R201 Intermediate Pressure Regulation Theory

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Pilot Operated Regulators

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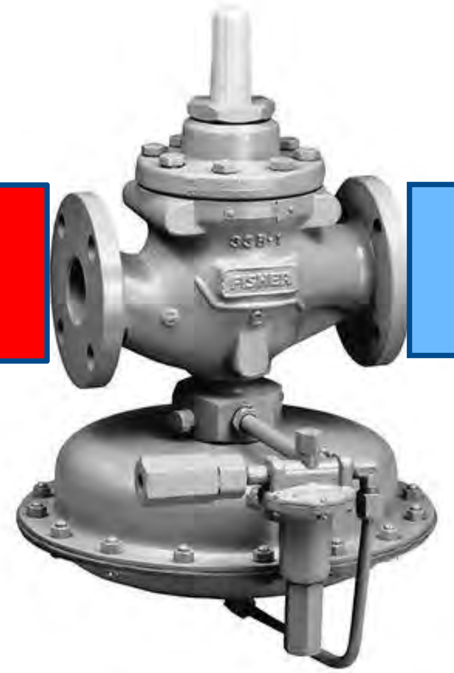
What is a Pressure Reducing Regulator?

- Definition of a Regulator
  - Any **self-contained** valve and actuator combination
- Purpose of a Regulator
  - To match the downstream demand while keeping the downstream pressure constant

Inlet Pressure: 100 psig



Outlet Pressure: 10 psig

Regulators Control Downstream Pressure to a Required Accuracy

Categories of Pressure Reducing Regulators

Self-Operated

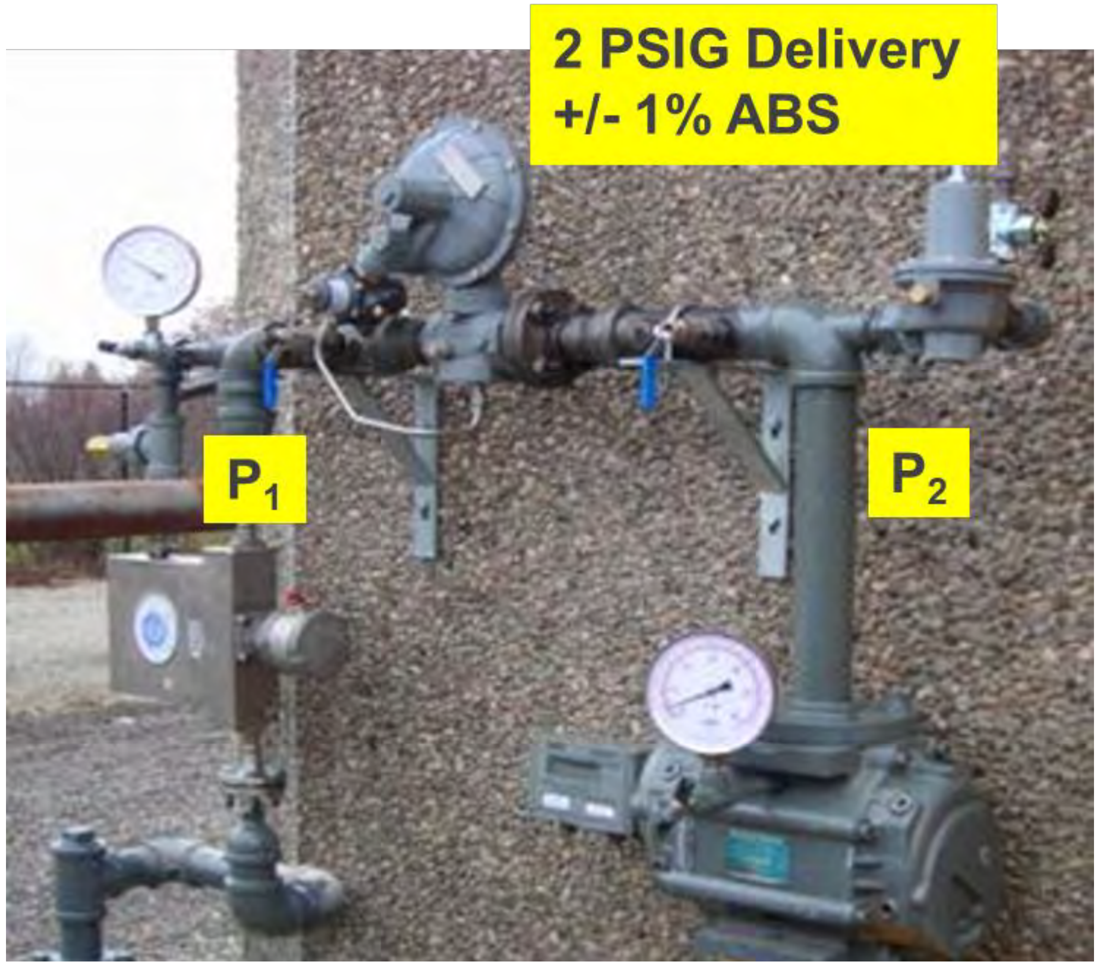
Pressure Loaded

Pilot-Operated

Complexity and Accuracy

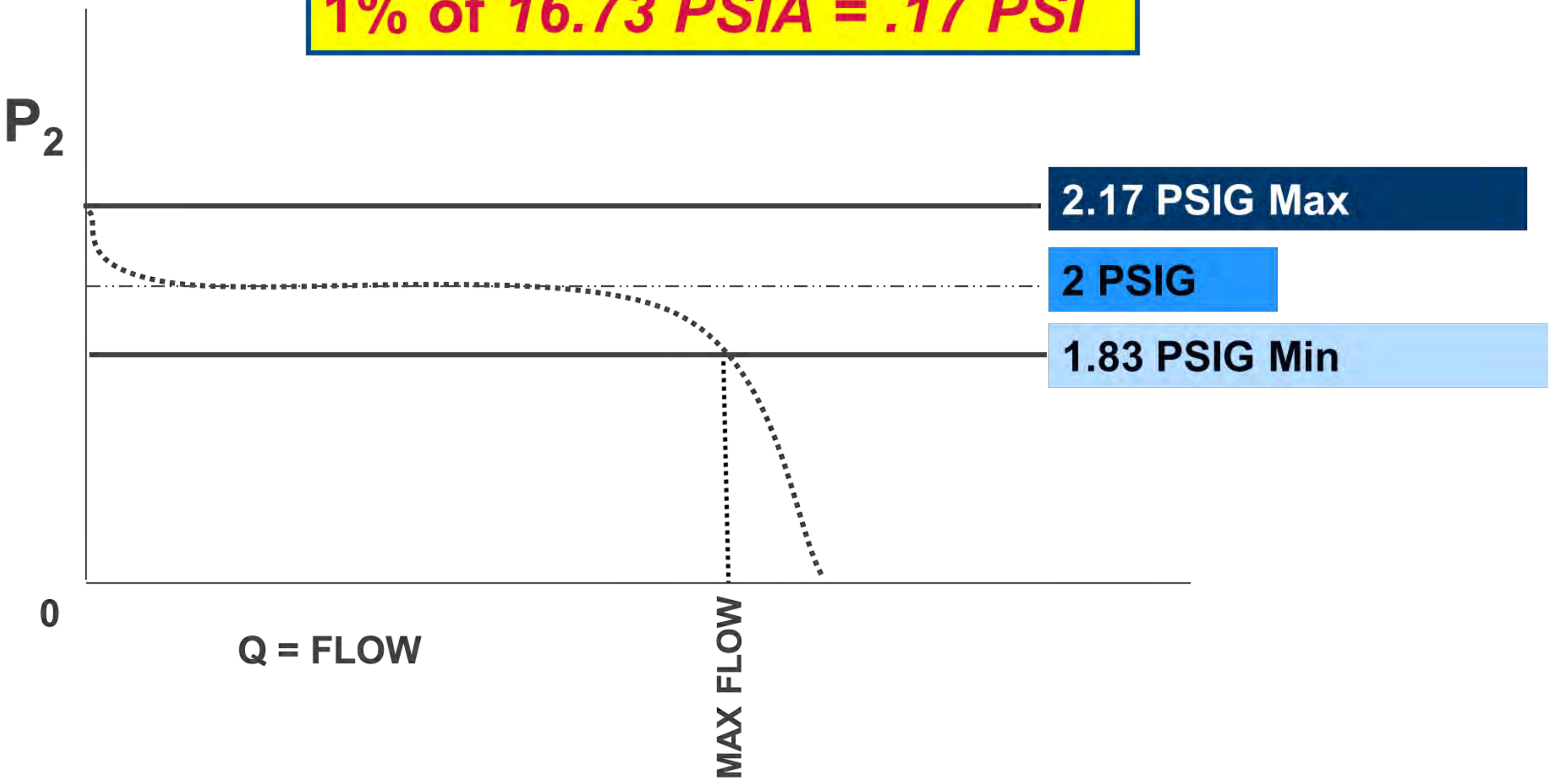
Application Example: Pressure Factor Measurement (PFM Measurement Canada)

Regulator accuracy held to typically +/- 1% ABS P_2 and allows a utility to meter gas without doing pressure correction at the meter.



$P_{2_{ABS}}$ = 2 PSIG + 14.73 (sea level) = ***16.73 PSIA***

1% of *16.73 PSIA = .17 PSI*



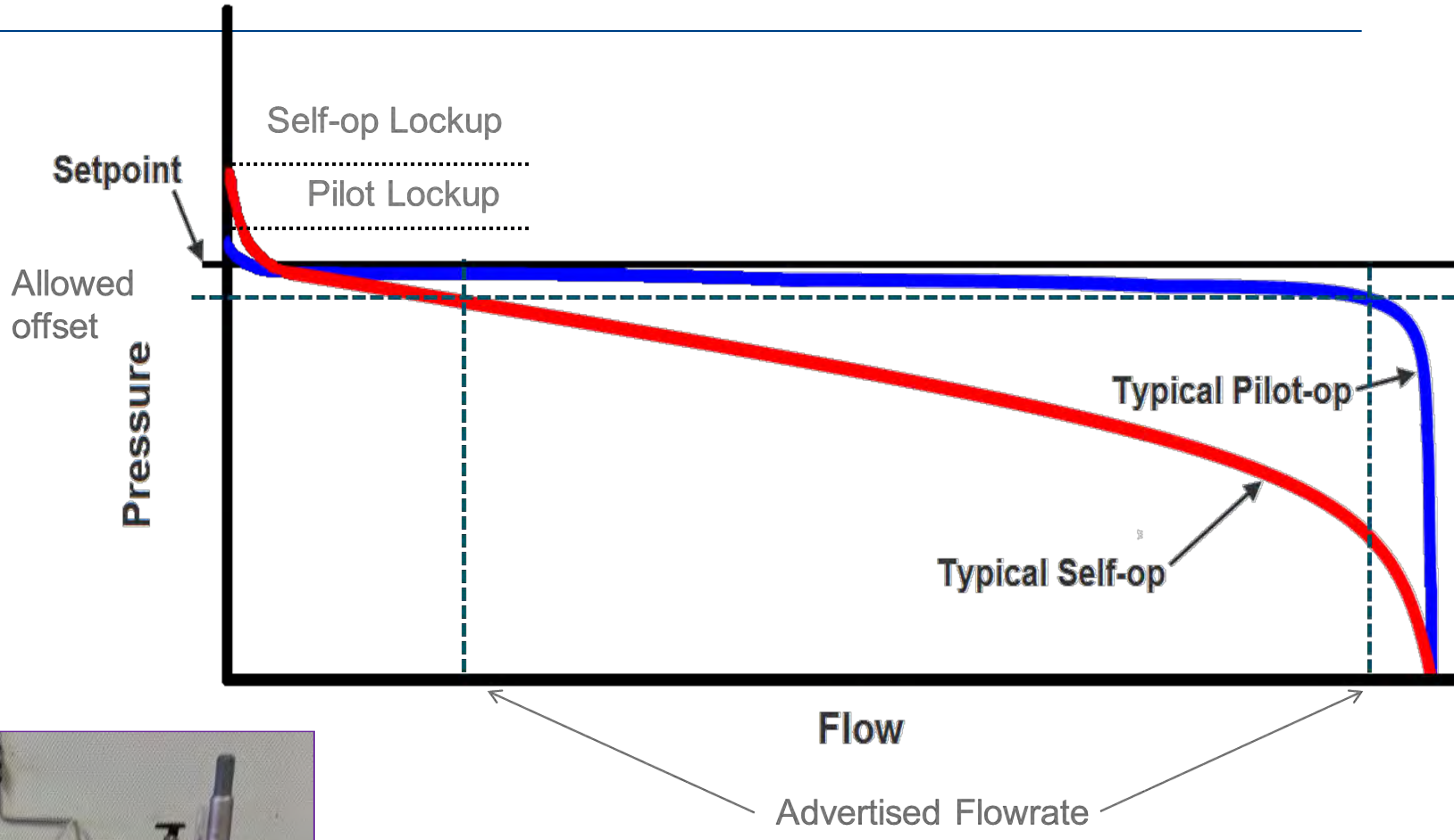
Common to all Three Types of Regulators: Self, Pressure Loaded, and Pilot Operated

Pilot-Operated Regulators

Why Use A Pilot-Operated Regulator?

Pilot Operated Attributes

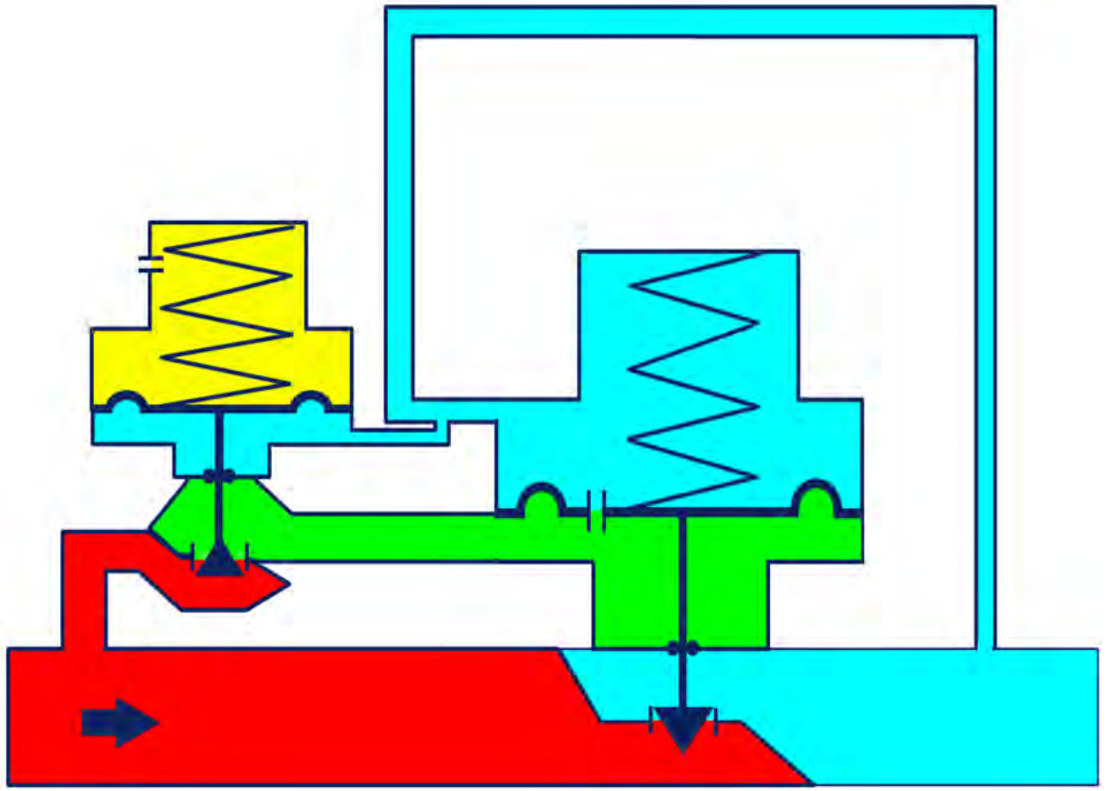
- Higher Accuracy: 0.5 – 2.5%
- Larger capacities
- Improved lockup
- Larger sizes than self operated
- Higher pressures than self operated



