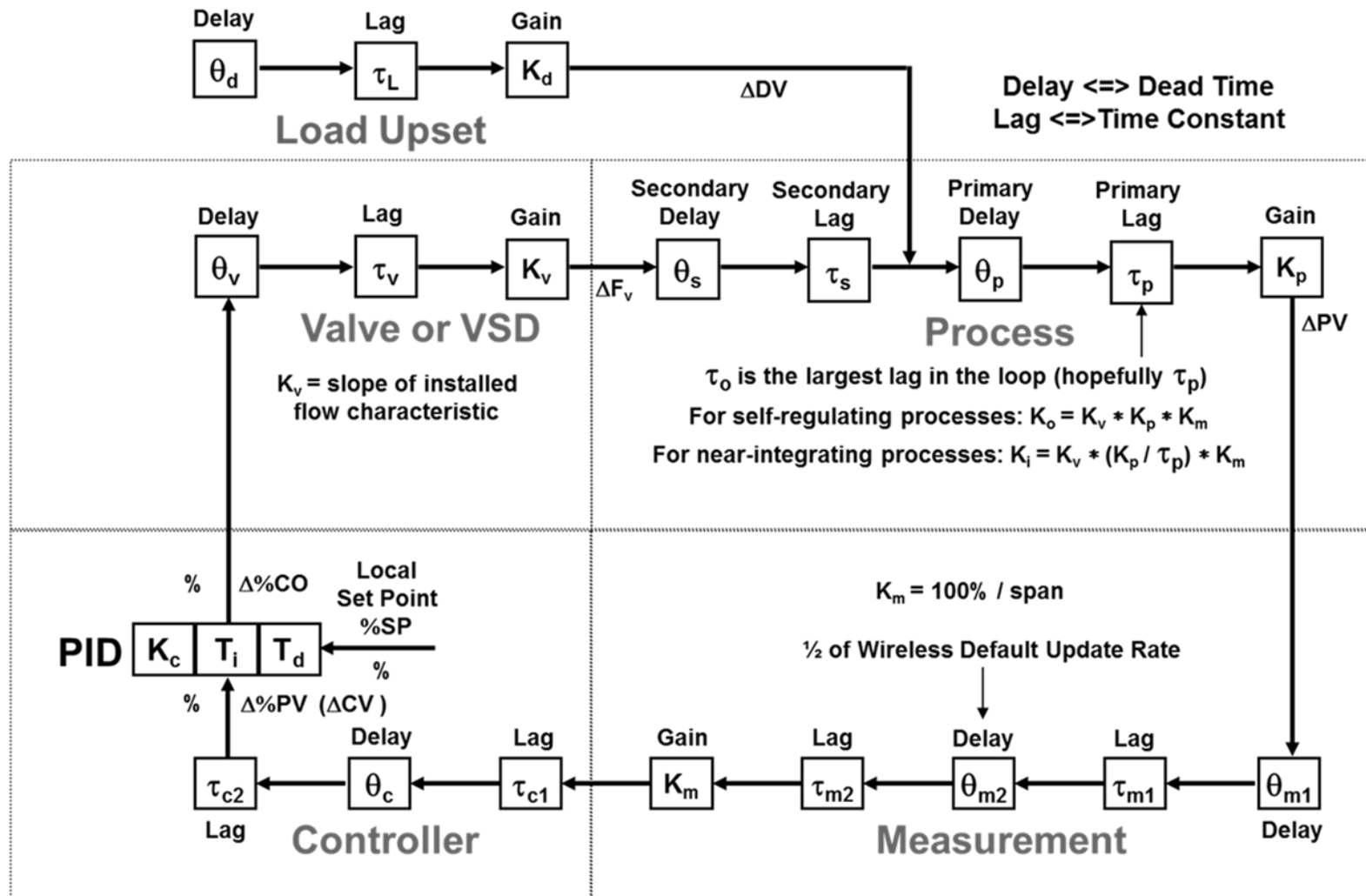
Compressor Surge Protection and Efficiency Maximization (Recirculation Valves)



Heat exchanger is needed to prevent excessive heat buildup in recirculation

The basic control strategy shown can be considered to be applicable to each stage of a multistage compressor. If the throughput flow is not equal for each stage (caused by separators and recycle streams), then compression ratio dividing is used.

