THREE BASIC ELEMENTS OF PRESSURE REDUCING REGULATORS

What is a regulator?

A pressure reducing regulator is a device which reduces a high source pressure, such as 3000 PSIG, to a lower working pressure, such as 100 PSIG, suitable for a user's application. Further, the regulator will attempt to maintain the outlet pressure within limits as other conditions vary. Source pressure and media (gas or liquid) flow would be among these varying conditions. How successful the regulator will be at this function is determined by the mix of the basic regulator elements designed into a specific regulator.

The basic elements of a regulator often will determine the regulator type and series selected for a specific application. In this manual we will discuss the three basic elements common to all pressure reducing regulators whether manufactured by Tescom or other manufacturers.

I. Three Basic Elements

The Three Basic Elements are:

1) THE LOAD MECHANISM provides the means by which the operator can set the force that determines the control pressure of the regulator. P2 is a term commonly used for "outlet pressure".

2) THE SENSING ELEMENT senses the changes in the outlet pressure permitting the regulator to react to the changes in the outlet (or P2) pressure cavity located underneath the sensing element.

The sensing element also provides a physical link between the loading element and the last of the three basic elements, the control element.

3) THE CONTROL ELEMENT acts to reduce the inlet pressure, commonly called "P1", to a lower working pressure and maintain it by increasing or decreasing the orifice area as the control element moves away or towards the seat.

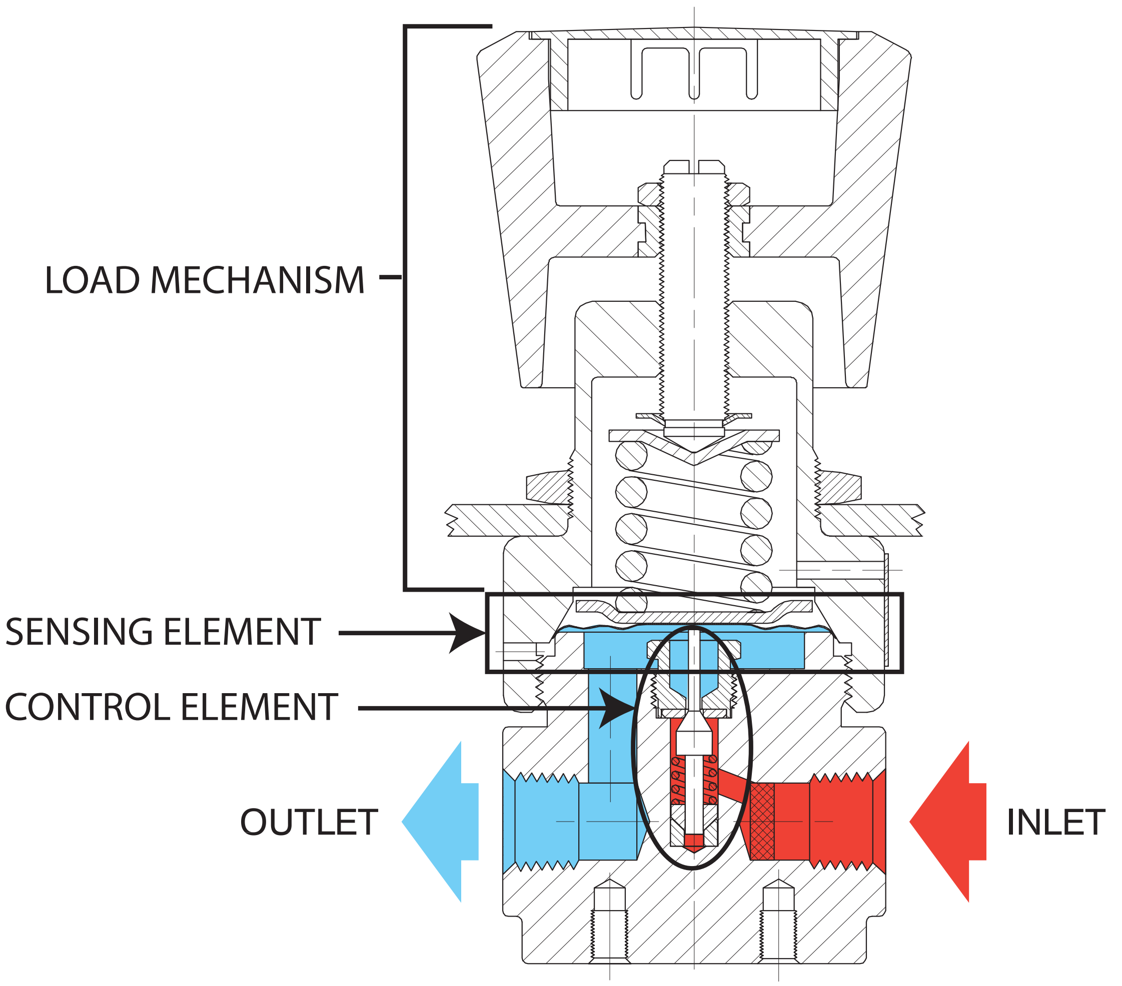


Figure 1

II. Loading Mechanisms

The first basic element is the LOADING mechanism of a regulator. It is this mechanism that determines what the regulator outlet pressure, or P2, will be.

The load element provides the force which is in turn transmitted through the SENSING element and to the CONTROL element, to provide the desired outlet pressure. It provides a preload force which establishes the demand level of the regulated or outlet pressure.

There are three types of loading:

A) Spring Loading

B) Dome Loading
(also called gas or liquid loading)

