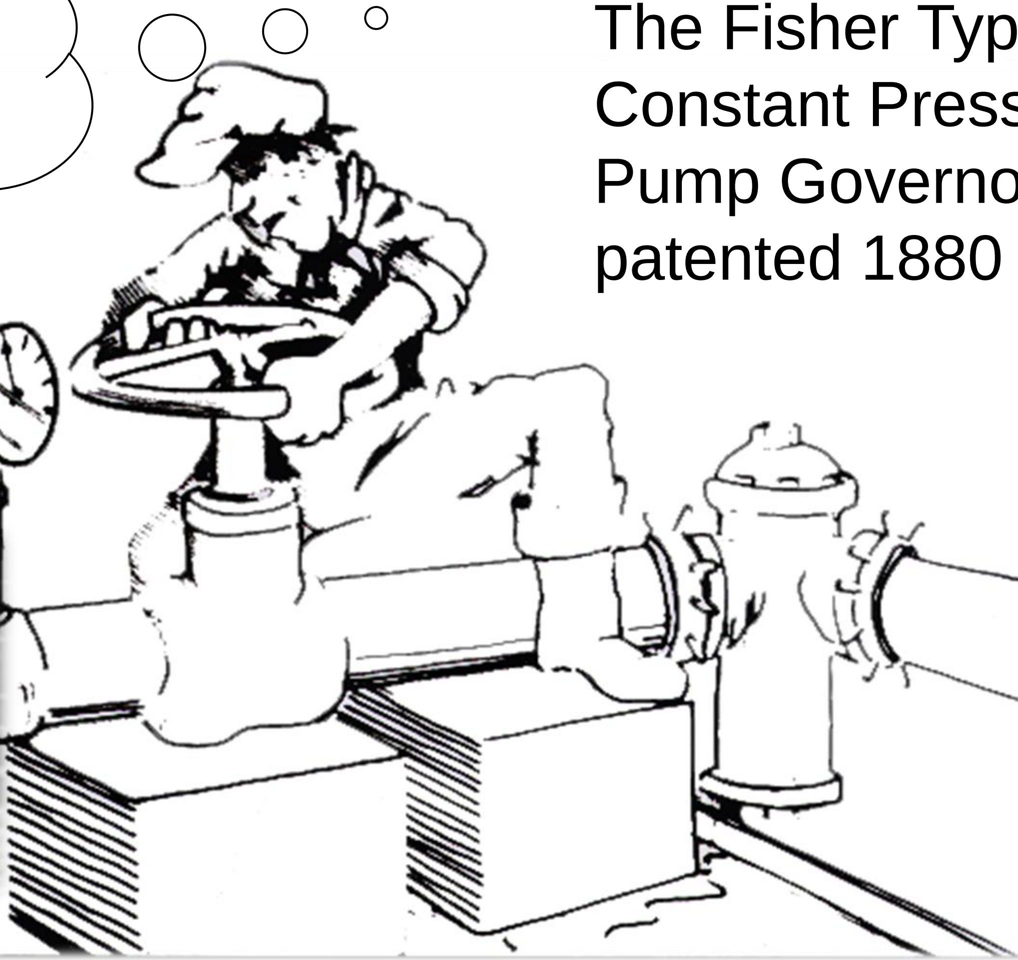
Self-Operated Regulators

EMERSON™

Regulators

- 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

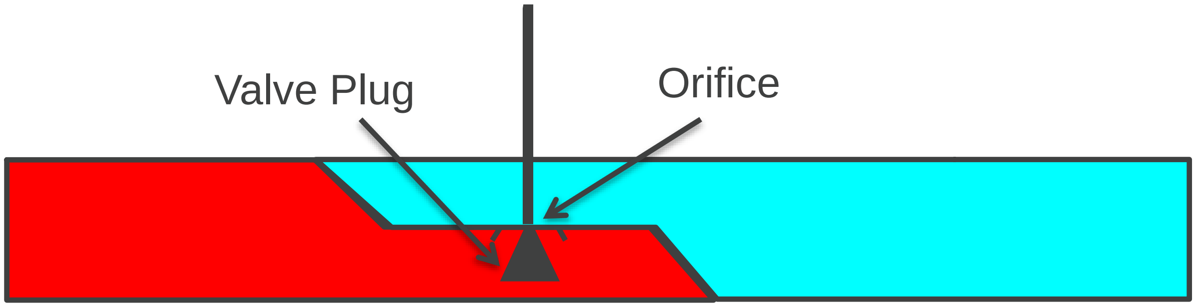
William Fisher (Marshalltown, Iowa)



The Fisher Type 1 Constant Pressure Pump Governor – patented 1880

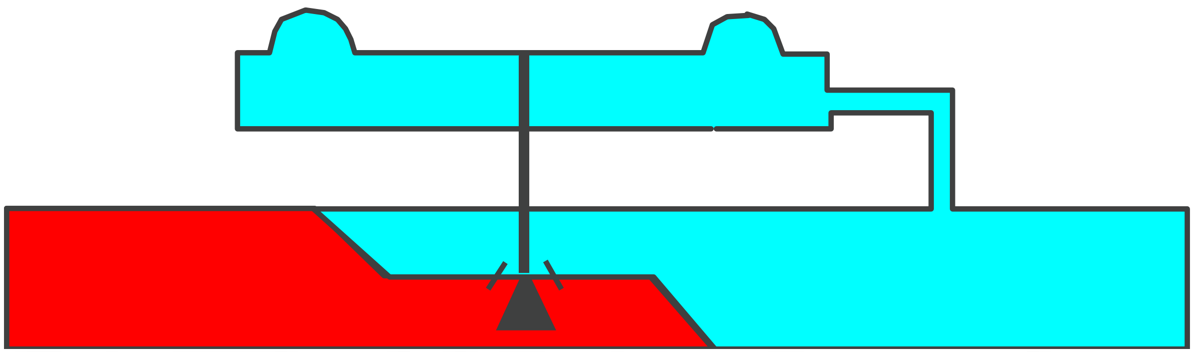
Three Essential Elements

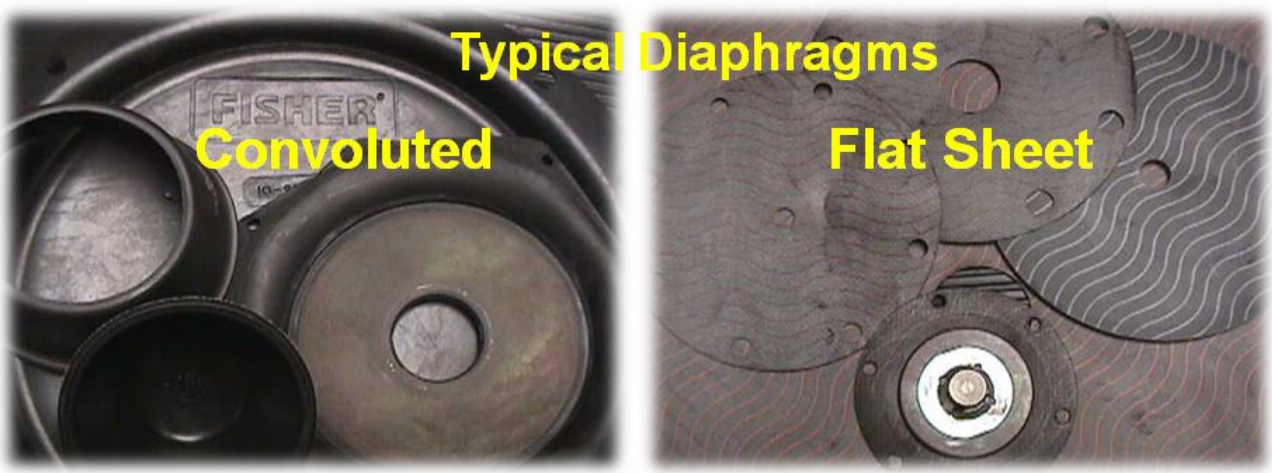
1. Restricting Element (Valve Plug and Orífice)



Three Essential Elements

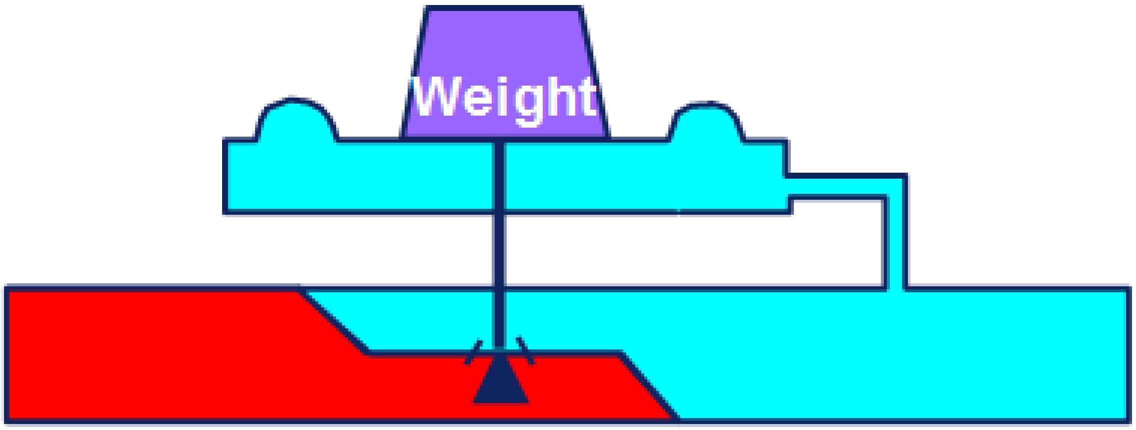
1. Restricting Element (Valve Plug & Orifice)
2. Measuring Element (Diaphragm)



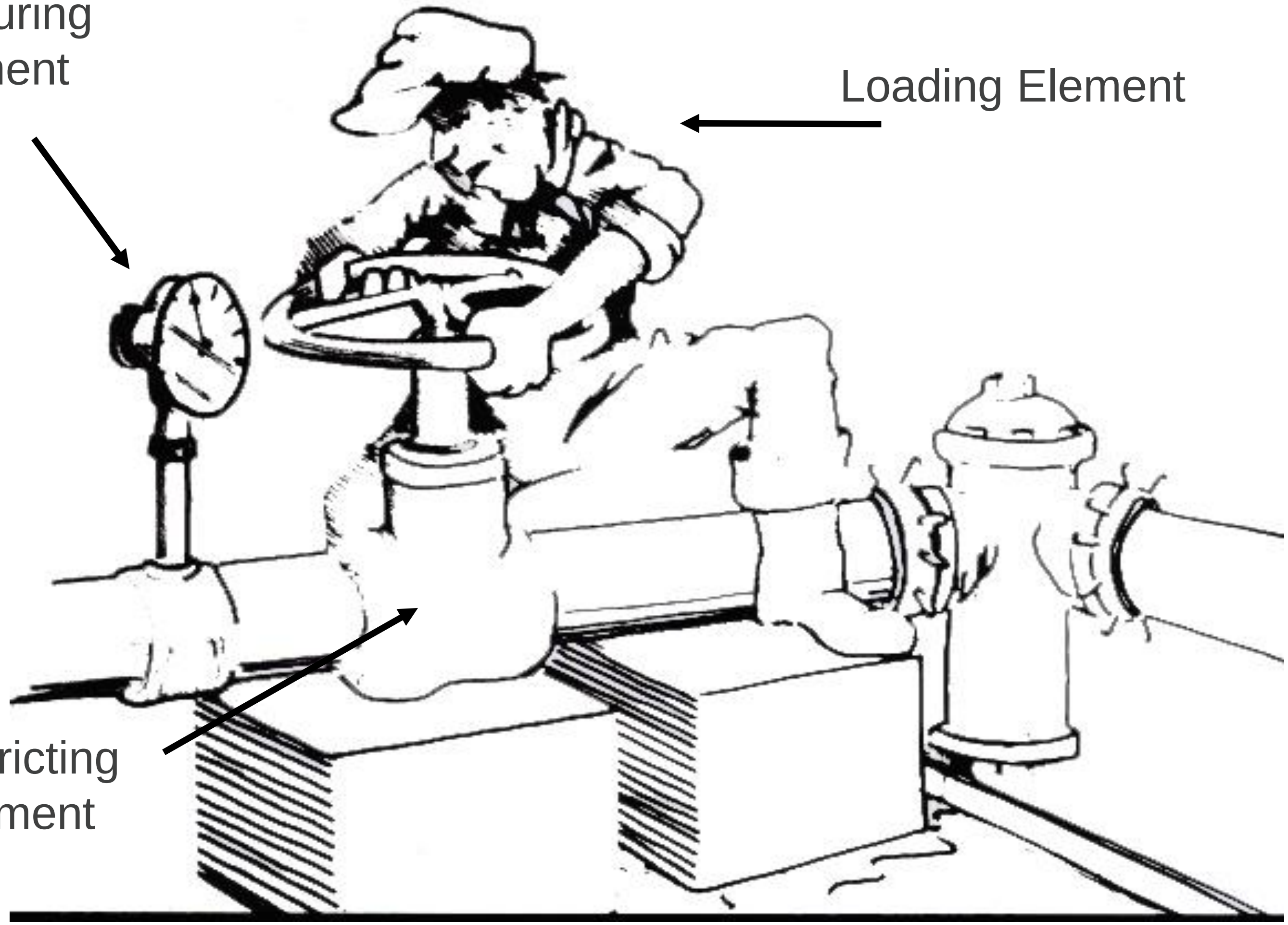


Three Essential Elements

1. Restricting Element (Valve Plug & Orifice)
2. Measuring Element (Diaphragm)
3. Loading Element (Weight)



Three Essential Elements



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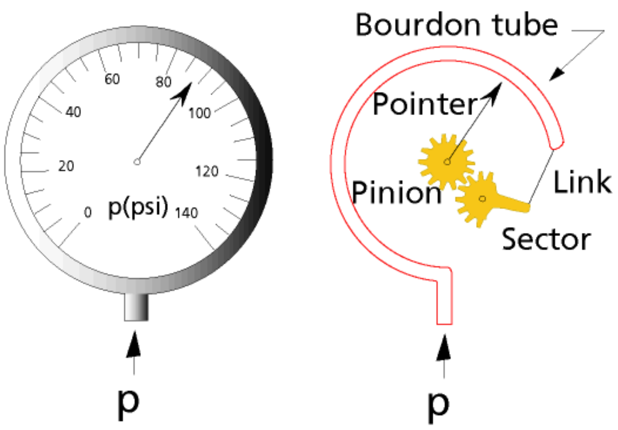
Three Essential Elements

- Restricting Element
  - Valve, valve plug, and orifice
- Measuring Element
  - Gauge, diaphragm
- Loading Element
  - Person, weight, spring



