Introduction to Regulator Theory and Operation
Agenda

• Pressure Reducing Regulator Operating Principle – Balance of Forces

• Sensing Elements

• Hard Seat vs. Soft Seat

• Loading Mechanisms

• Terms
Operating Principle

Pressure Reducing Regulator

The function of a pressure reducing regulator is to reduce a pressure and to keep this pressure as constant as possible while the inlet pressure and the flow may vary.
Operating Principle

The sensor (diaphragm or piston) balances the spring force and pressure forces.

As compression of spring increases, the poppet is pushed downwards and the regulator opens.

The poppet & seat ‘bleed’ the high pressure to low pressure side of the regulator.
Balance of Forces

Internal Forces
(Inlet & Outlet Pressure)

Loading Force
(Spring Force)

Sensing Element
Balance of Forces

\[ F_1 = \text{Loading Force} \]

\[ F_2 = \text{Inlet Spring Force} \]

\[ F_3 = \text{Outlet Pressure Force} \]

\[ F_4 = \text{Inlet Pressure Force} \]

\[ F_1 = F_2 + F_3 + F_4 \]

Loading Force

Internal Forces
Two Types of Sensing Elements

Diaphragm

Piston
Diaphragm vs. Piston Sensing

**Diaphragm**
- Greater sensitivity
- Choice of material

**Piston Sensing**
- Higher outlet pressure
- Less sensitive
Soft Seat vs. Hard Seat

Soft Seat

Hard Seat
Regulator with Soft Seat

Soft seat design for low-pressure applications

Rubber 0-ring
Regulator with Hard Seat

Hard seat design for high-pressure applications

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PCTFE or PEEK
Creep

An increase in outlet pressure typically caused by regulator seat leakage.

Regulators are not shut off devices…
Loading Mechanisms

3 TYPES

SPRINGLOADING

DOMEOLOADING

COMBINATION SPRING AND DOME
Spring-Loaded Regulators

Loading Mechanism
The loading mechanism is the component of the regulator that balances the force or pressure.

Spring-Loaded
In a spring-loaded regulator, a coil spring is used to generate a load ($F_S$) against the sensing mechanism. The amount of spring force or load can be adjusted by turning the handle or adjusting screw of the regulator.

$F_S \leq F$
Spring-Loaded Regulators

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$$F_S > F$$
Spring-Loaded Pressure Regulator

Instrumentation Type

Process Type
Spring-Loaded Regulator Flowcurves

Flow Coefficient: 3.79
Maximum Inlet Pressure: RS—1015 psig (70.0 bar)
Outlet Pressure Control Range: 0 to 3625 psig (0 to 250 bar)

Pressure Control Range:
- 0 to 43 psig (0 to 3.0 bar)
- 0 to 72 psig (0 to 5.0 bar)
- 0 to 145 psig (0 to 10.0 bar)
- 0 to 290 psig (0 to 20.0 bar)
- 0 to 580 psig (0 to 40.0 bar)

Nitrogen Flow, Nm³/h

Outlet Pressure, psig

Nitrogen Flow, std ft³/min

Inlet Pressure:
- A = 1015 psig (70.0 bar)
- B = 580 psig (40.0 bar)
- C = 218 psig (15.0 bar)

Pressure-Reducing Regulator
Droop

A decrease in outlet pressure caused by an increase in flow rate to a pressure reducing regulator.
Dome-Loaded Regulators

Loading Mechanism
The loading mechanism is the component of the regulator that balances the force or pressure.

Dome-Loaded
In a dome-loaded regulator, a gas is fed into the dome chamber above the sensing mechanism at a pressure equal to or slightly above the required outlet pressure. This volume of gas is used like a spring. The dome pressure ($F_d$) is typically supplied by a second regulator called a pilot regulator.

$$F_d \leq F$$
Dome-Loaded Regulators

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\[ F_d > F \]
Dome-Loaded Pressure Regulator
Dynamic Control

Bleed to outlet (restricted orifice)

Pressure to pilot from inlet
Dome-Loaded Regulator Flowcurves
Dome-Loading with External Feedback to Main
Dome-Loading with External Feedback to Pilot
Improving the Flow Curve

- Baseline (Figure 2)
- "Good" configuration (Figure 3)
- "Better" configuration (Figure 4)
- "Best" configuration (Figure 5)
Dome-Loaded with Feedback to Pilot
Combination Spring- and Dome-Loaded

The Spring-and Dome-Loaded mechanisms can be used in combination with one another to provide the function of a differential pressure regulator.

The regulator is designed to control pressure which is the sum of a reference pressure (provided by the dome) and a bias pressure (provided by the spring).
Differential Pressure Regulator

Dome-Loading Chamber

Load Spring

Control Pressure = Spring Force + Dome Pressure
Differential Pressure Regulator Application

Pressure in seal pump 15 psig higher than in pump.

Reference pressure from pump 100 psig

Differential pressure set at 15 psig

Inlet pressure 200 psig

Seal pressure 100 + 15 = 115 psig
Regulator Terminology

- Lock-up
- Seat Load Drop
- Supply Pressure Effect
Lockup

An increase in outlet pressure that occurs as the flow rate is decreased to zero.
Seat Load Drop

A decrease in outlet pressure that occurs as the flow rate is increased from zero. The opposite of Lockup.
Supply Pressure Effect

Supply Pressure Effect (SPE):
The effect on the set pressure of a pressure reducing regulator as a result of a change in inlet pressure, normally experienced as an increase in outlet pressure due to a decrease in inlet pressure. Also known as Dependency.
For example, suppose we have a regulator with SPE = 1% of the inlet pressure change.
SPE in Action

1. Upstream pressure decreases as cylinder is depleted

\[ P_{inlet} \text{ decreases from 3600 to 2600} = 1000 \text{ psig} \]

\[ 1\% \text{ of } 1000 \text{ psig} = 10 \text{ psig} \]

\[ P_{outlet} \text{ increases } 10 \text{ psig} \]

2. Downstream pressure increases 1% of the inlet decrease
1. Upstream pressure decreases as cylinder is depleted

\[ P_{\text{inlet}} \text{ decreases from 3600 to 1600 } = 2000 \text{ psig} \]

\[ 1\% \text{ of } 2000 \text{ psig } = 20 \text{ psig} \]

\[ P_{\text{outlet}} \text{ increases } 20 \text{ psig} \]

2. Downstream pressure increases 1\% of the inlet decrease
So how do we help manage SPE?

Two-stage Pressure Reduction

or

Modify the controlling mechanism…
Two-Stage Pressure Reduction
So how do we help manage SPE?

Two-stage Pressure Reduction

or

Modify the controlling mechanism…
Balancing reduces the area on which $P_{\text{inlet}}$ acts.

**Advantages:**
- Less sensitivity to Supply Pressure Effect
- Reduced Seat Load Larger seat can be used for more flow
Balanced Poppet
Swagelok Regulator Resources

Regulator Support Website
http://www.swagelok.com/CAregulatorsolutions/

Regulator Reference Guide

Local Swagelok Distributors

- Edmonton Valve & Fitting Inc.
  780.437.0640
- Swagelok Grande Prairie
  780.538.4280
- Calgary Valve & Fitting
  403.243.5646
- Swagelok Central Canada
  (Winnipeg)  204.633.4446
- Columbia Valve & Fitting Ltd.
  (Vancouver)  604.629.9355