Types of Pilot-Operated Regulators

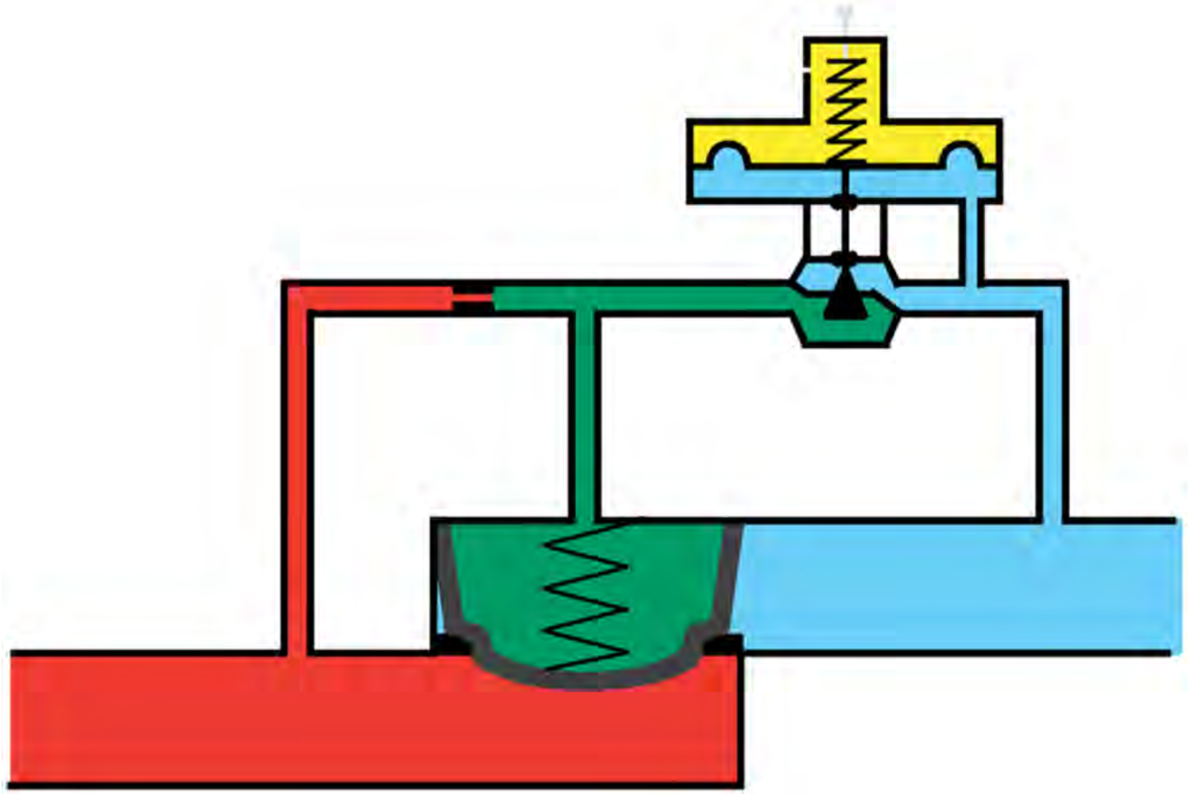
Loading Style/ Two Path

Pilot loads to open regulator

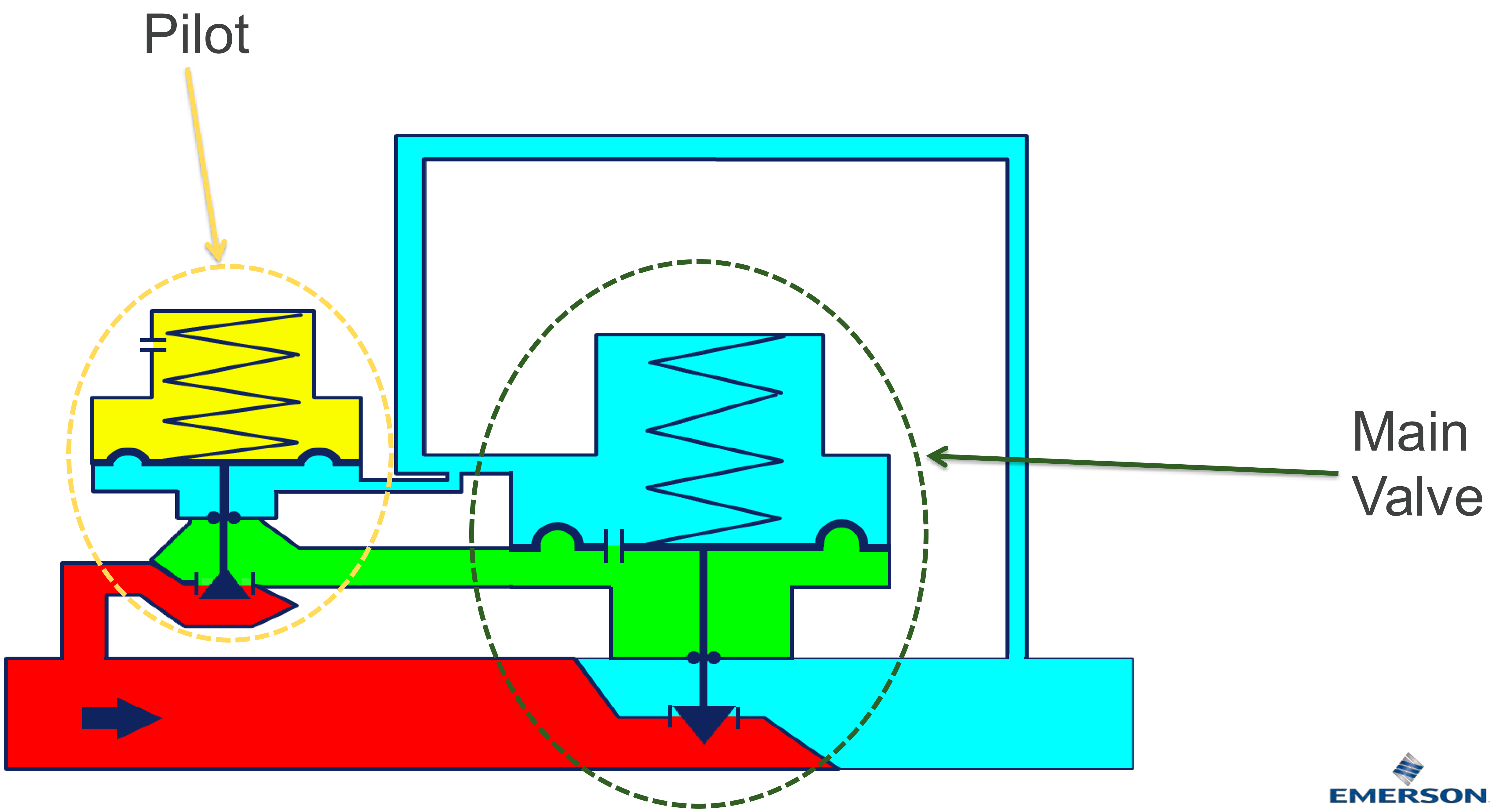


Unloading Style / Flexible Element

Pilot unloads to open regulator



Loading Style Pilot Operated Regulator Components



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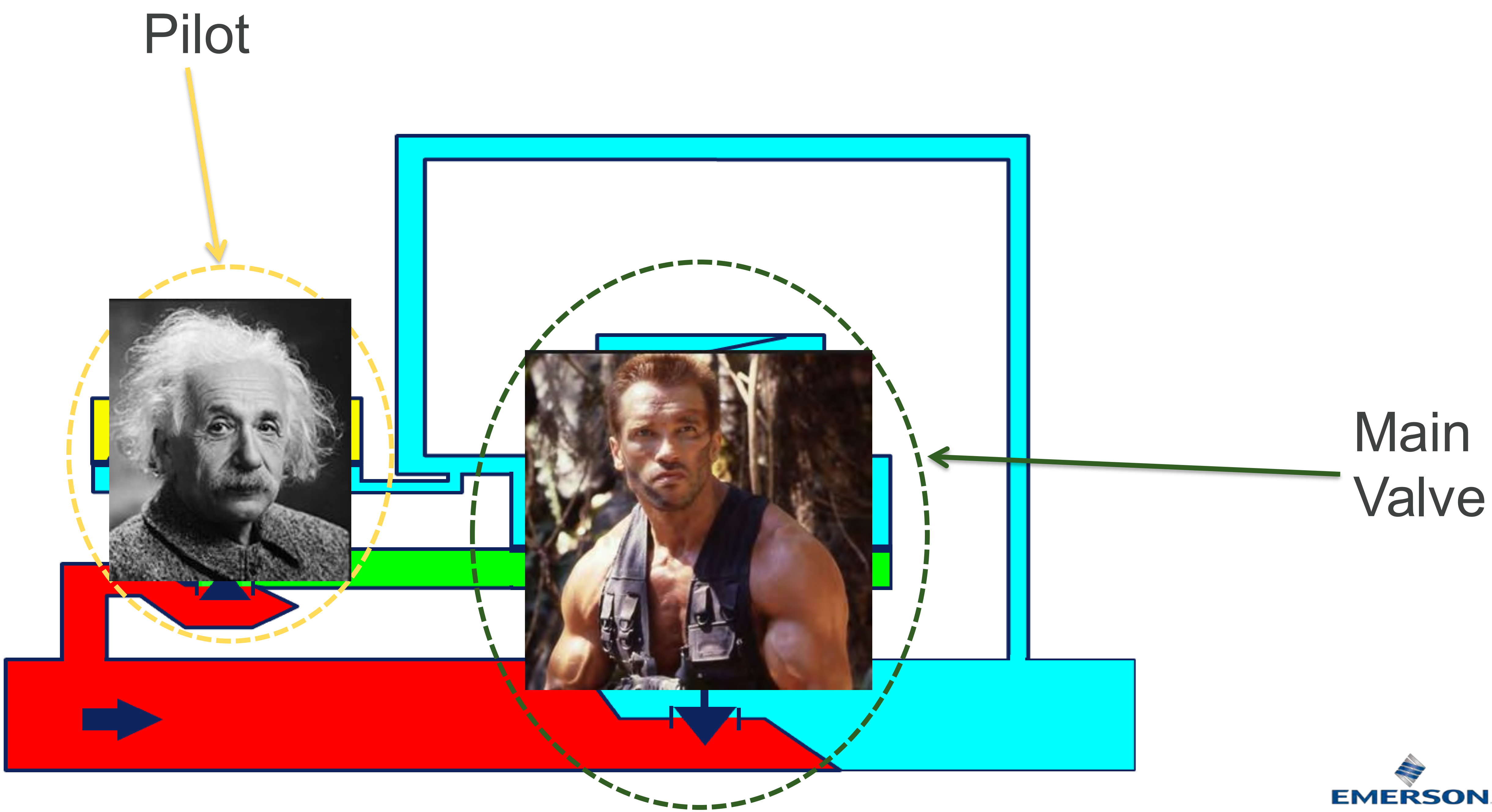
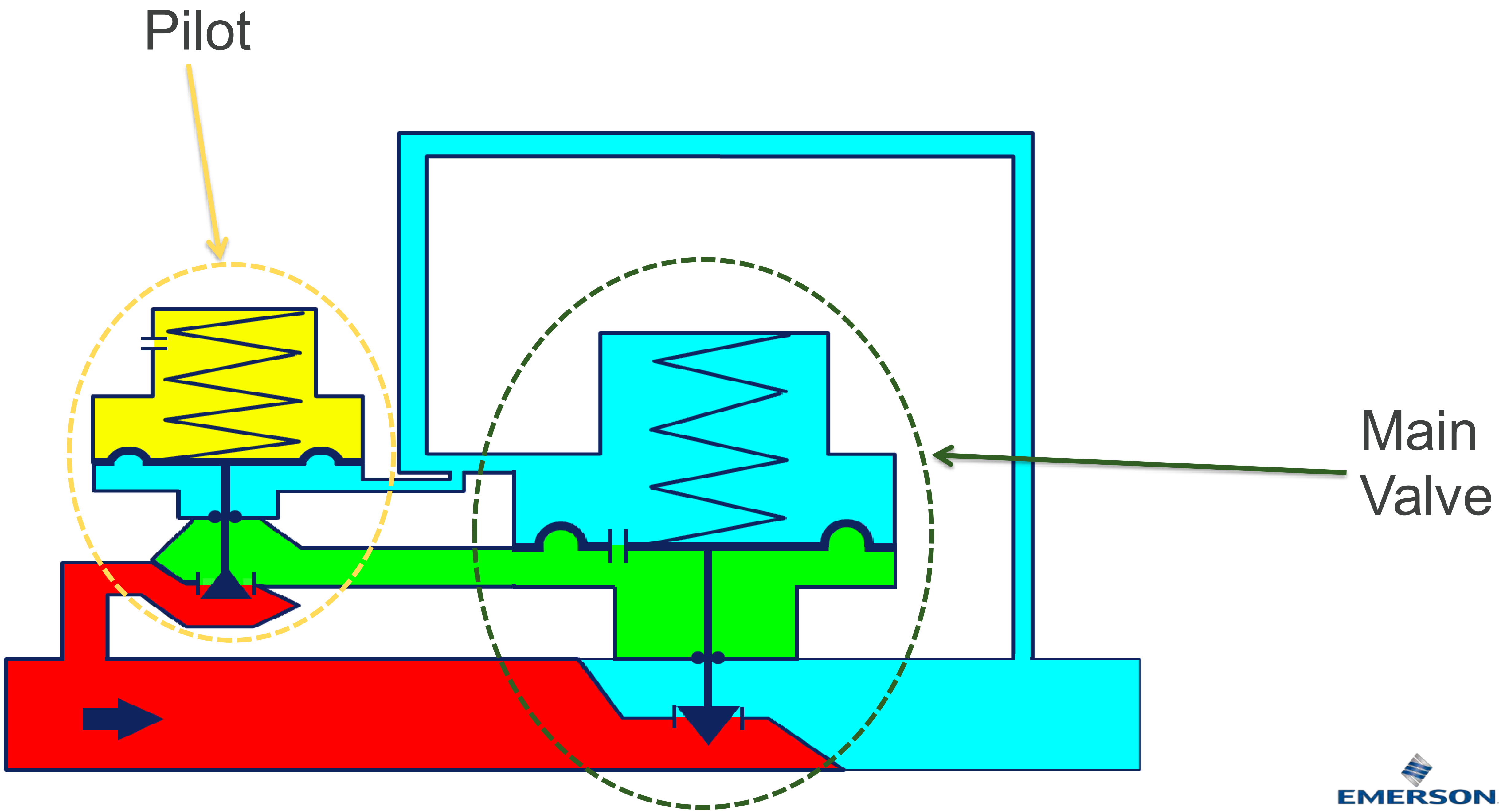
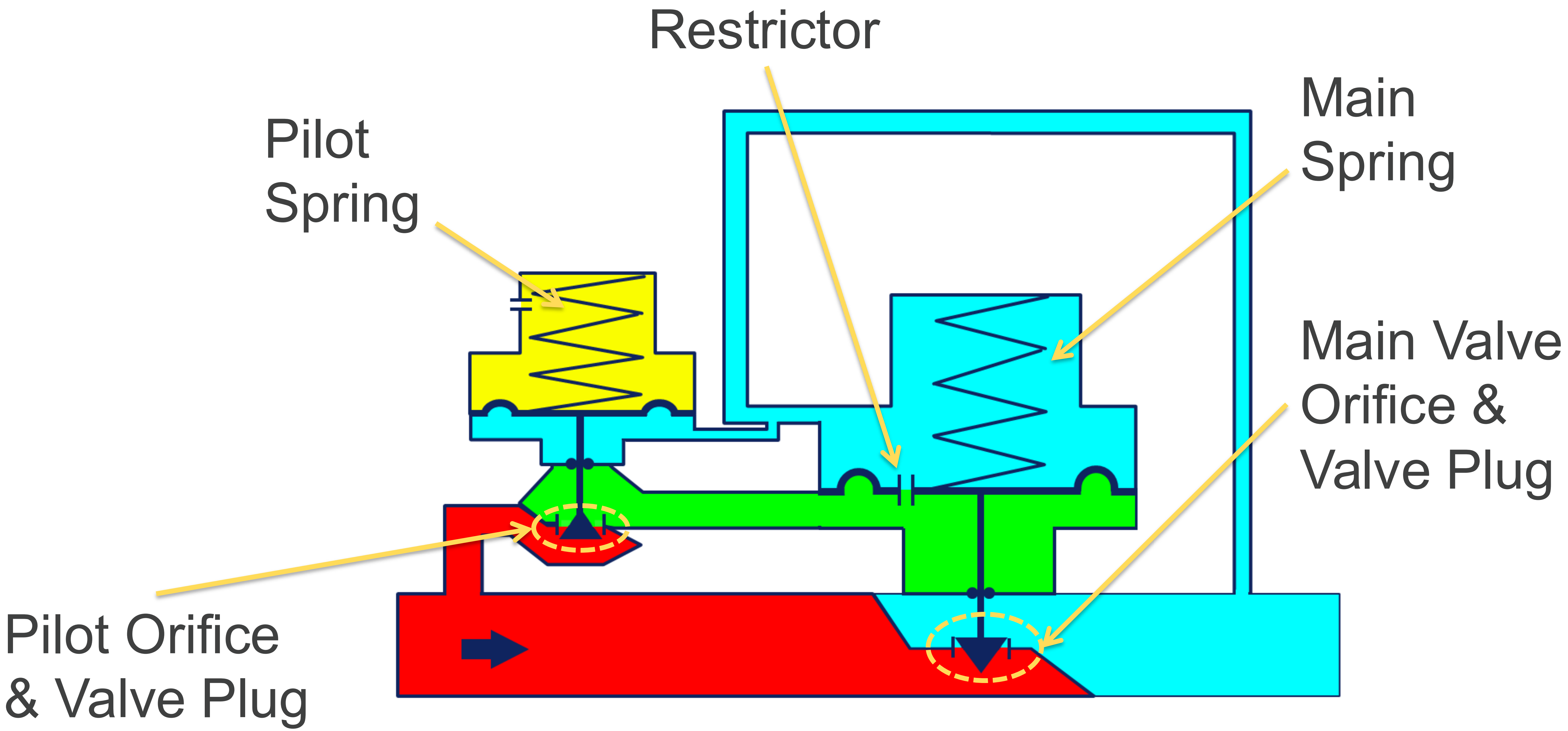
Loading Style Pilot Operated Regulator Components



Loading Style Pilot Operated Regulator Major Components



Internal Components of Loading Style Regulator



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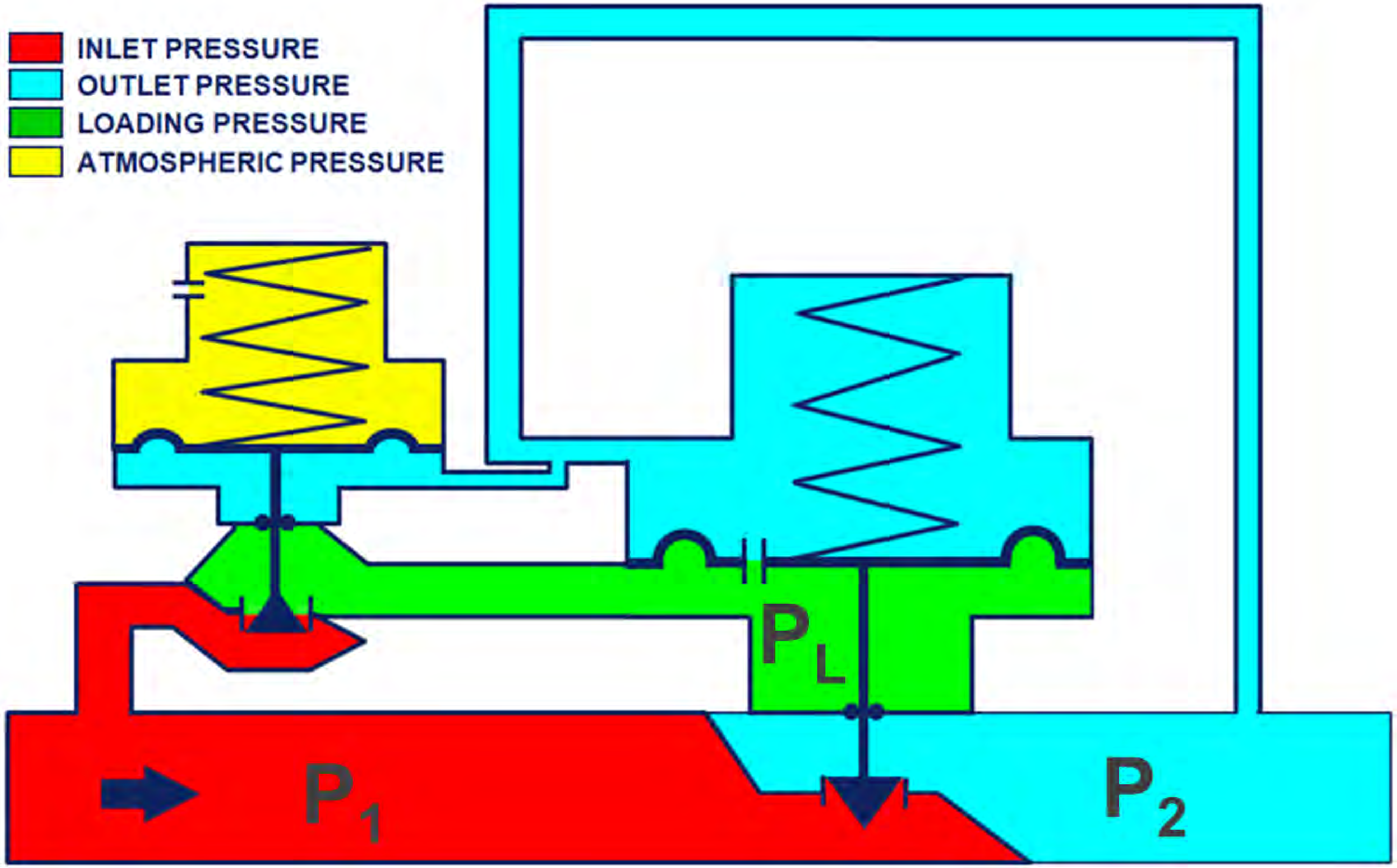
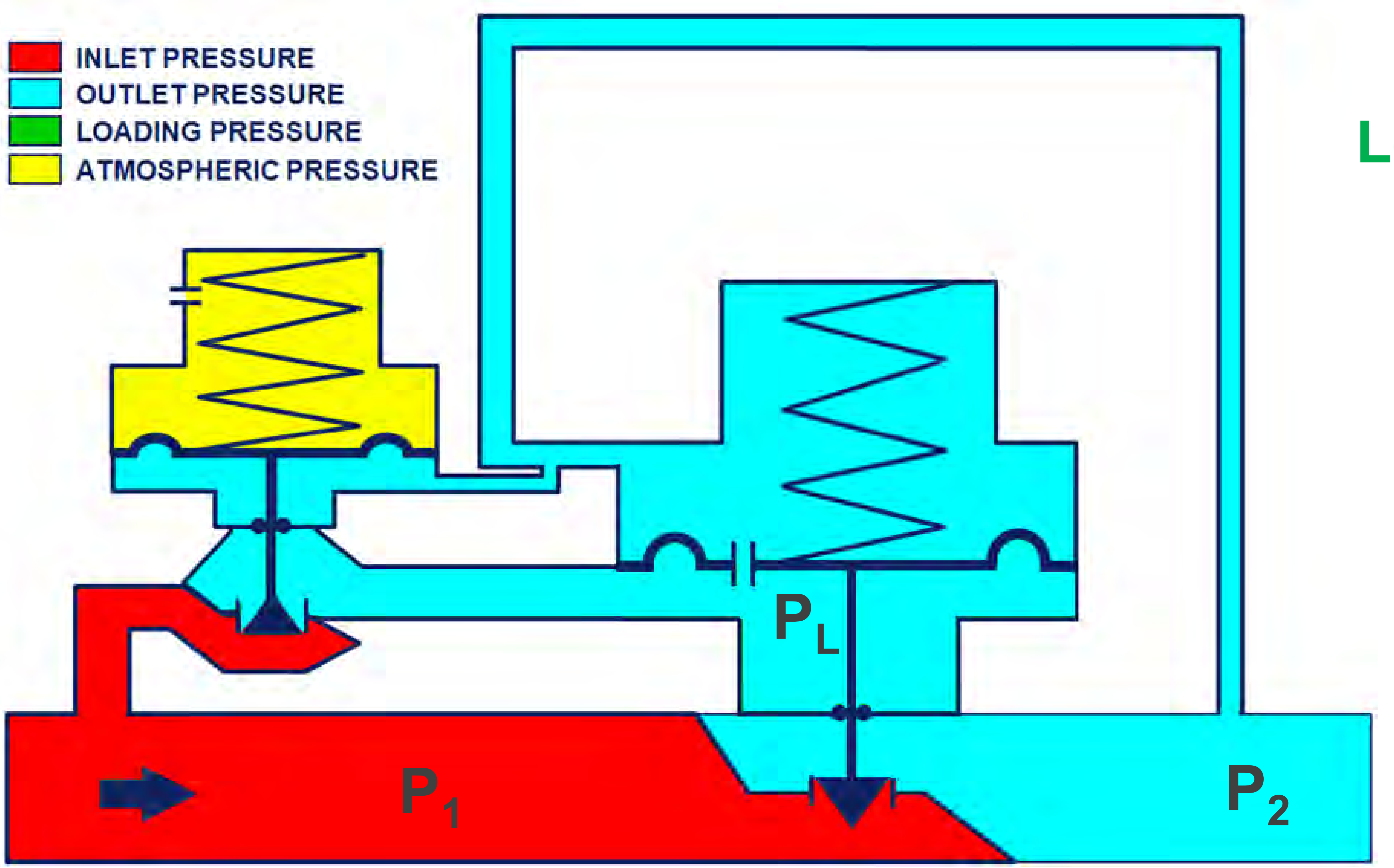
Process Conditions