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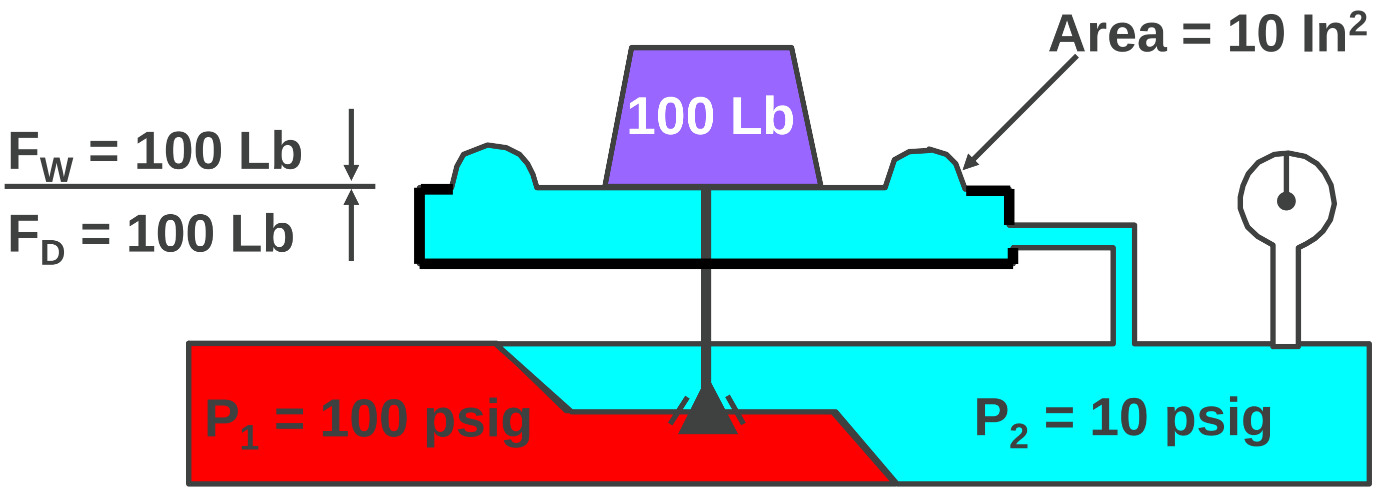
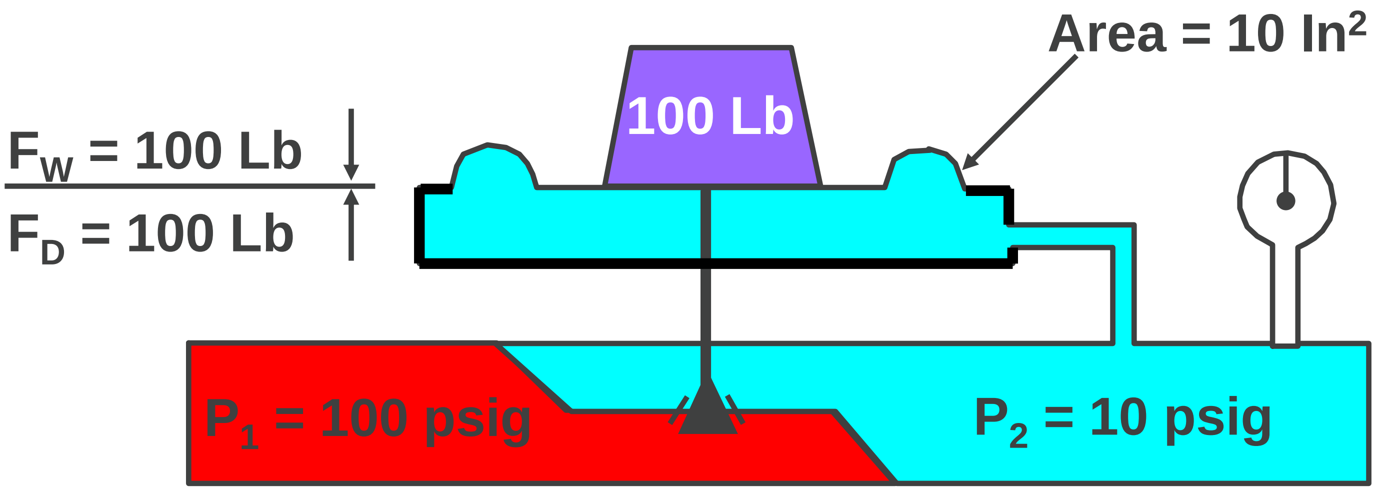
Three Essential Elements - @ Equilibrium



$$F_D = (P_2)(A_D) = (10 \text{ psig})(10 \text{ In}^2) = 100 \text{ Lb} \uparrow$$

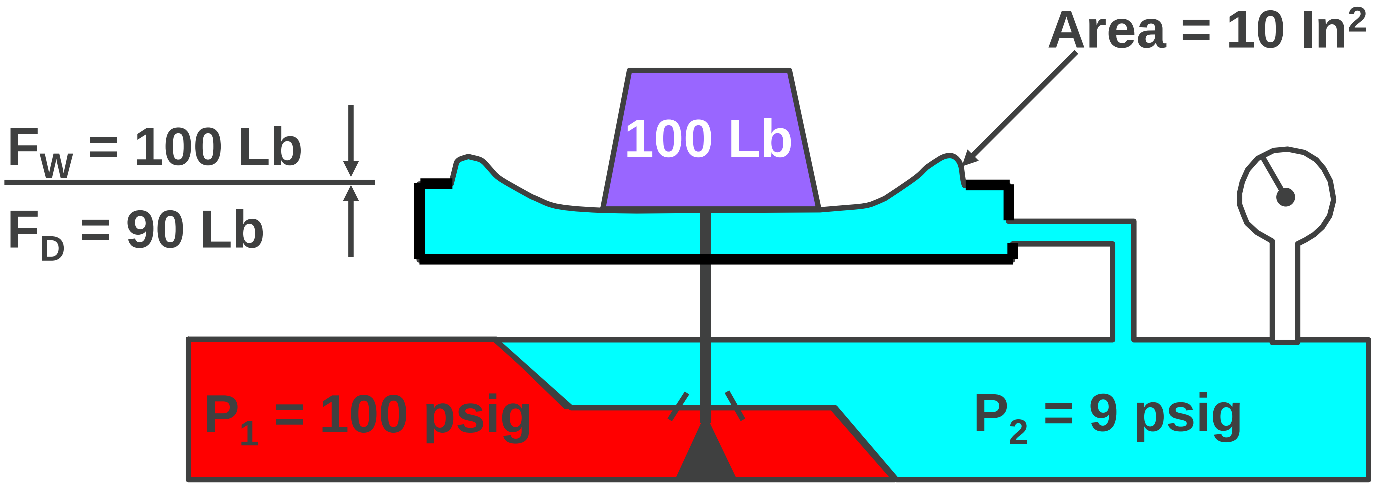
Three Essential Elements - @ Equilibrium



$$F_D = (P_2)(A_D) = (10 \text{ psig})(10 \text{ In}^2) = 100 \text{ Lb} \uparrow$$

What happens to outlet pressure when demand for gas goes up?

Three Essential Elements – Out of Equilibrium



$F_D = (P_2)(A_D) = (9\ psig)(10\ In^2) = 90\ Lb$ ↑

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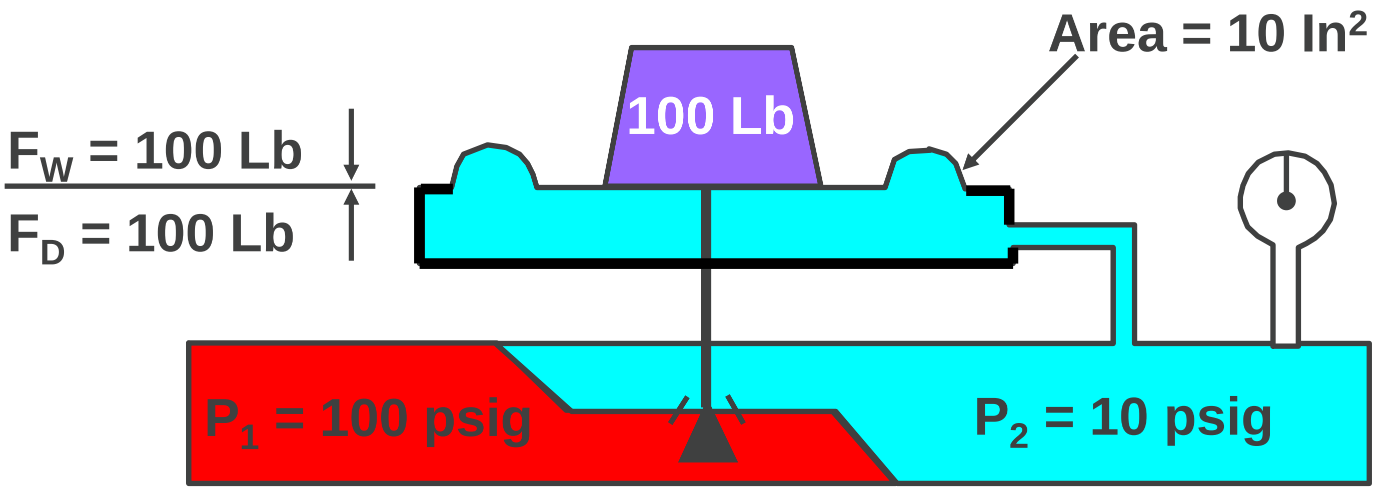
Three Essential Elements – Back @ Equilibrium



$$F_D = (P_2)(A_D) = (10\ \text{psig})(10\ \text{In}^2) = 100\ \text{Lb} \uparrow$$

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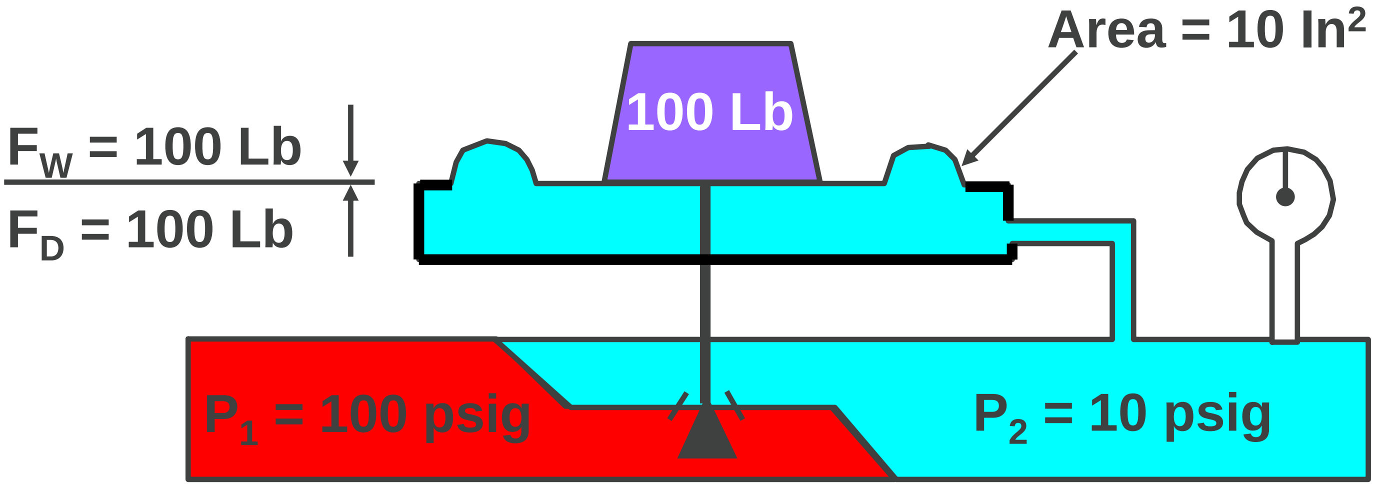
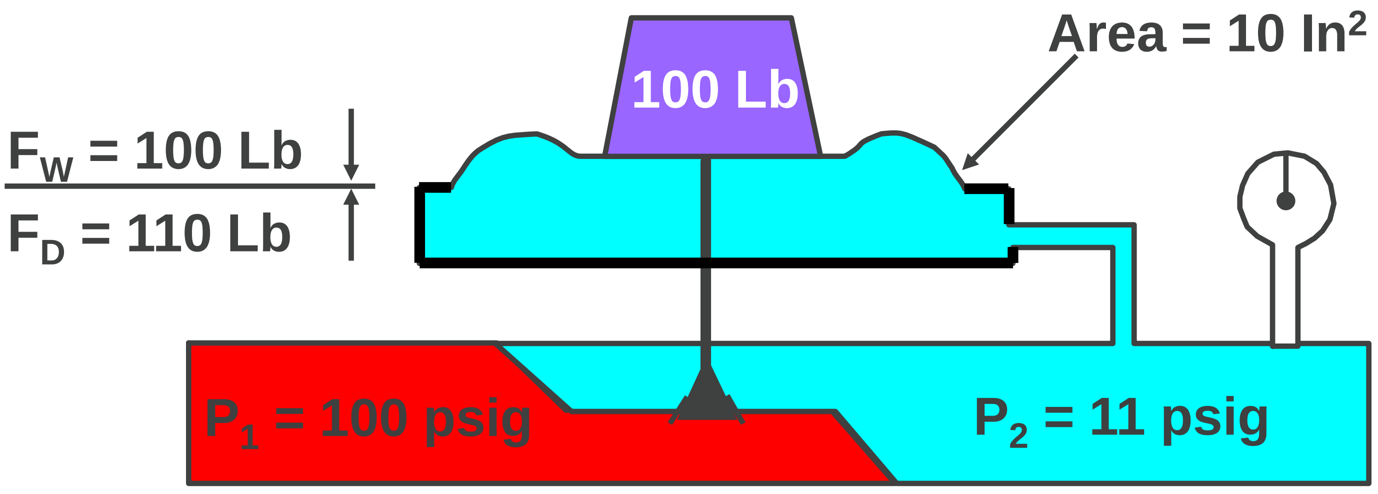
Three Essential Elements – Back @ Equilibrium



$$F_D = (P_2)(A_D) = (10 \text{ psig})(10 \text{ In}^2) = 100 \text{ Lb} \uparrow$$

What happens to outlet pressure when demand for gas stops?