C) Combination Spring and Dome Loading

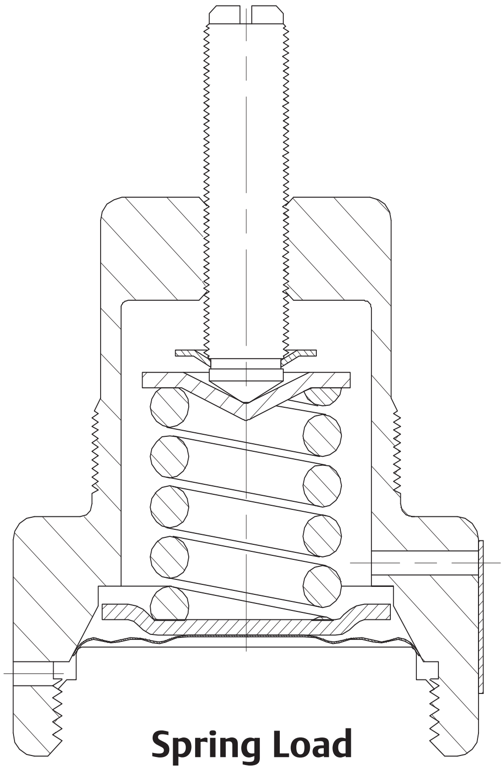


Figure 2

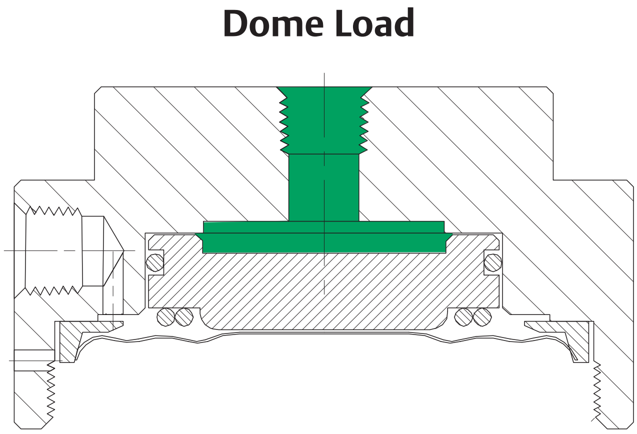


Figure 3

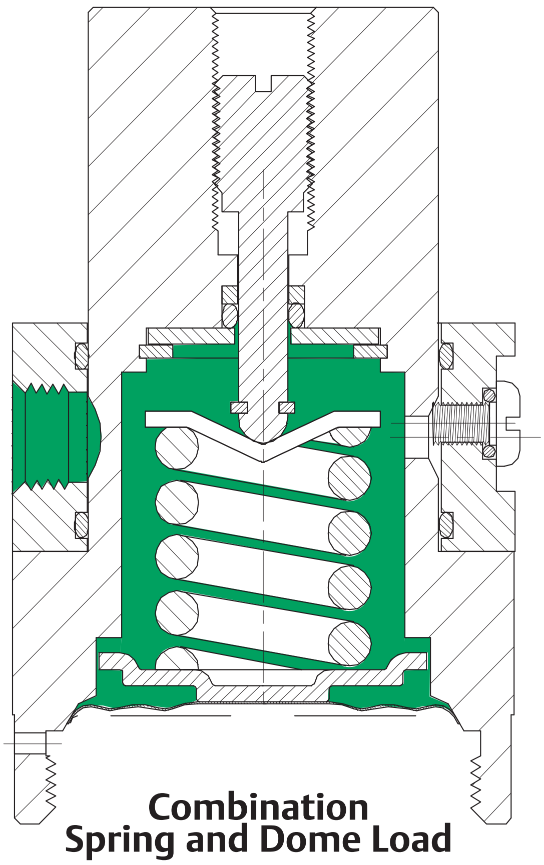
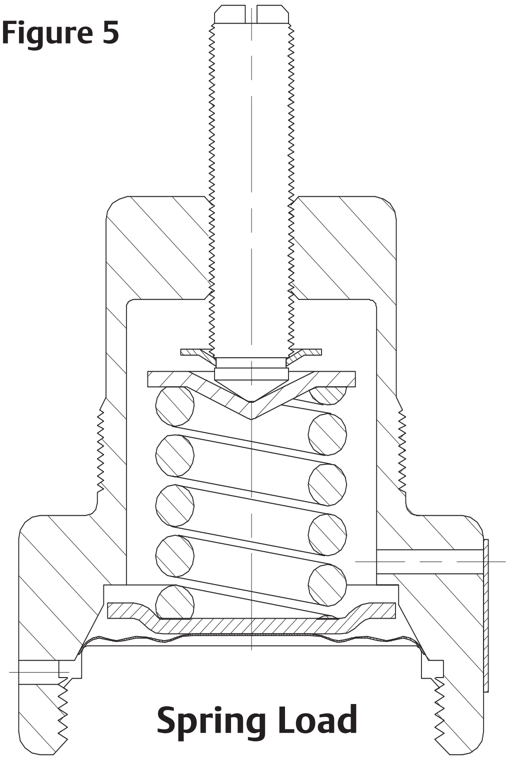


Figure 4

A. The Spring Load

Figure 5



Spring Load

The spring (Figure 5), is the most common loading device in regulators because of its dependability and low cost.

The spring load is determined by the amount of compression placed on the spring by the operator. This is accomplished by the operator turning the regulator knob or adjusting screw in a clockwise direction (Figure 6). The knob is turned, compressing the load spring, until the desired outlet or SET pressure is reached on the regulator's outlet pressure gauge.

Caution must be used during adjustment to prevent thread stripping. This commonly occurs when an operator attempts to set an outlet pressure which exceeds the regulator's capacity or the available inlet pressure.

The mechanical advantage of a standard adjusting screw or hand knob provides easy adjustment for outlet pressures up to 500 PSIG. For high pressures, up to 15,000 PSIG, Tescom used a non-rising stem hand-knob, with bearings that enables the operator to manually set pressures with only 30-40 inch pounds of torque.

Figure 6

Clockwise movement compresses load spring

Advantages:

1) Simplicity. There's little to go wrong.
2) Relatively small size. Springs can be wound of various thickness to provide outlet.
3) Economy. There are many spring sources and that keeps prices competitive.

Disadvantages:

1) The spring forces vary with compression and thus the load is not uniform.
2) Susceptible to the effects of SHOCK, VIBRATION and TEMPERATURE.

B. The Dome Load

The second loading method is call DOME LOADING (Figure 7). Instead of a spring, we use the dome area to provide the loading of the regulator. This is accomplished by sealing the DOME area to prevent leaks and then pressurizing it with gas from a pilot regulator.

The pressure in the dome determines the regulator's outlet pressure. The relationship between the dome pressure and the regulator outlet pressure is essentially one-to-one.

Dome Load

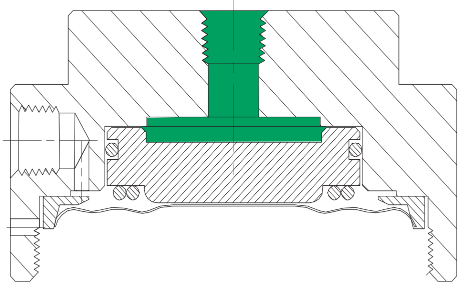


Figure 7

Here we have a 26-1200 series dome loaded regulator (Figure 8) that is connected to a 26-1000 series venting regulator. The 26-1000 regulator is acting as a pilot regulator and provides the pressure for the dome of the 26-1200 regulator.

If the dome is loaded to 1000 PSIG, then the outlet pressure will be close to 1000 PSIG. There is a slight difference primarily due to the control element (valve) spring force which acts to subtract from the dome load pressure force.

The operator uses the pilot regulator to set the pressure in the dome. The operator will continue adjusting the pressure until a gauge at the outlet of the dome regulator reads the desired SET pressure.

A pilot regulator with self-venting capability should be used to load DOME LOADED regulators. This venting capability is necessary to relieve excess pressure in the dome when the other two basic elements, the sensing and control elements, stroke upward. When the regulator strokes downward in response to increased flow, the pilot regulator will add more gas to make up the pressure lost due to the increase in the dome area and thereby keep the dome pressure constant.

The self-venting is also needed to lower dome pressure should there be a need to lower the dome regulator outlet pressure. By turning the pilot regulator handknob in the counter-clockwise direction, pressure can be reduced in the dome section of the dome regulator.

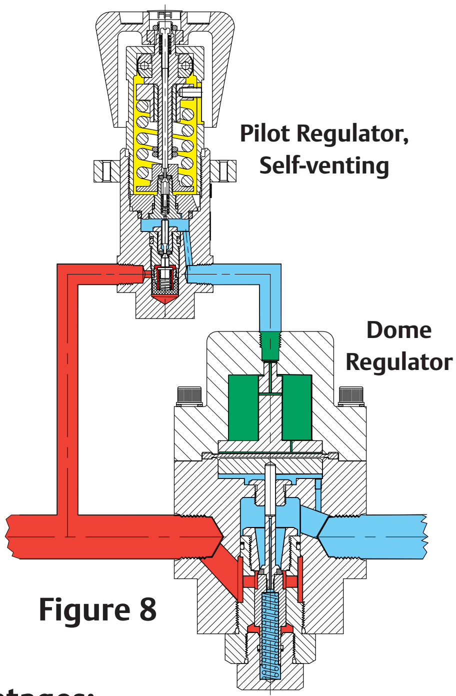


Figure 8

Advantages:

1) Enables remote pressure control. This can be a safety feature by keeping the operator away from hazardous gases or conditions. It can also be a matter of convenience by providing means of adjusting pressure when the dome regulator is located in an area difficult to reach.
2) Maintains outlet pressure more accurately under flowing conditions than a spring loaded regulator. Minimizes droop.
3) Provides high outlet pressure and high flows when used with a balanced main valve.
4) Faster response to pressure changes.