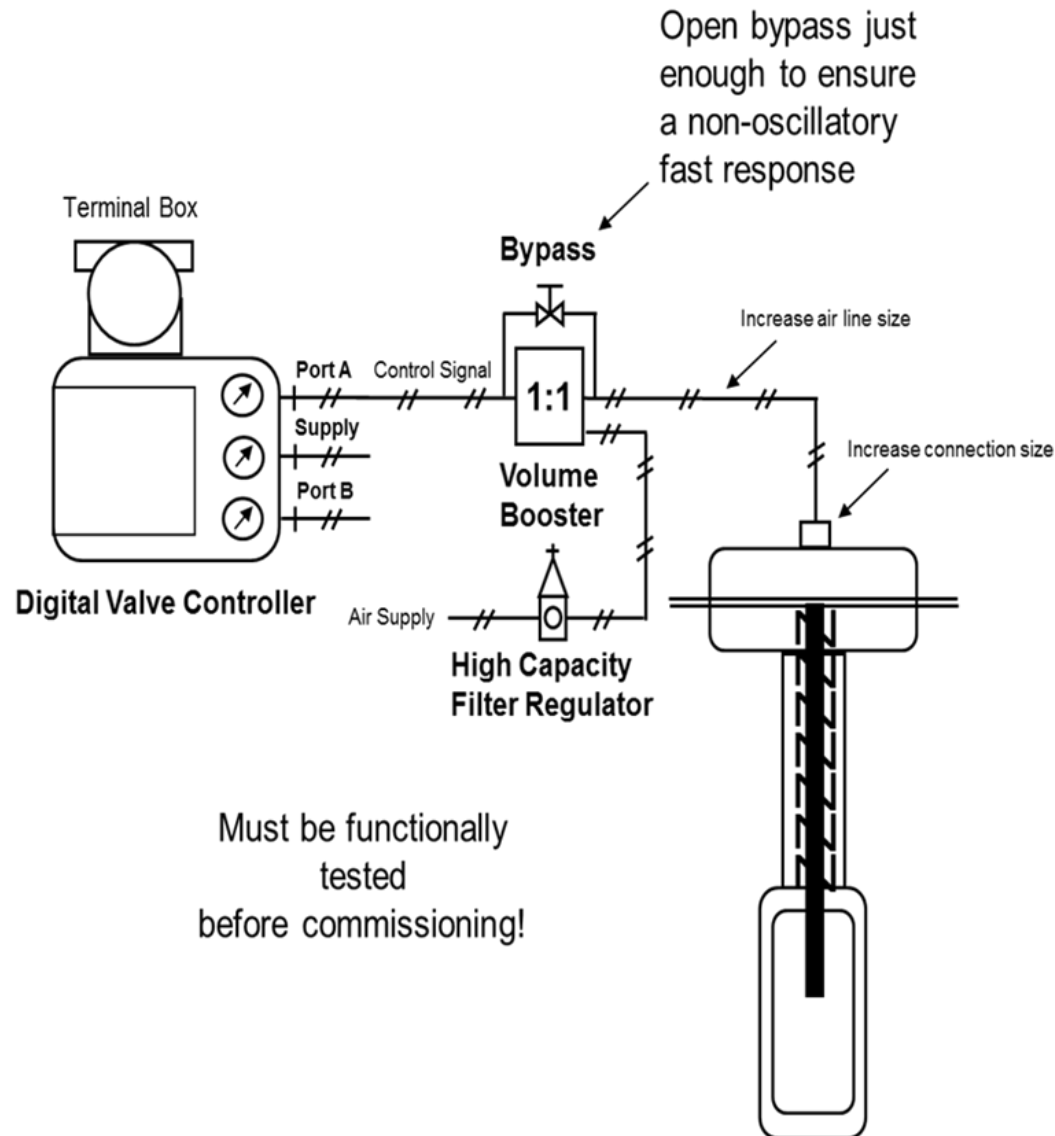
Sources of Automation System Dynamics



First Order Approximation: $\theta_o \cong \theta_v + \theta_s + \theta_p + \theta_{m1} + \theta_{m2} + \theta_c + Y * \tau_v + Y * \tau_s + Y * \tau_{m1} + Y * \tau_{m2} + Y * \tau_{c1} + Y * \tau_{c2}$