Three Essential Elements



$$F_D = (P_2)(A_D) = (11 \text{ psig})(10 \text{ In}^2) = 110 \text{ Lb} \uparrow$$

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Three Essential Elements

- Weight as a Loading Element
  - Although weights apply a constant force, they have inertia
  - Inertia causes weights to have trouble tracking quick or large changes in downstream pressure due to overshoot
  - A weight-loaded regulator could constantly be seeking its setpoint in situations with frequent changes in demand
  - Downstream pressure will not be steady in this case
  - Other issues: limited orientation, adjustability

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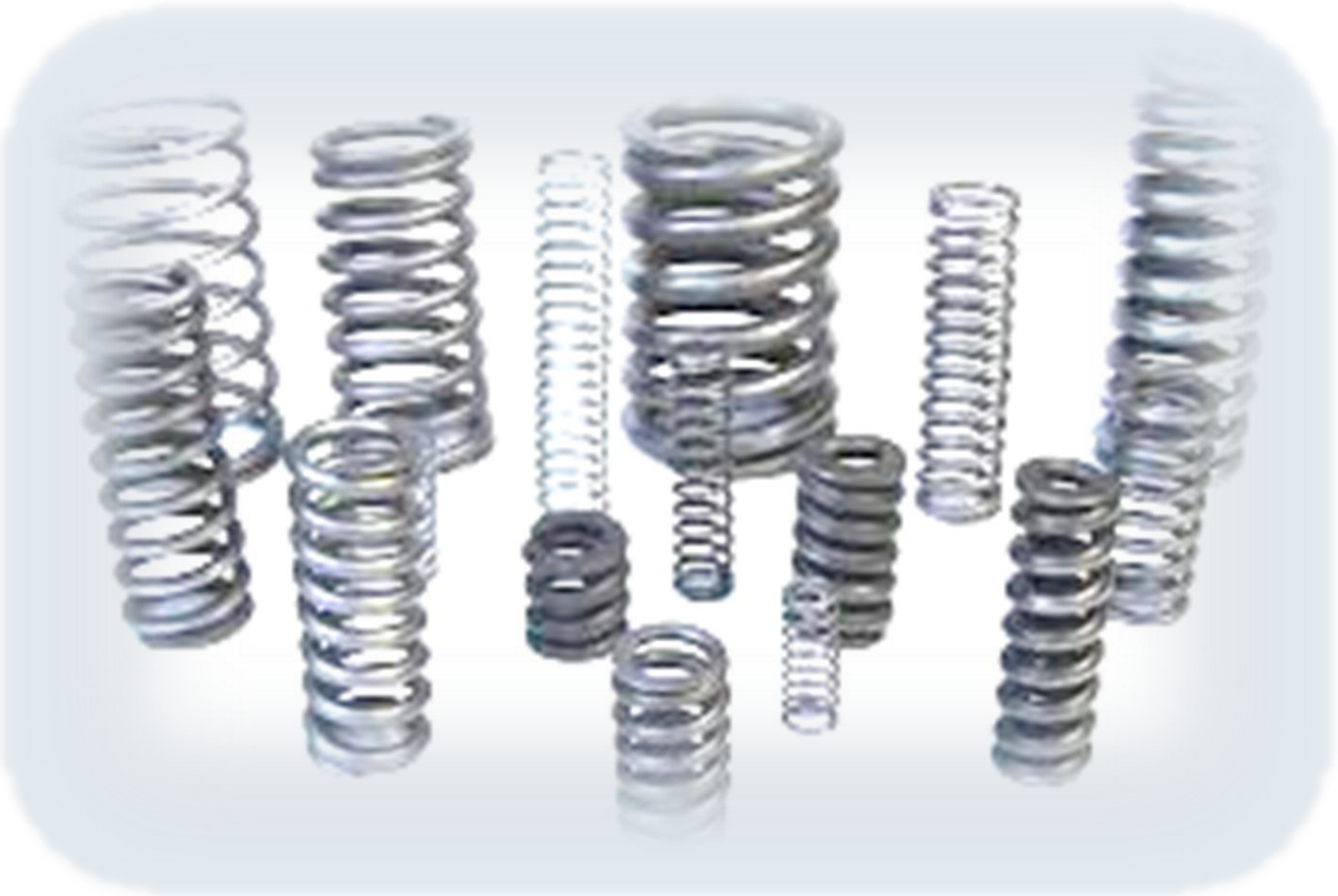
Spring-Loaded Regulator

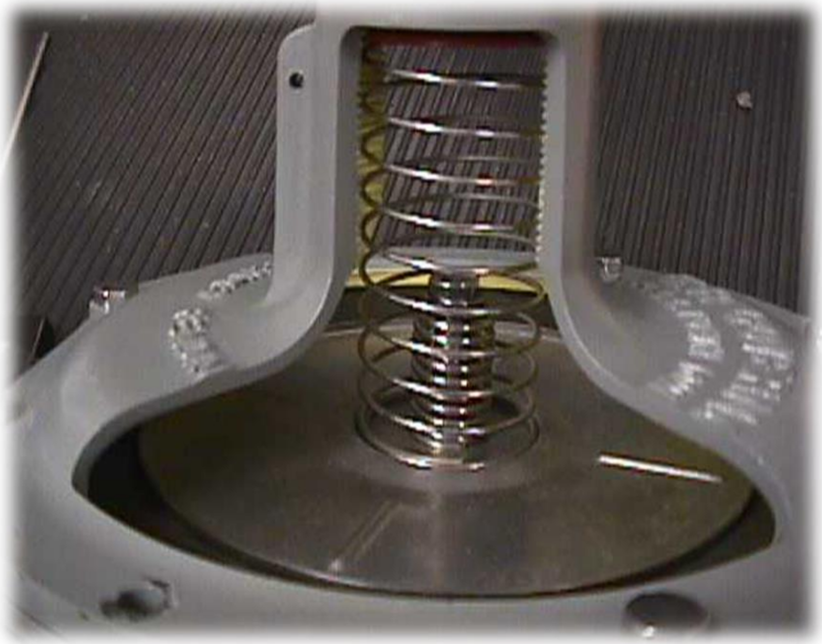


Spring-Loaded Regulator

Loading Element (Spring)

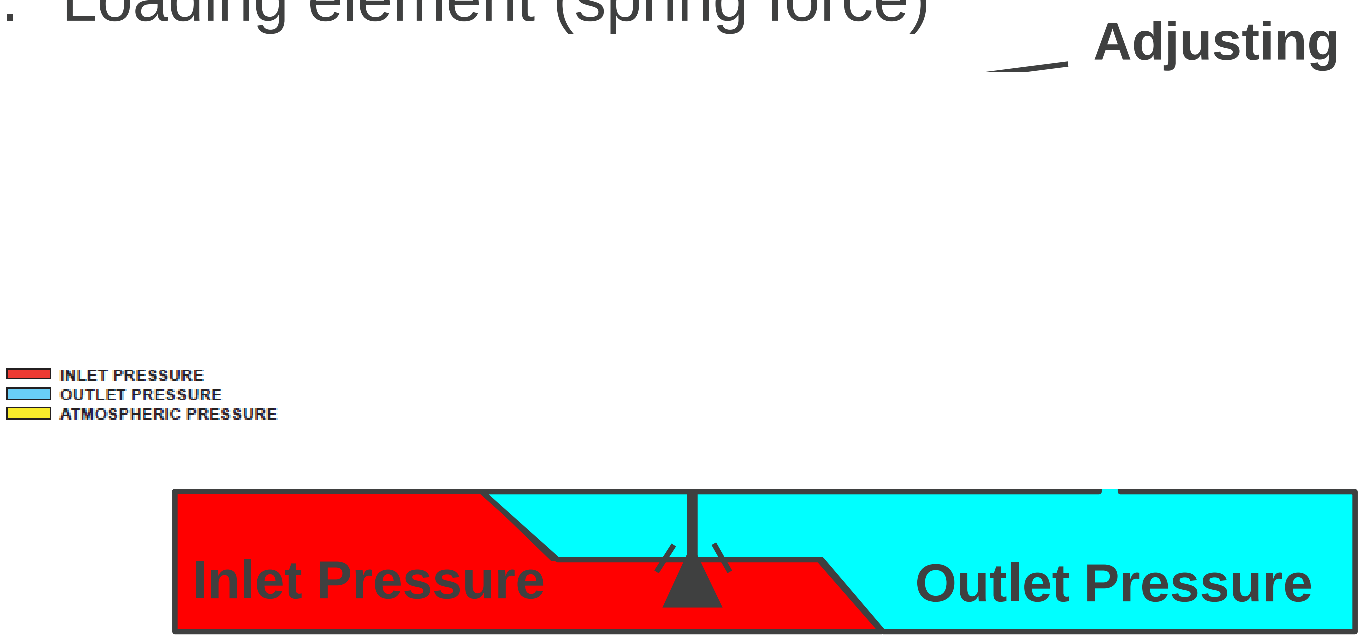
Advantages of spring-loaded regulators:

- Low mass – low inertia
- Easily adjustable set pressure
- Any mounting orientation
- Protection from the elements

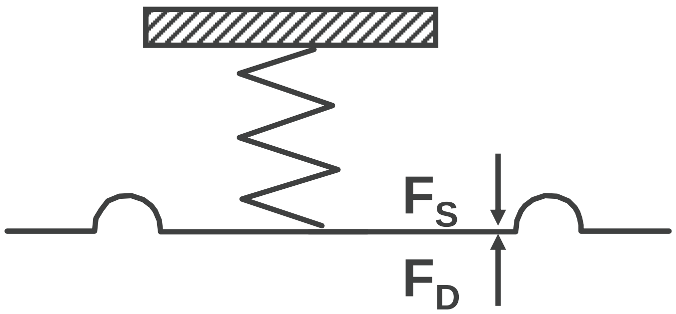


Three Essential Elements

1. Restricting element (valve plug & orifice)
2. Measuring element (diaphragm)
3. Loading element (spring force)



Force Balance



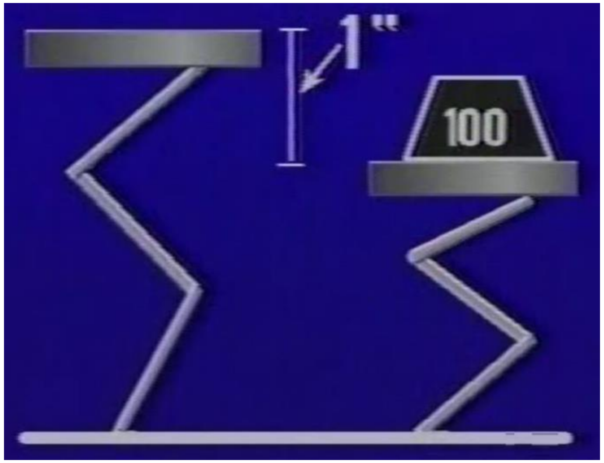
$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

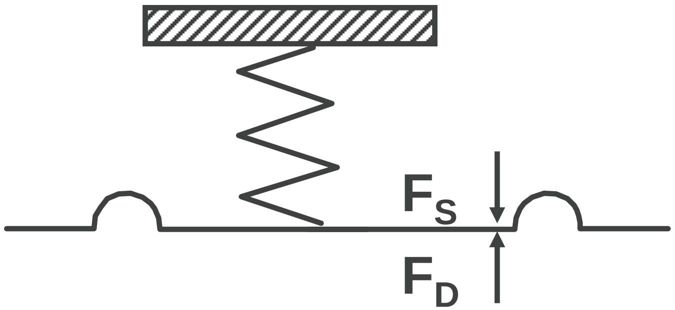
$F_S = (K)(X)$

K = Spring Rate = amount of force required to compress a spring one inch pounds per inch

X = Compression measured in inches



Spring Force



$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

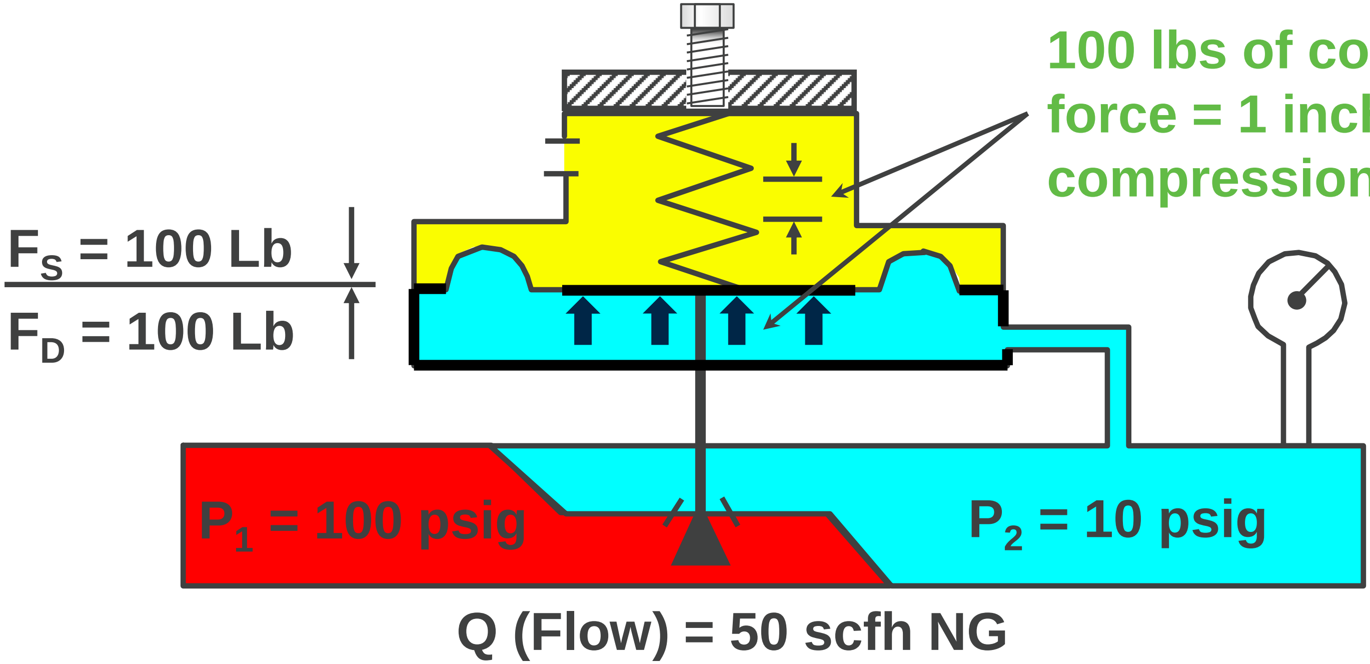
$F_S = F_D$
(In Order for Diaphragm Not to Move)

$F_D = (10 \text{ psig})(10 \text{ in}^2) = 100 \text{ Lb}$

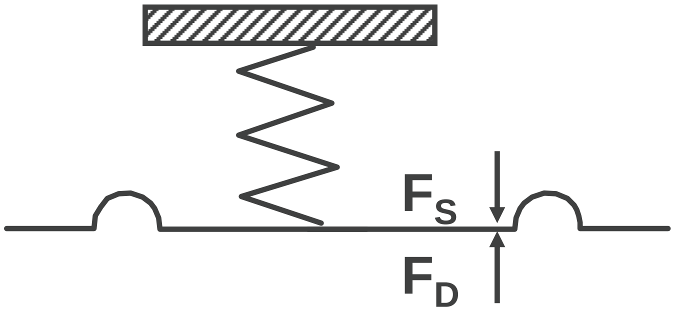
$F_S = (100 \text{ Lb/In})(X) = 100 \text{ Lb}$