Disadvantages:

1) Load pressure can vary with sensor displacement unless compensated for with a venting-type pilot regulator.
2) Two regulators are needed - the dome regulator and the pilot regulator. This creates:

   a. Increased cost
   b. A greater space requirement for the two regulators

C. Combination Spring & Dome

This hybrid regulator uses a combination of spring and dome loading (Figure 9) and is identified by several names...

- Bias Regulator
- Tracking Regulator
- Algebraic Regulator
- Differential Pressure Regulator

It is called a "Bias" regulator because the spring provides a "bias" or added force.

The term "tracking" is used because the regulator can follow the pressure of one system as the pressure goes up or down. The regulator supplies pressure equal to the bias setting plus the reference pressure and sends the total pressure of the two signals to a second system.

It is sometimes called an "algebraic" regulator because it can ADD or SUBTRACT pressure equal to it's bias spring setting. The pressure is added when the bias spring is located above the sensing element, diaphragm or piston, and subtracted when the bias spring is located below the sensing element.

This is how the combination dome and spring regulator works...

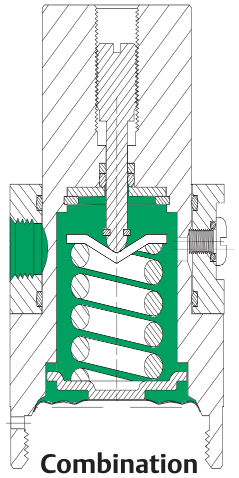
First, the bias spring is manually adjusted to provide a specific BIAS pressure, for instance 50 PSIG (Figure 10). The bias pressure will remain constant and maintain that difference above the reference pressure.

Then the dome is loaded with pressure from a "reference source", another system, at a pressure of 500 PSIG. The dome is now loaded with a total of 550 PSIG, the sum of 500 plus 50 PSIG. The regulator will now deliver an outlet pressure of 550 PSIG.

If for any reason the reference should change either up or down and provided there is flow or the regulator has venting feature, the outlet pressure will also change. An example: the reference pressure drops by 100 PSIG, from 500 PSIG down to 400 PSIG, the bias pressure set on the spring remains at 50 PSIG. Consequently the outlet pressure of the combination spring and dome regulator is now 450 PSIG.

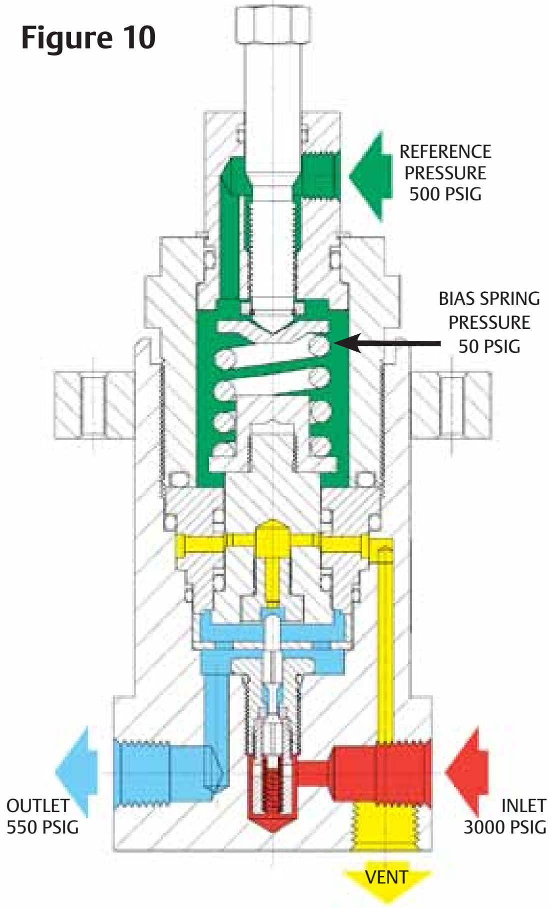
The regulator is used in a variety of applications and is especially useful in commercial diving, oil exploration, laboratory and autoclave applications.

Figure 9



Combination
Spring and Dome Load

Figure 10



Advantages:

1) It can provide gas pressure accurately for tracking applications.

Disadvantages:

1) It is more expensive than either a spring or a dome loaded regulator.

III. Sensing Elements

The function of the sensing element is to sense changes in the downstream or outlet pressure side of a regulator. The area sensed is immediately below the sensing element in the P2 cavity of the regulator.

There are three common types of sensing elements:

A. Diaphragm (Figure 11)

B. Piston (Figure 12)

C. Bellows (Figure 13)

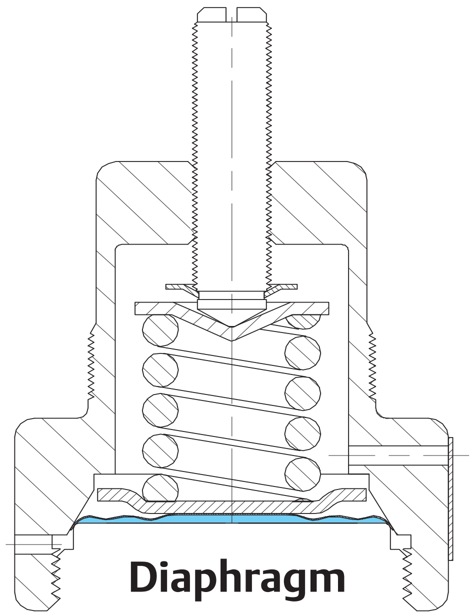


Figure 11

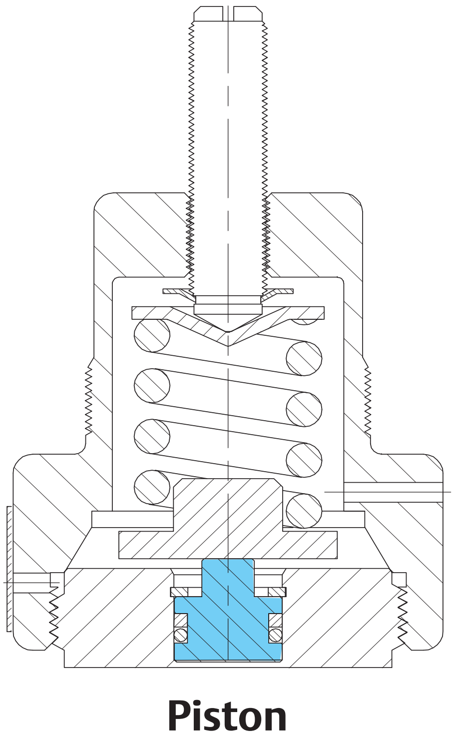


Figure 12

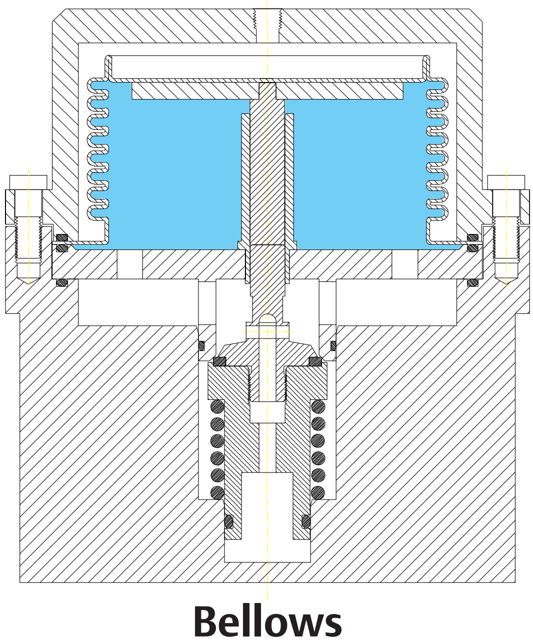


Figure 13

A. Diaphragm Sensing Element

The diaphragm (Figure 14) is relatively inexpensive and is adequate for most applications. The diaphragm provides sensitivity to pressure changes, especially with elastomer materials. Early natural rubber diaphragms have been replaced by elastomers, man-made rubber substitutes for many applications to provide increased compatibility with the wide variety of gases currently in use. Some of the elastomers in common use are Buna-N, Viton-A, and Ethylene Propylene.

Where elastomers fail to provide media compatibility, metal diaphragms have found their way into use. 316 Stainless Steel diaphragms are in wide use, especially in the semiconductor, specialty gas and petroleum regulator markets. Elgiloy, a cobalt-chrome-nickel alloy is also an excellent diaphragm material suitable for use in the semiconductor, specialty gas and petroleum applications. It is excellent for applications with wide temperature swings and high cycle life. It is also compatible with a wide range of gases.

However, outlet pressure ratings are limited due to possible diaphragm rupture. This is a consequence of high pressure loading on the underside of the diaphragm and only atmospheric pressure on the top side of the diaphragm (Figure 15). Tescom's position is to limit the use of diaphragms to outlet pressures up to a maximum of 500 PSIG.

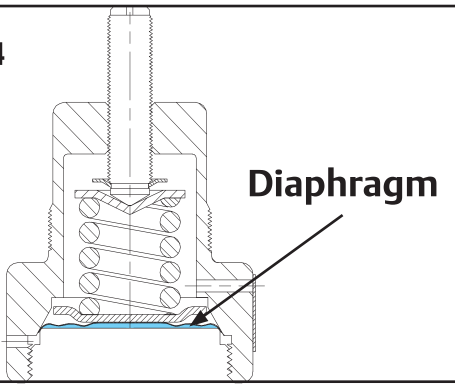
The valve stem motion must be restricted since diaphragm distortion can effect the actuating force characteristics. An additional consideration is the non-constant effective sensing area of the diaphragm as it flexes.

Tescom's metal diaphragms have two concentric rings (Figure 16) or convolutions to provide natural flexing areas and eliminate the oil-can effect which can lead to early metal fatigue and possible failure.

Diaphragms are made of the following materials:

Buna-N, Elgiloy, Ethylene Propylene, Teflon, Viton-A, 316 Stainless Steel, Hastelloy®, Gylon®, Chemraz®

Figure 14



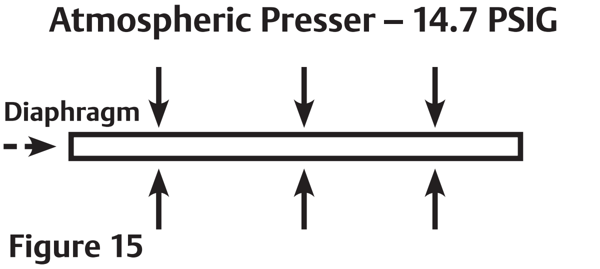


Figure 15

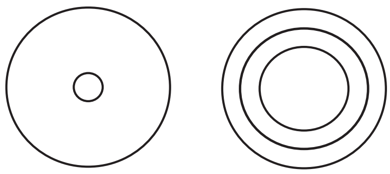


Figure 16

Advantages:

1) Sensitivity
2) Inexpensive
3) Simplicity
4) 316 Stainless Steel diaphragms are excellent for semiconductor, toxic and corrosive type applications.
5) Elgiloy diaphragms are an excellent choice for high cycle metal diaphragm uses. They are also excellent for applications with wide temperature swings.

Disadvantages:

1) Fabric reinforced diaphragms can "wick" water or other liquids leading to diaphragm failure or media contamination.
2) Diaphragms do not provide a constant effective sensing area.
3) Diaphragms can be difficult to seal.
4) Diaphragms can rupture due to a pressure differential.
5) Metal diaphragms are less sensitive than rubber or elastomer diaphragms.
6) Pressure limits

B. Piston Sensing Element

Piston sensing elements (Figure 17) are designed for higher OUTLET pressures than are the diaphragm sensing elements. While the diaphragms are limited to an OUTLET pressure of 500 PSIG, the piston sensing elements can control outlet pressures up to 20,000 PSIG. As you can see from the piston sensor (Figure 18), it is strong and heavy, and well suited for high outlet pressures.

The piston sensor is made up of a sensor back-up, sensor and dynamic seals or o-rings (Figure 19). The sensor back-up is held stationary between the body on the bottom and the regulator bonnet on the top. The sensor is allowed to move freely on the o-ring seal in response to changes in the outlet or P2 pressure cavity.

The function of the piston is the same as the diaphragm, to sense changes in the outlet pressure or P2 cavity and respond to them.

The materials used by Tescom for sensor assemblies are:

Brass, 303 Stainless Steel, 316 Stainless Steel, Hastelloy, Monel, N60, 17-4

The materials are chosen to be compatible with the media going through the regulator.

The piston sensor is the least sensitive of the three types of sensing elements, however it is the strongest and must be used when the outlet pressure exceeds 500 PSIG.

Advantages:

1) High pressure outlet capability, up to 20,000 PSIG.
2) Piston has constant effective sensing area.

Disadvantages:

1) Less sensitive than diaphragm or bellows sensing elements.
2) Cannot be used for high purity applications due to o-ring seals.
3) Lubrication of o-rings is critical for accurate pressure control.