Fraction Y of each small lag that is equivalent deadtime is a logarithmic function of the ratio of the small to largest lag ($Y = 0.28, 0.88$ for ratios = 1.0 and 0.01, respectively)

How to Make Valve Response Faster



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

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

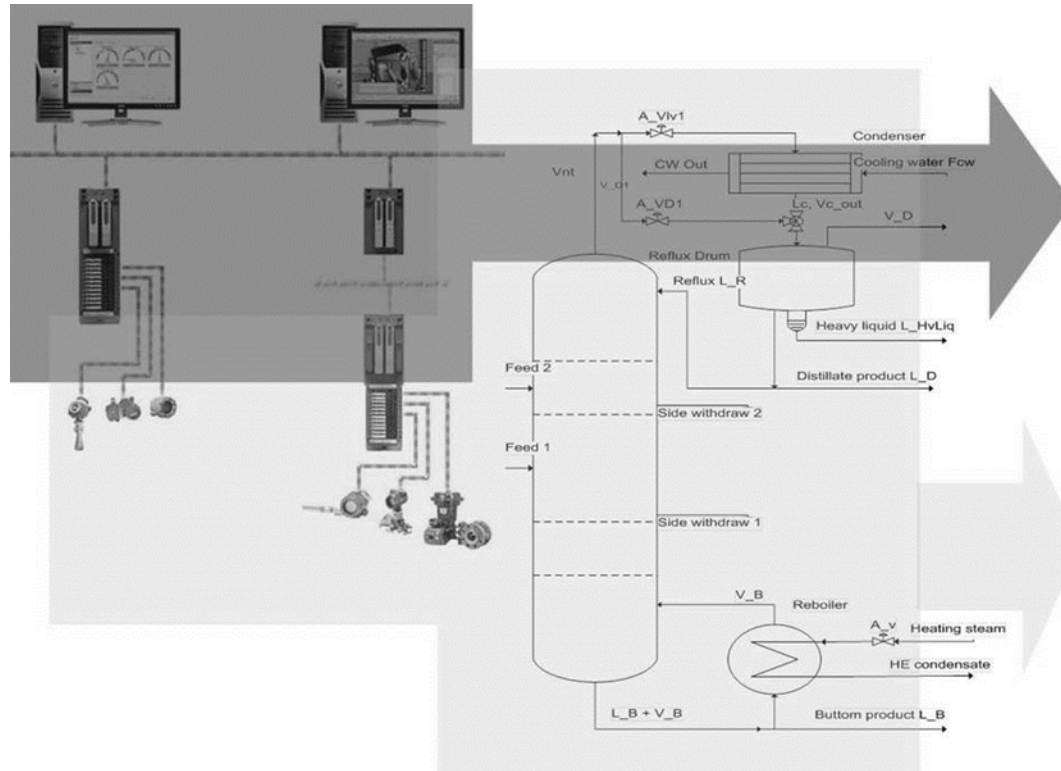
The air supply line from the air
header to booster air set must
be short and large and dedicated
to booster. This air supply should
not be shared with positioner and
other users of air to ensure no dip
and restriction in booster air flow.

Must be functionally
tested
before commissioning!