X = 1 Inch Compression

Force Balance



Valve Travel - Spring Relaxing



$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

$F_S = F_D$

$F_D = (9 \text{ psig})(10 \text{in}^2) = 90 \text{ Lb}$

$F_S = (100 \text{ Lb/in})(X) = 90 \text{ Lb}$

X = .9 inch compression

Spring has relaxed 1 - 0.9 = 0.1 inches

So diaphragm has moved down <u>0.1 inches</u>

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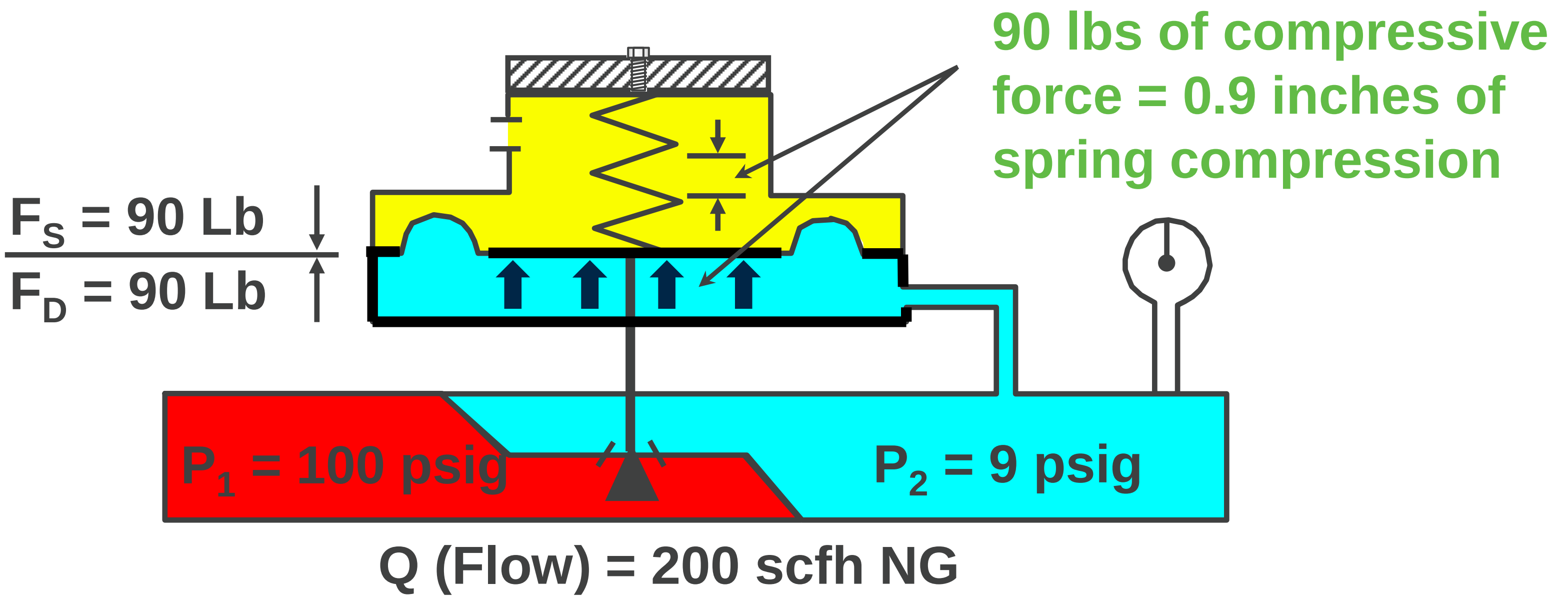
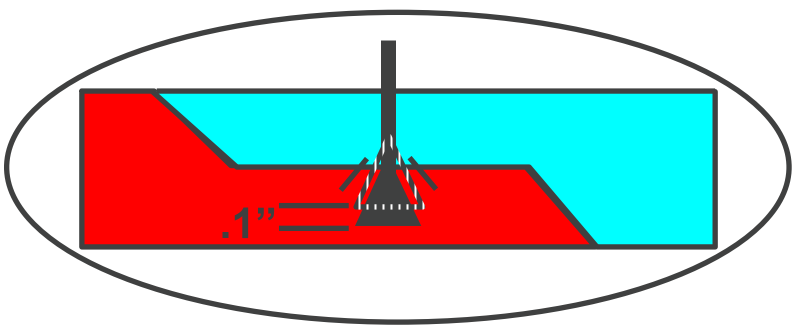
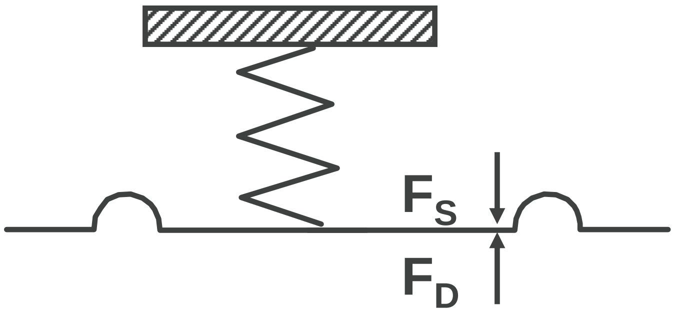
Valve Travel





Valve Travel



$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

$F_S = F_D$

$F_D = (8 \text{ psig})(10 \text{in}^2) = 80 \text{ Lb}$

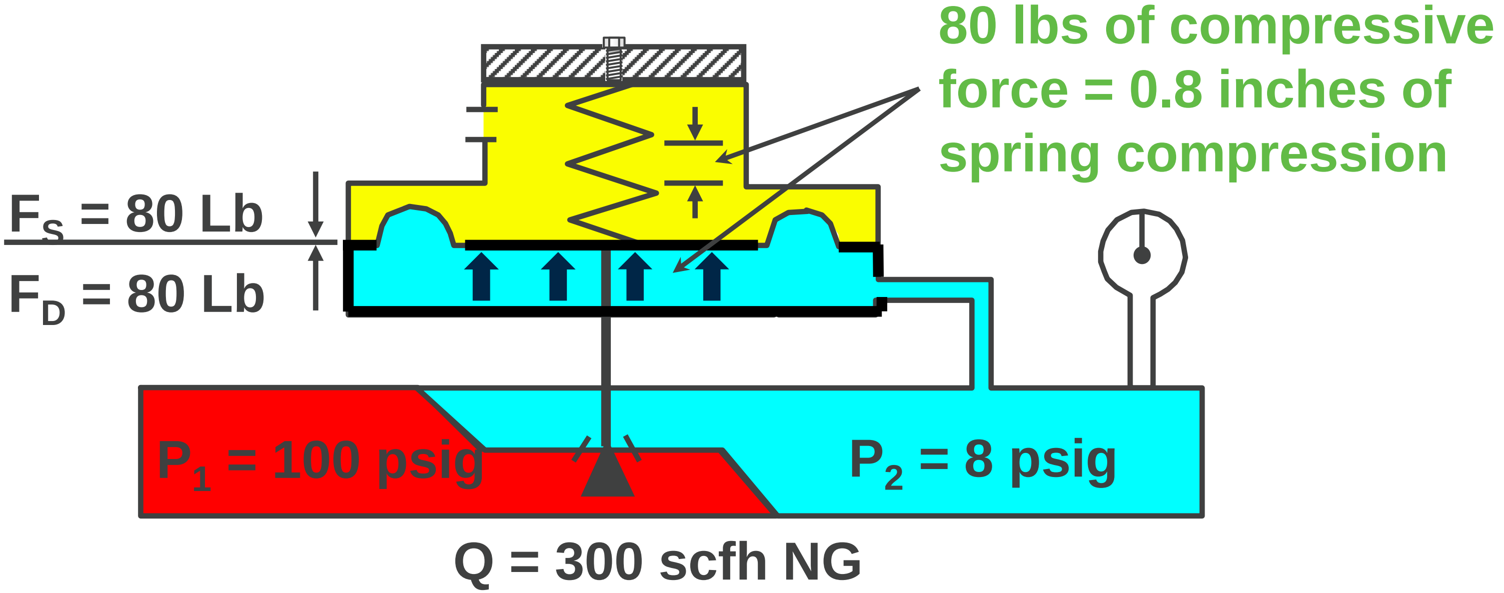
$F_S = (100 \text{ Lb/in})(X) = 80 \text{ Lb}$

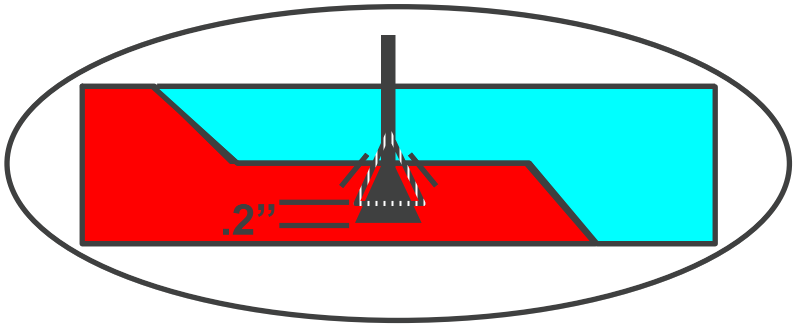
X = .8 inch compression

Spring has relaxed 0.9 - 0.8 = 0.1 inches

So diaphragm has moved down 0.1 inches

Valve Travel





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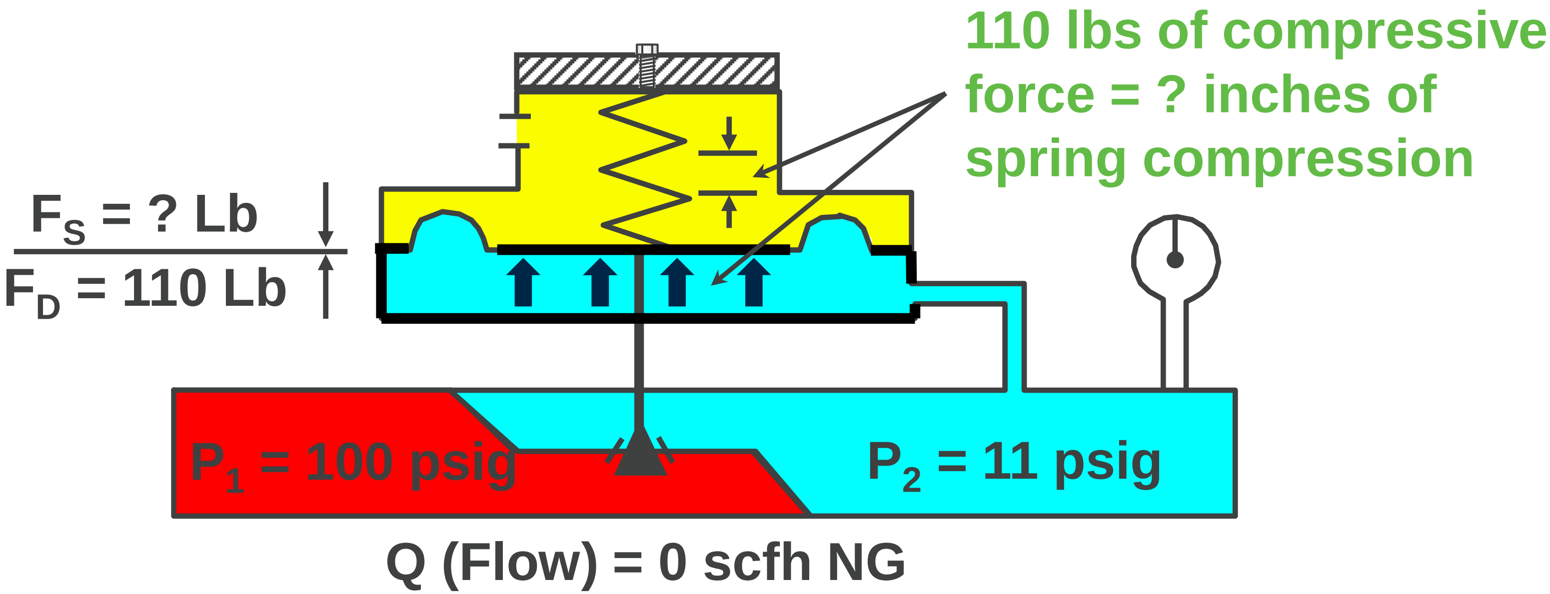
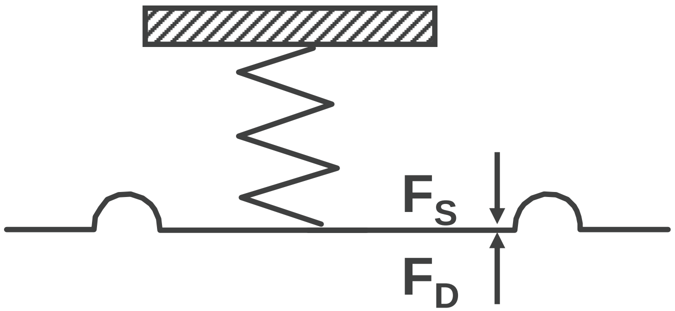
Valve Travel - Spring Compressing

What happens if an appliance downstream was suddenly shut off?

Ex: 8 psig jumps up to 11 psig



Valve Travel



$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

$F_S = F_D$

$F_D = (11\ \text{psig})(10\text{in}^2) = 110\ \text{Lb}$

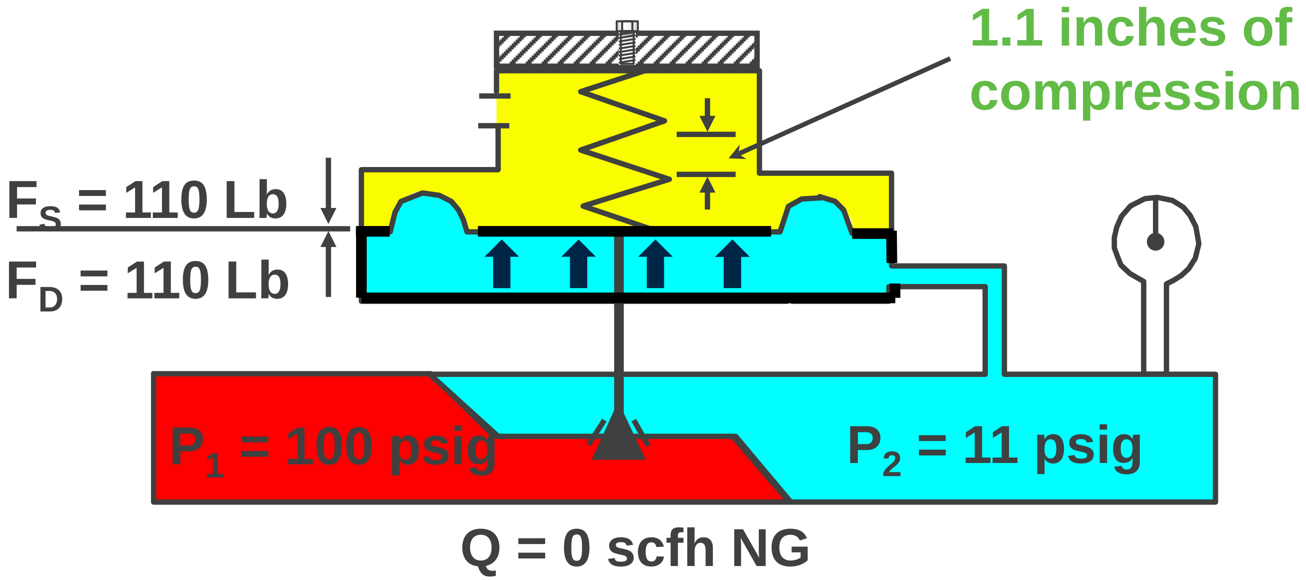
$F_S = (100\ \text{Lb/in})(X) = 110\ \text{Lb}$