Figure 17

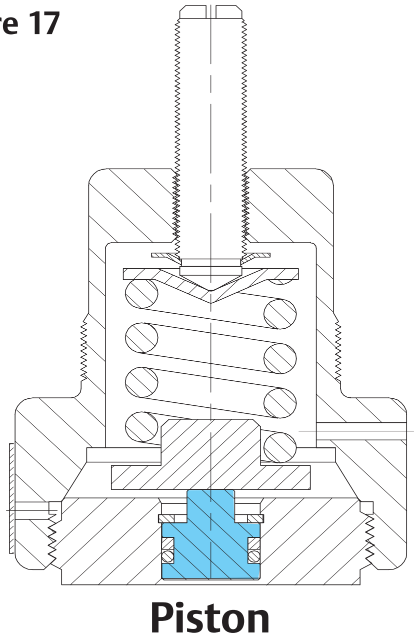


Figure 18

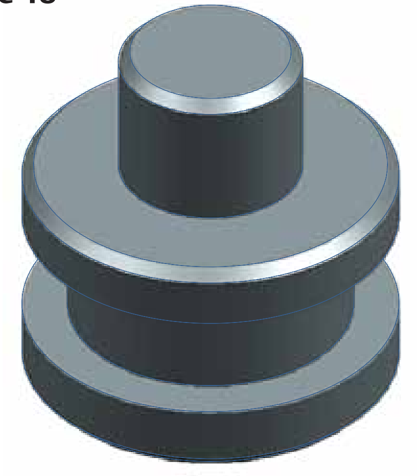
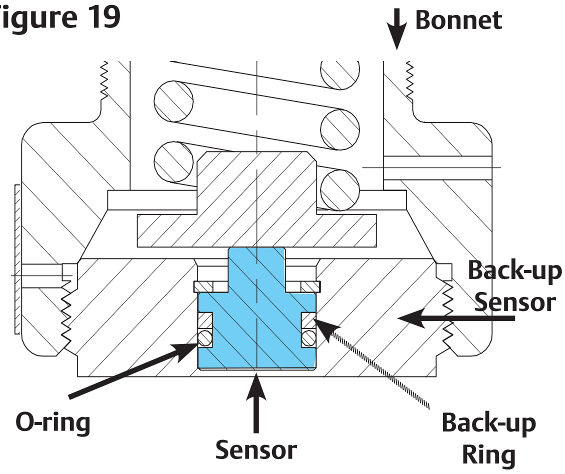


Figure 19



C. Bellows Sensing Element

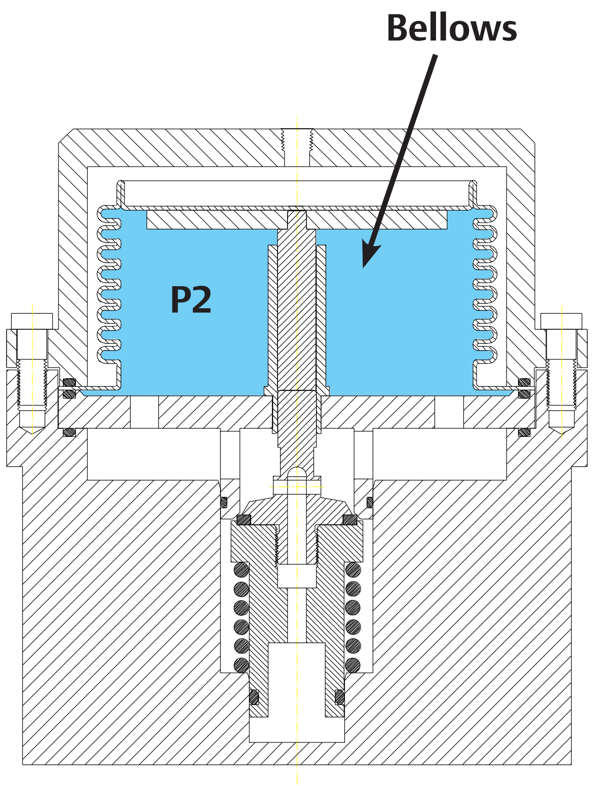


Figure 20


Figure 21

The bellows type sensing element is the third and last of the traditional sensing elements. It is the most accurate or sensitive of the three sensing elements: the diaphragm, the piston and the bellows.

As you can see from the bellows used in the 15 Series (Figure 20) the sensor is much larger than the first two sensing elements. The bellows can also be made in smaller sizes than used in the 15 Series regulator.

The superior performance of the bellows as a sensing device is accomplished by the ability to allow longer travel of the valve with a minimum of resistance and forces. The accordion style pleats or flexing points (Figure 21) provide the capability for longer travel of the valve.

While the sensitivity is high, the cost of making a 316 Stainless Steel metal bellows is also very high. Because of it's high cost the stainless bellows is a rarely used sensing element in regulators. Most users do not want to pay the high price associated with it.

The bellows sensing element is used in our 15 Series regulator. This is our facilities regulator designed to provide high flow capacity at relatively low pressures. Pressures on the order of 300 PSIG inlet and 130 PSIG outlet. This regulator is designed for the semiconductor industry and features 316L Stainless Steel welded construction with internally threadless design. It offers a Cv of 20.

Advantages:

1) Very sensitive
2) Increased valve travel capability

Disadvantages:

1) Expensive
2) Few sources

IV. The Control Elements

The third and last element is the CONTROL element.

There are two types of control elements:

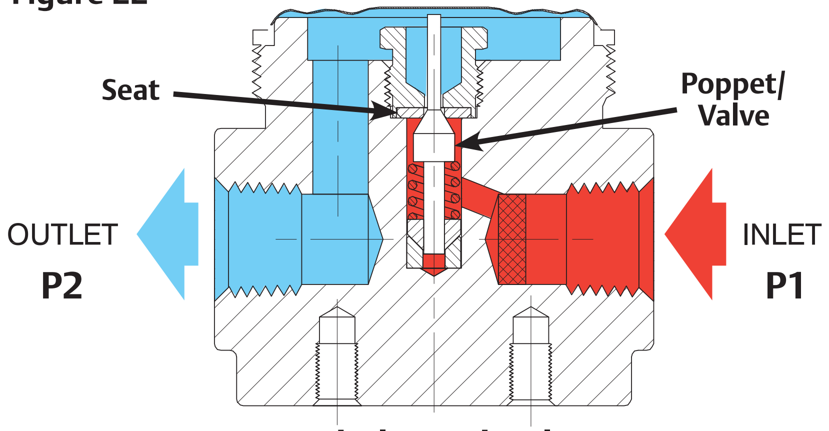
A. The UNBALANCED control element (Figure 22)
B. The BALANCED control element (Figure 23)

The function of the control element is to do the actual reduction of the high inlet pressure down to the lower P2 or outlet pressure. The control element is frequently called a valve, valve stem or poppet.

Media pressure (gas or liquid) is reduced by taking the high pressure gas from a cylinder, compressor, or pump and passing it through a variable size orifice.

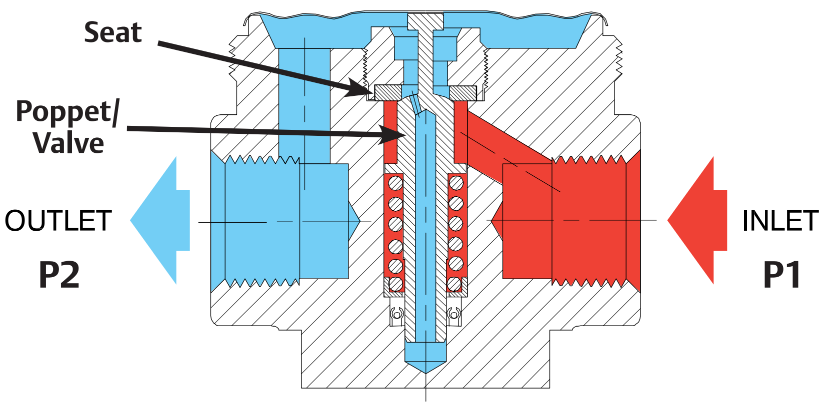
The valve moves towards or away from the regulator seat causing the orifice to become larger or smaller in order to provide the flow demanded and maintain the desired SET pressure.