$P_1 = 100$ psig

$P_{2,set} = 10$ psig

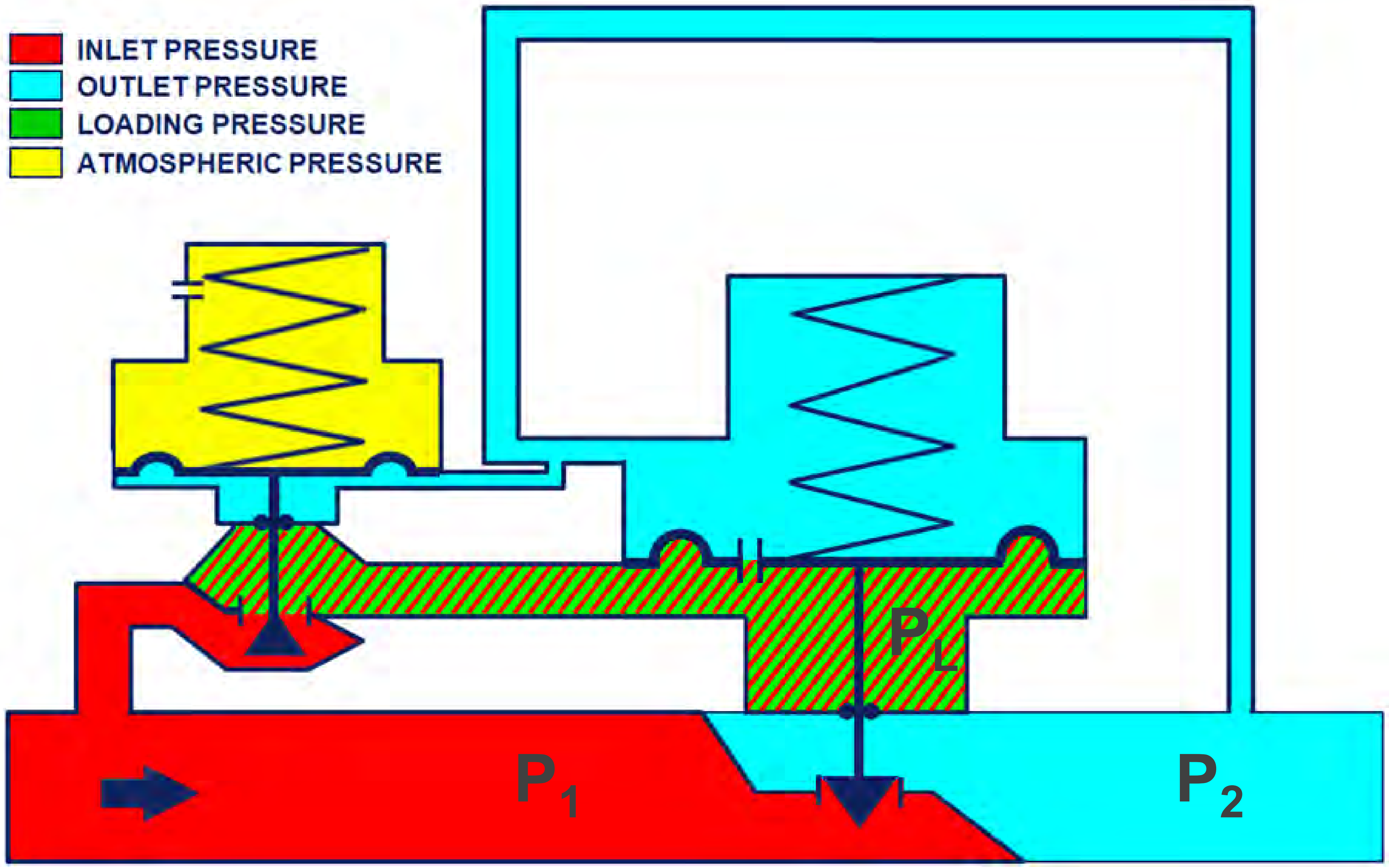
Operating Basics - Pilot Closed



Loading Pressure

$P_L = P_2$

Operating Basics - Pilot Open

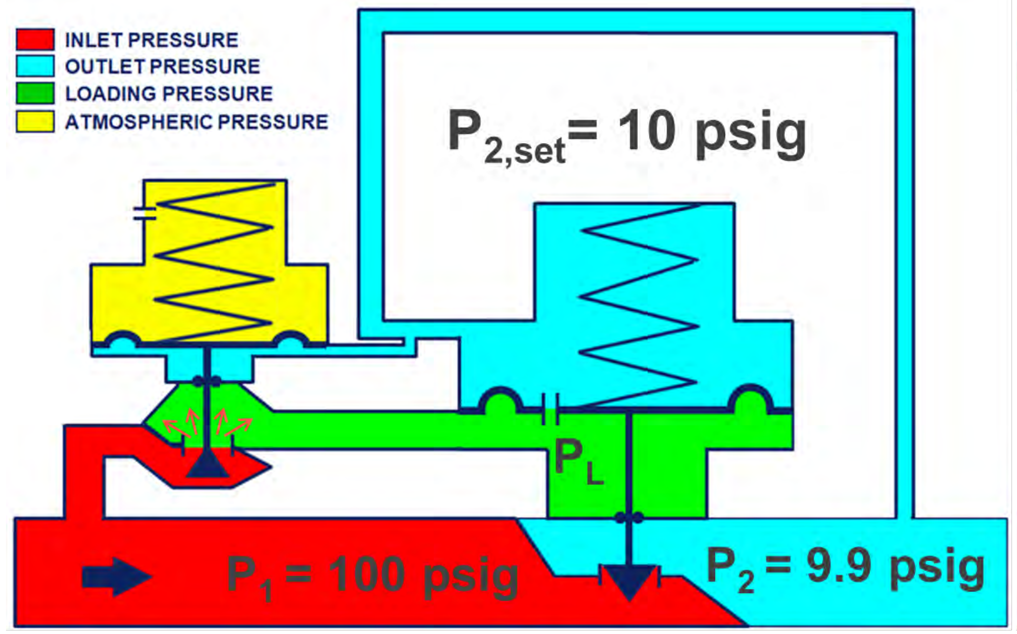


Loading Pressure

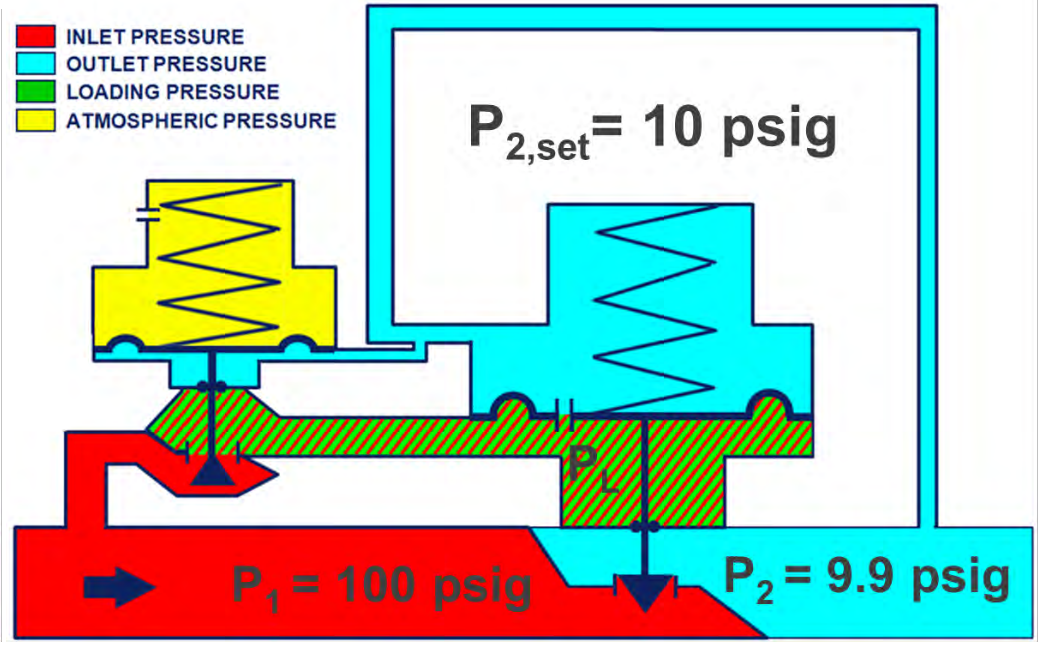
$P_2 < P_L \leq P_1$

Loading Style Operation: Demand Increases

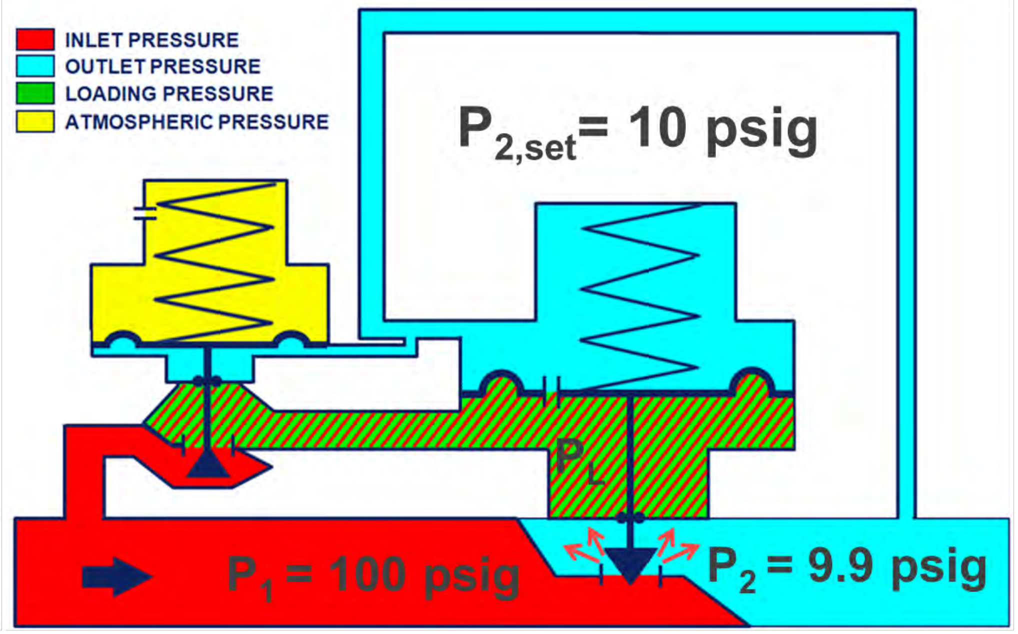
1. Pilot opens



2. P_L increases



3. Main valve opens



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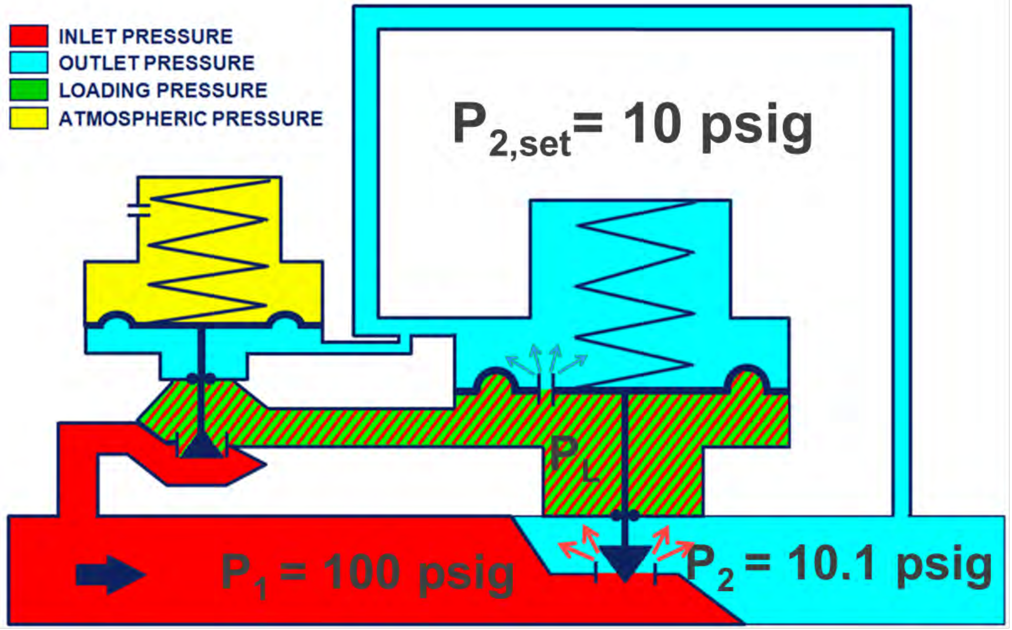
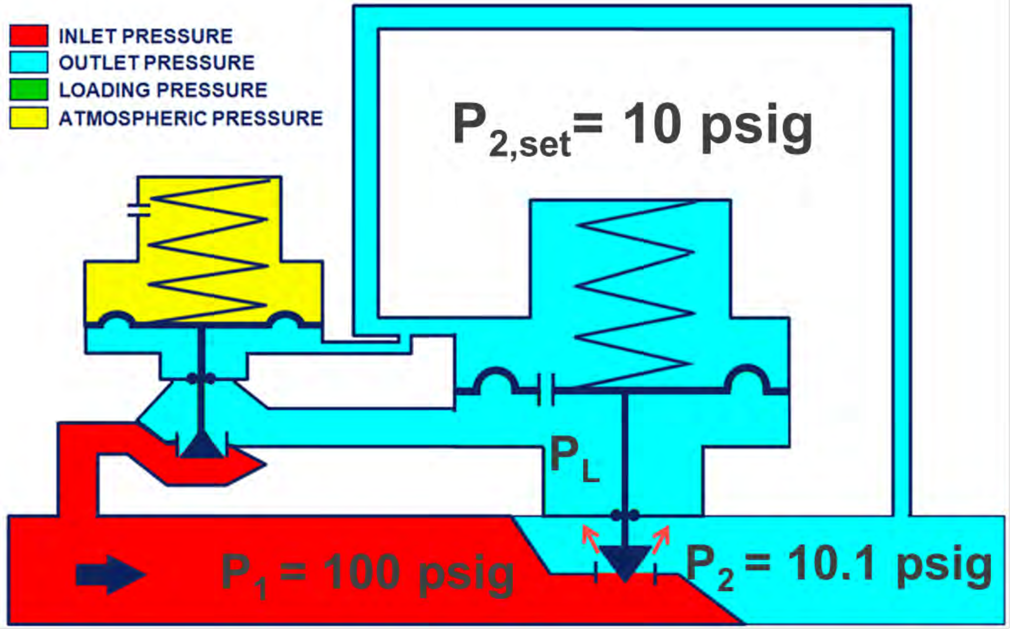
Loading Style Operation: Demand Decreases

