

Principles of Direct-Operated Regulators

Introduction

Pressure regulators have become very familiar items over the years, and nearly everyone has grown accustomed to seeing them in factories, public buildings, by the roadside, and even on the outside of their own homes. As is frequently the case with such familiar items, we have a tendency to take them for granted. It's only when a problem develops, or when we are selecting a regulator for a new application, that we need to look more deeply into the fundamentals of the regulator's operation.

Regulators provide a means of controlling the flow of a gas or other fluid supply to downstream processes or customers. An ideal regulator would supply downstream demand while keeping downstream pressure constant; however, the mechanics of direct-operated regulator construction are such that there will always be some deviation (droop or offset) in downstream pressure.

The service regulator mounted on the meter outside virtually every home serves as an example. As appliances such as a furnace or stove call for the flow of more gas, the service regulator responds by delivering the required flow. As this happens, the pressure should be held constant. This is important because the gas meter, which is the cash register of the system, is often calibrated for a given pressure.

Direct-operated regulators have many commercial and residential uses. Typical applications include industrial, commercial, and domestic gas service, instrument air supply, and a broad range of applications in industrial processes.

Regulators automatically adjust flow to meet downstream demand. Before regulators were invented, someone had to watch a pressure gauge for pressure drops which signaled an increase in downstream demand. When the downstream pressure decreased, more flow was required. The operator then opened the regulating valve until the gauge pressure increased, showing that downstream demand was being met.

Essential Elements

Direct-operated regulators have three essential elements:

- A restricting element—a valve, disk, or plug
- A measuring element—generally a diaphragm
- A loading element—generally a spring



Figure 1. Direct-Operated Regulators

Regulator Basics

A pressure reducing regulator must satisfy a downstream demand while maintaining the system pressure within certain acceptable limits. When the flow rate is low, the regulator plug or disk approaches its seat and restricts the flow. When demand increases, the plug or disk moves away from its seat, creating a larger opening and increased flow. Ideally, a regulator should provide a constant downstream pressure while delivering the required flow.

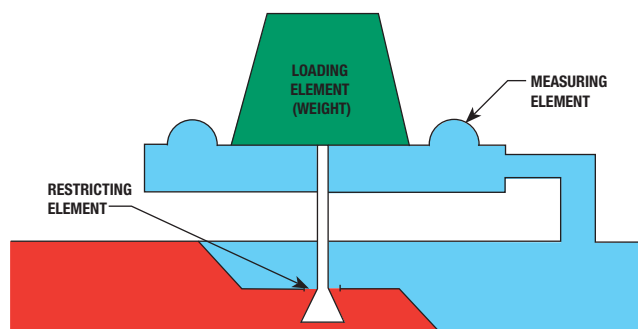


Figure 2. Three Essential Elements

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Restricting Element

The regulator's restricting element is generally a disk or plug that can be positioned fully open, fully closed, or somewhere in between to control the amount of flow. When fully closed, the disk or plug seats tightly against the valve orifice or seat ring to shutoff flow.

Measuring Element

The measuring element is usually a flexible diaphragm that senses downstream pressure (P_2). The diaphragm moves as pressure beneath it changes. The restricting element is often attached to the diaphragm with a stem so that when the diaphragm moves, so does the restricting element.

Loading Element

A weight or spring acts as the loading element. The loading element counterbalances downstream pressure (P_2). The amount of unbalance between the loading element and the measuring element determines the position of the restricting element. Therefore, we can adjust the desired amount of flow through the regulator, or setpoint, by varying the load. Some of the first direct-operated regulators used weights as loading elements. Most modern regulators use springs.

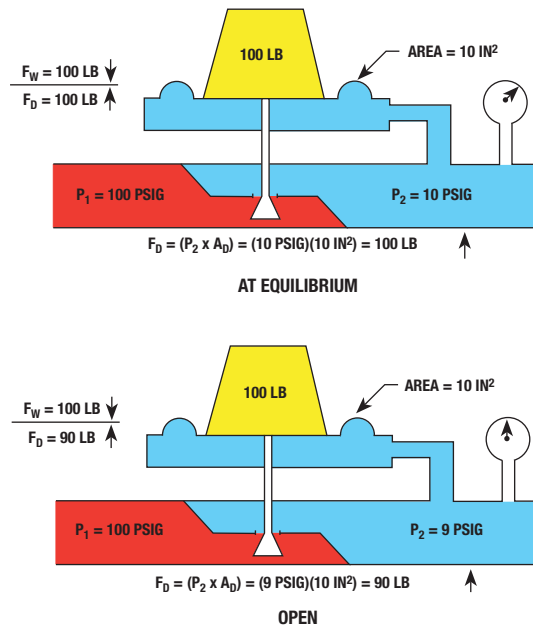


Figure 3. Elements

Regulator Operation

To examine how the regulator works, let's consider these values for a direct-operated regulator installation:

- Upstream Pressure (P_1) = 100 psig
- Downstream Pressure (P_2) = 10 psig
- Pressure Drop Across the Regulator (P) = 90 psi
- Diaphragm Area (A_D) = 10 square inches
- Loading Weight = 100 pounds

Let's examine a regulator in equilibrium as shown in Figure 3. The pressure acting against the diaphragm creates a force acting up to 100 pounds.

$$\text{Diaphragm Force (F}_D\text{)} = \text{Pressure (P}_2\text{)} \times \text{Area of Diaphragm (A}_D\text{)}$$

or

$$F_D = 10 \text{ psig} \times 10 \text{ square inches} = 100 \text{ pounds}$$

The 100 pounds weight acts down with a force of 100 pounds, so all the opposing forces are equal, and the regulator plug remains stationary.

Increasing Demand

If the downstream demand increases, P_2 will drop. The pressure on the diaphragm drops, allowing the regulator to open further. Suppose in our example P_2 drops to 9 psig. The force acting up then equals

90 pounds (9 psig x 10 square inches = 90 pounds). Because of the unbalance of the measuring element and the loading element, the restricting element will move to allow passage of more flow.

Decreasing Demand

If the downstream demand for flow decreases, downstream pressure increases. In our example, suppose P_2 increases to 11 psig. The force acting up against the weight becomes 110 pounds (11 psig x 10 square inches = 110 pounds). In this case, unbalance causes the restricting element to move up to pass less flow or lockup.

Weights versus Springs

One of the problems with weight-loaded systems is that they are slow to respond. So if downstream pressure changes rapidly, our weight-loaded regulator may not be able to keep up. Always behind, it may become unstable and cycle—continuously going from the fully open to the fully closed position. There are other problems. Because the amount of weight controls regulator setpoint, the regulator is not easy to adjust. The weight will always have to be on top of the diaphragm. So, let's consider using a spring. By using a spring instead of a weight, regulator stability increases because a spring has less stiffness.

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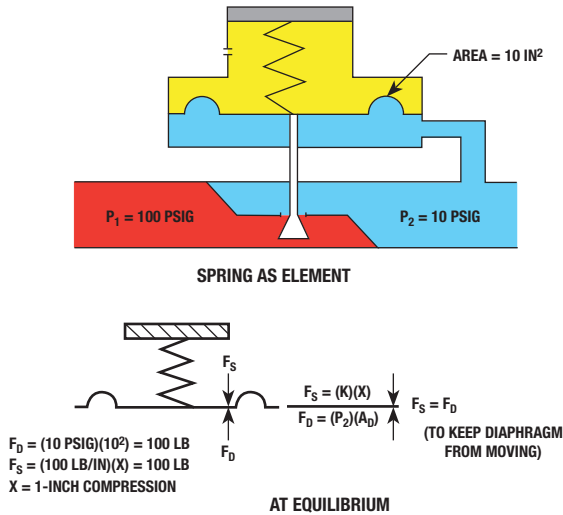


Figure 4. Spring as Element

Spring Rate

We choose a spring for a regulator by its spring rate (K). K represents the amount of force necessary to compress the spring one inch. For example, a spring with a rate of 100 pounds per inch needs 100 pounds of force to compress it one inch, 200 pounds of force to compress it two inches, and so on.

Equilibrium with a Spring

Instead of a weight, let's substitute a spring with a rate of 100 pounds per inch. And, with the regulator's spring adjuster, we'll wind in one inch of compression to provide a spring force (F_S) of 100 pounds. This amount of compression of the regulator spring determines setpoint, or the downstream pressure that we want to hold constant. By adjusting the initial spring compression, we change the spring loading force, so P_2 will be at a different value in order to balance the spring force.

Now the spring acts down with a force of 100 pounds, and the downstream pressure acts up against the diaphragm producing a force of 100 pounds ($F_D = P_2 \times A_D$). Under these conditions the regulator has achieved equilibrium; that is, the plug or disk is holding a fixed position.

Spring as Loading Element

By using a spring instead of a fixed weight, we gain better control and stability in the regulator. The regulator will now be less likely to go fully open or fully closed for any change in downstream pressure (P_2). In effect, the spring acts like a multitude of different weights.