Figure 22



Unbalanced Valve

Figure 23



Balanced Valve

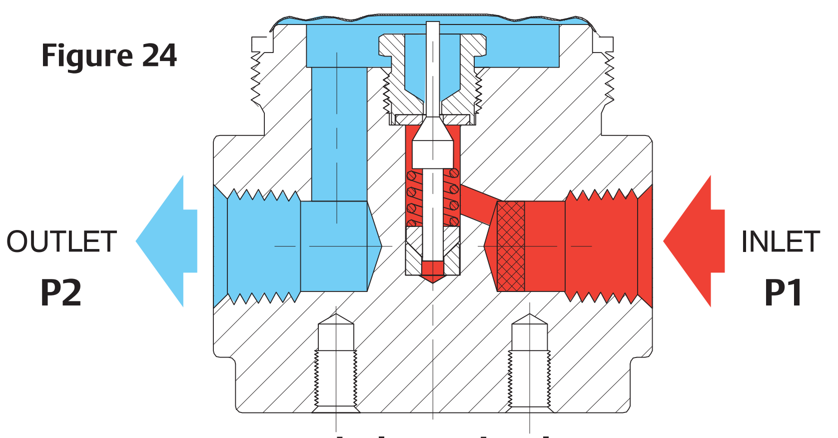
A. Unbalanced Control Element

The UNBALANCED control element or valve has only one sealing point. That being the coned shape area of the valve. With this design, the valve is assisted to the closed position by the valve spring and the supply pressure. While the force of the spring is relatively constant at all times, the force on the valve will increase as the supply pressure increases. And the force on the valve will decrease as the supply pressure decreases. By knowing the orifice size and the supply pressure, one can determine the closing force that is being applied to the valve. As you can see in Figures 24 and 25, the P1 zone, which is 3000 psig starts from the inlet connection and ends at the point of contact of the valve and seat. The P2 zone which is 100 psig starts at that same valve point and continues to the outlet connection.

The UNBALANCED valve has a characteristic called the DECAYING INLET CHARACTERISTIC.

The decaying inlet characteristic is not acceptable to some users because it will lead to a change in the outlet pressure as the inlet pressure changes. This occurs when cylinders are the pressure source for a customer's system.

Figure 24



Unbalanced Valve

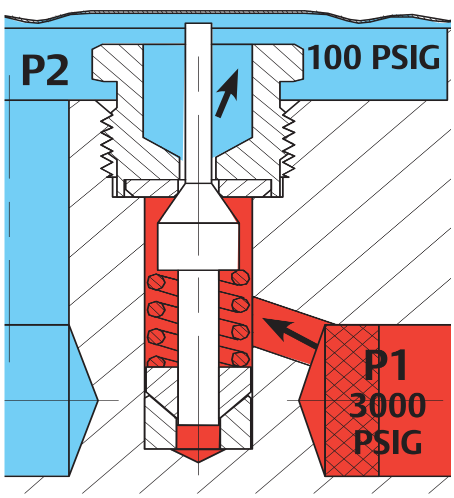


Figure 25

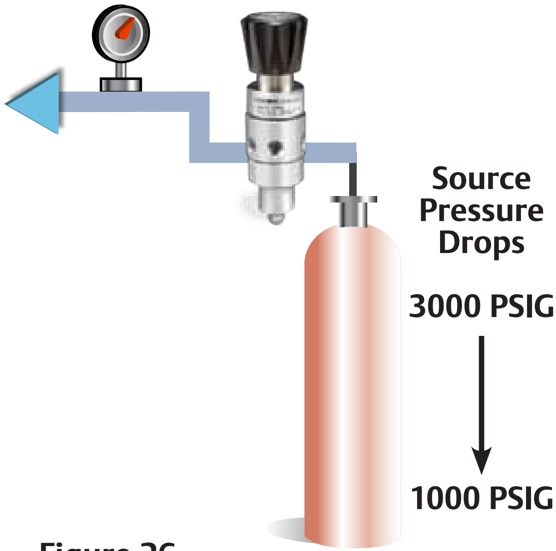


Figure 26

A. Unbalanced Control Element (cont.)

The cylinders come with a finite amount of gas and pressure. As the contents of the cylinder (Figure 26) will drop. As you look at the outlet pressure gauge (Figure 27) on the cylinder regulator you will notice that the pressure on the outlet gauge will go up, while the pressure on the inlet gauge goes down. This is a result of the decaying inlet characteristic.

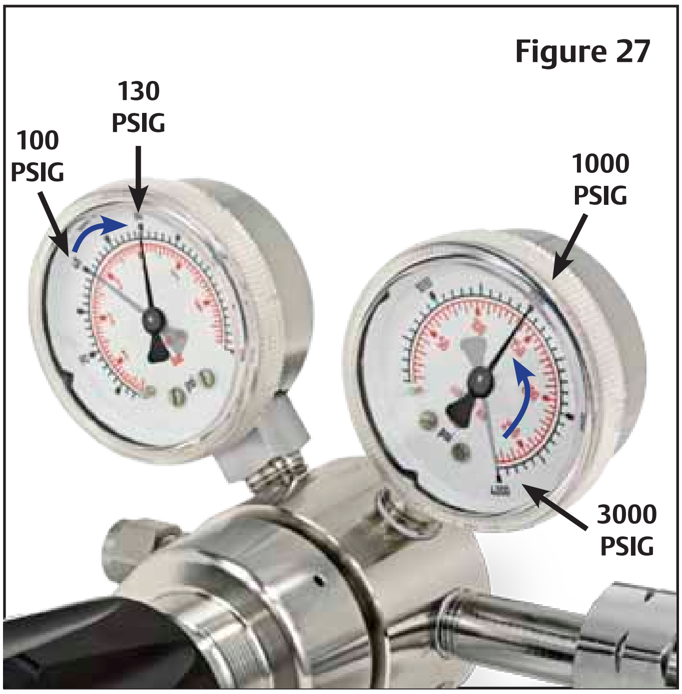


Figure 27

Like the teeter-totter in the kids' playground. When one side goes up, the other side must go down. Each side goes in the opposite (Figure 28) direction of the other.

In most applications this is fine, the user has no problem with this. For customers who cannot tolerate a change in the outlet pressure when the inlet pressure changes they have four options.

They can decide to go to:

a. Two-stage regulator
b. Balanced type valve
c. Two regulators in series

We will cover only the BALANCED type valve.

Advantages:

1) Inexpensive
2) Simple
3) Easy to manufacture
4) Inlet pressure is main shut-off force

Disadvantages:

1) Limited to small orifice sizes
2) Decaying Inlet Characteristic
3) High seat forces with high inlet pressures
4) Requires harder seat material at high pressures

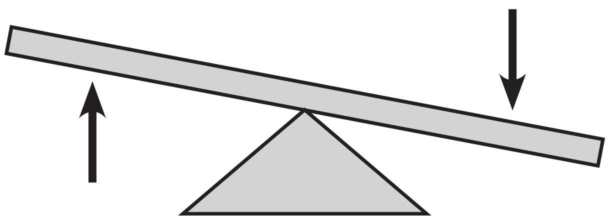


Figure 28

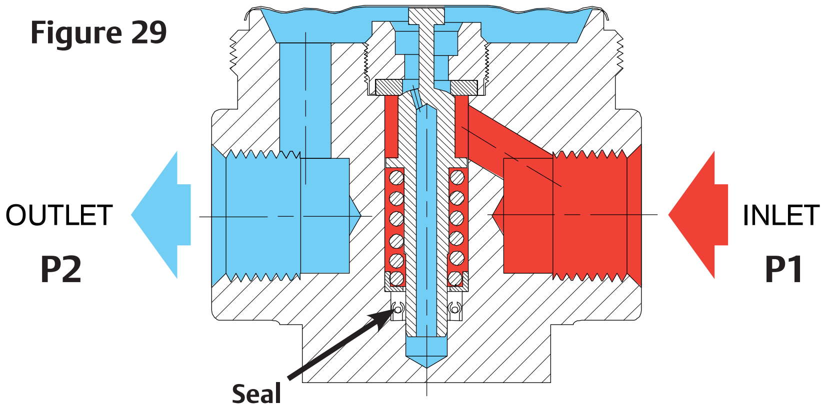
B. Balanced Control Element

The BALANCED control element or valve has two sealing points. One being identical to the UNBALANCED valve. The other seal is located near the end of the valve in the P1 zone (Figure 29). In effect, by sealing both ends of the valve the supply pressure can not force the valve closed or open. Hence the name BALANCED valve (Figure 30). With this design, the supply pressure has little effect on the amount of force on the valve.