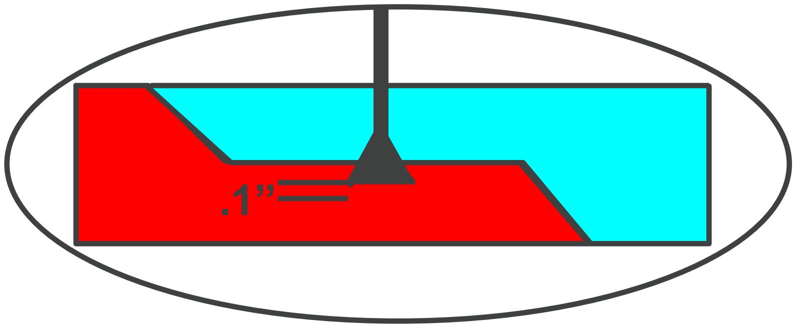
X = 1.1 Inches of compression

Spring has compressed 0.8 - 1.1 = - 0.3 inches

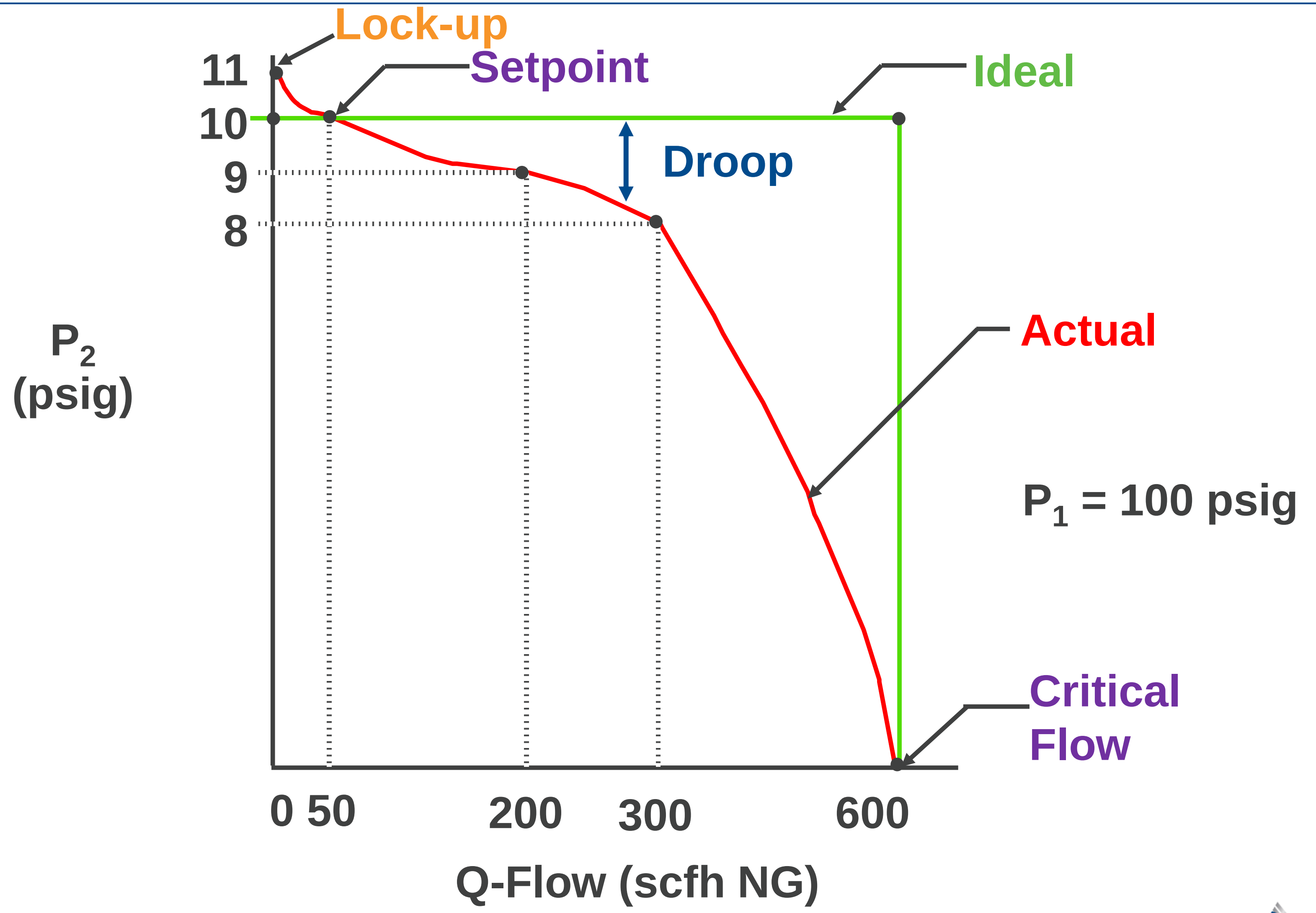
So diaphragm has moved up <u>0.3 Inches</u>

Valve Travel





Capacity Curves



Capacity Curve Terms – To Be Defined

- Set Pressure (Setpoint)
- Droop/Offset/Accuracy
- Lock-up
- Critical Flow

Set Pressure

Definition: The pressure at which the regulator is set (P_2) at a given inlet pressure (P_1) and flow (Q_{scfh})

Establishing setpoint on a regulator – setting adjusting screw:

- Make sure inlet pressure is constant (ex. 100 psig)
- For small regulators (ex. House Service) use a small valve to simulate ~ 50 scfh load downstream
- Once flow is established, make adjustment to the outlet pressure via the regulator adjusting screw (ex. 10 psig)
- Once setpoint is established, shut small valve slowly and check lockup
  - Note: Establishing setpoint at a high flow will cause your regulator to have a high lockup pressure

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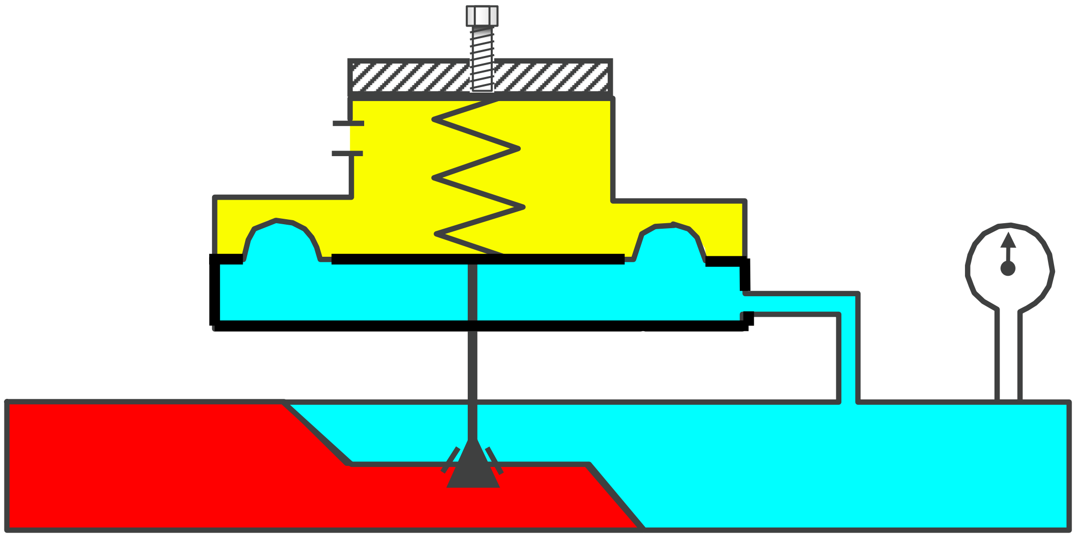
Droop

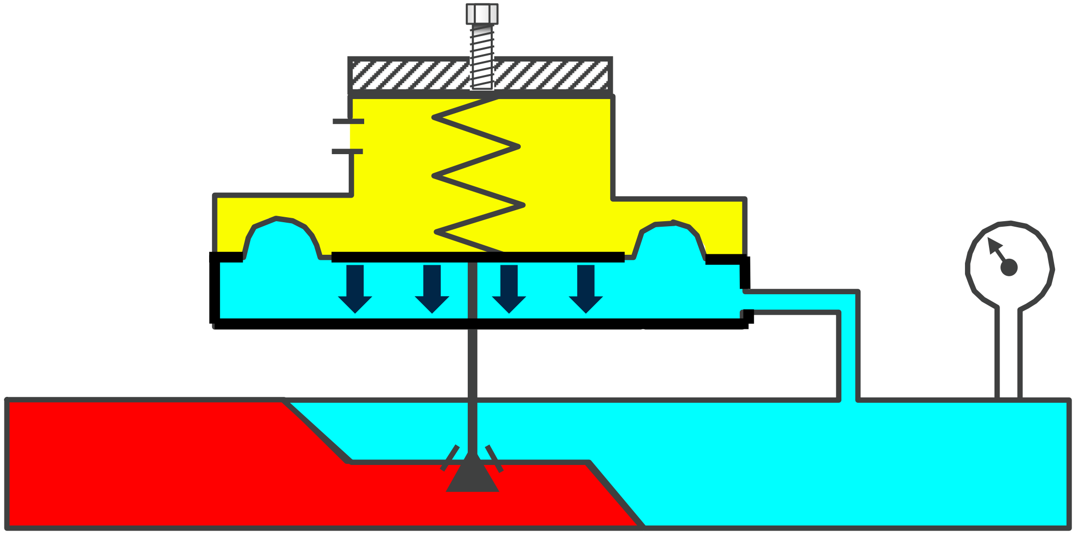
Definition: The offset from setpoint required to open the regulator to match a need for more gas to flow



10 psig
Setpoint

Droop

Definition: The offset from setpoint required to open the regulator to match a need for more gas to flow



9 psig @
higher flow

Calculating Droop

- Calculated by comparing:

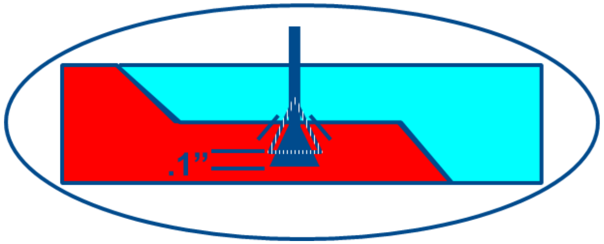
  The change in outlet pressure vs. the original setpoint:

  - P_2 (original set point): 10 psig
  - P_2 (after increase in flow): 9 psig

  - $\Delta P_2 = P_2$ (original) – P_2 (after)
  - ΔP_2 = 10 psig – 9 psig
  - $\Delta P_2 = 1$

  - Droop = $\Delta P_2 / P_2$ (original)
  - Droop = 1 psi / 10 psig
  - Droop = .1 or 10%
  - Q = 200 SCFH

10% Droop results in .1 inch in valve plug travel



How Do You Know What the Droop is?

- It is advertised in manufacturers’ bulletins:
  - As a “%”, example 10%
  - or Offset

SETPOINT	ACCURACY + / - 10%		SET RANGE	PART NUMBER / COLOR
2 psig	-0.2 psi	0.2 psi	1 to 2 psig	GE30190X012 / Black
138 mbar	-14 mbar	14 mbar	69 to 138 mbar	

CAPACITIES IN SCFH / Nm³/h OF 0.6 SPECIFIC GRAVITY NATURAL GAS															
Inlet Pressure		Orifice Size, In. / mm													
		3/16	4.8	1/4	6.4	5/16	7.9	3/8	9.5	1/2	13	5/8	16	3/4	19
		SCFH	Nm³/h	SCFH	Nm³/h	SCFH	Nm³/h	SCFH	Nm³/h	SCFH	Nm³/h	SCFH	Nm³/h	SCFH	Nm³/h
psig	bar	Body Size: NPS 1-1/4													
3	0.21	270	7.2	330	8.8	630	16.9	850	22.8	860	23.0	870	23.3	1000	26.8
5	0.34	500	13.4	740	19.8	730	19.5	1000	26.8	1200	32.2	1600	42.9	1900	51.0
10	0.69	680	18.2	1000	26.8	1100	29.5	1700	45.6	2200	59.0	2900	77.8	3400	91.2
15	1.0	640	17.1	1300	34.8	1700	45.6	2500	67.1	3200	85.9	4600	123	5300	142

OUTLET PRESSURE RANGE, CONTROL SPRING PART NUMBER, AND COLOR	OFFSET FROM SETPOINT	OUTLET PRESSURE SETTING	INLET PRESSURE, PSIG (bar)	3/4 NPT BODY SIZE Capacities in SCFH (Nm³/h) of 0.6 Specific Gravity Natural Gas Orifice Size, Inches (mm)					
				1/8 (3,2)	3/16 (4,8)	1/4 (6,3)	3/8 (9,5)	1/2 (13)	9/16 (14)
1.2 to 2.5 psig (83 to 172 mbar) 1B537127022 Green	0.2 psig (14 mbar)	1.2 psig (83 mbar)	2 (0,14)	120 (3,2)	170 (4,6)	220 (5,9)	350 (9,4)	490 (13,1)	520 (13,9)
			6 (0,41)	180 (4,8)	340 (9,1)	450 (12,1)	740 (19,8)	850 (22,8)	1070 (28,7)
			10 (0,69)	190 (5,1)	440 (11,8)	590 (15,8)	1010 (27,0)	1170 (31,3)	
			30 (2,1)	560 (15,0)	900 (24,1)	1550 (41,5)	1720 (46,1)		
			60 (4,1)	860 (23,1)	1110 (29,7)	2480 (66,5)	2340 (62,7)		
			150 (10,3)	1990 (53,3)	3480 (93,3)	3500 (93,8)			
		2.5 psig (172 mbar)	6 (0,41)	140 (3,8)	190 (5,1)	260 (7,0)	450 (12,1)	590 (15,8)	680 (18,2)
			10 (0,69)	170 (4,6)	340 (9,1)	490 (13,1)	570 (15,3)	860 (23,1)	
			30 (2,1)	430 (11,5)	660 (17,7)	980 (26,3)	1030 (27,6)		
			60 (4,1)	750 (20,1)	850 (22,8)	1940 (51,9)	2250 (60,3)		
			150 (10,3)	1480 (39,7)	2320 (62,2)	3350 (89,8)			

Lock-up Tail

Definition: The amount of pressure buildup over setpoint to achieve zero flow (bubble tight shut-off)

- What contributes to buildup in pressure?
  - Increase of P_2 to overcome spring force
  - Increase of P_2 to push the soft seat into the orifice
- What affects lockup?
  - Damaged orifice / seat ring
  - Damaged soft seat
  - Different durometers of elastomeric materials (nitrile vs. nylon)
  - The amount of flow going through the regulator when setpoint is made

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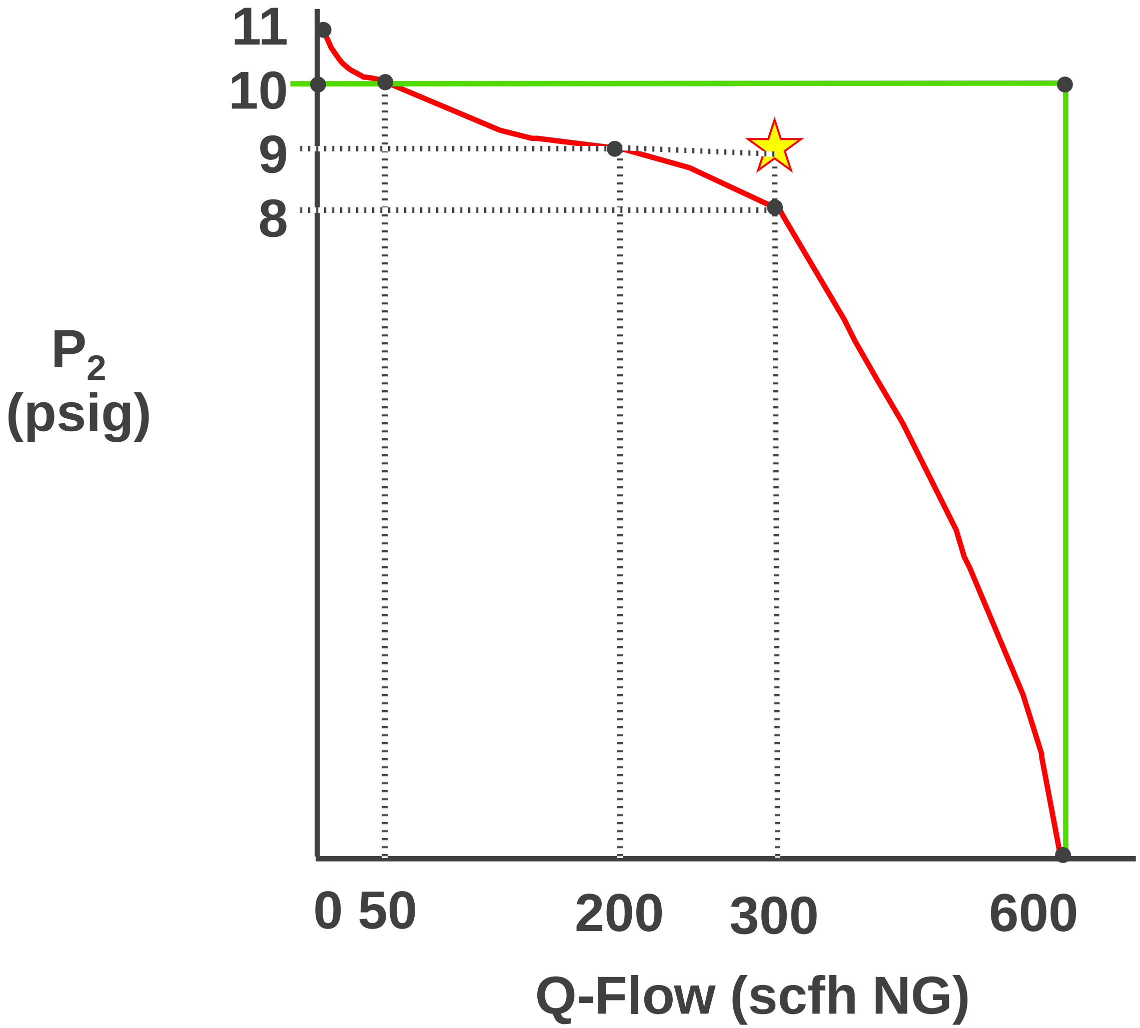
Critical Flow