Throttling Example

Assume we still want to maintain 10 psig downstream. Consider what happens now when downstream demand increases and pressure P_2 drops to 9 psig. The diaphragm force (F_D) acting up is now 90 pounds.

$$F_D = P_2 \times A_D$$

$$F_D = 9 \text{ psig} \times 10 \text{ in}^2$$

$$F_D = 90 \text{ pounds}$$

We can also determine how much the spring will move (extend) which will also tell us how much the disk will travel. To keep the regulator in equilibrium, the spring must produce a force (F_S) equal to the force of the diaphragm. The formula for determining spring force (F_S) is:

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

where K = spring rate in pounds/inch and X = travel or compression in inches.

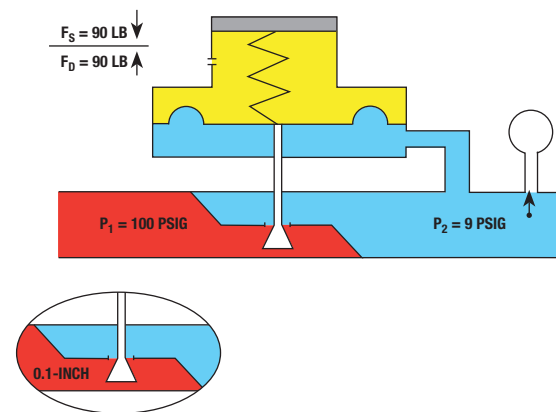
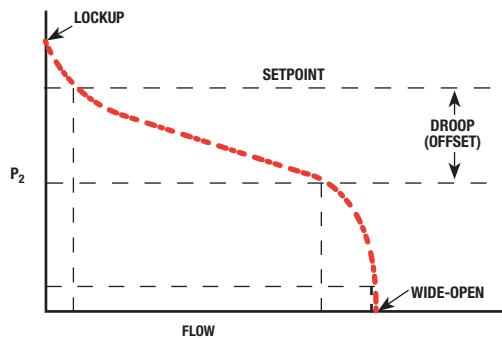


Figure 5. Plug Travel

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AS THE FLOW RATE APPROACHES ZERO, P_2 INCREASES STEEPLY. LOCKUP IS THE TERM APPLIED TO THE VALUE OF P_2 AT ZERO FLOW.

Figure 6. Typical Performance Curve

We know F_S is 90 pounds and K is 100 pounds/inch, so we can solve for X with:

$$X = F_S \div K$$

$$X = 90 \text{ pounds} \div 100 \text{ pounds/inch}$$

$$X = 0.9 \text{ inch}$$

The spring, and therefore the disk, has moved down 1/10-inch, allowing more flow to pass through the regulator body.

Regulator Operation and P_2

Now we see the irony in this regulator design. We recall that the purpose of an ideal regulator is to match downstream demand while keeping P_2 constant. But for this regulator design to increase flow, there must be a change in P_2 .

Regulator Performance

We can check the performance of any regulating system by examining its characteristics. Most of these characteristics can be best described using pressure versus flow curves as shown in Figure 6.

Performance Criteria

We can plot the performance of an ideal regulator such that no matter how the demand changes, our regulator will match that demand (within its capacity limits) with no change in the downstream pressure (P_2). This straight line performance becomes the standard against which we can measure the performance of a real regulator.

Setpoint

The constant pressure desired is represented by the setpoint. But no regulator is ideal. The downward sloping line on the diagram represents pressure (P_2) plotted as a function of flow for an actual direct-operated regulator. The setpoint is determined by the initial compression of the regulator spring. By adjusting the initial spring compression you change the spring loading force, so P_2 will be at a different value in order to balance the spring force. This establishes setpoint.

Droop

Droop, proportional band, and offset are terms used to describe the phenomenon of P_2 dropping below setpoint as flow increases. Droop is the amount of deviation from setpoint at a given flow, expressed as a percentage of setpoint. This “droop” curve is important to a user because it indicates regulating (useful) capacity.

Capacity

Capacities published by regulator manufacturers are given for different amounts of droop. Let’s see why this is important.

Let’s say that for our original problem, with the regulator set at 10 psig, our process requires 200 SCFH (standard cubic feet per hour) with no more than a 1 psi drop in setpoint. We need to keep the pressure at or above 9 psig because we have a low limit safety switch set at 9 psig that will shut the system down if pressure falls below this point.

Figure 6 illustrates the performance of a regulator that can do the job. And, if we can allow the downstream pressure to drop below 9 psig, the regulator can allow even more flow.

The capacities of a regulator published by manufacturers are generally given for 10% droop and 20% droop. In our example, this would relate to flow at 9 psig and at 8 psig.

Accuracy

The accuracy of a regulator is determined by the amount of flow it can pass for a given amount of droop. The closer the regulator is to the ideal regulator curve (setpoint), the more accurate it is.

Lockup

Lockup is the pressure above setpoint that is required to shut the regulator off tight. In many regulators, the orifice has a knife edge while the disk is a soft material. Some extra pressure, P_2 , is

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required to force the soft disk into the knife edge to make a tight seal. The amount of extra pressure required is lockup pressure. Lockup pressure may be important for a number of reasons. Consider the example above where a low pressure limit switch would shut down the system if P_2 fell below 9 psig. Now consider the same system with a high pressure safety cut out switch set a 10.5 psig. Because our regulator has a lockup pressure of 11 psig, the high limit switch will shut the system down before the regulator can establish tight shutoff. Obviously, we'll want to select a regulator with a lower lockup pressure.

Spring Rate and Regulator Accuracy

Using our initial problem as an example, let's say we now need the regulator to flow 300 SCFH at a droop of 10% from our original setpoint of 10 psig. Ten percent of 10 psig = 1 psig, so P_2 cannot drop below 10 to 1, or 9 psi. Our present regulator would not be accurate enough. For our regulator to pass 300 SCFH, P_2 will have to drop to 8 psig, or 20% droop.

Spring Rate and Droop

One way to make our regulator more accurate is to change to a lighter spring rate. To see how spring rate affects regulator accuracy, let's return to our original example. We first tried a spring with a rate of 100 pounds/inch. Let's substitute one with a rate of 50 pounds/inch. To keep the regulator in equilibrium, we'll have to initially adjust the spring to balance the 100 pound force produced by P_2 acting on the diaphragm. Recall how we calculate spring force:

$$F_S = K (\text{spring rate}) \times X (\text{compression})$$

Knowing that F_S must equal 100 pounds and $K = 50$ pounds/inch, we can solve for X , or spring compression, with:

$$X = F_S \div K, \text{ or } X = 2 \text{ inches}$$

So, we must wind in 2-inches of initial spring compression to balance diaphragm force, F_D .

Effect on Plug Travel

We saw before that with a spring rate of 100 pounds/inch, when P_2 dropped from 10 to 9 psig, the spring relaxed (and the valve disk traveled) 0.1 inch. Now let's solve for the amount of disk travel with the lighter spring rate of 50 pounds per inch. The force produced by the diaphragm is still 90 pounds.

$$F_D = P_2 \times A_D$$

To maintain equilibrium, the spring must also produce a force of 90 pounds. Recall the formula that determines spring force:

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

Because we know F_S must equal 90 pounds and our spring rate (K) is 50 pounds/inch, we can solve for compression (X) with:

$$X = F_S \div K$$

$$X = 90 \text{ pounds} \div 50 \text{ pounds/inch}$$

$$X = 1.8 \text{ inches}$$

To establish setpoint, we originally compressed this spring 2 inches. Now it has relaxed so that it is only compressed 1.8 inches, a change of 0.2-inch. So with a spring rate of 50 pounds/inch, the regulator responded to a 1 psig drop in P_2 by opening twice as far as it did with a spring rate of 100 pounds/inch. Therefore, our regulator is now more accurate because it has greater capacity for the same change in P_2 . In other words, it has less droop or offset. Using this example, it is easy to see how capacity and accuracy are related and how they are related to spring rate.

Light Spring Rate

Experience has shown that choosing the lightest available spring rate will provide the most accuracy (least droop). For example, a spring with a range of 35 to 100 psig is more accurate than a spring with a range of 90 to 200 psig. If you want to set your regulator at 100 psig, the 35 to 100 psig spring will provide better accuracy.

Practical Limits

While a lighter spring can reduce droop and improve accuracy, using too light a spring can cause instability problems. Fortunately, most of the work in spring selection is done by regulator manufacturers. They determine spring rates that will provide good performance for a given regulator, and publish these rates along with other sizing information.

Diaphragm Area and Regulator Accuracy

Diaphragm Area

Until this point, we have assumed the diaphragm area to be constant. In practice, the diaphragm area changes with travel. We're interested in this changing area because it has a major influence on accuracy and droop.