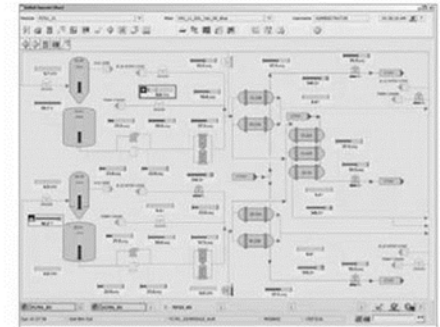
Valve Alerts

- Common mistakes
 - Minimizing leakage
 - Maximizing capacity
 - 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 $> 1\%$ and $< 10\%$
 - On-off valves posing as throttle valves
 - Huge error between actuator shaft feedback and internal ball or disk position
 - Smart positioner gives dumb diagnostics
 - Booster used instead of positioner
 - Integral action in positioner turned on

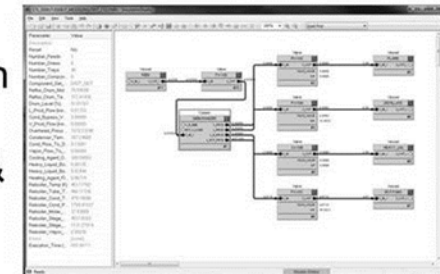
Digital Twin Use and Improvements



Digital Twin control system, displays, alarms, historian & tools



Dynamic simulation of process, final control elements, & measurements



Digital Twin offers improvements in:

- exploring** \Leftrightarrow **discovering** \Leftrightarrow **prototyping** \Leftrightarrow **testing** \Leftrightarrow **justifying**
- \Leftrightarrow **deploying** \Leftrightarrow **testing** \Leftrightarrow **training** \Leftrightarrow **commissioning** \Leftrightarrow
- maintaining** \Leftrightarrow **troubleshooting** \Leftrightarrow **auditing** \Rightarrow **operator, system and process performance**

showing the “before” and “after” benefits of solutions from online metrics

Digital Twin Plant Knowledge Opportunities

- Cause and effect relationships
- Interactions and resonance
- Process safety stewardship
- Startups, transitions and abnormal operation (Procedure Automation)
- Process response
- Equipment response
- Measurement response
- PID strategies, features, options and response
- Control valve response
- Equipment, valve and sensor degradation

Digital Twin Key New Blocks

Compute dynamic compressor response including hidden flow characteristic during surge

Compressor w/ Surge

SRGCOMP1	
<input type="checkbox"/> COMPRESSOR_SPEED	<input type="checkbox"/> C_PRESSURE_RISE
<input type="checkbox"/> DS_VLV_PRESSURE	<input type="checkbox"/> P_PRESSURE_RISE
<input type="checkbox"/> S_VLV_PCT_OPEN	<input type="checkbox"/> C_MASS_FLOW
<input type="checkbox"/> T_VLV_PCT_OPEN	<input type="checkbox"/> T_MASS_FLOW
<input type="checkbox"/> DS_HDR_PRESSURE	<input type="checkbox"/> S_MASS_FLOW
<input type="checkbox"/> US_HDR_PRESSURE	<input type="checkbox"/> T_PRESSURE_DROP
<input type="checkbox"/> SUCT_DENSITY	<input type="checkbox"/> COMPRESSOR_ACFM
<input type="checkbox"/> SUCT_SONIC_VELO	
<input type="checkbox"/> T_VLV_K	
<input type="checkbox"/> S_VLV_K	

#1

Compute future value to predict surge, capture surge curve points, and identify changes in compressor characteristic curves

Future Value

FV1	
<input type="checkbox"/> PV	<input type="checkbox"/> FUTURE_VALUE_1
<input type="checkbox"/> PV_FILTER_TIME	<input type="checkbox"/> FUTURE_VALUE_2
<input type="checkbox"/> PREDICT_TIME_1	<input type="checkbox"/> RATE_OF_CHANGE
<input type="checkbox"/> PREDICT_TIME_2	<input type="checkbox"/> PEAK_RATE_VALUE
<input type="checkbox"/> RATE_THRESHOLD	<input type="checkbox"/> PEAK_RATE_TIME
<input type="checkbox"/> RATE_DIRECTION	
<input type="checkbox"/> INITIALIZATION	

#1

Compute backlash (deadband) and stiction (resolution) response

Backlash Stiction

BLSTICT1	
<input type="checkbox"/> SIGNAL	<input type="checkbox"/> STROKE
<input type="checkbox"/> SOLENOID_VALVE	
<input type="checkbox"/> ON_OFF_DISCRETE	
<input type="checkbox"/> FOLLOW	