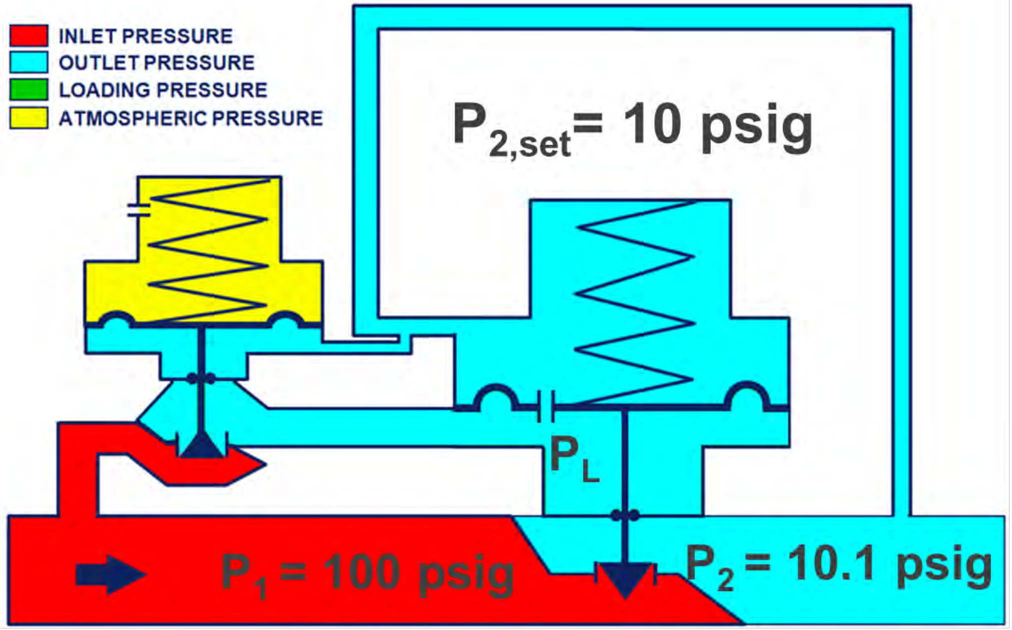
1. Pilot closes



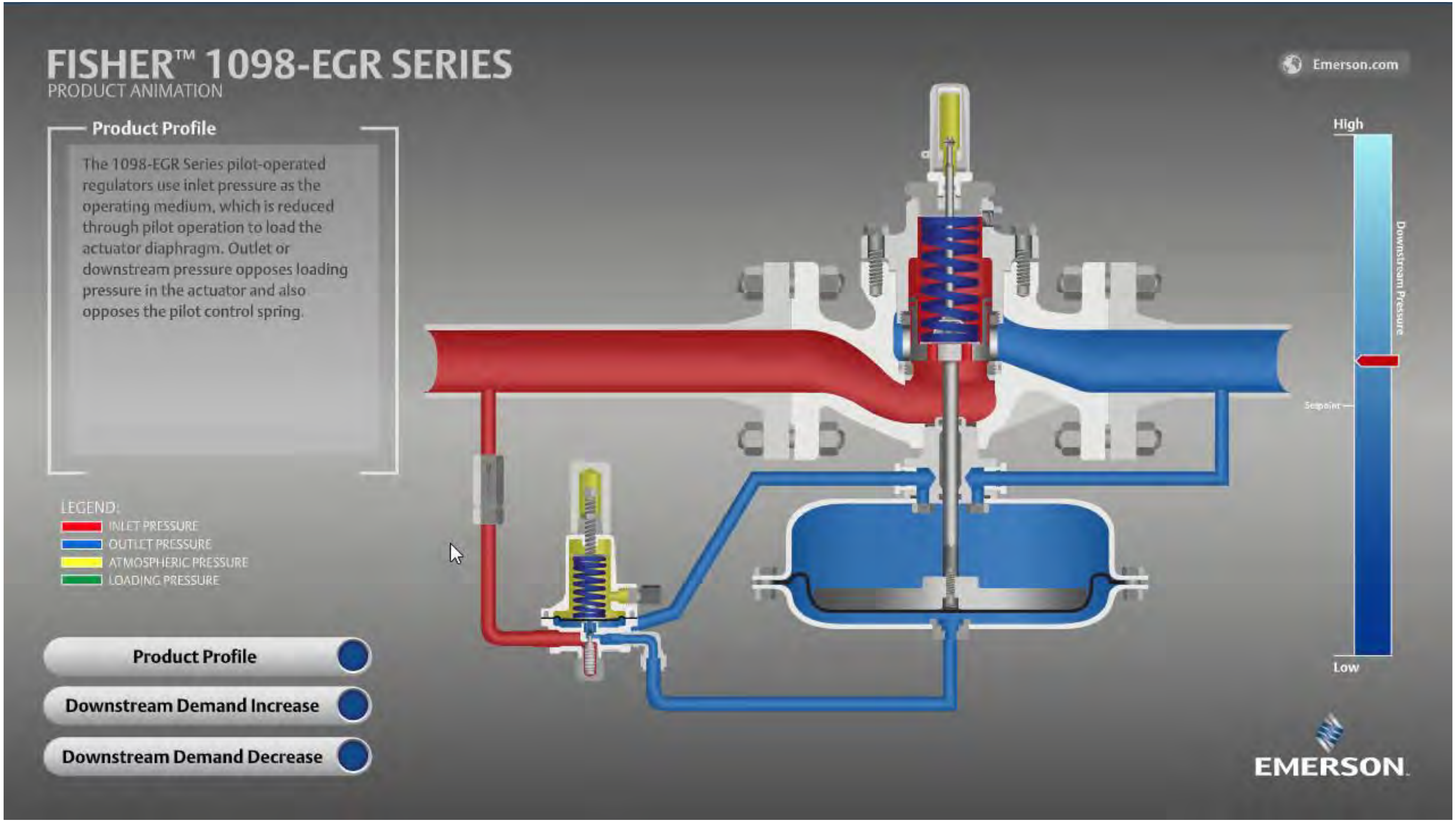
2. P_L decreases



3. Main valve closes



Loading Style Animation



Types of Pilot-Operated Regulators

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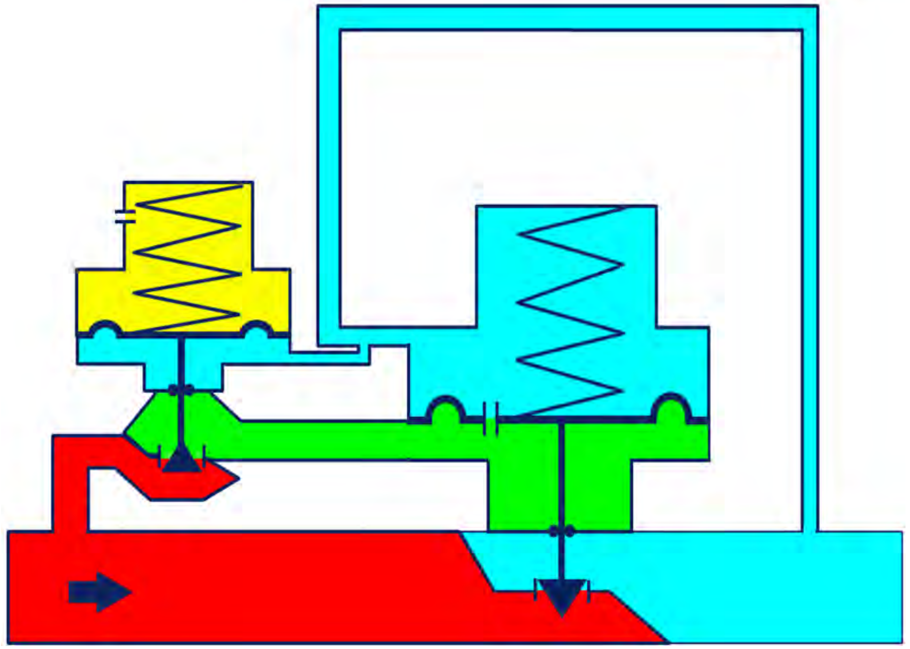
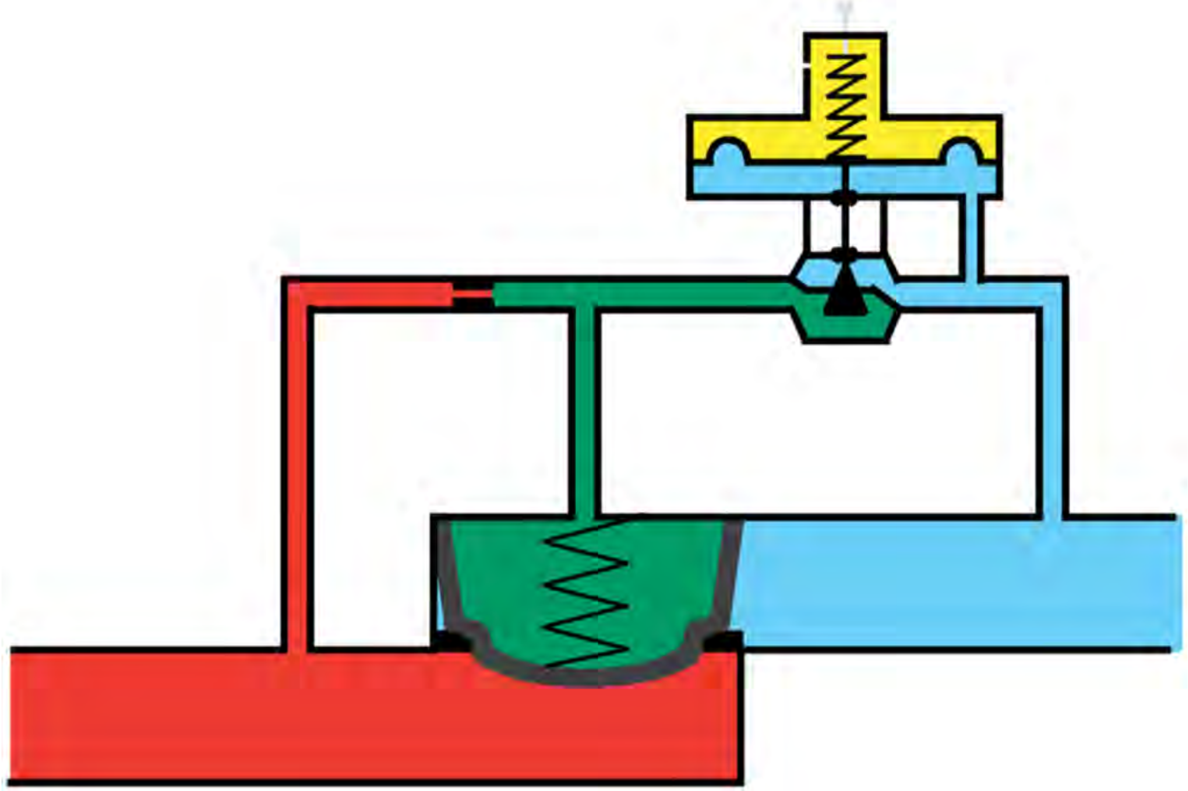
Pilot loads to open regulator