Diaphragms have convolutions in them so that they are flexible enough to move over a rated travel range. As they change position,

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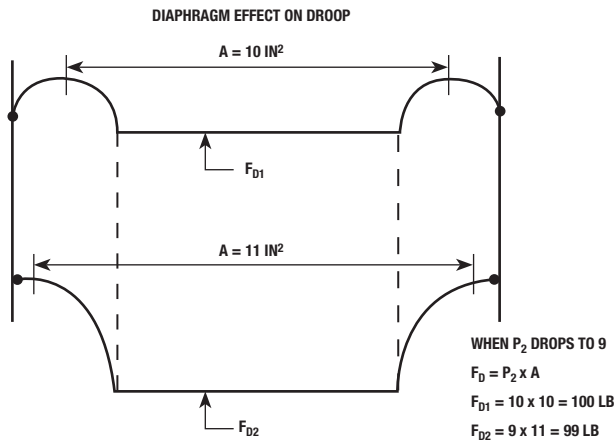


Figure 7. Changing Diaphragm Area

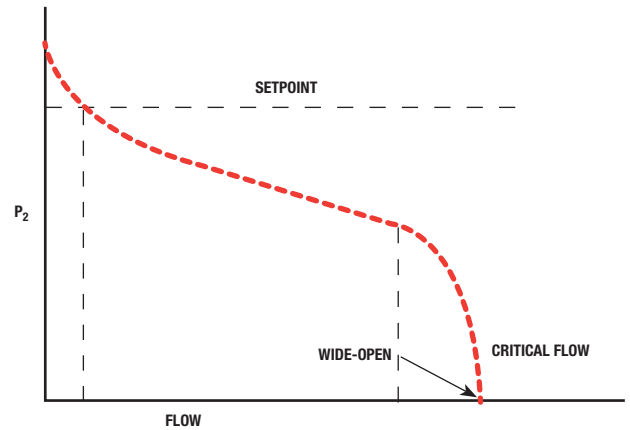


Figure 8. Critical Flow

they also change shape because of the pressure applied to them. Consider the example shown in Figure 7. As downstream pressure (P_2) drops, the diaphragm moves down. As it moves down, it changes shape and diaphragm area increases because the centers of the convolutions become further apart. The larger diaphragm area magnifies the effect of P_2 so even less P_2 is required to hold the diaphragm in place. This is called diaphragm effect. The result is decreased accuracy because incremental changes in P_2 do not result in corresponding changes in spring compression or disk position.

Increasing Diaphragm Area

To better understand the effects of changing diaphragm area, let's calculate the forces in the exaggerated example given in Figure 7. First, assume that the regulator is in equilibrium with a downstream pressure P_2 of 10 psig. Also assume that the area of the diaphragm in this position is 10 square inches. The diaphragm force (F_D) is:

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

$$F_D = (10 \text{ psi})(10 \text{ square inches})$$

$$F_D = 100 \text{ pounds}$$

Now assume that downstream pressure drops to 9 psig signaling the need for increased flow. As the diaphragm moves, its area increases to 11 square inches. The diaphragm force now produced is:

$$F_D = (9 \text{ psi})(11 \text{ square inches})$$

$$F_D = 99 \text{ pounds}$$

The change in diaphragm area increases the regulator's droop. While it's important to note that diaphragm effect contributes to

droop, diaphragm sizes are generally determined by manufacturers for different regulator types, so there is rarely a user option.

Diaphragm Size and Sensitivity

Also of interest is the fact that increasing diaphragm size can result in increased sensitivity. A larger diaphragm area will produce more force for a given change in P_2 . Therefore, larger diaphragms are often used when measuring small changes in low-pressure applications. Service regulators used in domestic gas service are an example.

Restricting Element and Regulator Performance

Critical Flow

Although changing the orifice size can increase capacity, a regulator can pass only so much flow for a given orifice size and inlet pressure, no matter how much we improve the unit's accuracy. Shown in Figure 8, after the regulator is wide-open, reducing P_2 does not result in higher flow. This area of the flow curve identifies critical flow. To increase the amount of flow through the regulator, the flowing fluid must pass at higher and higher velocities. But, the fluid can only go so fast. Holding P_1 constant while decreasing P_2 , flow approaches a maximum which is the speed of sound in that particular gas, or its sonic velocity. Sonic velocity depends on the inlet pressure and temperature for the flowing fluid. Critical flow is generally anticipated when downstream pressure (P_2) approaches a value that is less than or equal to one-half of inlet pressure (P_1).

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Orifice Size and Capacity

One way to increase capacity is to increase the size of the orifice. The variable flow area between disk and orifice depends directly on orifice diameter. Therefore, the disk will not have to travel as far with a larger orifice to establish the required regulator flow rate, and droop is reduced. Sonic velocity is still a limiting factor, but the flow rate at sonic velocity is greater because more gas is passing through the larger orifice.

Stated another way, a given change in P_2 will produce a larger change in flow rate with a larger orifice than it would with a smaller orifice. However, there are definite limits to the size of orifice that can be used. Too large an orifice makes the regulator more sensitive to fluctuating inlet pressures. If the regulator is overly sensitive, it will have a tendency to become unstable and cycle.

Orifice Size and Stability

One condition that results from an oversized orifice is known as the “bathtub stopper” effect. As the disk gets very close to the orifice, the forces of fluid flow tend to slam the disk into the orifice and shutoff flow. Downstream pressure drops and the disk opens. This causes the regulator to cycle—open, closed, open, closed. By selecting a smaller orifice, the disk will operate farther away from the orifice so the regulator will be more stable.

Orifice Size, Lockup, and Wear

A larger orifice size also requires a higher shutoff pressure, or lockup pressure. In addition, an oversized orifice usually produces faster wear on the valve disk and orifice because it controls flow with the disk near the seat. This wear is accelerated with high flow rates and when there is dirt or other erosive material in the flow stream.

Orifice Guideline

Experience indicates that using the smallest possible orifice is generally the best rule-of-thumb for proper control and stability.

Increasing P_1

Regulator capacity can be increased by increasing inlet pressure (P_1).

Factors Affecting Regulator Accuracy

As we have seen, the design elements of a regulator—the spring, diaphragm, and orifice size—can affect its accuracy. Some of these inherent limits can be overcome with changes to the regulator design.

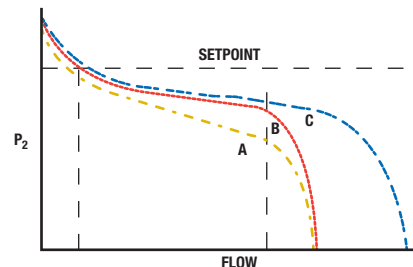


Figure 9. Increased Sensitivity

Performance Limits

The three curves in Figure 9 summarize the effects of spring rate, diaphragm area, and orifice size on the shape of the controlled pressure-flow rate curve. Curve A is a reference curve representing a typical regulator. Curve B represents the improved performance from either increasing diaphragm area or decreasing spring rate. Curve C represents the effect of increasing orifice size. Note that increased orifice size also offers higher flow capabilities. But remember that too large an orifice size can produce problems that will negate any gains in capacity.

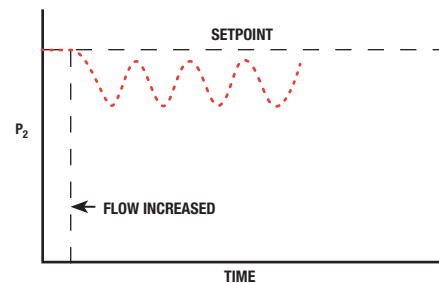


Figure 10. Cycling

Cycling

The sine wave in Figure 10 might be what we see if we increase regulator sensitivity beyond certain limits. The sine wave indicates instability and cycling.

Design Variations

All direct-operated regulators have performance limits that result from droop. Some regulators are available with features designed to overcome or minimize these limits.

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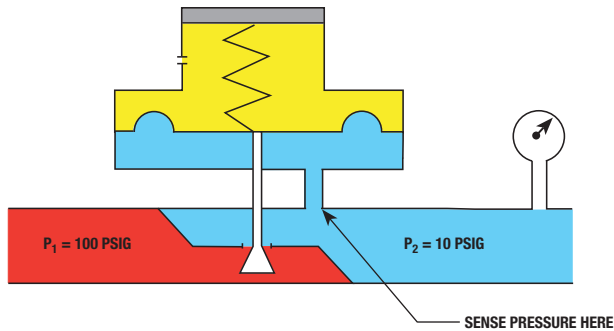


Figure 11. Pitot Tube

Improving Regulator Accuracy with a Pitot Tube

In addition to the changes we can make to diaphragm area, spring rate, orifice size, and inlet pressure, we can also improve regulator accuracy by adding a pitot tube as shown in Figure 11. Internal to the regulator, the pitot tube connects the diaphragm casing with a low-pressure, high velocity region within the regulator body. The pressure at this area will be lower than P_2 further downstream. By using a pitot tube to measure the lower pressure, the regulator will make more dramatic changes in response to any change in P_2 . In other words, the pitot tube tricks the regulator, causing it to respond more than it would otherwise.