One other difference between the UNBALANCED and BALANCED valve is that a balanced valve will also have a passageway from the P2 zone to the other side of the valve seal (Figure 30). This is required so that the P2 pressure is equalized on both sides of the valve and the valve remains balanced.

In actual practice, the balanced valve is designed to be slightly unbalanced. If there should be a regulator failure, it is desirable to have the inlet pressure help close the valve tightly.

Figure 29



Balanced Valve

Advantages:

1) Reduced seat load
2) Reduced decaying inlet characteristics
2) Larger seat orifice at high pressures
3) High flow capability

Disadvantages:

1) More expensive to make
2) Large seats make low flows difficult

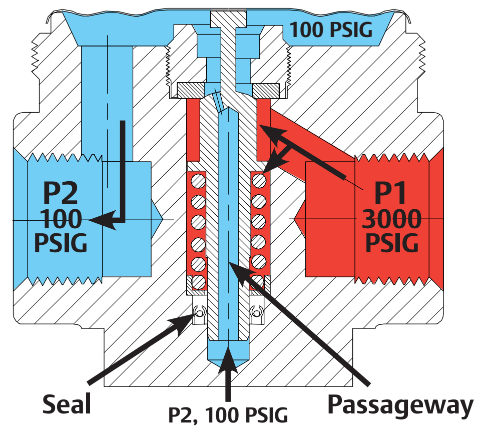


Figure 30

V. Putting all the Elements Together

Now that we have covered the three basic elements of regulators, lets put them together and demonstrate how they work.

Figure 31 illustrates a regulator with all three basic elements: the loading mechanism, the sensing element, and the control element.

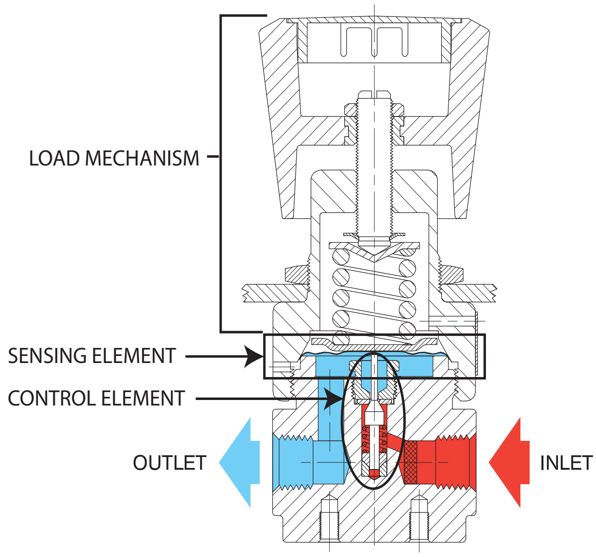
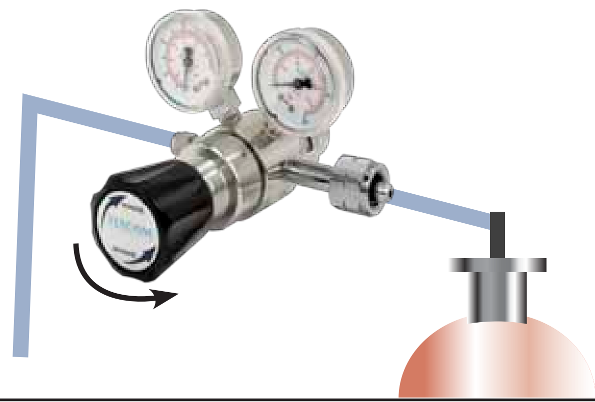


Figure 31

Figure 32



As we work together with the regulator, we have it connected to the gas cylinder and join to a system downstream of the pressure regulator (Figure 32). The handknob or adjusting screw of the regulator is turned all the way out (counter-clockwise) and the regulator is shut off.

The cylinder valve is then opened, releasing the contents of the cylinder to the inlet side of the regulator. The pressure reading on the inlet gauge climbs and stops at the pressure reading indicating the pressure in the cylinder. The outlet pressure gauge indicates zero pressure (Figure 33).

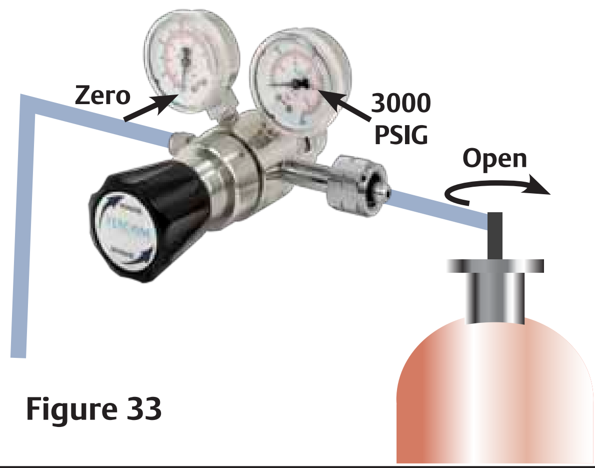
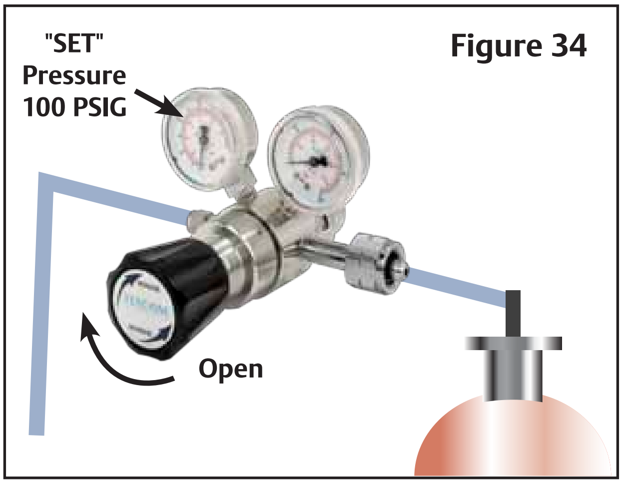
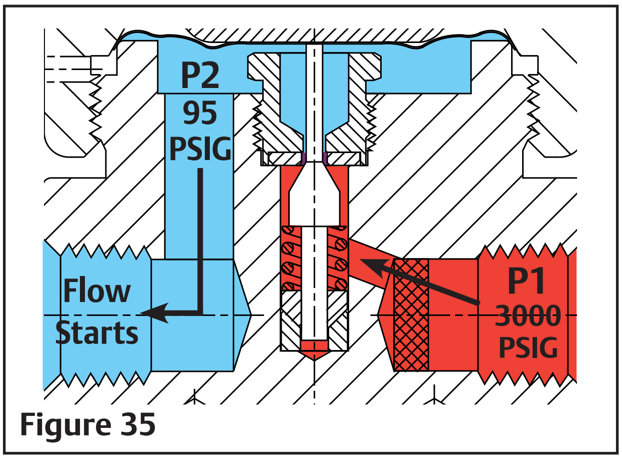