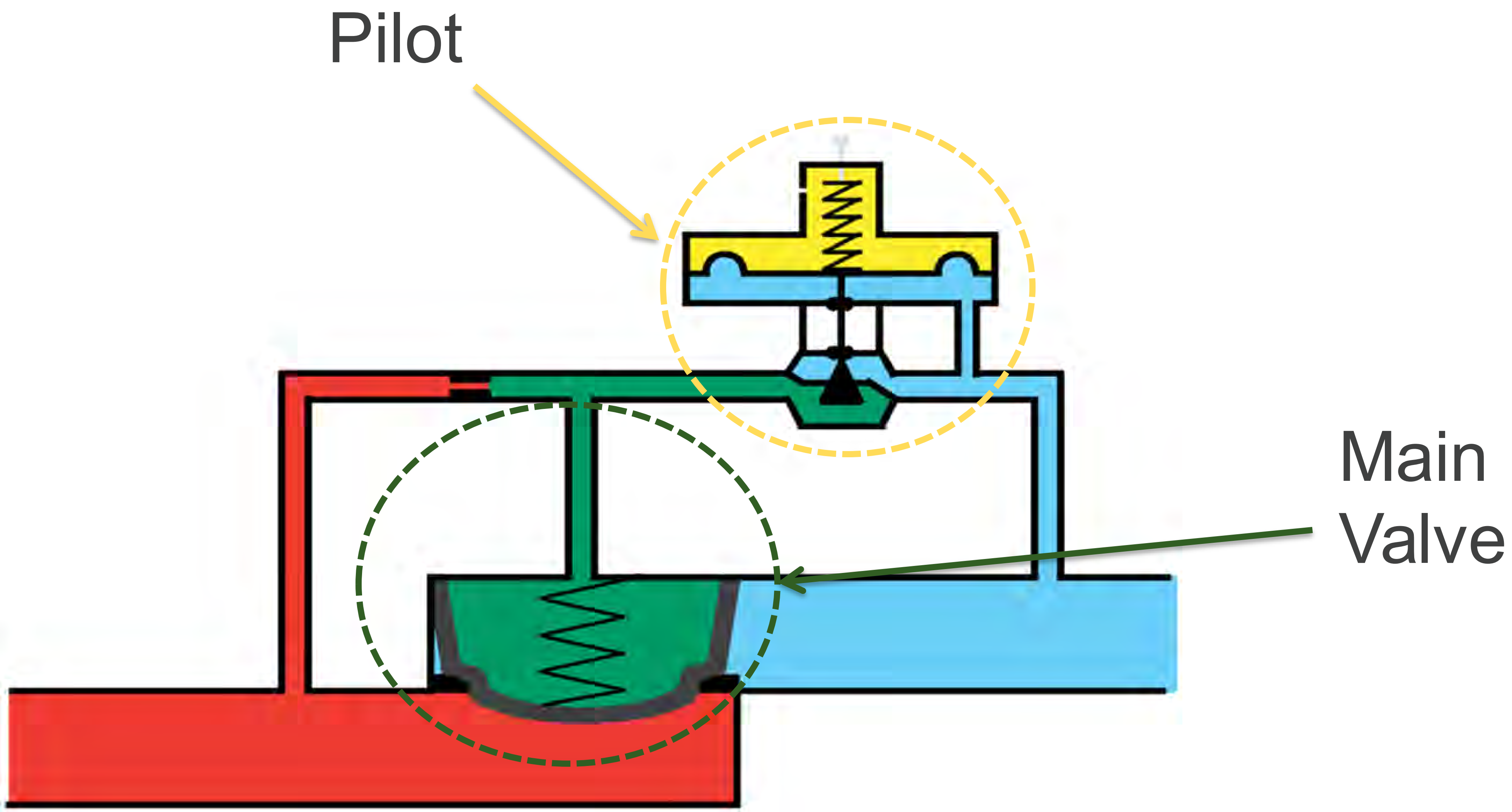


Unloading Style / Flexible Element

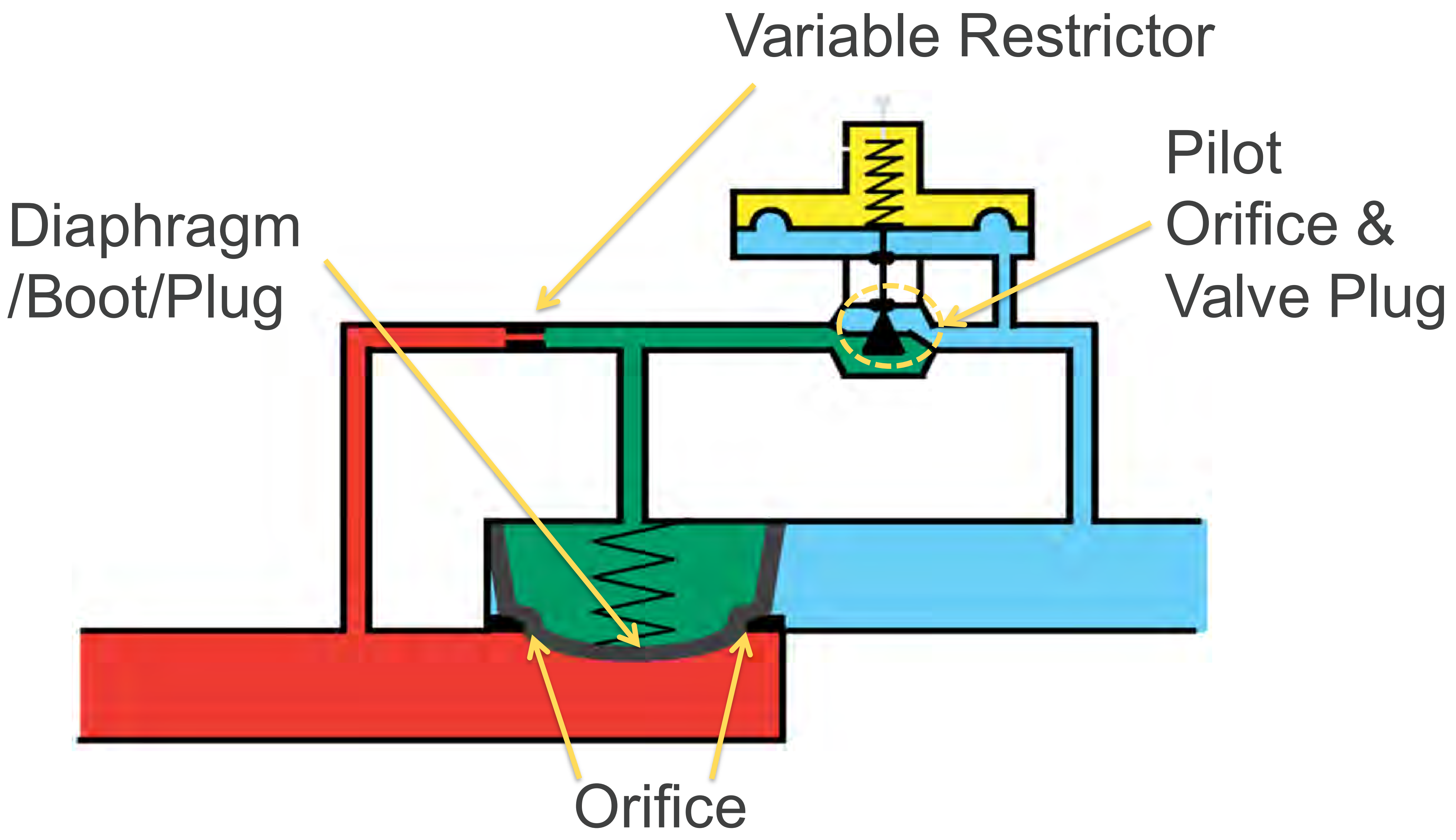
Pilot unloads to open regulator



Unloading Style Pilot Operated Regulator Components

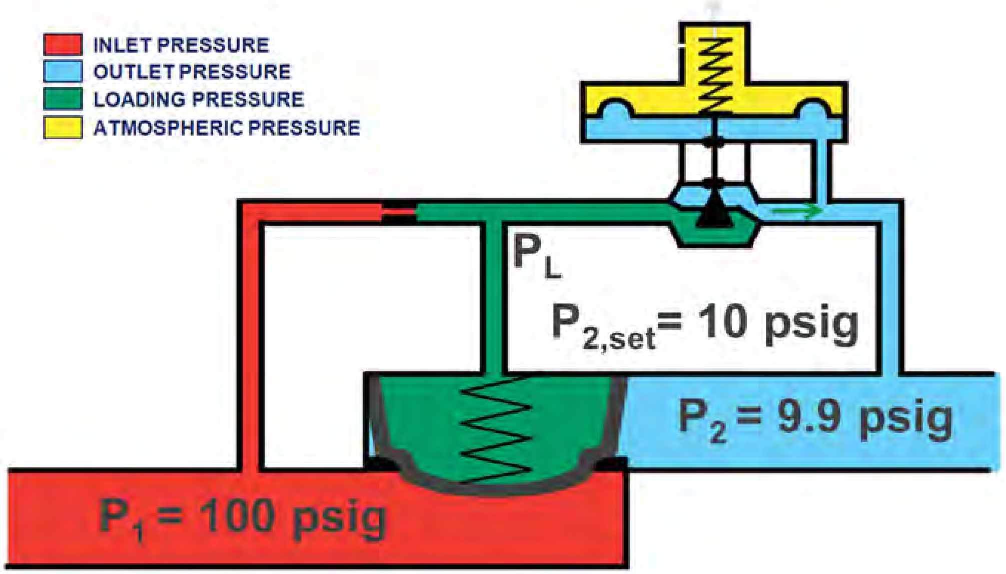


Unloading Style Pilot Operated Regulator Internal Components

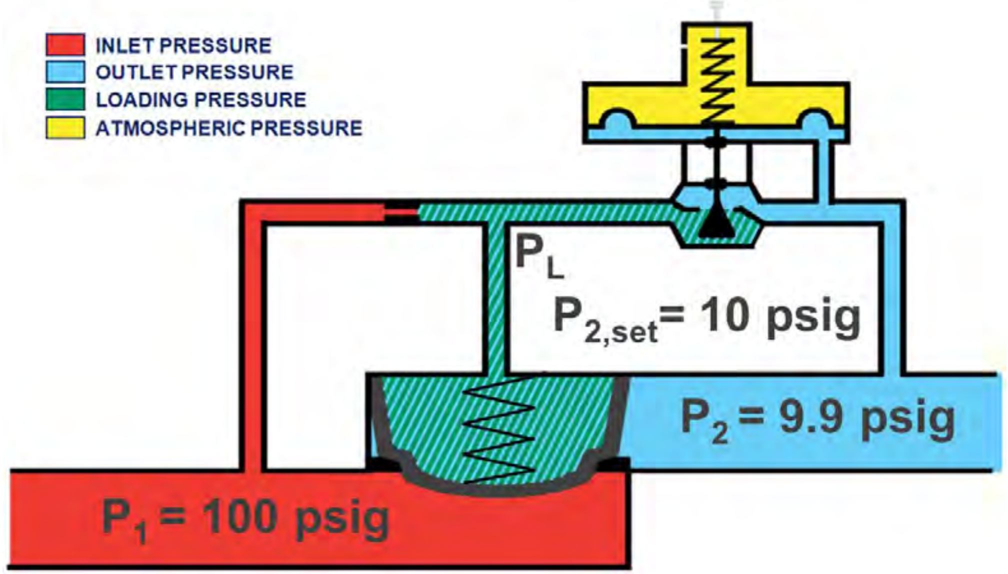


Unloading Style Operation: Demand Increases

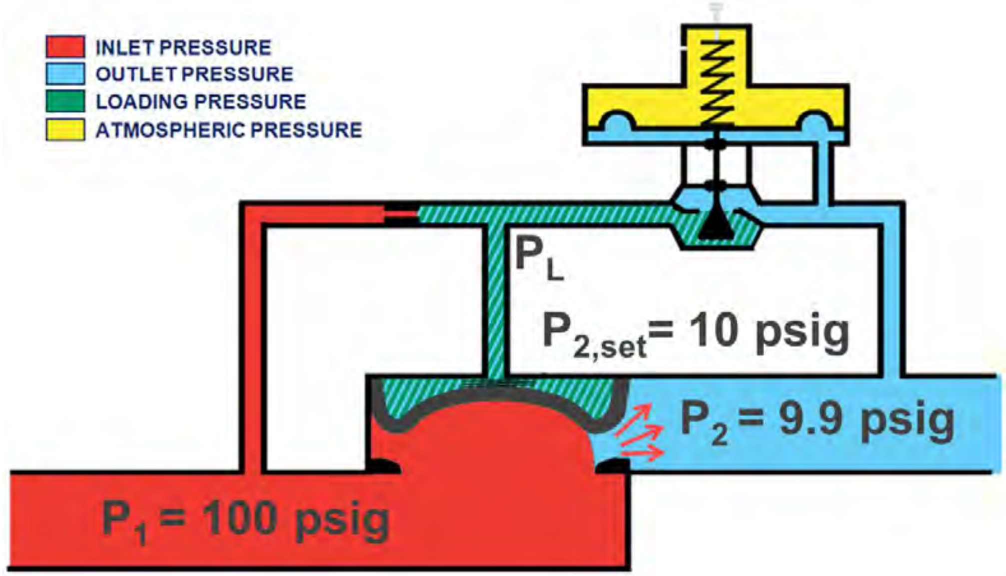
1. Pilot opens



2. P_L decreases

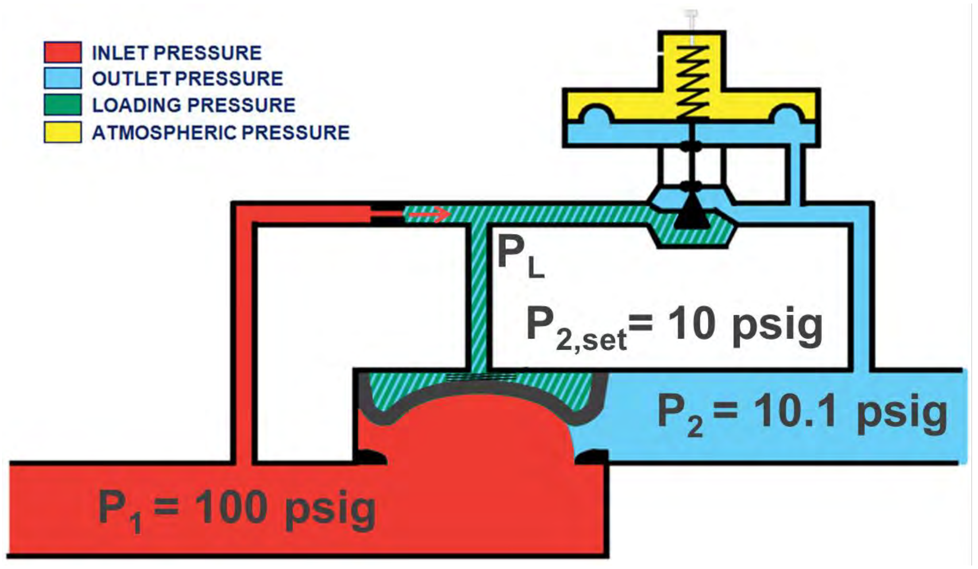


3. Main valve opens

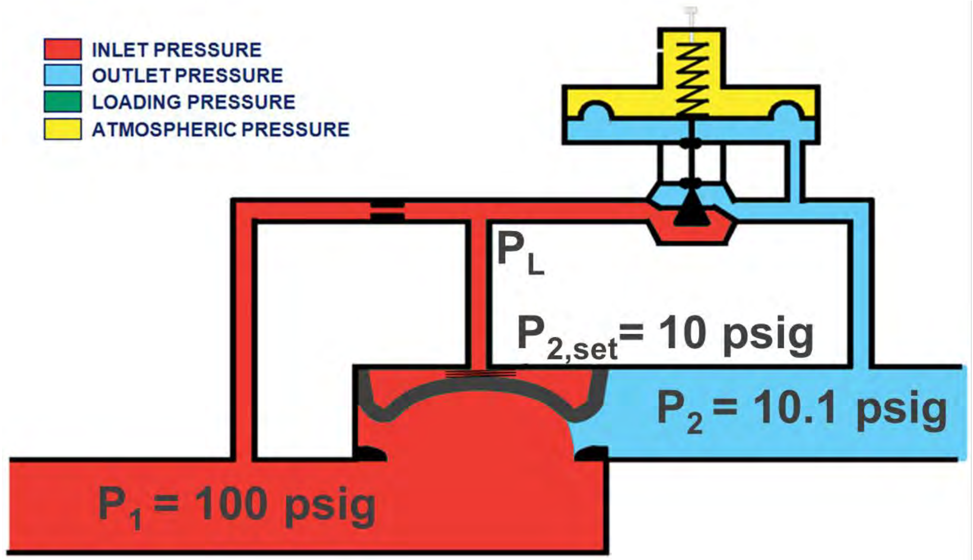


Loading Style Operation: Demand Decreases

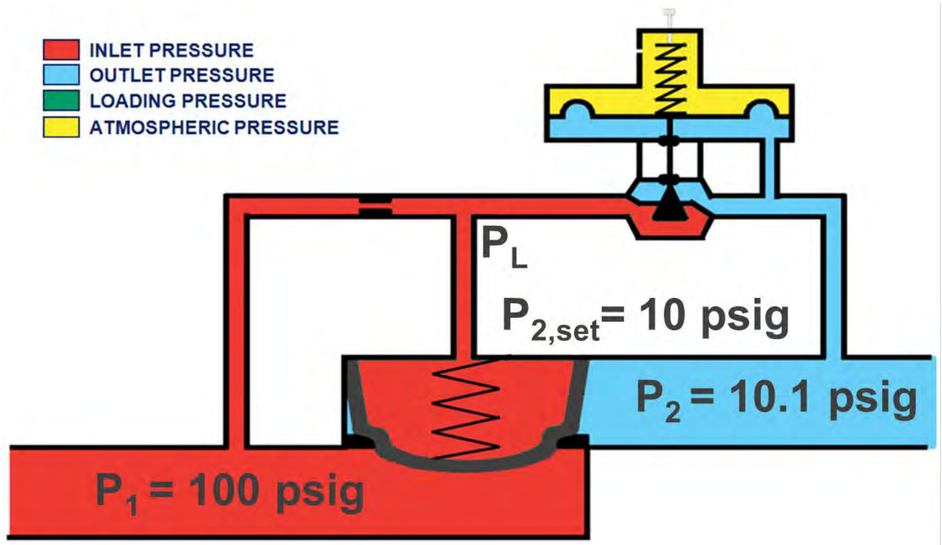
1. Pilot closes



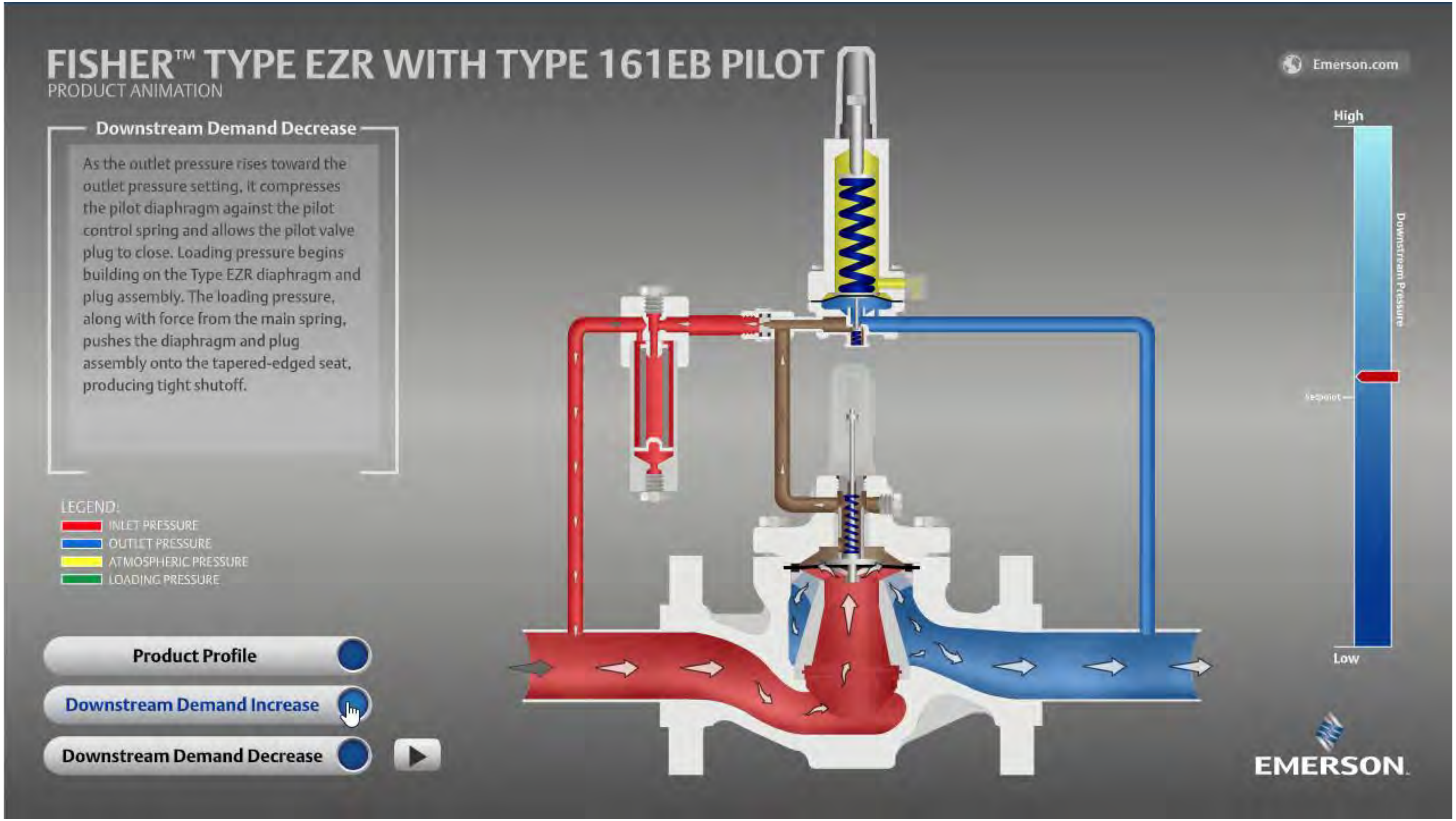
2. P_L increases



3. Main valve closes



Unloading Style Animation



Pilot Regulator Attributes

Why is a Pilot-Operated Regulator More Accurate?

Initial Condition:
Flow demand is zero
P_1 = 100 psig
P_2 = 10.1 psig
P_L = 10.1 psig

Secondary Condition:
Flow demand increases
P_1 = 100 psig
P_2 = 9.9 psig
P_L ~ 30 psig

Answer: Gain (pressure amplification from the pilot)

- **Gain = $\Delta P_L / \Delta P_2$**

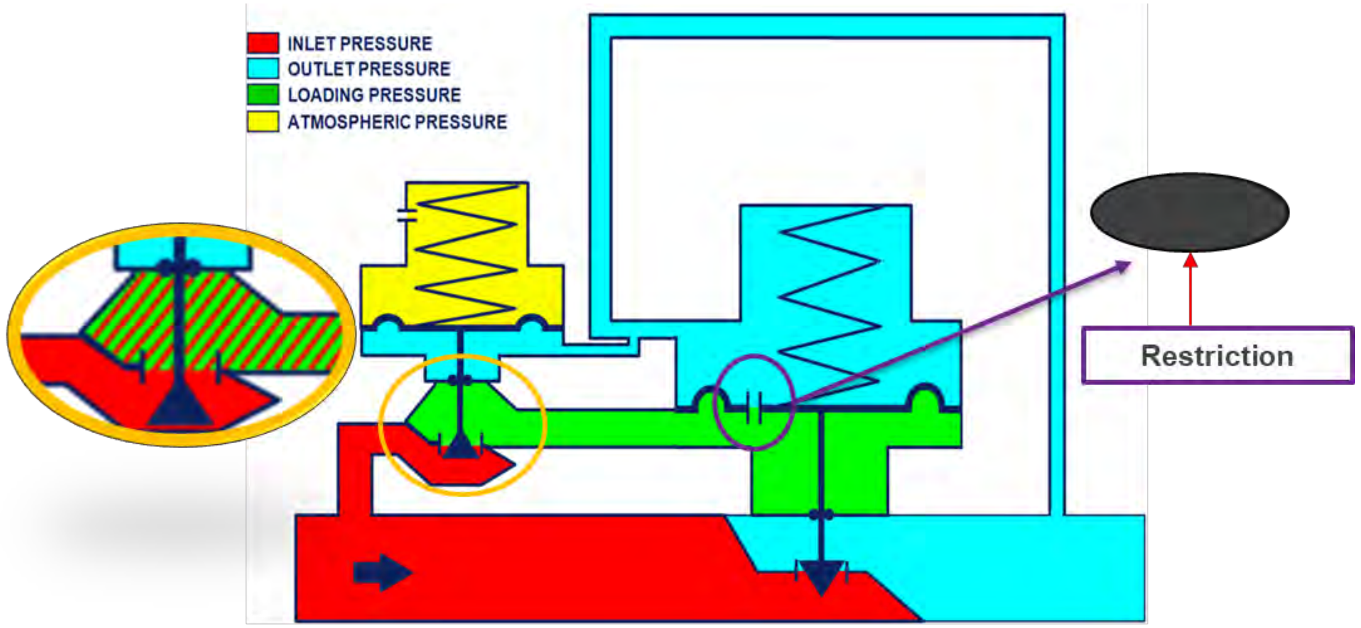
$$\frac{\Delta P_L}{\Delta P_2} = \frac{30 - 10 \text{ PSI}}{10.1 - 9.9 \text{ PSI}} = \frac{20 \text{ PSI}}{.2 \text{ PSI}}$$

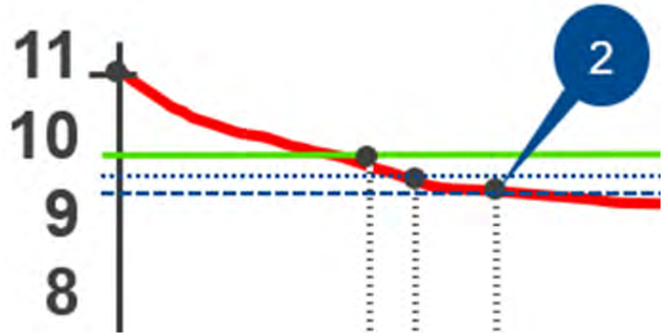
A small change in P_2 can cause a big change in P_L

Gain: Physical Explanation and Attributes

Low Gain:
- Larger restriction or smaller pilot orifice
- More pilot travel
- Less Accurate (more droop)

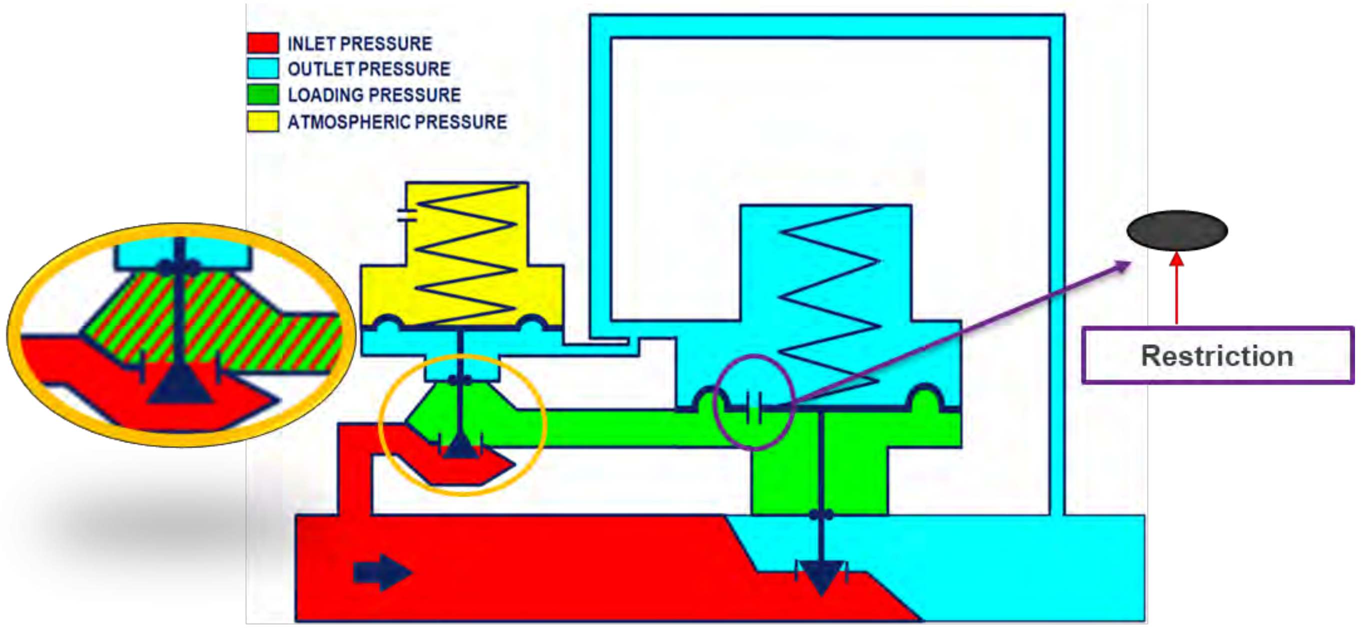
Slow to Open / Fast to Close

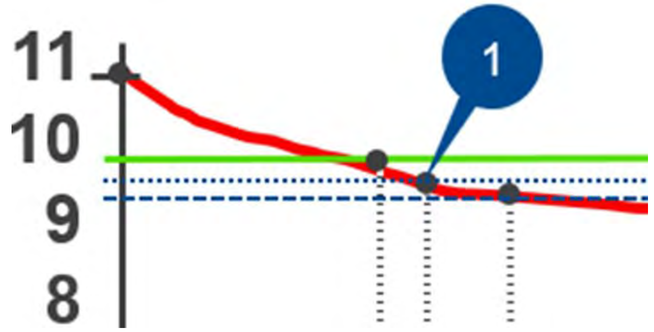




High Gain:
- Smaller restriction or larger pilot orifice
- Less pilot travel
- More accurate (less droop)

Fast to Open / Slow to Close



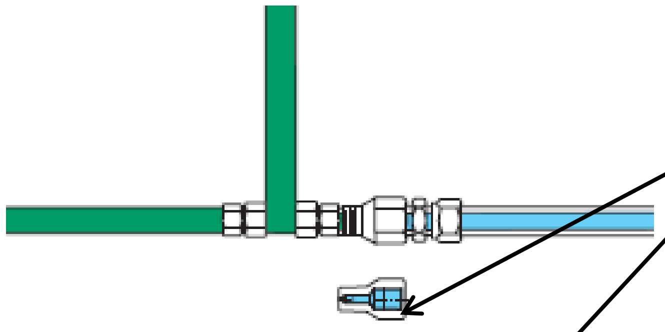


Where is the Bleed?