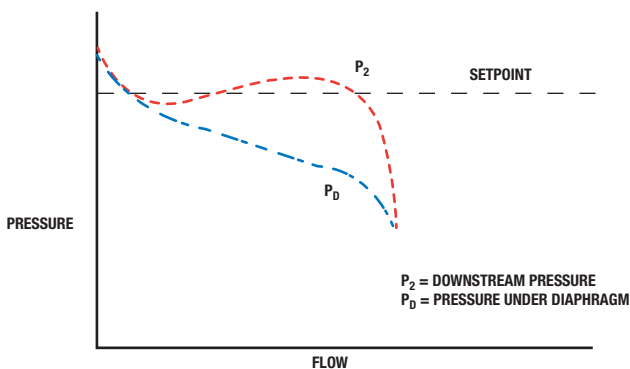


Figure 12. Performance with Pitot Tube

Numerical Example

For example, we'll establish setpoint by placing a gauge downstream and adjusting spring compression until the gauge reads 10 psig for P_2 . Because of the pitot tube, the regulator might actually be sensing a lower pressure. When P_2 drops from 10 psig to 9 psig, the pressure sensed by the pitot tube may drop from 8 psig to 6 psig. Therefore, the regulator opens further than it would if it were sensing actual downstream pressure.

Decreased Droop (Boost)

The pitot tube offers one chief advantage for regulator accuracy, it decreases droop. Shown in Figure 12, the diaphragm pressure, P_D , must drop just as low with a pitot tube as without to move the disk far enough to supply the required flow. But the solid curve shows that P_2 does not decrease as much as it did without a pitot tube. In fact, P_2 may increase. This is called boost instead of droop. So the use of a pitot tube, or similar device, can dramatically improve droop characteristics of a regulator.

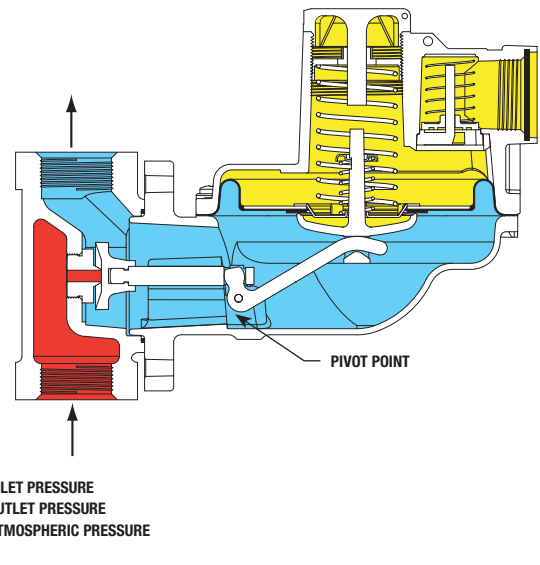


Figure 13. Lever Style Regulator

Improving Performance with a Lever

The lever style regulator is a variation of the simple direct-operated regulator. It operates in the same manner, except that it uses a lever to gain mechanical advantage and provide a high shutoff force.

In earlier discussions, we noted that the use of a larger diaphragm can result in increased sensitivity. This is because any change in P_2 will result in a larger change in diaphragm force. The same result is obtained by using a lever to multiply the force produced by the diaphragm as shown in Figure 13.

The main advantage of lever designs is that they provide increased force for lockup without the extra cost, size, and weight associated with larger diaphragms, diaphragm casings, and associated parts.

Principles of Pilot-Operated Regulators

Pilot-Operated Regulator Basics

In the evolution of pressure regulator designs, the shortcomings of the direct-operated regulator naturally led to attempts to improve accuracy and capacity. A logical next step in regulator design is to use what we know about regulator operation to explore a method of increasing sensitivity that will improve all of the performance criteria discussed.

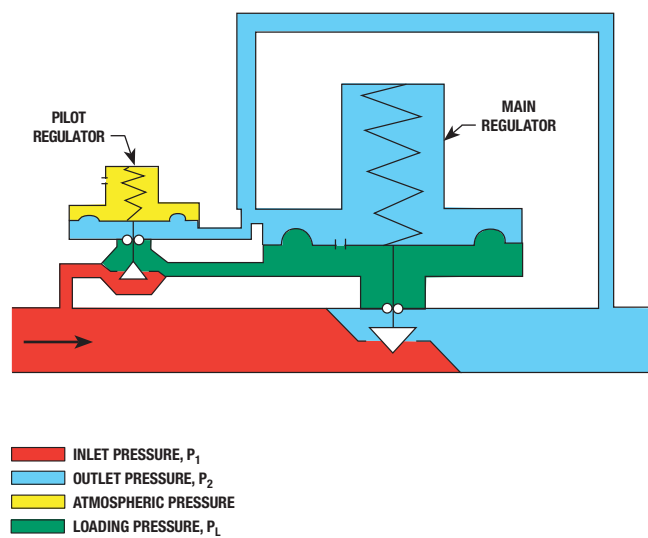


Figure 1. Pilot-Operated Regulator

Regulator Pilots

To improve the sensitivity of our regulator, we would like to be able to sense P_2 and then somehow make a change in loading pressure (P_L) that is greater than the change in P_2 . To accomplish this, we can use a device called a pilot, or pressure amplifier.

The major function of the pilot is to increase regulator sensitivity. If we can sense a change in P_2 and translate it into a larger change in P_L , our regulator will be more responsive (sensitive) to changes in demand. In addition, we can significantly reduce droop so its effect on accuracy and capacity is minimized.

Gain

The amount of amplification supplied by the pilot is called “gain”. To illustrate, a pilot with a gain of 20 will multiply the effect of a 1 psi change on the main diaphragm by 20. For example, a decrease in P_2 opens the pilot to increase P_L 20 times as much.

Identifying Pilots

Analysis of pilot-operated regulators can be simplified by viewing them as two independent regulators connected together. The smaller of the two is generally the pilot.

Setpoint

We may think of the pilot as the “brains” of the system. Setpoint and many performance variables are determined by the pilot. It senses P_2 directly and will continue to make changes in P_L on the main regulator until the system is in equilibrium. The main regulator is the “muscle” of the system, and may be used to control large flows and pressures.

Spring Action

Notice that the pilot uses a spring-open action as found in direct-operated regulators. The main regulator, shown in Figure 1, uses a spring-close action. The spring, rather than loading pressure, is used to achieve shutoff. Increasing P_L from the pilot onto the main diaphragm opens the main regulator.

Pilot Advantage

Because the pilot is the controlling device, many of the performance criteria we have discussed apply to the pilot. For example, droop is determined mainly by the pilot. By using very small pilot orifices and light springs, droop can be made small. Because of reduced droop, we will have greater usable capacity. Pilot lockup determines the lockup characteristics for the system. The main regulator spring provides tight shutoff whenever the pilot is locked up.

Gain and Restrictions

Stability

Although increased gain (sensitivity) is often considered an advantage, it also increases the gain of the entire pressure regulator system. If the system gain is too high, it may become unstable. In other words, the regulator might tend to oscillate; over-reacting by continuously opening and closing. Pilot gain can be modified to tune the regulator to the system. To provide a means for changing gain, every pilot-operated regulator system contains both a fixed and a variable restriction. The relative size of one restriction compared to the other can be varied to change gain and speed of response.

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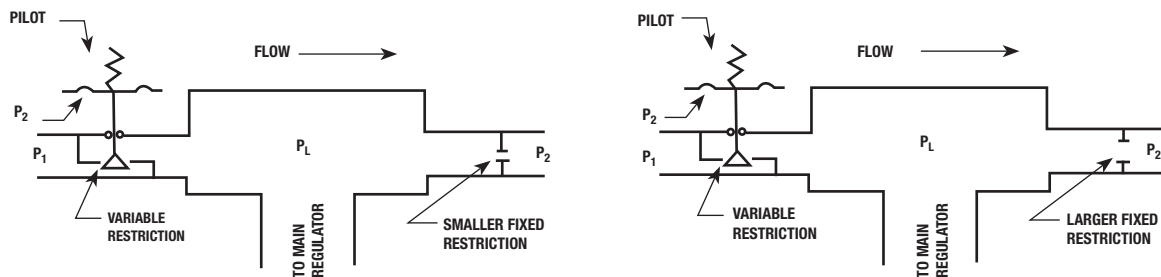


Figure 2. Fixed Restrictions and Gain (Used on Two-Path Control Systems)

Restrictions, Response Time, and Gain

Consider the example shown in Figure 2 with a small fixed restriction. Decreasing P_2 will result in pressure P_L increasing. Increasing P_2 will result in a decrease in P_L while P_L bleeds out through the small fixed restriction.