Definition: The rate a which a fluid flows through an orifice when the stream velocity at the orifice is equal to the velocity of sound in the fluid

- The rate of flow may be increased by
  - Increase in upstream pressure *(increase P_1)*
  - Increase in the restriction size *(increase orifice size)*
  - Will not be affected by a decrease in downstream pressure or *by cranking in the adjusting screw*
- Critical Flow occurs when P_2 is approximately less than or equal to ½ (P_1 absolute)
  - $P_2 <= \frac{1}{2} P_{1abs}$

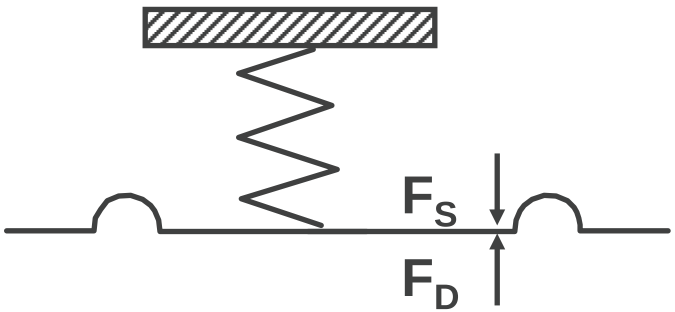
Application: Customer Need: 10% Droop, 300 scfh NG

Will the current regulator meet the application??



P_1 = 100 psig

Use a Lighter Spring with Smaller K Factor



$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

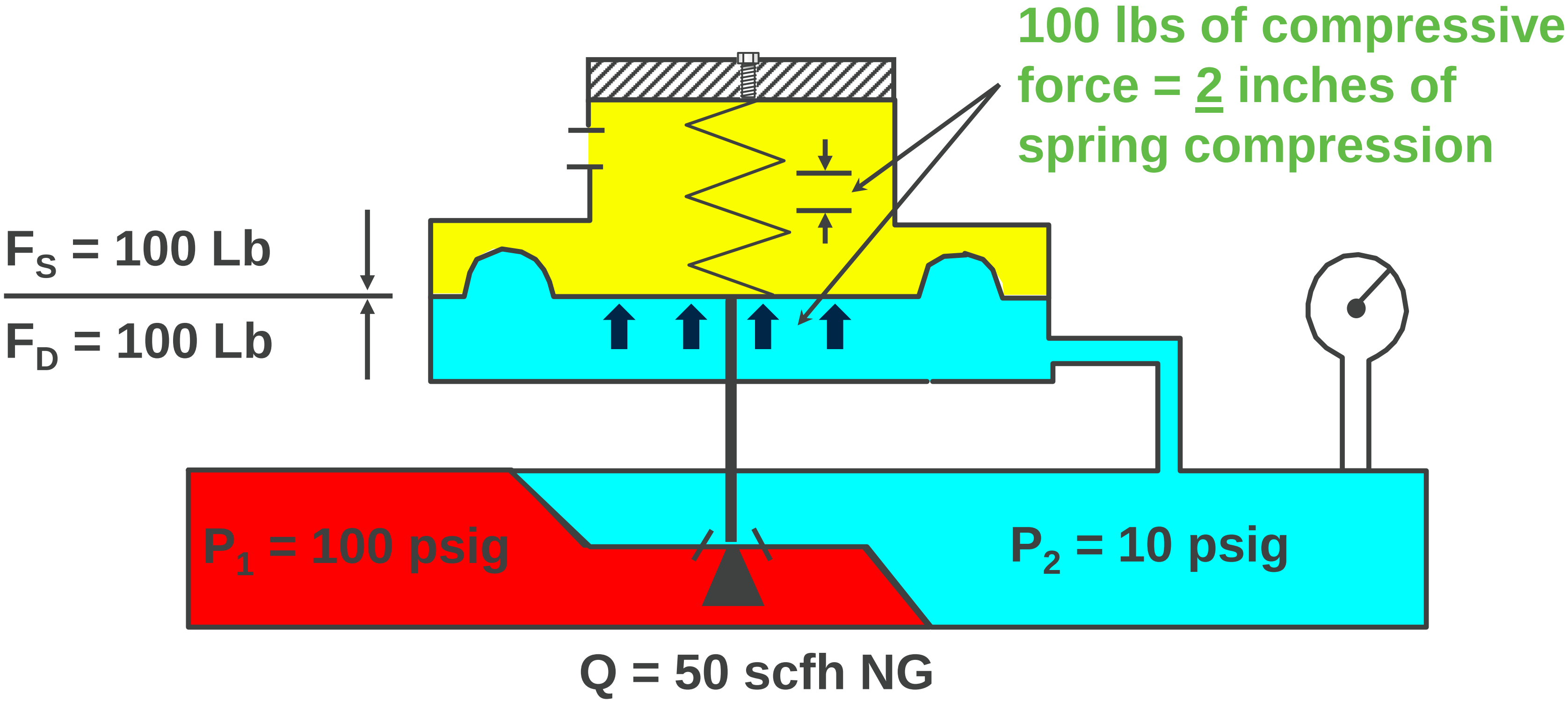
$F_S = F_D$

$F_D = (10 \text{ psig})(10 \text{ in}^2) = 100 \text{ Lb}$ ↑

$F_s = (50 \text{ Lb/in})(X) = 100 \text{ Lb}$ ↓

X = 2 Inches Compression

Using a Lighter Spring



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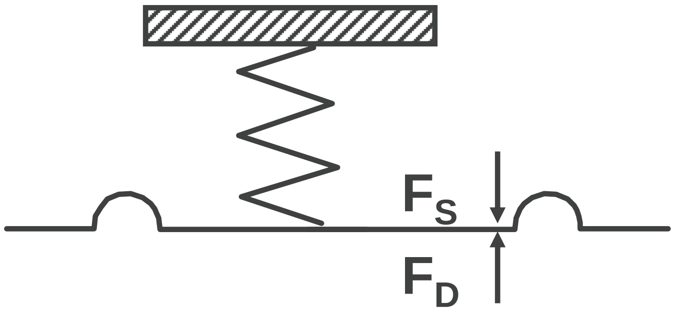
Using a Lighter Spring



$F_S = (K)(X)$

$F_D = (P_2)(A_D)$

$F_S = F_D$

$F_D = (9\ \text{psig})(10\text{in}^2) = 90\ \text{Lb}$ ↑

$F_S = (50\ \text{Lb/in})(X) = 90\ \text{Lb}$ ↓

X = 1.8 inches compression

Spring has relaxed 2 - 1.8 = 0.2 inches

So diaphragm has moved down <u>0.2 inches</u>

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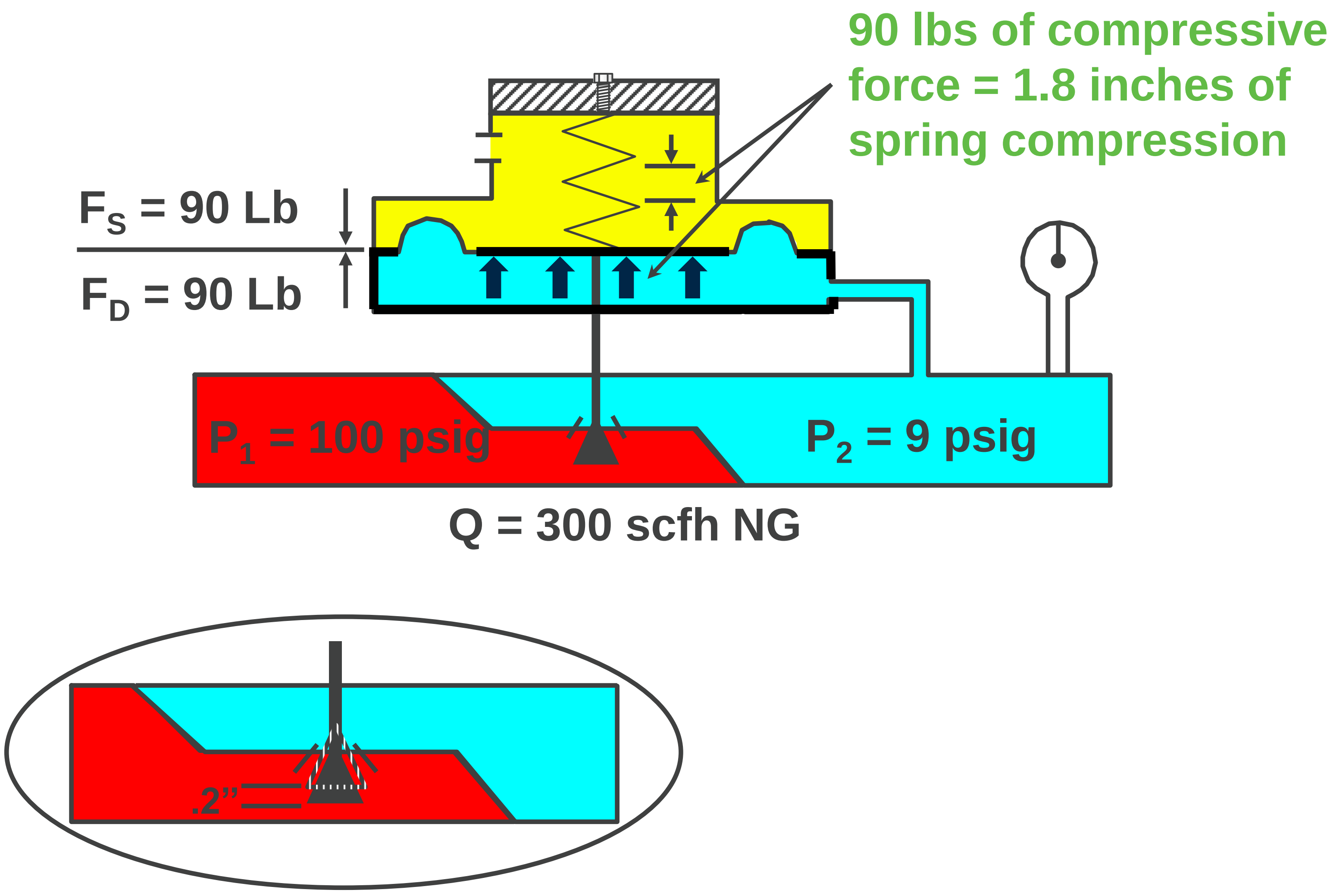
Using a Lighter Spring



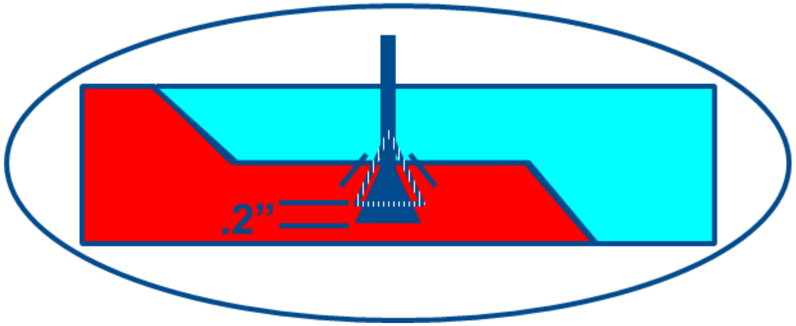
Calculating Droop: Lighter Rate Spring

- Calculated by comparing the change in outlet pressure vs. the original setpoint:
  - P_2 (original set point): 10 psig
  - P_2 (after increase in flow): 9 psig

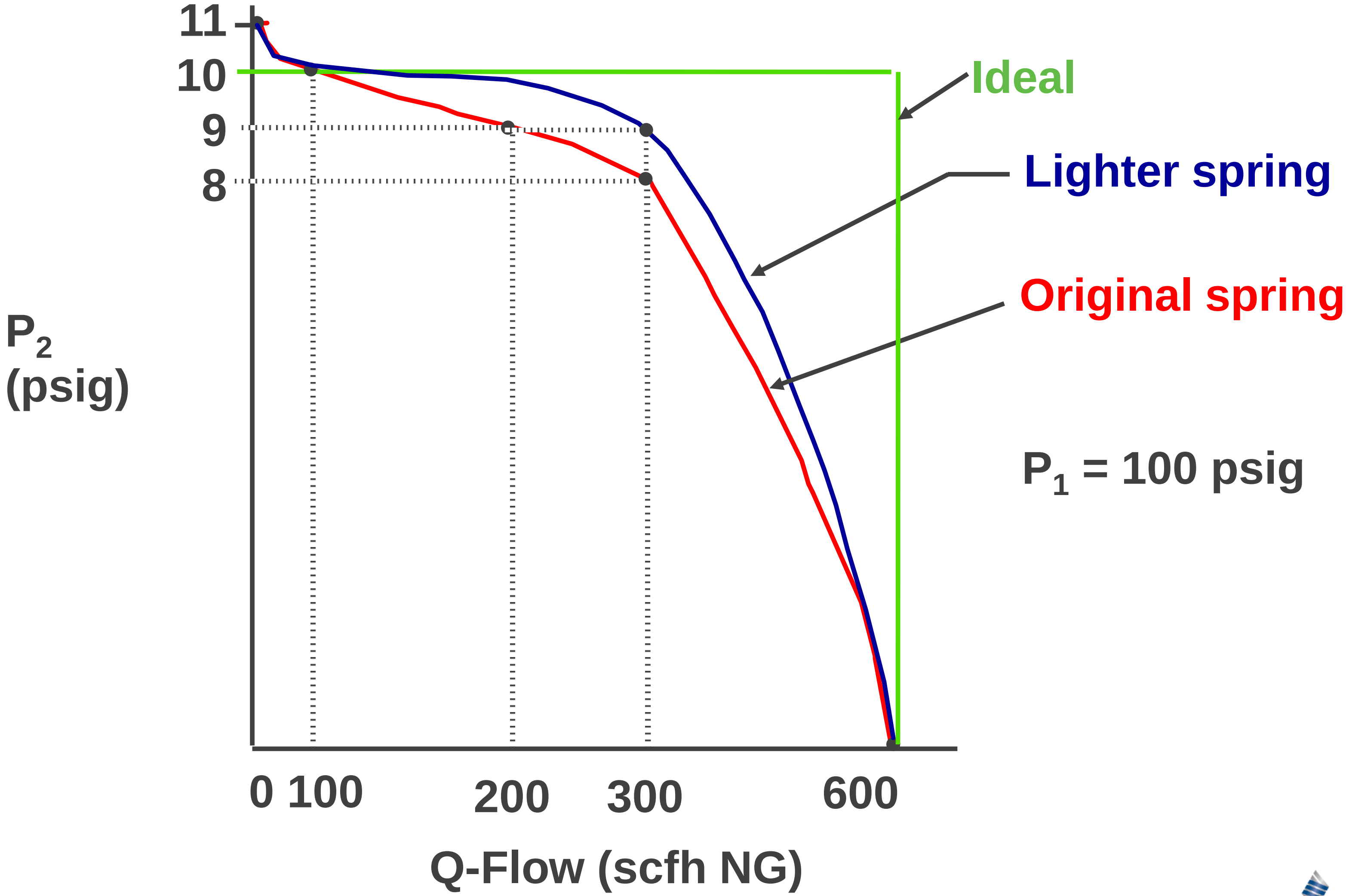
  - $\Delta P_2 = P_2$ (original) – P_2 (after)
  - $\Delta P_2 = 10$ psig – 9 psig
  - $\Delta P_2 = 1$

  - Droop = $\Delta P_2 / P_2$ (original)
  - Droop = 1 psi / 10 psig
  - Droop = .1 or 10%
  - Flow = 300 SCFH

10% Droop results in .2 inch in valve plug travel



Spring Effect on Accuracy



What is Accuracy to a Regulator?