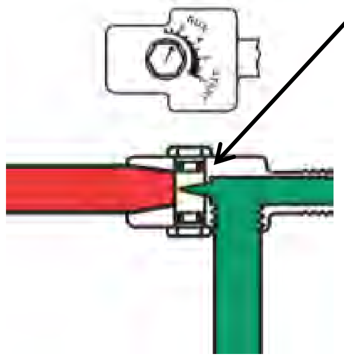
External of Pilot/Main

Bleed

Internal to Pilot

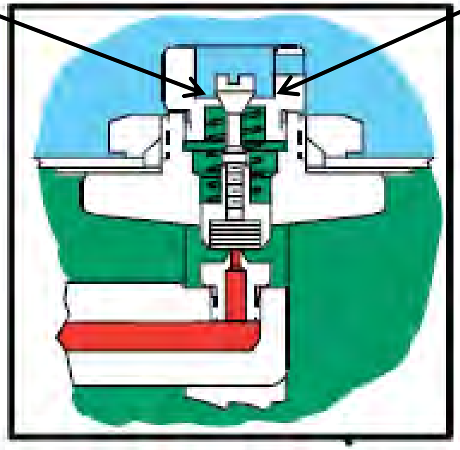


FIXED RESTRICTOR

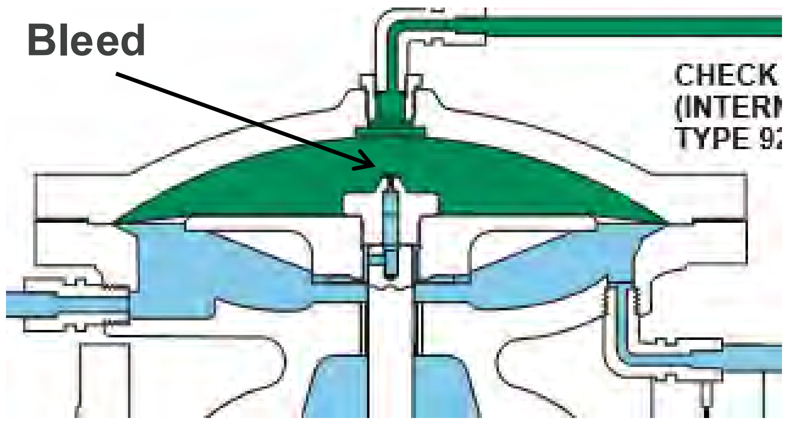


Variable Restrictor

Quick Dump



Internal to Main



- INLET PRESSURE
- OUTLET PRESSURE
- ATMOSPHERIC PRESSURE
- LOADING PRESSURE

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Influencing Gain

Lower Gain

- Large restriction
- Small pilot diaphragm area
- Heavier pilot spring
- Less pressure differential
- Smaller orifice on pilot

Higher Gain

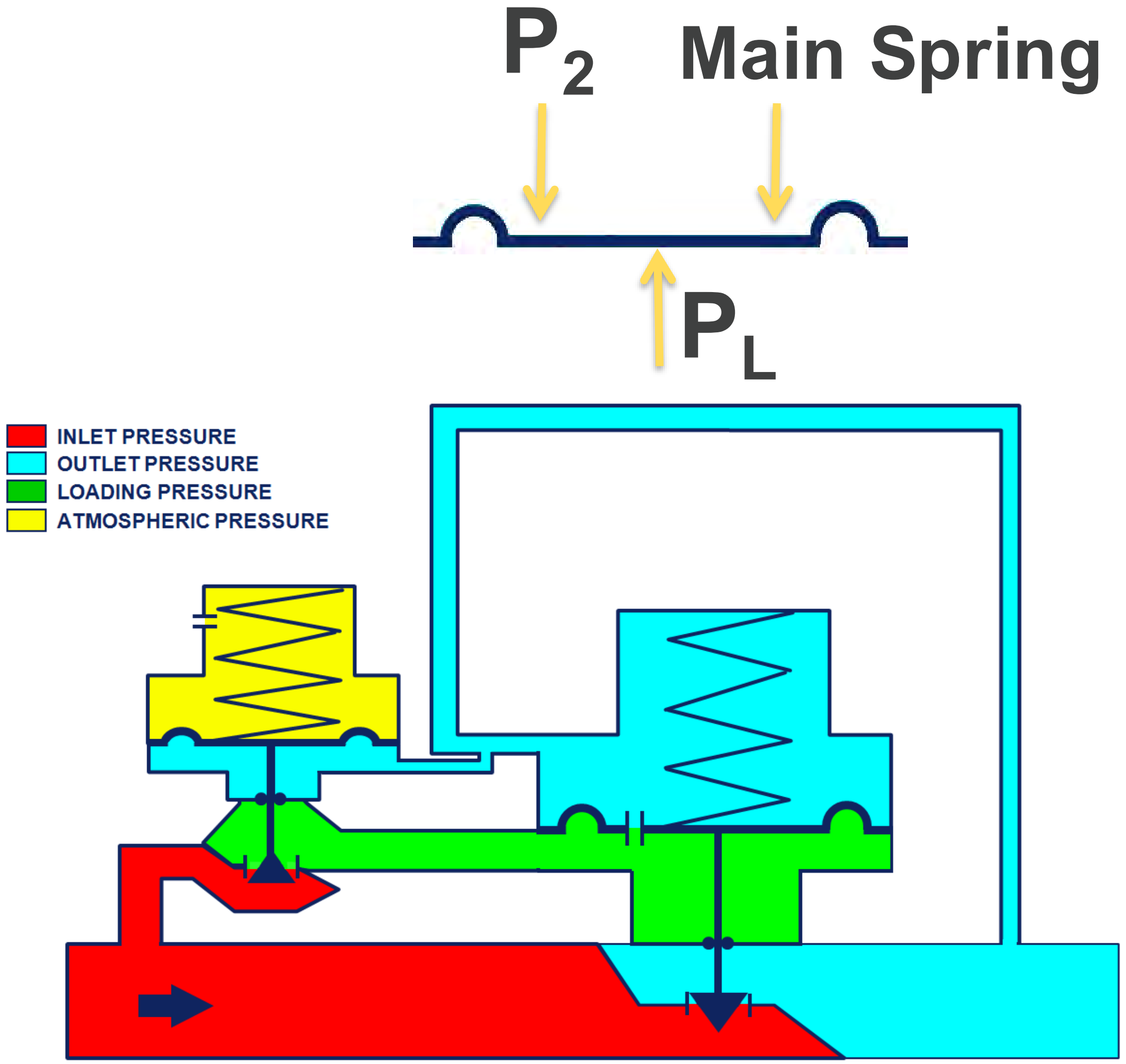
- Small restriction
- Larger pilot diaphragm area
- Lighter pilot spring
- Larger pressure differential
- Larger Orifice on pilot

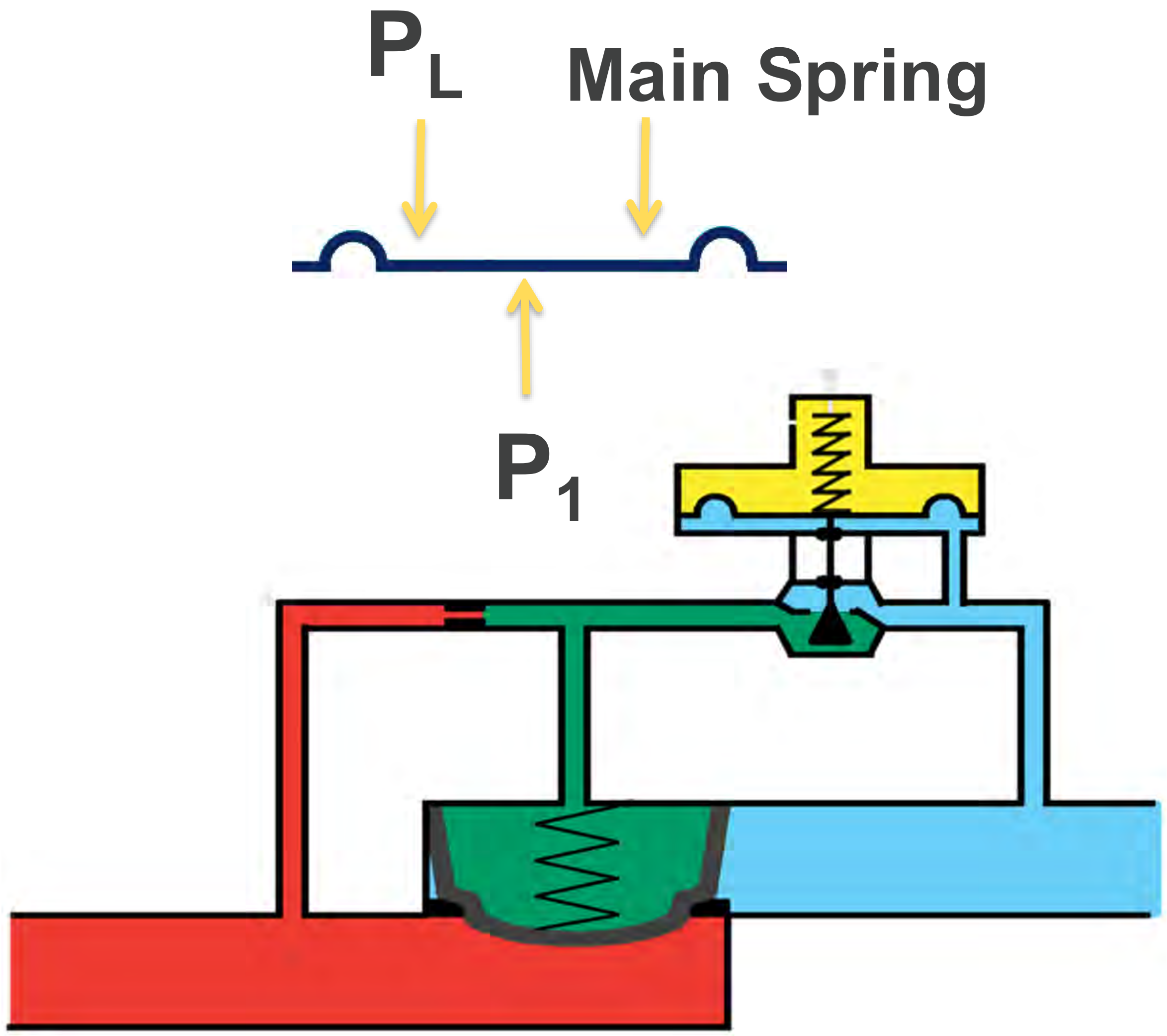
Various Factors can Influence the Gain of the System

Minimum Differential Pressure (3 Major Factors Influence It)

$P_{L,max} = P_1$

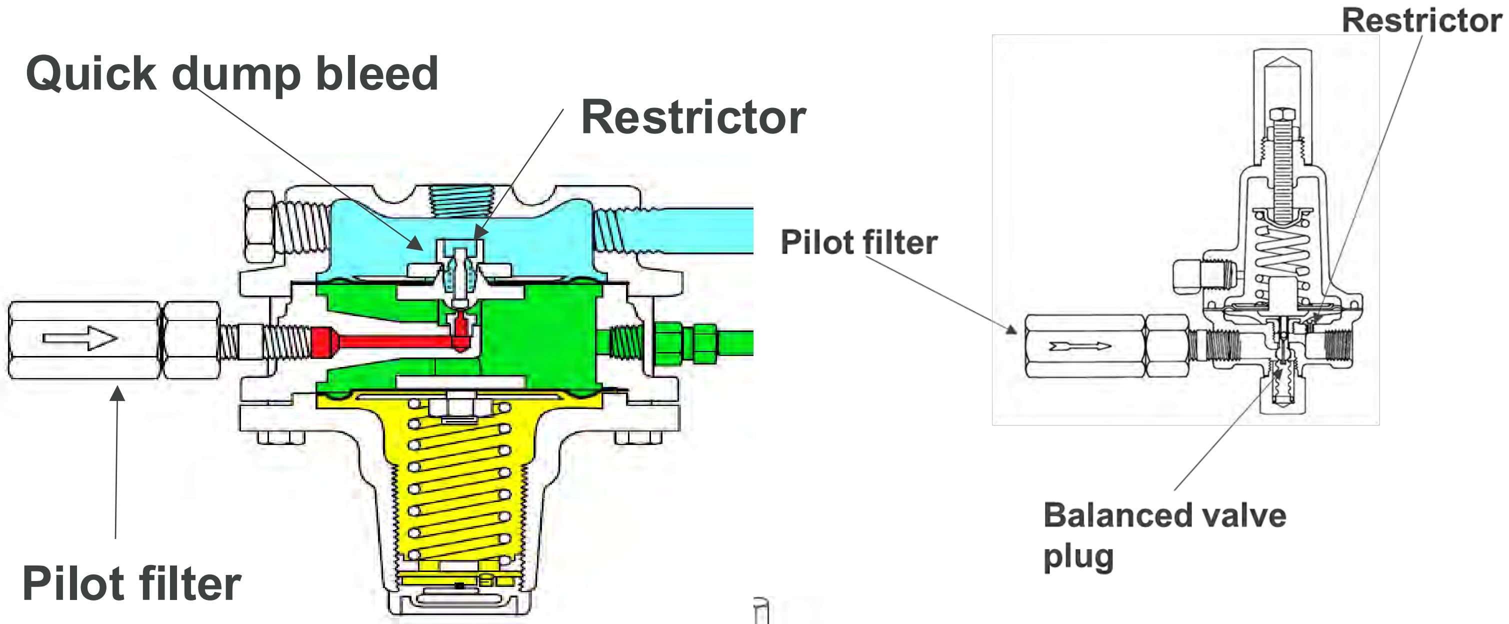
Minimum Wide-Open Differential: the pressure difference ($P_1 – P_2$) required to fully stroke the main valve open