If a larger fixed restriction is used with a variable restriction, the gain (sensitivity) is reduced. A larger decrease in P_2 is required to increase P_L to the desired level because of the larger fixed restriction.

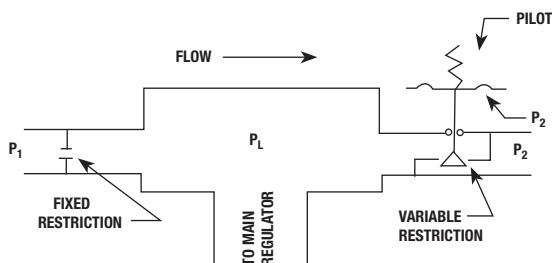


Figure 3. Unloading Systems

Loading and Unloading Designs

A loading pilot-operated design (Figure 2), also called two-path control, is so named because the action of the pilot loads P_L onto the main regulator measuring element. The variable restriction, or pilot orifice, opens to increase P_L .

An unloading pilot-operated design (Figure 3) is so named because the action of the pilot unloads P_L from the main regulator.

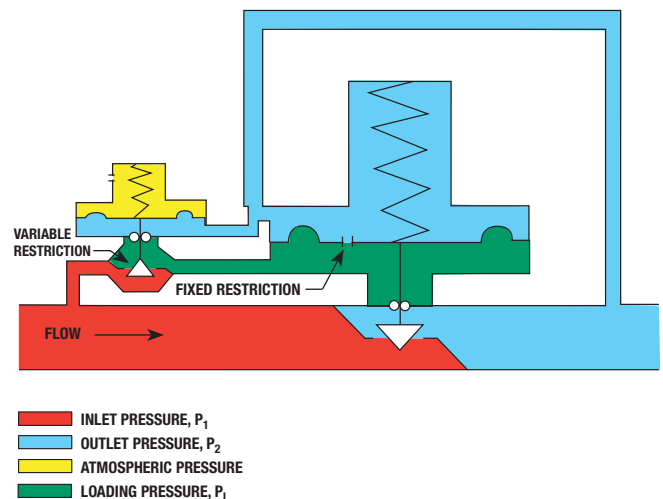


Figure 4. Two-Path Control

Two-Path Control (Loading Design)

In two-path control systems (Figure 4), the pilot is piped so that P_2 is registered on the pilot diaphragm and on the main regulator diaphragm at the same time. When downstream demand is constant, P_2 positions the pilot diaphragm so that flow through the pilot will keep P_2 and P_L on the main regulator diaphragm. When P_2 changes, the force on top of the main regulator diaphragm and on the bottom of the pilot diaphragm changes. As P_2 acts on the main diaphragm, it begins repositioning the main valve plug. This immediate reaction to changes in P_2 tends to make two-path designs faster than other pilot-operated regulators. Simultaneously, P_2 acting on the pilot diaphragm repositions the pilot valve and

Principles of Pilot-Operated Regulators

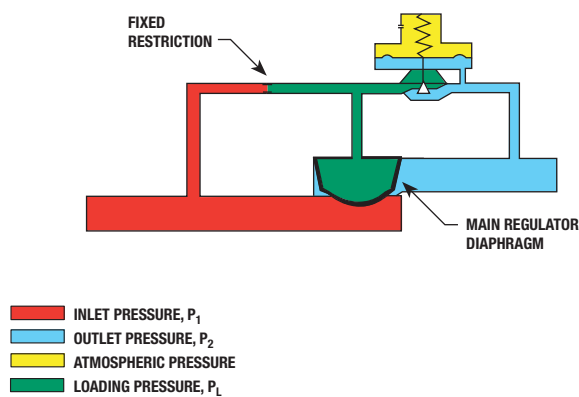


Figure 5. Unloading Control

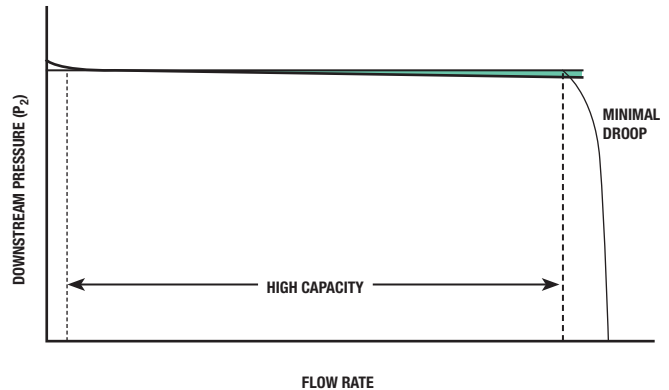


Figure 6. Pilot-Operated Regulator Performance

changes P_L on the main regulator diaphragm. This adjustment to P_L accurately positions the main regulator valve plug. P_L on the main regulator diaphragm bleeds through a fixed restriction until the forces on both sides are in equilibrium. At that point, flow through the regulator valve matches the downstream demand.

Two-Path Control Advantages

The primary advantages of two-path control are speed and accuracy. These systems may limit droop to less than 1%. They are well suited to systems with requirements for high accuracy, large capacity, and a wide range of pressures.

Unloading Control

Unloading systems (Figure 5) locate the pilot so that P_2 acts only on the pilot diaphragm. P_1 constantly loads under the regulator diaphragm and has access to the top of the diaphragm through a fixed restriction.

When downstream demand is constant, the pilot valve is open enough that P_L holds the position of the main regulator diaphragm. When downstream demand changes, P_2 changes and the pilot diaphragm reacts accordingly. The pilot valve adjusts P_L to reposition and hold the main regulator diaphragm.

Unloading Control Advantages

Unloading systems are not quite as fast as two-path systems, and they can require higher differential pressures to operate. However, they are simple and more economical, especially in large regulators. Unloading control is used with popular elastomer diaphragm style regulators. These regulators use a flexible membrane to throttle flow.

Performance Summary

Accuracy

Because of their high gain, pilot-operated regulators are extremely accurate. Droop for a direct-operated regulator might be in the range of 10 to 20 % whereas pilot-operated regulators are between one and 3% with values under 1% possible.

Capacity

Pilot-operated designs provide high capacity for two reasons. First, we have shown that capacity is related to droop. And because droop can be made very small by using a pilot, capacity is increased. In addition, the pilot becomes the “brains” of the system and controls a larger, sometimes much larger, main regulator. This also allows increased flow capabilities.

Principles of Pilot-Operated Regulators

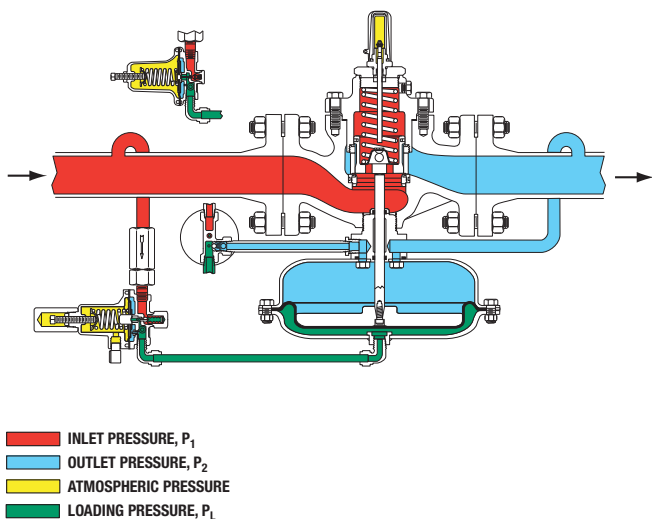


Figure 7. Type 1098-EGR, Typical Two-Path Control

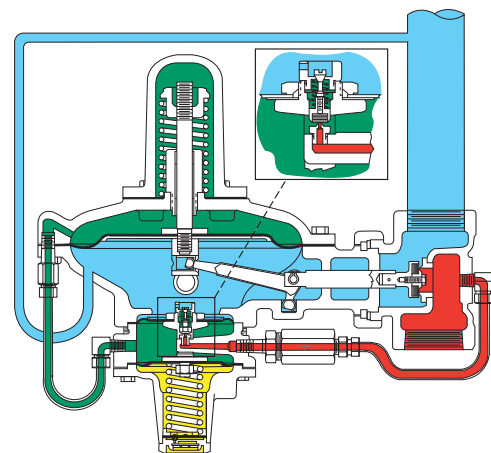


Figure 8. Type 99, Typical Two-Path Control with Integrally Mounted Pilot

Lockup

The lockup characteristics for a pilot-operated regulator are the lockup characteristics of the pilot. Therefore, with small orifices, lockup pressures can be small.

Applications

Pilot-operated regulators should be considered whenever accuracy, capacity, and/or high pressure are important selection criteria. They can often be applied to high capacity services with greater economy than a control valve and actuator with controller.

Two-Path Control

In some designs (Figure 7), the pilot and main regulator are separate components. In others (Figure 8), the system is integrated into a single package. All, however, follow the basic design concepts discussed earlier.