#1

Some Details on Control System Implementation



- A deadtime block can be used to detect an operating point approaching the flat part of the curve where flow is changing but pressure is not. The changes are obtained by subtracting the block input from block output. The deadtime is chosen to provide a good signal to noise ratio but is generally not more than two executions of the controller. A significant drop in flow at the start of the controller execution should be used to signal surge has occurred triggering the open loop backup. The detection of changes in flow and pressure and required changes in valve position must be computed in less than 0.2 seconds.
- The open loop backup must hold the surge valves open for at least 10 seconds with a bumpless transfer back to feedback surge control if compressor flow is stabilized.
- The surge control valves must respond to 86% of opening demanded in less than 1 second. For pressure control, the requirements are almost as fast to help prevent surge and high pressure shutdowns from users tripping. The surge valves must go wide open on air, electrical or signal failure.

More Details on Control System Implementation



- The compressor supplier should provide the surge curve for different operating conditions. The surge curve should be updated online by the detection of approach to flat part of the characteristic curve or detection of a precipitous drop in flow.
- Negative flow may not be measurable by the flow meter and may be prevented by equipment and piping design including check valves.
- The number of surge oscillations and the amplitude of the oscillations should be historized along with the number of excursions to the flat characteristic curve that did not result in surge. This requires fast historian update time of 0.1 seconds.
- The point at which the surge valve starts to open can be determined by when the contribution from the proportional mode exceeds that from the integral mode. If integral contribution does not drop below proportional contribution till reversal of error sign, the surge valve will not open until the suction flow drops below its setpoint. In general, the integral contribution starts out being the output limit minus the proportional contribution (no rate action).

Best Practices - 1

- An accurate surge curve for different operating conditions must be provided by the supplier for each compressor and stage, particularly for changes in suction composition.
- The surge curve should be updated online by detection of an operating point approaching a flat portion of the characteristic curve indicating an approach to surge and a precipitous drop in flow in less than 0.05 seconds indicating an actual surge.
- The number of close approaches to the surge curve and the number of actual surge cycles along with surge oscillation amplitude should be historized.
- Historian must have not compression and have a fast update time (e.g., 0.2 second).
- The surge control valves must fail open with a fast 86% response time for small and large changes in signal (e.g., < 1 second).
- Resolution and deadband should be less than 0.4% near closed position

Best Practices - 2

- The transmitters must have damping set to minimum (e.g., 0.2 second).
- The controller execution rate must not be slower than 0.1 second.
- Signal filters greater than 0.05 seconds must not be used.
- An open loop backup must activate and hold surge valve(s) open for an approach too close to the surge line or upon detection of actual surge until stable operation is assured before bumplessly returning to feedback surge control (e.g., 10 seconds).
- Individual surge lines and surge control must be used to prevent each compressor or stage from going into surge.
- For compressors in series or stages, the total pressure rise required is ratioed into individual pressure control setpoints for the compressors or stages.
- For compressors in parallel, the total flow required is ratioed into individual flow control setpoints for the compressors

Resources

- “Compressor surge control: Deeper understanding, simulation can eliminate instabilities”, *Control*, Oct 2018
<https://www.controlglobal.com/articles/2018/compressor-surge-control-deeper-understanding-simulation-can-eliminate-instabilities/?stage=Live>
- “Virtual plant virtuosity”, *Control*, April 2017
<https://www.controlglobal.com/articles/2017/virtual-plant-virtuosity/?stage=Live>
- “How to specify valves and positioners that don’t compromise control”, *Control*, May 2016
<https://www.controlglobal.com/articles/2016/how-to-specify-valves-and-positioners-that-dont-compromise-control/?stage=Live>
- ***Centrifugal and Axial Compressor Control***, Momentum Press, 2010
<http://www.momentumpress.net/books/centrifugal-and-axial-compressor-control>
- ***Process/Industrial Instruments and Controls Handbook Sixth Edition***, McGraw-Hill, 2019 <https://www.mhprofessional.com/9781260117974-usa-process-industrial-instruments-and-controls-handbook-sixth-edition>