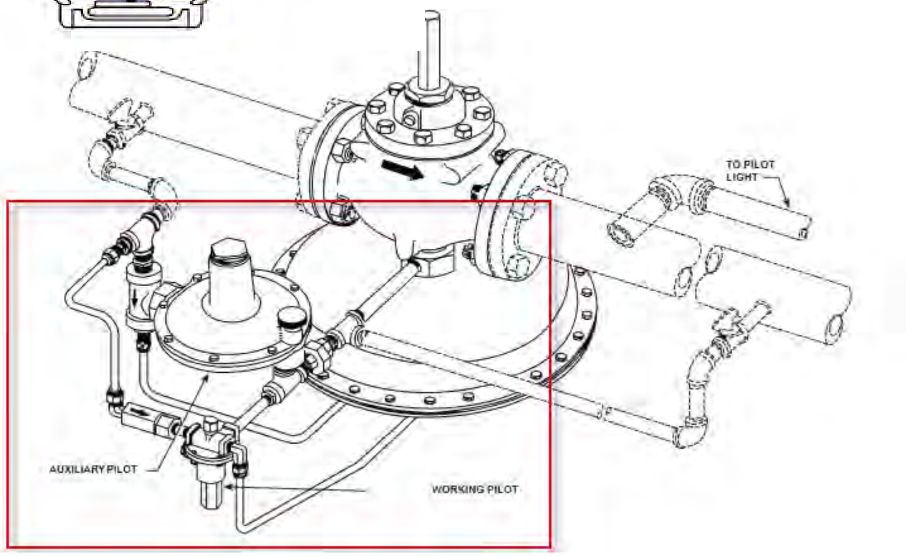




Pilots Differ and Influence Performance

Loading Style

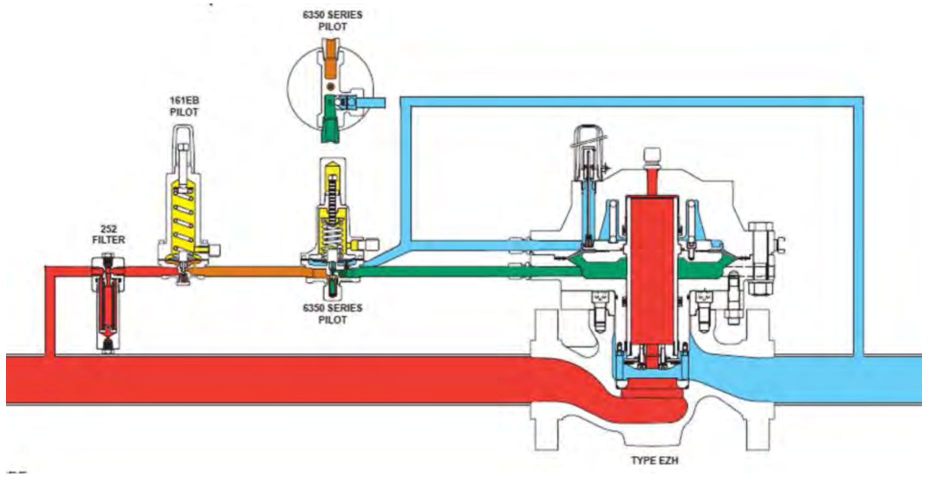


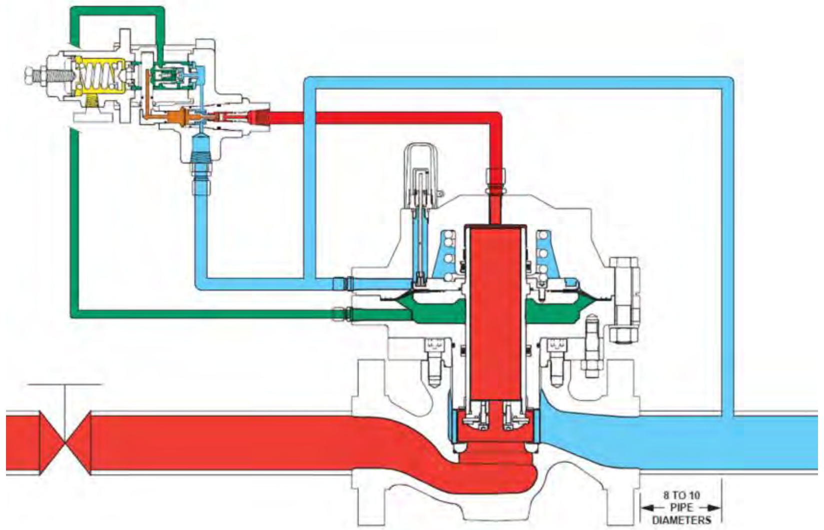


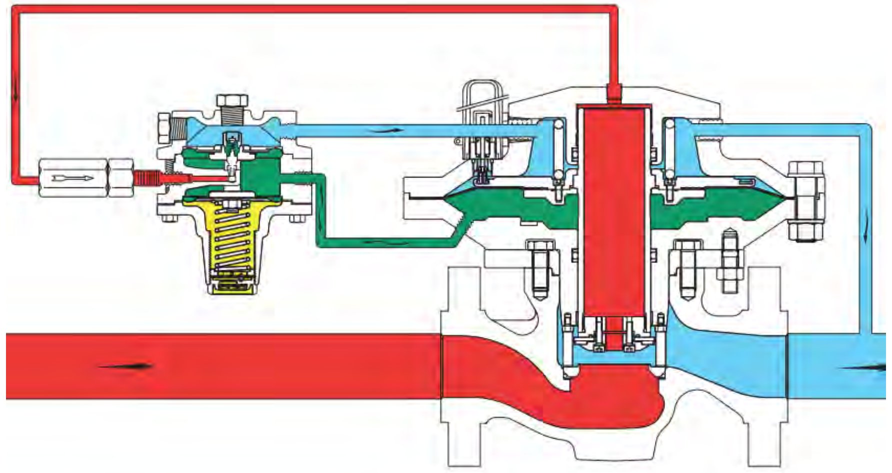
Unloading Style

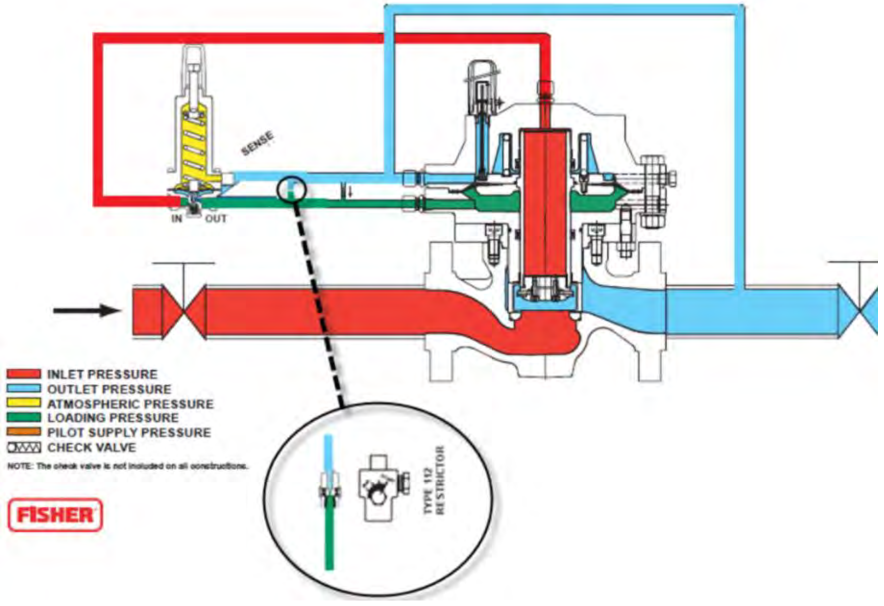
Alternative Pilots are an Option!!!

6350 Series, 61 Series, 161EBM/EM, 32A, or Others!

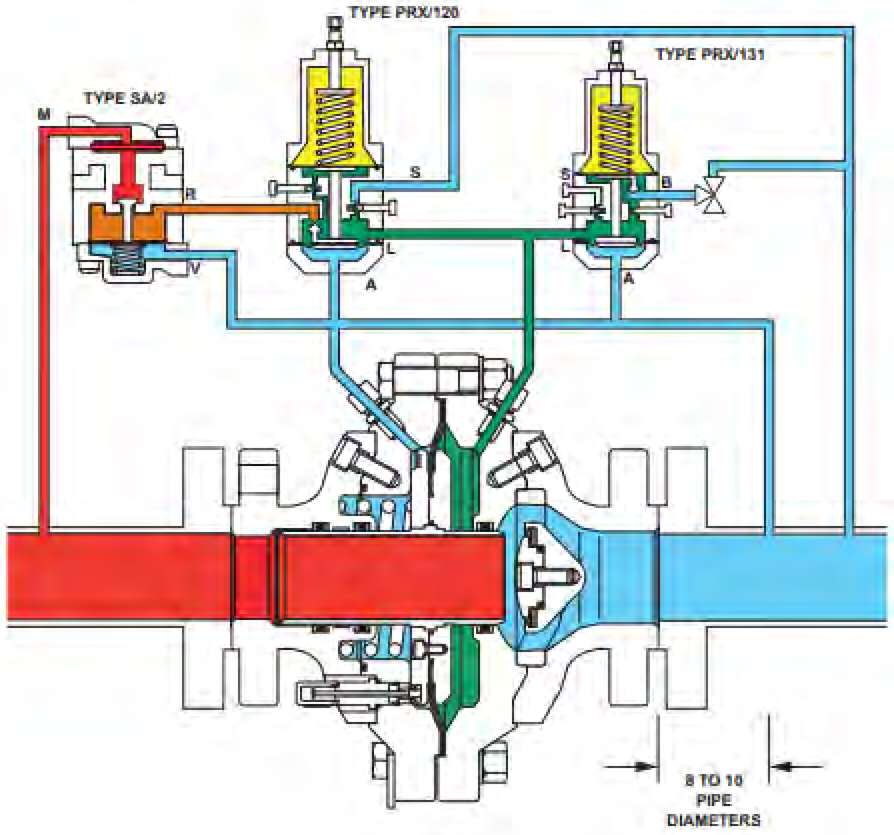


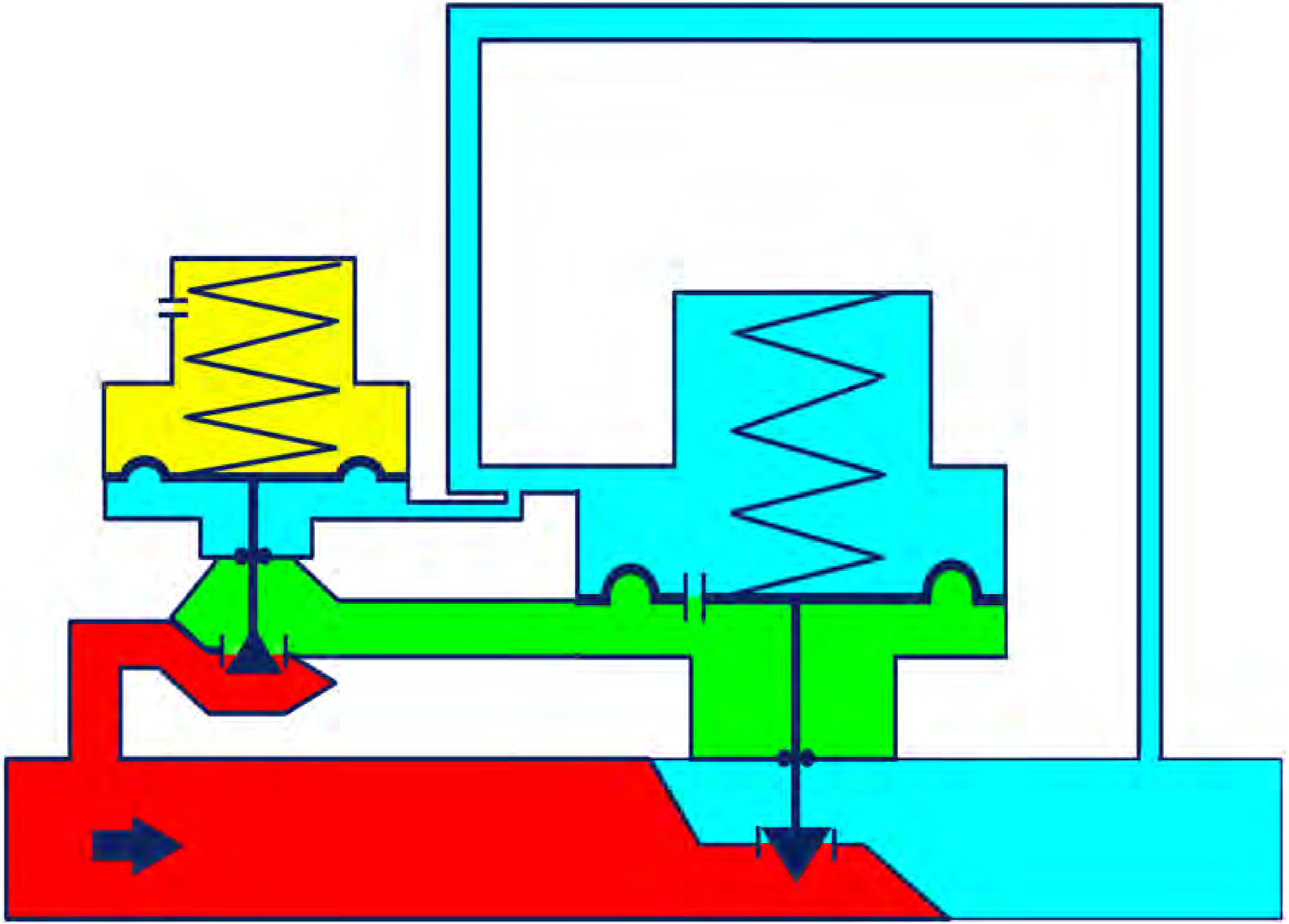






131 Booster Pilot





Which Pilot Operated Regulator should I choose?

Loading Style

- Generally more expensive
- Higher capacities than unloading
- Lower minimum differentials
- More customizability (speed, min diff, pilots)
- Higher pressure drops
- More noise attenuation options
- Failure mode more easily defined

Typical Application

- City Gate or High-Pressure District
- Power Plant / Turbine
- Short Piping Runs: Asphalt Plants / Boiler
- Failure Mode defined
- Shutoff critical

Unloading Style

- Generally less expensive
- Simple maintenance
- Medium to lower pressure drop applications
- Applications where speed is not a factor
- Noise not a factor
- Flexible element failure mode depends on location of failure on diaphragm

Typical Application

- Lower Pressure City Gate
- District stations
- Large commercial/industrial
- Speed isn't as important
- Failure mode isn't critical

Choosing a Regulator

Gather Process Conditions → **Narrow Selection** → **Size Selection**

Sizing a Pressure Reducing Regulator

1. Gather the necessary data
   - Inlet Pressure, Outlet Pressure, Flow, Accuracy Required, Application, etc.
2. Select an appropriate regulator
   - Narrow selection by P1max, P2, max flow rate, and specific attributes
   - Understand the application and accuracy requirements
3. Specify the body size, spring range, orifice size, pilot, etc.
   - Size to P1min, P2, and max flow rate
4. Determine the materials of construction
5. Verify the pressure and temperature ratings

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Installation and Failure Modes

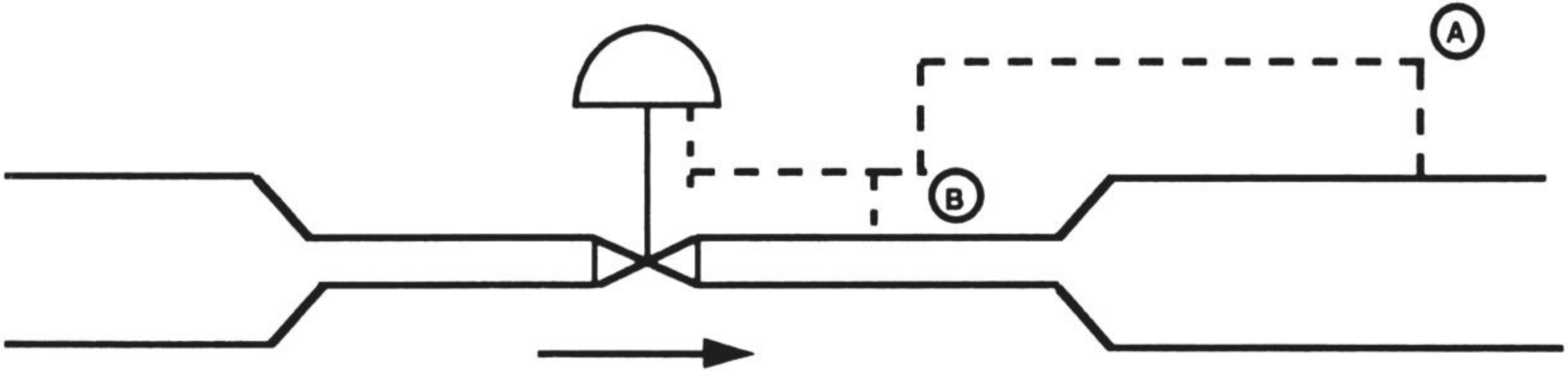
Control Line Installation

Improper control installation can cause a regulator to cycle, control the wrong pressure, or respond slowly. Control lines are also called sense lines and static lines.

Plan the installation ahead of time using these guidelines:

- Make the control line as short and straight as practical
- Connect the control line **6 to 10 pipe diameters downstream of a turbulence generator** (valve, tee, elbow, swage)
- Connect the control line to the point where the pressure is to be controlled

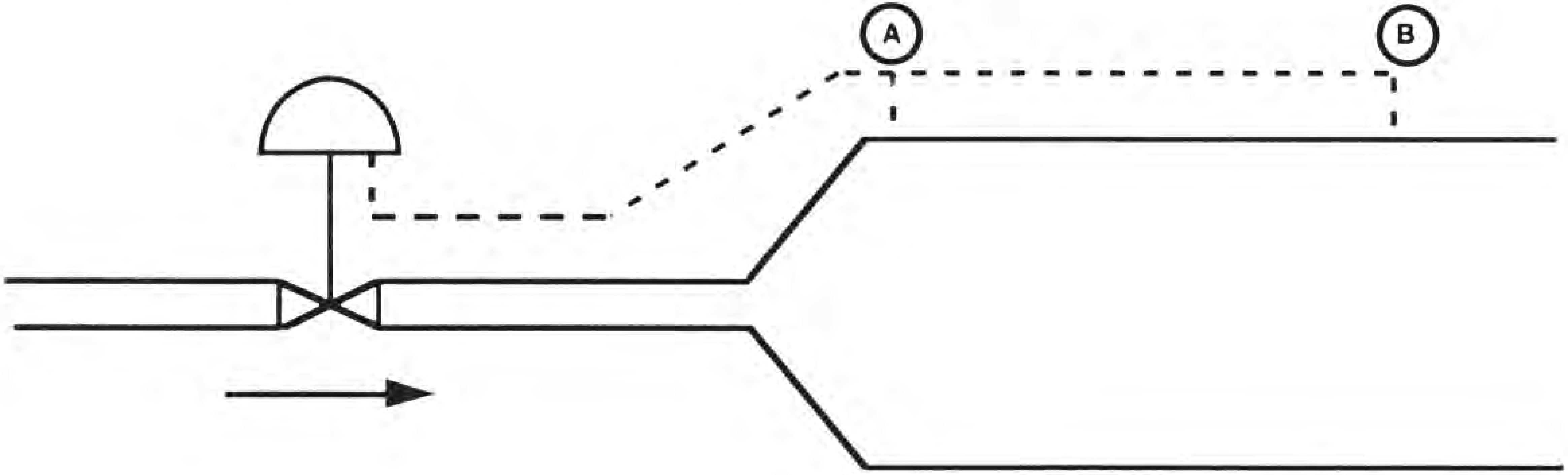
Regulator In Swages



A CORRECT

B WRONG – PRESSURE MAY BE LOWER IN THE SMALLER PIPING DUE TO HIGHER VELOCITY

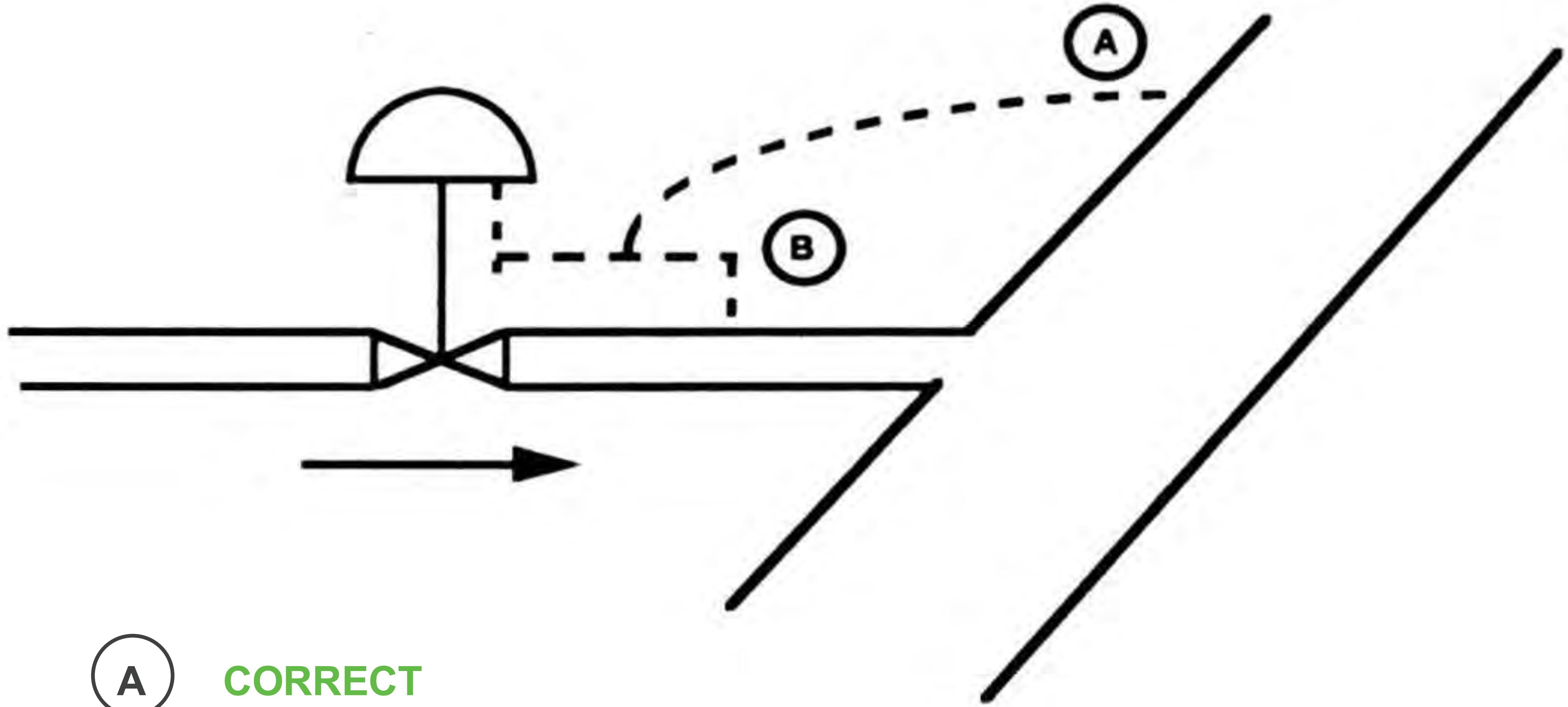
Connect the Control Line at a Location Relatively Free of Turbulence