Type 1098-EGR

The schematic in Figure 7 illustrates the Type 1098-EGR regulator's operation. It can be viewed as a model for all two-path, pilot-operated regulators. The pilot is simply a sensitive direct-operated regulator used to send loading pressure to the main regulator diaphragm.

Identify the inlet pressure (P_1). Find the downstream pressure (P_2). Follow it to where it opposes the loading pressure on the main regulator diaphragm. Then, trace P_2 back to where it opposes the control spring in the pilot. Finally, locate the route of P_2 between the pilot and the regulator diaphragm.

Changes in P_2 register on the pilot and main regulator diaphragms at the same time. As P_2 acts on the main diaphragm, it begins repositioning the main valve plug. Simultaneously, P_2 acting on the pilot diaphragm repositions the pilot valve and changes P_L on the main regulator diaphragm. This adjustment in P_L accurately positions the main regulator valve plug.

Principles of Pilot-Operated Regulators

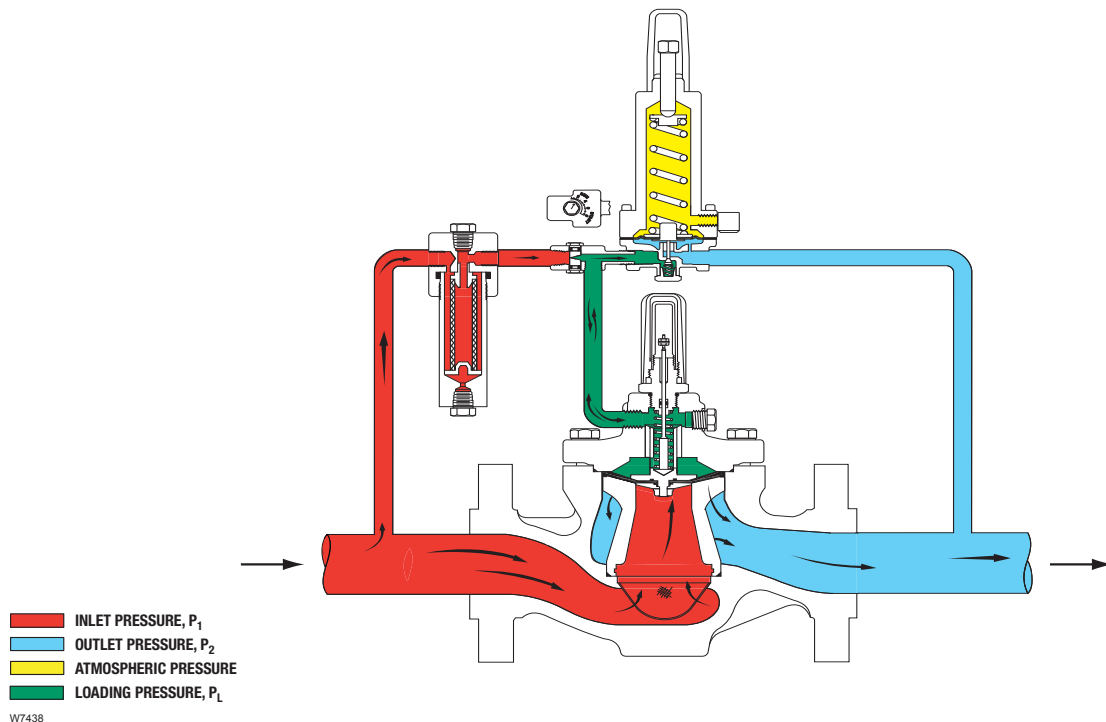


Figure 9. Type EZR, Unloading Design

As downstream demand is met, P_2 rises. Because P_2 acts directly on both the pilot and main regulator diaphragms, this design provides fast response.

Type 99

The schematic in Figure 8 illustrates another typical two-path control design, the Type 99. The difference between the Type 1098-EGR and the Type 99 is the integrally mounted pilot of the Type 99.

The pilot diaphragm measures P_2 . When P_2 falls below the pilot setpoint, the diaphragm moves away from the pilot orifice and allows loading pressure to increase. This loads the top of the main regulator diaphragm and strokes the main regulator valve open further.

Unloading Design

Unloading designs incorporate a molded composition diaphragm that serves as the combined loading and restricting component of the main regulator. Full upstream pressure (P_1) is used to load the regulator diaphragm when it is seated. The regulator shown in Figure 9 incorporates an elastomeric valve closure member.

Unloading regulator designs are slower than two-path control systems because the pilot must first react to changes in P_2 before the main regulator valve moves. Recall that in two-path designs, the pilot and main regulator diaphragms react simultaneously.

P_1 passes through a fixed restriction and fills the space above the regulator diaphragm. This fixed restriction can be adjusted to increase or decrease regulator gain. P_1 also fills the cavity below the regulator diaphragm. Because the surface area on the top side of the diaphragm is larger than the area exposed to P_1 below, the diaphragm is forced down against the cage to close the regulator.

When downstream demand increases, the pilot opens. When the pilot opens, regulator loading pressure escapes downstream much faster than P_1 can bleed through the fixed restriction. As pressure above the regulator diaphragm decreases, P_1 forces the diaphragm away from its seat.

When downstream demand is reduced, P_2 increases until it's high enough to compress the pilot spring and close the pilot valve. As the pilot valve closes, P_1 continues to pass through the fixed restriction and flows into the area above the main regulator diaphragm. This loading pressure, P_L , forces the diaphragm back toward the cage, reducing flow through the regulator.

Selecting and Sizing Pressure Reducing Regulators

Introduction

Those who are new to the regulator selection and sizing process are often overwhelmed by the sheer number of regulator types available and the seemingly endless lists of specifications in manufacturer's literature. This application guide is designed to assist you in selecting a regulator that fits your application's specific needs.

Although it might seem obvious, the first step is to consider the application itself. Some applications immediately point to a group of regulators designed specifically for that type of service. The Application Guide has sections to help identify regulators that are designed for specific applications. There are Application Maps, Quick Selection Guides, an Applications section, and Product Pages. The Application Map shows some of the common applications and the regulators that are used in those applications. The Quick Selection Guide lists the regulators by application, and provides important selection information about each regulator. The Applications section explains the applications covered in the section and it also explains many of the application considerations. The Product Pages provide specific details about the regulators that are suitable for the applications covered in the section. To begin selecting a regulator, turn to the Quick Selection Guide in the appropriate Applications section.

Quick Selection Guides

Quick Selection Guides identify the regulators with the appropriate pressure ratings, outlet pressure ranges, and capacities. These guides quickly narrow the range of potentially appropriate regulators. The choices identified by using a Quick Selection Guide can be narrowed further by using the Product Pages to find more information about each of the regulators.

Product Pages

Identifying the regulators that can pass the required flow narrows the possible choices further. When evaluating flow requirements, consider the minimum inlet pressure and maximum flow requirements. Again, this worst case combination ensures that the regulator can pass the required flow under all anticipated conditions.

After one or more regulators have been identified as potentially suitable for the service conditions, consult specific Product Pages to check regulator specifications and capabilities. The application requirements are compared to regulator specifications to narrow the

range of appropriate selections. The following specifications can be evaluated in the Product Pages:

- Product description and available sizes
- Maximum inlet and outlet pressures (operating and emergency)
- Outlet pressure ranges
- Flow capacity
- End connection styles
- Regulator construction materials
- Accuracy
- Pressure registration (internal or external)
- Temperature capabilities

After comparing the regulator capabilities with the application requirements, the choices can be narrowed to one or a few regulators. Final selection might depend upon other factors including special requirements, availability, price, and individual preference.

Special Requirements

Finally, evaluate any special considerations, such as the need for external control lines, special construction materials, or internal overpressure protection. Although overpressure protection might be considered during sizing and selection, it is not covered in this section.

The Role of Experience

Experience in the form of knowing what has worked in the past, and familiarity with specific products, has great value in regulator sizing and selection. Knowing the regulator performance characteristics required for a specific application simplifies the process. For example, when fast speed of response is required, a direct-operated regulator may come to mind; or a pilot-operated regulator with an auxiliary, large capacity pilot to speed changes in loading pressure.

Sizing Equations

Sizing equations are useful when sizing pilot-operated regulators and relief valves. They can also be used to calculate the wide-open flow of direct-operated regulators. Use the capacity tables or curves in this application guide when sizing direct-operated regulators and relief/backpressure regulators. The sizing equations are in the Valve Sizing Calculations section.

Selecting and Sizing Pressure Reducing Regulators

General Sizing Guidelines

The following are intended to serve only as guidelines when sizing pressure reducing regulators. When sizing any regulator, consult with experienced personnel or the regulator manufacturer for additional guidance and information relating to specific applications.

Body Size

Regulator body size should never be larger than the pipe size. However, a properly sized regulator may be smaller than the pipeline.

Construction

Be certain that the regulator is available in materials that are compatible with the controlled fluid and the temperatures used. Also, be sure that the regulator is available with the desired end connections.