- For a given set of conditions (see below), the regulator that gives you the most flow is the most accurate
  - Example:
    - Inlet Pressure: P_1 = 100 psig
    - Outlet Pressure: P_2 = 10 psig
    - Orifice Size: assume ¼”
    - Droop: 10%

Which Regulator is more accurate?

- ***Ex. 1: Q = 200 SCFH @ 10% droop***
- ***Ex. 2: Q = 300 SCFH @ 20% droop***
- ***Ex. 3: Q = 300 SCFH @ 10% droop***

Spring Effect on Droop

- Manufacturers provide spring ranges
- Remember: Lighter Spring = More Accuracy = More Travel = More Flow
- Stay within recommended spring range

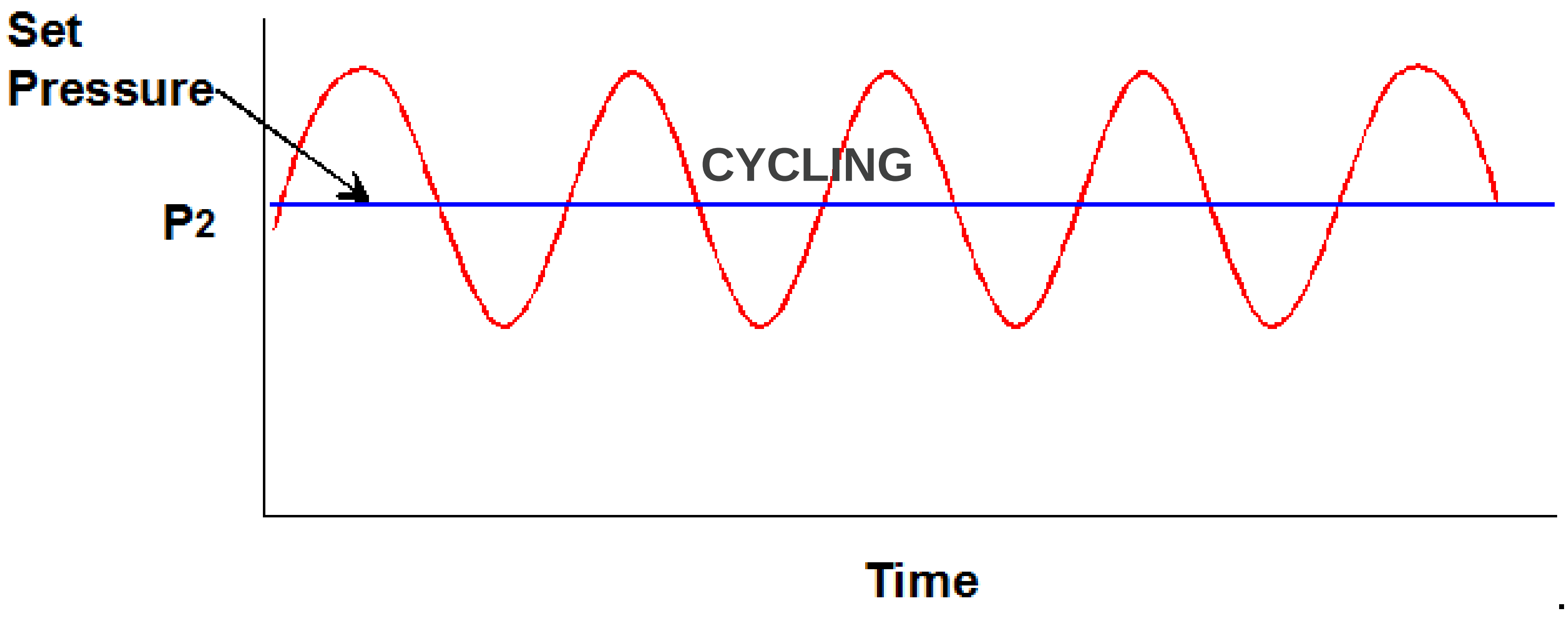
1st Rule of Thumb: Always select the lightest spring for the application

First Rule of Thumb

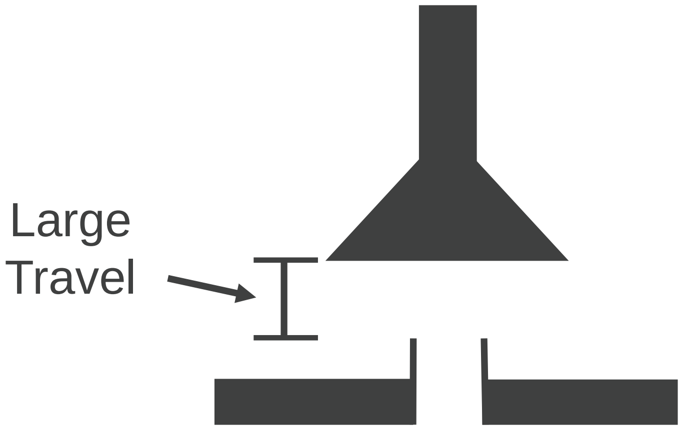
- <u>*Always select the lightest rate spring (less droop)*</u>
- If the setpoint on a 627 is 20 psig, choose the best spring for the application <u>*(if accuracy is important):*</u>
  a) **Spring range: 5 to 20 psig**
  b) **Spring range: 15 to 40 psig**
  c) **Spring range: 35 to 80 psig**

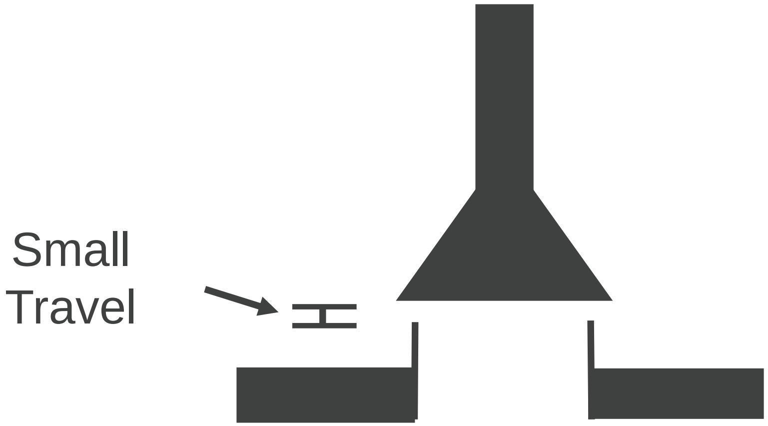
Spring Rate & Stability

- Always **start** with the lightest rate spring



Orifice Considerations





- Larger orifice results in less travel for same flow
- Oversized orifice causes disc to ‘hover’ near orifice
  - Disc will have a tendency to try and shut off
  - May cause instability at low flows

2nd Rule of Thumb: Always use the smallest orifice

Orifice Considerations

- Smaller Orifice
  - Less area to seal against results in better lockup

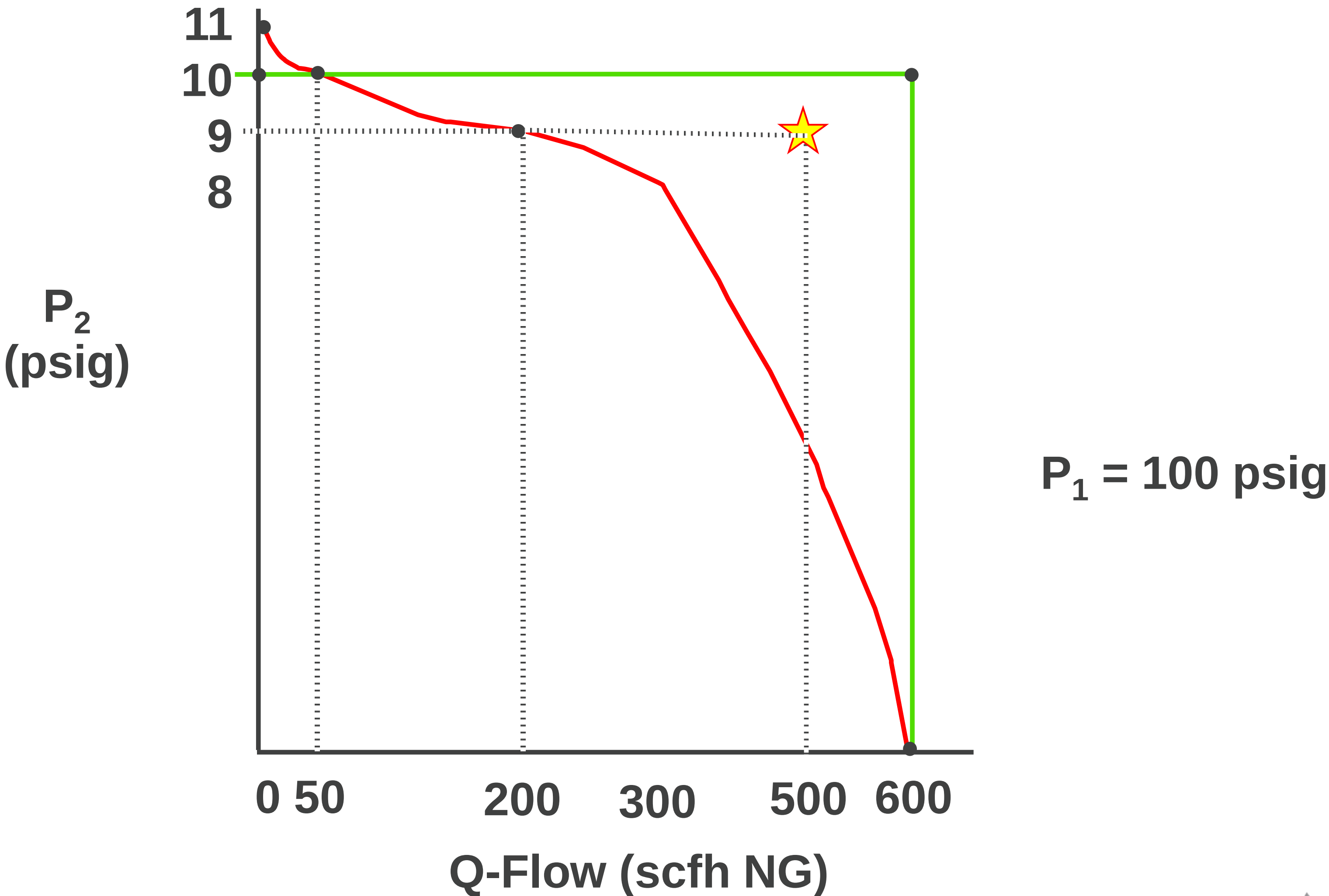
- Smaller orifice results in $$$ savings for overpressure protection (OPP)
  - Smaller relief valve is needed

2nd Rule of Thumb: Always use the smallest orifice

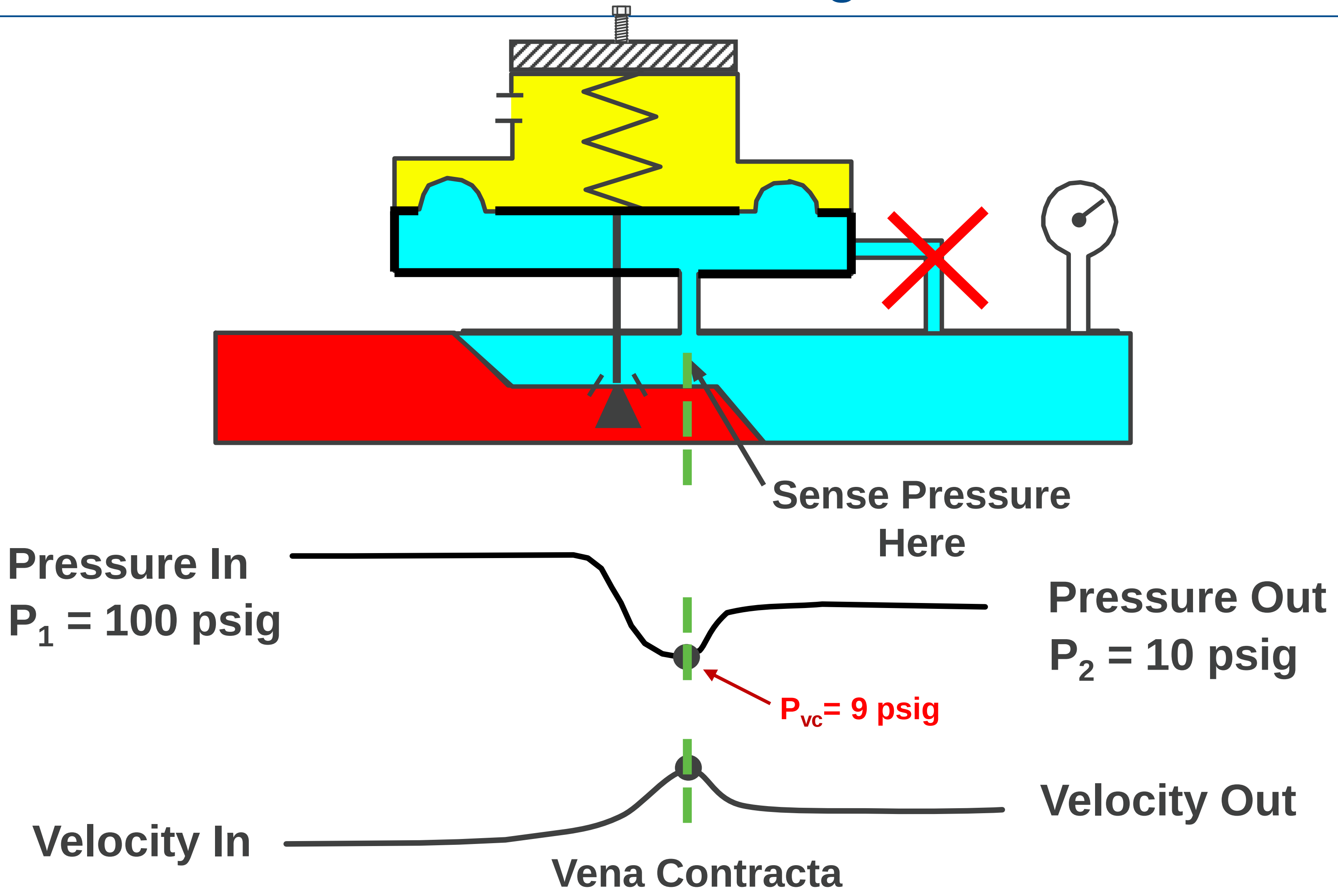
Rules of Thumb

- What is the first rule of thumb?
  - Always use the lightest spring for a given application
    - Improved accuracy (less droop)
- What is the second rule of thumb?
  - Always use the smallest orifice for a given application
    - Better lockup
    - More stability