Figure 33



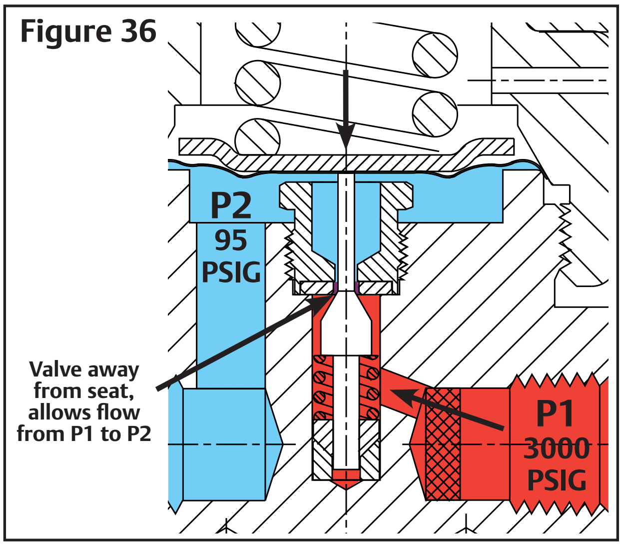
We now turn the handknob in the clockwise direction (Figure 34) to open the regulator's valve. The pressure reading on the outlet pressure gauge climbs until it reaches the desired outlet pressure or SET pressure. SET pressure is the outlet pressure at no flow.

By turning the handknob clockwise we have compressed the load spring to provide the outlet pressure required for our downstream system. This is the pressure that we determined was necessary for the operation of the system. The system downstream is not presently in operation and therefore the regulator shuts off. In other words, the valve or control element is closed tight against the seat permitting no flow passed it.



We now start the system downstream of the regulator. When the system starts it demands a flow, a quantity of gas, from the regulator. When this flow starts, there is an initial drop in the P2, or outlet cavity of the regulator (Figure 35) as indicated by the outlet gauge. The diaphragm, or sensing element senses this drop in pressure and it moves down because of the lower pressure and is assisted by the force of the load spring.

At this point the load spring force is greater than the force it was balanced against... the inlet pressure, the area of the seat, the main valve spring, and the P2 pressure against the area of the diaphragm. Since the load spring force is greater it helps move the diaphragm against the valve and thereby moves the valve away from the seat (Figure 36) allowing gas to flow through the seat opening and into the outlet or P2 cavity of the regulator.



The valve stays open trying to build up the outlet pressure to its initial SET pressure. As long as the system downstream is demanding flow, the spring loaded regulator will not be able to reach the initial SET pressure. However, it will keep on trying to reach the initial set pressure as long as the system downstream is in operation and demanding flow. The difference between the initial SET pressure and the flowing pressure is called DROOP.

When the system downstream is shut-off, the demand for flow and pressure ends. The P2 pressure now builds up in the P2 cavity to the point of the original SET pressure, plus an additional 1 to 3 PSIG needed to firmly force the valve against the seat for a positive gas tight shut-off (Figure 37). The additional 1 to 3 pounds closing pressure is called LOCK-UP, and is normal for pressure reducing regulators.

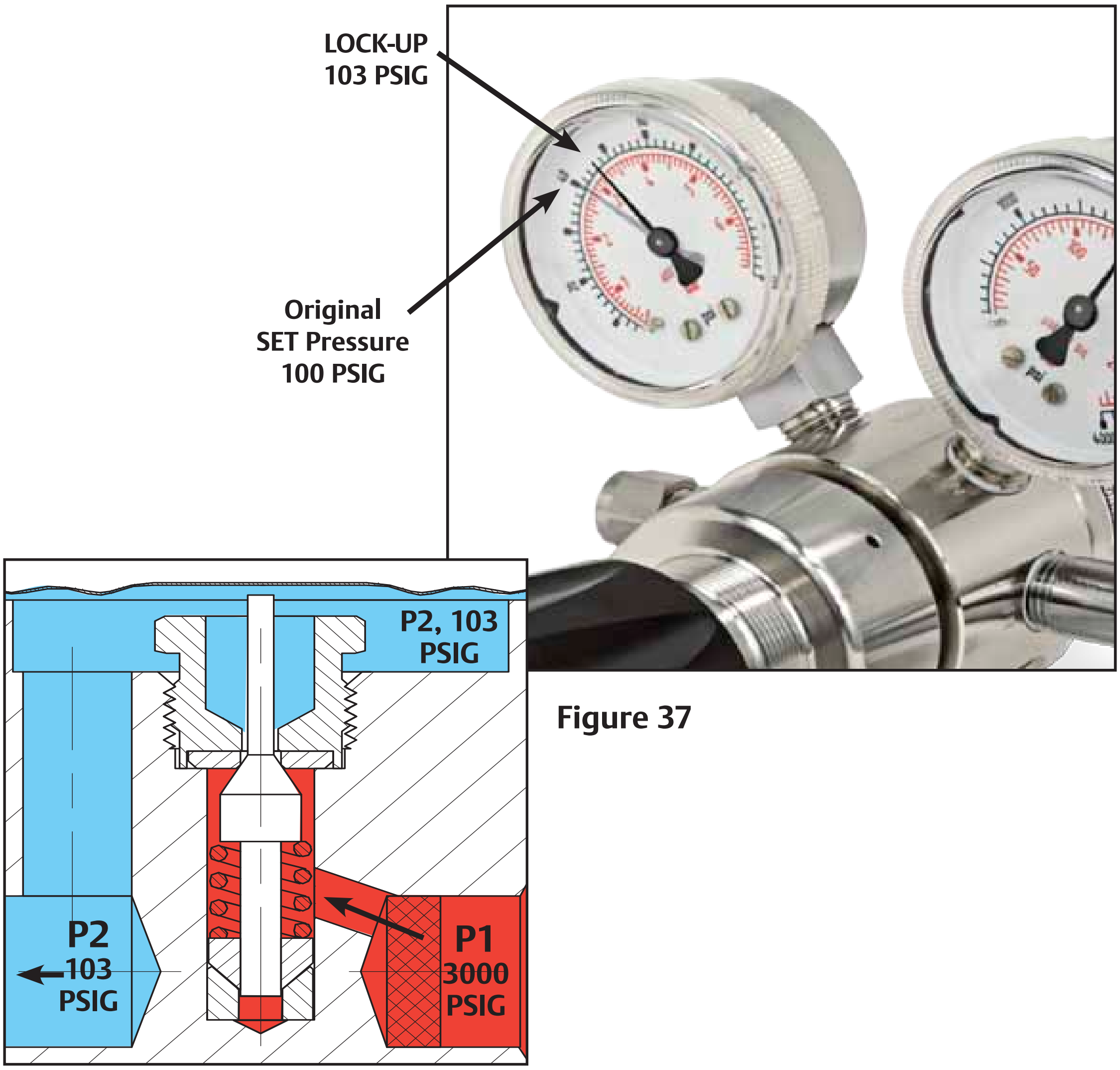


Figure 37

To completely shut down a regulator the cylinder valve must be closed, the pressure drained from the regulator and the handknob or adjusting screw turned counter-clockwise until no pressure is felt from the load spring.

This completes the normal working cycle of a spring loaded, pressure reducing, single stage regulator.

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