Pressure Ratings

While regulators are sized using minimum inlet pressures to ensure that they can provide full capacity under all conditions, pay particular attention to the maximum inlet and outlet pressure ratings.

Wide-Open Flow Rate

The capacity of a regulator when it has failed wide-open is usually greater than the regulating capacity. For that reason, use the regulating capacities when sizing regulators, and the wide-open flow rates only when sizing relief valves.

Outlet Pressure Ranges and Springs

If two or more available springs have published outlet pressure ranges that include the desired pressure setting, use the spring with the lower range for better accuracy. Also, it is not necessary to attempt to stay in the middle of a spring range, it is acceptable to use the full published outlet pressure range without sacrificing spring performance or life.

Accuracy

Of course, the need for accuracy must be evaluated. Accuracy is generally expressed as droop, or the reduction of outlet pressure experienced as the flow rate increases. It is stated in percent, inches of water column, or pounds per square inch. It indicates the difference between the outlet pressure at low flow rates and the outlet pressure at the published maximum flow rate. Droop is also called offset or proportional band.

Inlet Pressure Losses

The regulator inlet pressure used for sizing should be measured directly at the regulator inlet. Measurements made at any distance upstream from the regulator are suspect because line loss can significantly reduce the actual inlet pressure to the regulator. If the regulator inlet pressure is given as a system pressure upstream, some compensation should be considered. Also, remember that downstream pressure always changes to some extent when inlet pressure changes.

Orifice Diameter

The recommended selection for orifice size is the smallest diameter that will handle the flow. This can benefit operation in several ways: instability and premature wear might be avoided, relief valves may be smaller, and lockup pressures may be reduced.

Speed of Response

Direct-operated regulators generally have faster response to quick flow changes than pilot-operated regulators.

Turn-Down Ratio

Within reasonable limits, most soft-seated regulators can maintain pressure down to zero flow. Therefore, a regulator sized for a high flow rate will usually have a turndown ratio sufficient to handle pilot-light sized loads during periods of low demand.

Sizing Exercise: Industrial Plant Gas Supply

Regulator selection and sizing generally requires some subjective evaluation and decision making. For those with little experience, the best way to learn is through example. Therefore, these exercises present selection and sizing problems for practicing the process of identifying suitable regulators.

Our task is to select a regulator to supply reduced pressure natural gas to meet the needs of a small industrial plant. The regulated gas is metered before entering the plant. The selection parameters are:

- Minimum inlet pressure, $P_{1min} = 30$ psig
- Maximum inlet pressure, $P_{1max} = 40$ psig
- Outlet pressure setting, $P_2 = 1$ psig
- Flow, $Q = 95\ 000$ SCFH
- Accuracy (droop required) = 10% or less

Selecting and Sizing Pressure Reducing Regulators

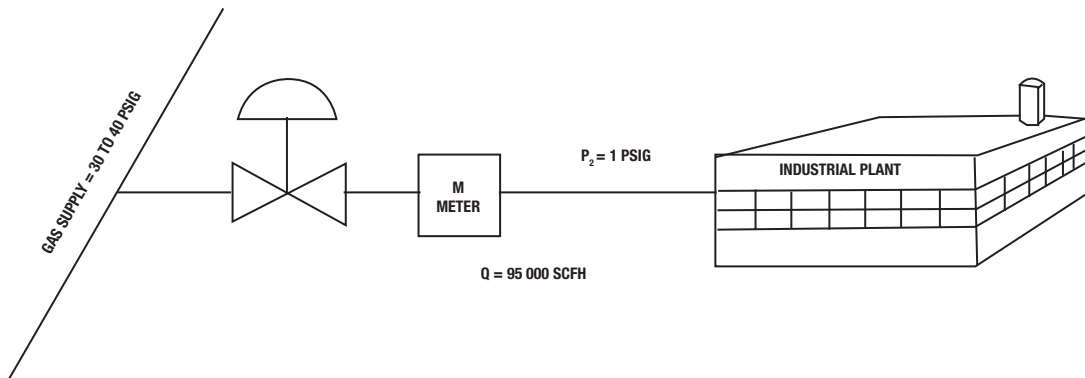


Figure 1. Natural Gas Supply

Quick Selection Guide

Turn to the Commercial/Industrial Quick Selection Guide. From the Quick Selection Guide, we find that the choices are:

- Type 133
- Type 1098-EGR

Product Pages

Under the product number on the Quick Selection Guide is the page number of the product page. Look at the flow capacities of each of the possible choices. From the product pages we found the following:

- At 30 psig inlet pressure and 10% droop, the Type 133 has a flow capacity of 90 000 SCFH. This regulator does not meet the required flow capacity.
- At 30 psig inlet pressure, the Type 1098-EGR has a flow capacity of 131 000 SCFH. By looking at the Proportional Band (Droop) table, we see that the Type 6352 pilot with the yellow pilot spring and the green main valve has 0.05 psig droop. This regulator meets the selection criteria.

Final Selection

We find that the Type 1098-EGR meets the selection criteria.

Overpressure Protection Methods

Overpressure protective devices are of vital concern. Safety codes and current laws require their installation each time a pressure reducing station is installed that supplies gas from any system to another system with a lower maximum allowable operating pressure.

Methods of Overpressure Protection

The most commonly used methods of overpressure protection, not necessarily in order of use or importance, include:

- Relief Valves (Figure 1)
- Monitors (Figures 2 and 3)
- Series Regulation (Figure 4)
- Shutoff (Figure 5)
- Relief Monitor (Figure 6)

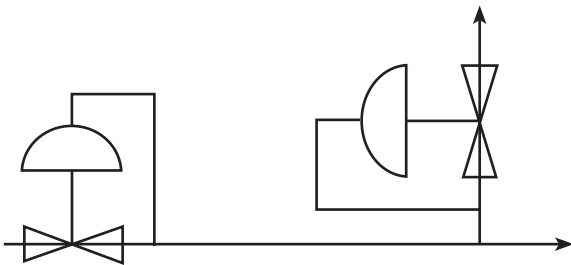


Figure 1. Relief Valve Schematic

Relief Valves

A relief valve is a device that vents process fluid to atmosphere to maintain the pressure downstream of the regulator below the safe maximum pressure. Relief is a common form of overpressure protection typically used for low to medium capacity applications. (Note: Fisher® relief valves are not ASME safety relief valves.)

Types of Relief Valves

The basic types of relief valves are:

- Pop type
- Direct-operated relief valves
- Pilot-operated relief valves
- Internal relief valves

The pop type relief valve is the simplest form of relief. Pop relief valves tend to go wide-open once the pressure has exceeded its setpoint by a small margin. The setpoint can drift over time, and because of its quick opening characteristic the pop relief can sometimes become unstable when relieving, slamming open and closed. Many have a non-adjustable setpoint that is set and pinned at the factory.

If more accuracy is required from a relief valve, the direct-operated relief valve would be the next choice. They can throttle better than a pop relief valve, and tend to be more stable, yet are still relatively simple. Although there is less drift in the setpoint of the direct-operated relief valve, a significant amount of build-up is often required to obtain the required capacity.

The pilot-operated relief valves have the most accuracy, but are also the most complicated and expensive type of relief. They use a pilot to dump loading pressure, fully stroking the main valve with very little build-up above setpoint. They have a large capacity and are available in larger sizes than other types of relief.

Many times, internal relief will provide adequate protection for a downstream system. Internal relief uses a relief valve built into the regulator for protection. If the pressure builds too far above the setpoint of the regulator, the relief valve in the regulator opens up, allowing excess pressure to escape through the regulator vent.

Advantages

The relief valve is considered to be the most reliable type of overpressure protection because it is not subject to blockage by foreign objects in the line during normal operations. It also imposes no decrease in the regulator capacity which it is protecting, and it has the added advantage of being its own alarm when it vents. It is normally reasonable in cost and keeps the customer in service despite the malfunction of the pressure reducing valve.

Disadvantages

When the relief valve blows, it could possibly create a hazard in the surrounding area by venting. The relief valve must be sized carefully to relieve the gas or fluid that could flow through the pressure reducing valve at its maximum inlet pressure and in the wide-open position, assuming no flow to the downstream. Therefore, each application must be sized individually. The requirement for periodic testing of relief valves also creates an operational and/or public relations problem.

Overpressure Protection Methods

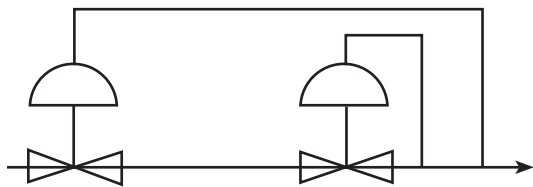


Figure 2. Monitoring Regulators Schematic

Monitoring Regulators

Monitoring is overpressure control by containment. When the working pressure reducing valve ceases to control the pressure, a second regulator installed in series, which has been sensing the downstream pressure, goes into operation to maintain the downstream pressure at a slightly higher than normal pressure. The monitoring concept is gaining in popularity, especially in low-pressure systems, because very accurate relay pilots permit reasonably close settings of the working and monitoring regulators.