Customer Need: 10% Droop, 500 SCFH NG



Use Vena Contracta for Sensing Pressure



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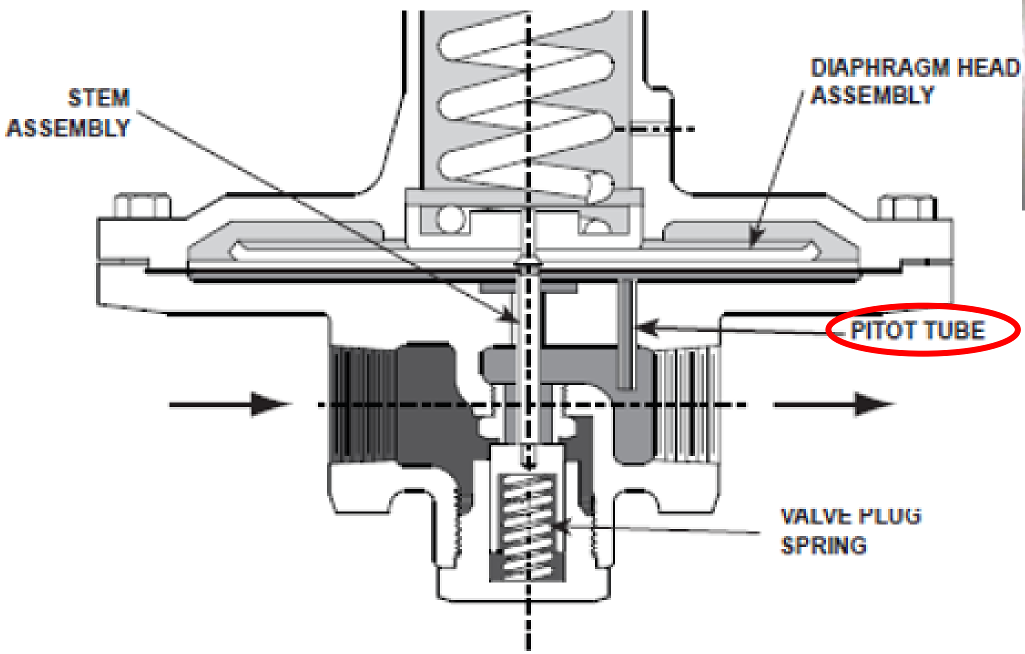
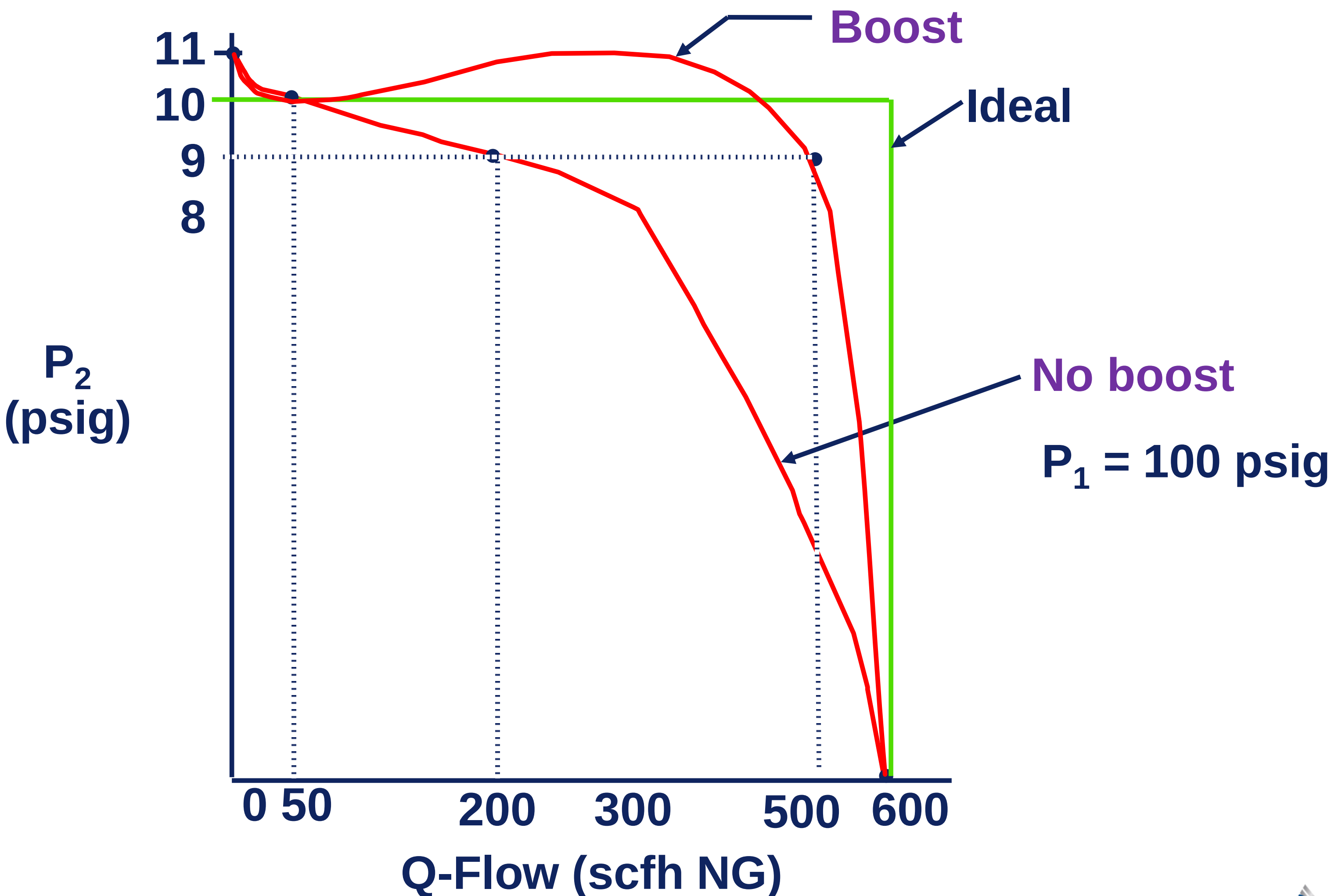
Boost Components in Regulators



Boost Effect

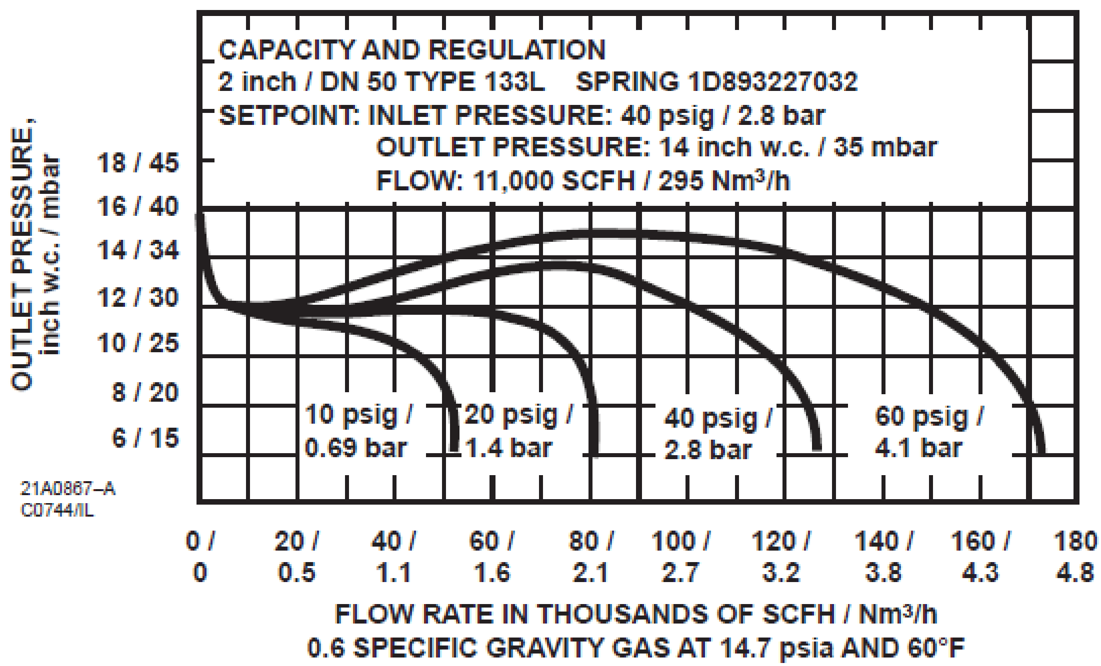


Boost Effect in Capacity Tables

***Table 17.** Types CS800[1,3], CS803[2,3] and CS804[3,5] Internal Registration Flow Capacities for 7 in. w.c. / 17 mbar Setpoint for 2 in. / DN 50 Body Size, Enhanced Low Inlet (LIN) Option*

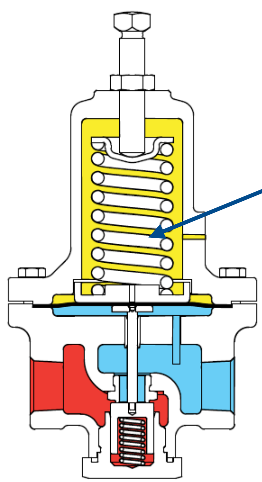
SETPOINT	ACCURACY		SPRING	
	Droop	Boost	Set Range	Part Number / Color
7 in. w.c.	-1 in. w.c.	2 in. w.c.	5.5 to 8.5 in. w.c.	GE49043X012 / Brown
17 mbar	-2.5 mbar	5 mbar	13 to 21 mbar	

OUTLET PRESSURE SETTING, SPRING RANGE, DROOP AND BOOST
5 in. w.c. / 12 mbar
4 to 6 in. w.c. / 10 to 15 mbar
1 in. w.c. droop 2 in. w.c. boost



Diaphragm Size and Pressure Ranges

- Diaphragm size is correlated with the ability to control certain pressure ranges
  - Larger diaphragms = lower set pressures
  - Smaller diaphragms = higher set pressures
- Larger diaphragms are more sensitive to changes in downstream pressure

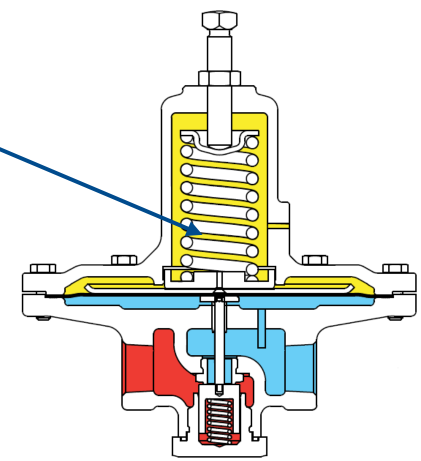


Same Spring

$$F_S = (K)(X)$$

$$F_D = (P_2)(A_D)$$

$$F_S = F_D$$



Spring Range: 15-30 psig

Spring Range: 2-6 psig

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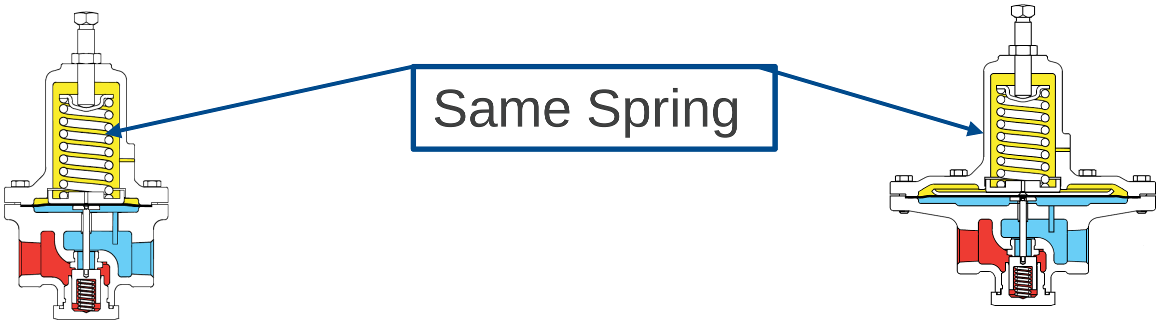
Diaphragm Size and Pressure Ranges

Smaller Diaphragm Area | **Larger Diaphragm Area**



Smaller Diaphragm Area

Diaphragm Area= 5 in^2

Spring Rate= 100 lb/in

Compression= 1 inch

$$\mathbf{F_S = (100\ lb/in)(1)}$$

$$\mathbf{F_D = (P_2)(5\ in^2)}$$

$$\mathbf{F_S = F_D}$$

$(P2)(5in^2)\ = (100\ Lb/in)(1)$

P_2set= 20 psig

Larger Diaphragm Area

Diaphragm Area= 20 in^2

Spring Rate= 100 lb/in

Compression= 1 inch

$$\mathbf{F_S = (100\ lb/in)(1)}$$

$$\mathbf{F_D = (P_2)(20\ in^2)}$$

$$\mathbf{F_S = F_D}$$

$(P2)(20in^2)= (100\ Lb/in)(X)$

P_2set= 5 psig

Diaphragm Size Impacts the Spring Range of a Product

Diaphragm Size and Other Considerations

- Diaphragm size is correlated with the ability to control certain pressure ranges
  - Larger diaphragms = lower set pressures
  - Smaller diaphragms = higher set pressures

- Larger diaphragms are more sensitive to changes in downstream pressure
  - More force generated from pressure changes

- Diaphragm Effect: The change in the effective diaphragm area which contributes to droop. Effective diaphragm area changes with stroke.
  - Less impact for larger flat sheet diaphragms vs. smaller diaphragms.
  - Molded diaphragms maintain the effective area throughout the stroke of the regulator.

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Self-Operated Regulators

- Advantages:
  - Low cost
  - Simple maintenance
  - High speed of response

Typical Applications:

1. **Residential**
2. **Farm taps**
3. **Commercial meter sets**
4. **Fuel gas**

- Limitations:
  - Accuracy
  - Body size
  - Flow limited by droop

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ANY
QUESTIONS