A **WRONG** – PIPE SIZE CHANGE (SWAGE) CAUSES TURBULENCE

B **CORRECT** – CONNECTION IS 6 TO 10 PIPE DIAMETERS DOWNSTREAM OF THE SWAGE

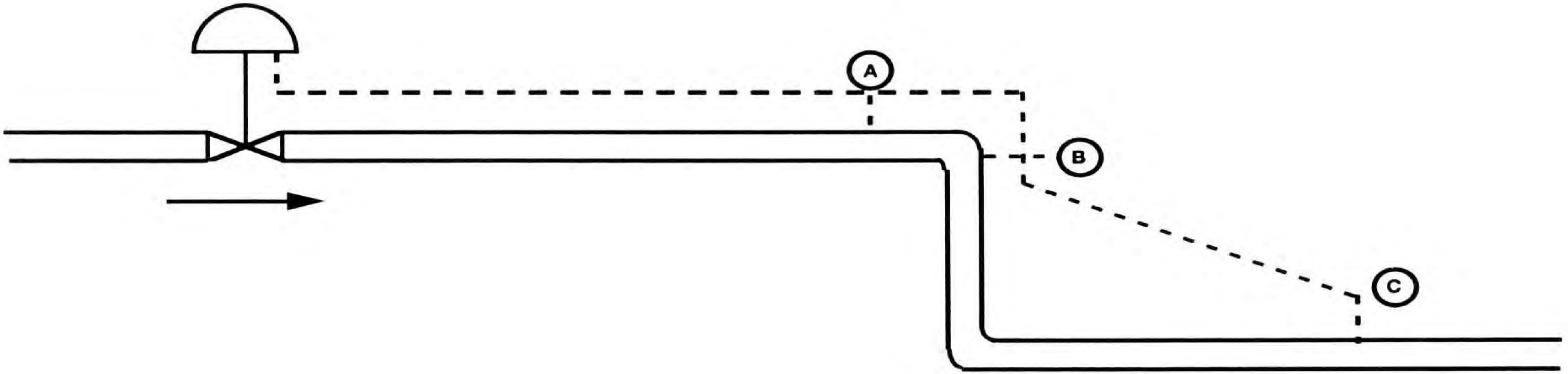
Regulator Supplying to Large Header



A CORRECT

B WRONG – PRESSURE MAY BE LOWER IN THE CONNECTING PIPING DUE TO HIGHER VELOCITY

Connect the Control Line at a Location Relatively Free of Turbulence



A — **CORRECT** – CONNECTION IS **6 TO 10 PIPE DIAMETERS DOWNSTREAM** OF THE REGULATOR

B — **WRONG** – TOO MUCH TURBULENCE AT AN ELBOW

C — **CORRECT** – CONNECTION IS **6 TO 10 PIPE DIAMETERS DOWNSTREAM** OF THE SECOND ELBOW. WITH THE CONNECTION AT THIS POINT, THE REGULATOR WILL COMPENSATE FOR PRESSURE LOSS THROUGH THE TWO ELBOWS.

Control Line in a Turbulent Location

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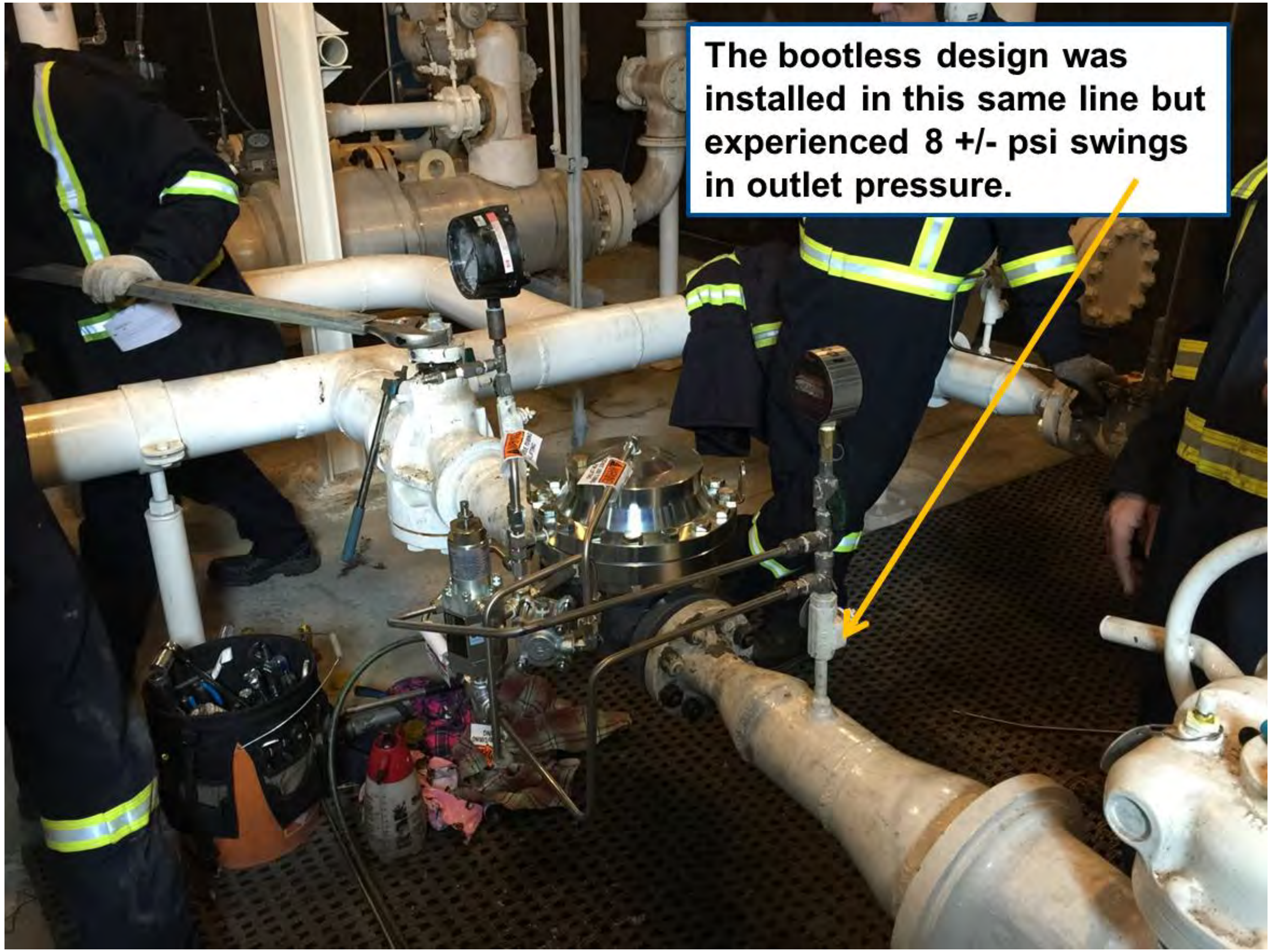
Control Line in a Turbulent Location

Application Example: Troubleshooting Instability



Control Line Tips

- Control Line Diameter
  - The control line diameter should be selected to match the connection provided on the regulator.
  - If the control line is long (over 10 feet), the size should be increased 1 pipe diameter if possible, especially with lower pressure set points

- Control Line Length
  - Direct-Operated Regulators
    - The control line can be any length. If the system is subject to quick load changes, friction in a long control line may delay the pressure wave and slow the regulator response time.

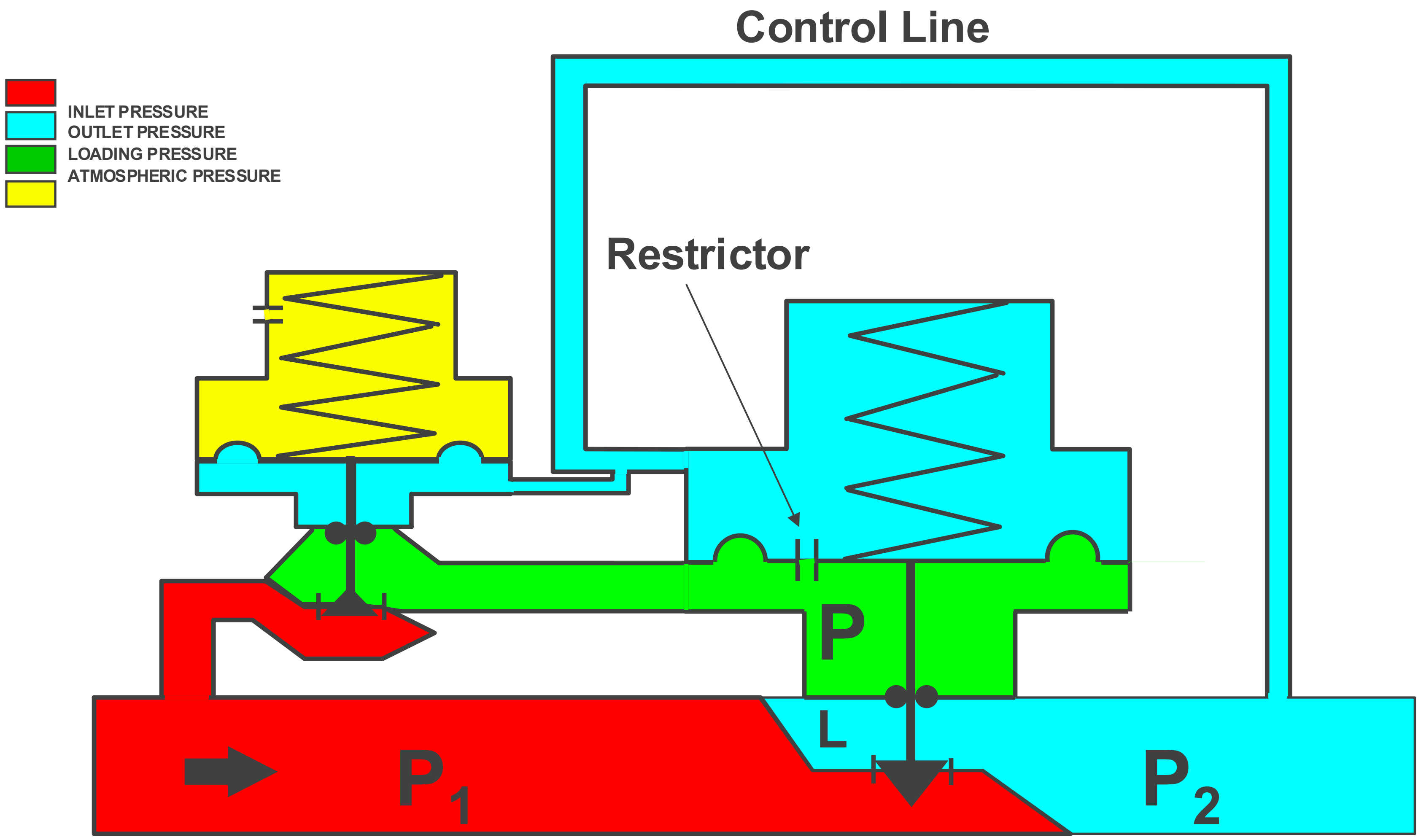
  - Pilot-Operated Regulators
    - The control line can be any length. If the control line is over 10 feet long, the diameter may be increased. A long, small diameter control line can restrict pilot bleed gas flow.

Properly Designed Regulator Pressure Reduction Stations will Prevent Most Problems

Two-Path Pilot-Operated Regulator Failure Modes

What happens when:

- $P_1 = P_2$
- Control line break
- Pilot failed open
- Restrictor plugged
- Main spring broken
- Diaphragms broken
- No pilot P_1 pressure
- Control line closed



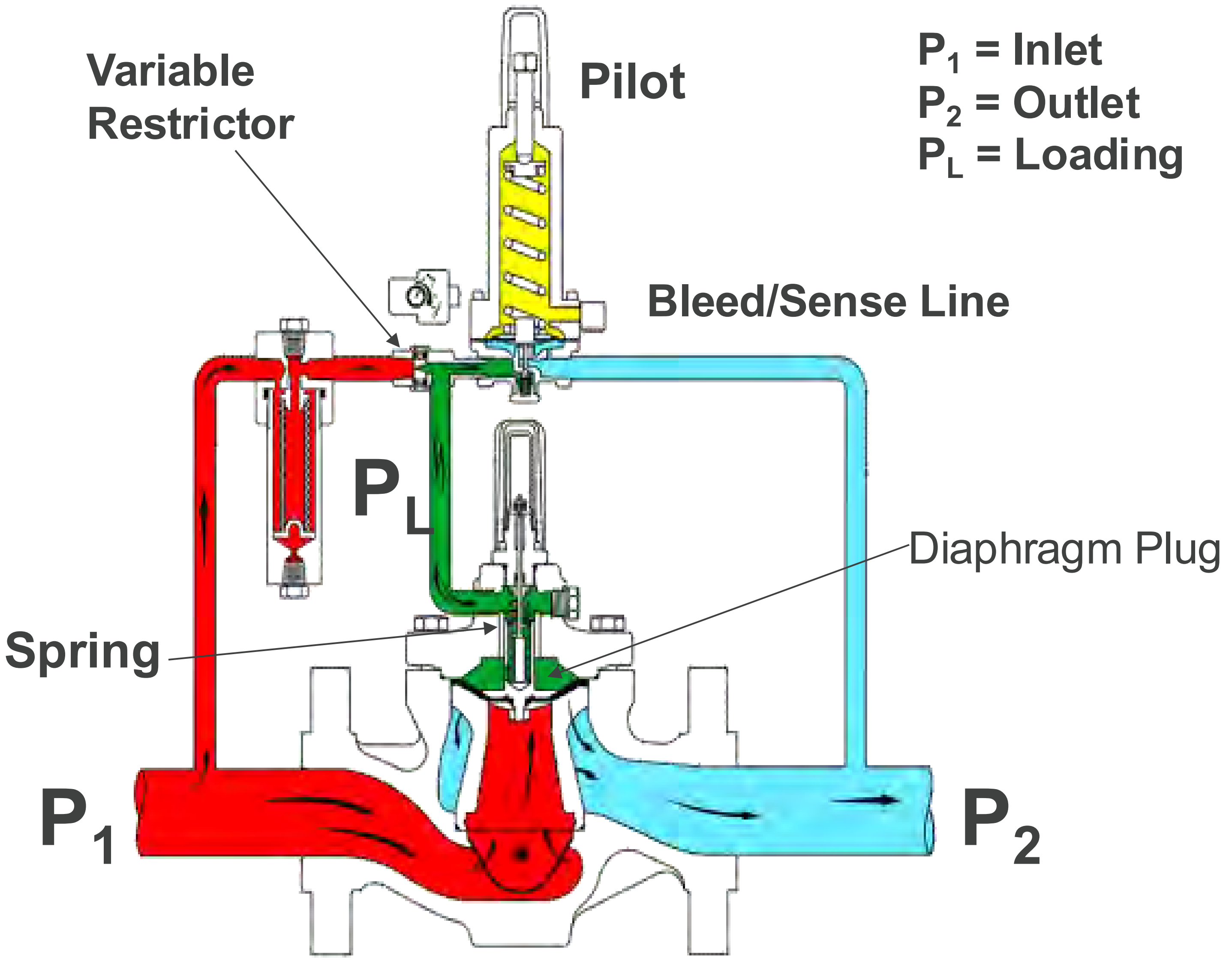
Spring open or spring closed design?

Flow to open or close design?

Flexible Element Pilot-Operated Regulator Failure Modes

What happens when:

- $P_1 = P_2$
- Control line break
- Pilot failed open
- Restrictor plugged
- Main spring broken
- Diaphragms broken
- No pilot P_1 pressure
- Control line closed



Spring open or spring closed design?

Summary of Pilot Operated Failure Modes

System Issue	Regulator Technology		
	Unloading Flexible Element	Loading Spring Closed Plug	Loading Spring Open Plug
Loss of Pilot Supply	Fail Open	Fail Closed	Fail Open
Diaphragm Damage	Fail Open or Closed	Fail Closed	Fail Open
Low Inlet Supply Pressure	Fails Open or Closed	Closed until min ΔP is reached	Fail Open
Pilot or Filter, Plugged or Iced Up Closed	Fails Open	Fails Closed	Fail Open
Seat Damage	Leaks to Fails Open	Leaks across seat*	Leaks across seat*
Fire	Fails Wide Open	Leakage*	Fail Open

Loading Style Product Issues

Failure Type	Regulator Symptom	Common
Control Line Break	Regulator will fail wide open	No
Control Line Closed	Regulator will not respond	No
Inlet Filter Clogged or inlet supply closed to pilot	Regulator will not open	No
Restrictor Plugged	Regulator will not close	No
Internal Ice buildup	Regulator will either fail open or closed	No
External Ice buildup over vent	Sluggish response	No
Orifice/Plug damage	Regulator will not lockup	Yes
Main diaphragm rupture	Regulator will not open	No
Pilot diaphragm rupture	Regulator will fail wide open	No

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Loading Style Application Issues

Issue	Common Causes
Low Flow Instability	Oversizing / Regulator type / Control line placement/other
Instability	Control line / Downstream pipe volume / bleed line location
Speed of Response	Type of regulator/pilot chosen for application/plugged vent
Outlet pressure accuracy	Undersized, minimum differential violated, inlet sensitivity, gain
Noise	High pressure drops at high flows
Buzzing	Harmonic resonance
Freezing	Water content in my gas
Lockup	Debris/fallout

Unloading Style Product Issues

Failure Type	Regulator Symptom	Common
Control Line Break	Regulator will fail wide open	No
Control Line Closed	Regulator will fail closed	No
Inlet Filter Clogged or inlet supply closed to pilot	Regulator will fail open	No
Restrictor Plugged	Regulator will fail open	No
Internal Ice buildup	Regulator will either fail open or closed	No
External Ice buildup over vent or plugged vent	Sluggish response	No
Orifice/Plug damage	Regulator will not lockup	Yes
Main diaphragm rupture	Regulator fail open or closed	Depends on Industry/Application
Pilot diaphragm rupture	Regulator will fail wide open	No

Unloading Style Application Issues

Issue	Common Causes
Low Flow Instability	Oversizing / Regulator type / Control line placement/ other
Instability	Control line / Downstream pipe volume / bleed line location
Speed of Response	Type of regulator/pilot chosen for application / vent plugged
Outlet pressure accuracy	Undersized, minimum differential violated, inlet sensitivity, gain
Buzzing	Harmonic resonance
Freezing	Water content in my gas
Lockup	Debris/fallout

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Overall Regulator Comparison

	Self-op	Press-Loaded	Loading Pilot-op	Unloading Pilot-op
Accuracy	★	★★	★★★	★★★
Capacity	★	★½	★★★	★★
Response time	★★★	★★½	★★	★
Min Differential	None Required	★★½	★★	★
Cost	★★★	★★½	★	★★
Maintenance	★★★	★★½	★	★★

Questions?

Remember to follow the recommendations and ratings in the manufacturer's technical documentation!

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