The two types of wide-open monitoring are upstream and downstream monitoring. One question often asked is, “Which is better, upstream or downstream monitoring?” Using two identical regulators, there is no difference in overall capacity with either method.

When using monitors to protect a system or customer who may at times have zero load, a small relief valve is sometimes installed downstream of the monitor system with a setpoint just above the monitor. This allows for a token relief in case dust or dirt in the system prevents bubble tight shutoff of the regulators.

Advantages

The major advantage is that there is no venting to atmosphere. During an overpressure situation, monitoring keeps the customer on line and keeps the downstream pressure relatively close to the setpoint of the working regulator. Testing is relatively easy and safe. To perform a periodic test on a monitor, increase the outlet set pressure of the working device and watch the pressure to determine if the monitor takes over.

Disadvantages

Compared to relief valves, monitoring generally requires a higher initial investment. Monitoring regulators are subject to blocking, which is why filters or strainers are specified with increasing frequency. Because the monitor is in series, it is an added restriction in the line. This extra restriction can sometimes force one to use a larger, more expensive working regulator.

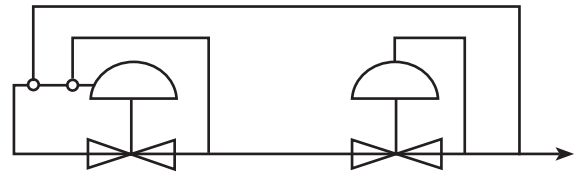


Figure 3. Working Monitor Schematic

Working Monitor

A variation of monitoring overpressure protection that overcomes some of the disadvantages of a wide-open monitor is the “working monitor” concept wherein a regulator upstream of the working regulator uses two pilots. This additional pilot permits the monitoring regulator to act as a series regulator to control an intermediate pressure during normal operation. In this way, both units are always operating and can be easily checked for proper operation. Should the downstream pressure regulator fail to control, however, the monitoring pilot takes over the control at a slightly higher than normal pressure and keeps the customer on line. This is pressure control by containment and eliminates public relations problems.

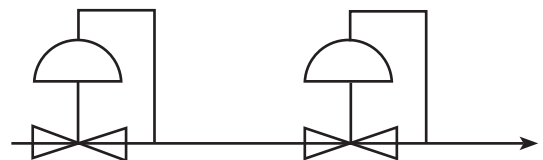


Figure 4. Series Regulation Schematic

Series Regulation

Series regulation is also overpressure protection by containment in that two regulators are set in the same pipeline. The first unit maintains an inlet pressure to the second valve that is within the maximum allowable operating pressure of the downstream system. Under this setup, if either regulator should fail, the resulting downstream pressure maintained by the other regulator would not exceed the safe maximum pressure.

This type of protection is normally used where the regulator station is reducing gas to a pressure substantially below the maximum allowable operating pressure of the distribution system being supplied. Series regulation is also found frequently in farm taps and in similar situations within the guidelines mentioned above.

Overpressure Protection Methods

Advantages

Again, nothing is vented to atmosphere.

Disadvantages

Because the intermediate pressure must be cut down to a pressure that is safe for the entire downstream, the second-stage regulator often has very little pressure differential available to create flow. This can sometimes make it necessary to increase the size of the second regulator significantly. Another drawback occurs when the first-stage regulator fails and no change in the final downstream pressure is noticed because the system operates in what appears to be a “normal” manner without benefit of protection. Also, the first-stage regulator and intermediate piping must be capable of withstanding and containing maximum upstream pressure.

The second-stage regulator must also be capable of handling the full inlet pressure in case the first-stage unit fails to operate. In case the second-stage regulator fails, its actuator will be subjected to the intermediate pressure set by the first-stage unit. The second-stage actuator pressure ratings should reflect this possibility.

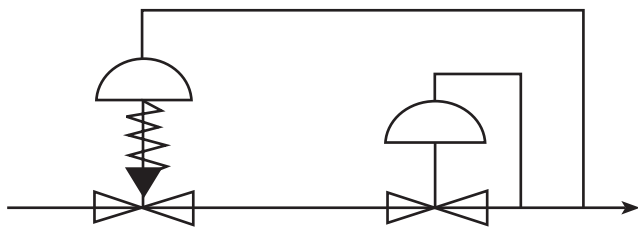


Figure 5. Shutoff Schematic

Shutoff Devices

The shutoff device also accomplishes overpressure protection by containment. In this case, the customer is shutoff completely until the cause of the malfunction is determined and the device is manually reset. Many gas distribution companies use this as an added measure of protection for places of public assembly such as schools, hospitals, churches, and shopping centers. In those cases, the shutoff device is a secondary form of overpressure protection. Shutoff valves are also commonly used by boiler manufacturers in combustion systems.

Advantages

By shutting off the customer completely, the safety of the downstream system is assured. Again, there is no public relations problem or hazard from venting gas or other media.

Disadvantages

The customer may be shutoff because debris has temporarily lodged under the seat of the operating regulator, preventing tight shutoff. A small relief valve can take care of this situation.

On a distribution system with a single supply, using a slam-shut can require two trips to each customer, the first to shutoff the service valve, and the second visit after the system pressure has been restored to turn the service valve back on and re-light the appliances. In the event a shutoff is employed on a service line supplying a customer with processes such as baking, melting metals, or glass making, the potential economic loss could dictate the use of an overpressure protection device that would keep the customer online.

Another problem associated with shutoffs is encountered when the gas warms up under no-load conditions. For instance, a regulator locked up at approximately 7-inches w.c. could experience a pressure rise of approximately 0.8-inch w.c. per degree Fahrenheit rise, which could cause the high-pressure shutoff to trip when there is actually no equipment failure.

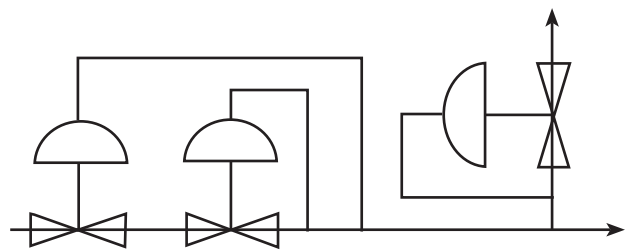


Figure 6. Relief Monitor Schematic

Relief Monitor

Another concept in overpressure protection for small industrial and commercial loads, up to approximately 10 000 cubic feet per hour, incorporates both an internal relief valve and a monitor. In this device, the relief capacity is purposely restricted to prevent excess venting of gas in order to bring the monitor into operation more quickly. The net result is that the downstream pressure is protected, in some cases to less than 1 psig. The amount of gas vented under maximum inlet pressure conditions does not exceed the amount vented by a domestic relief type service regulator.

Overpressure Protection Methods

Types of Overpressure Protection						
PERFORMANCE QUESTIONS	RELIEF	WORKING MONITOR	MONITOR	SERIES REGULATION	SHUTOFF	RELIEF MONITOR
Keeps application online?	Yes	Yes	Yes	Yes	No	Yes
Venting to atmosphere?	Yes	No	No	No	No	Minor
Manual resetting required after operation?	No	No	No	No	Yes	No
Reduces capacity of regulator?	No	Yes	Yes	Yes	No	No
Constantly working during normal operation?	No	Yes	No	Yes	No	Yes
Demands "emergency" action?	Yes	No	No	No	Yes	Maybe
Will surveillance of pressure charts indicate partial loss of performance of overpressure devices?	No	Yes	Maybe	Yes	No	No
Will surveillance of pressure charts indicate regulator has failed and safety device is in control?	Yes	Yes	Yes	Yes	Yes	Yes

With this concept, the limitation by regulator manufacturers of inlet pressure by orifice size, as is found in "full relief" devices, is overcome. Downstream protection is maintained, even with abnormally high inlet pressure. Public relations problems are kept to a minimum by the small amount of vented gas. Also, the unit does not require manual resetting, but can go back into operation automatically.

Dust or dirt can clear itself off the seat, but if the obstruction to the disk closing still exists when the load goes on, the customer would be kept online. When the load goes off, the downstream pressure will again be protected. During normal operation, the monitoring portion of the relief monitor is designed to move slightly with minor fluctuations in downstream pressure or flow.

Summary

From the foregoing discussion, it becomes obvious that there are many design philosophies available and many choices of equipment to meet overpressure protection requirements. Also, assume the

overpressure device will be called upon to operate sometime after it is installed. The overall design must include an analysis of the conditions created when the protection device operates.

The accompanying table shows:

- What happens when the various types of overpressure protection devices operate
- The type of reaction required
- The effect upon the customer or the public
- Some technical conditions

These are the general characteristics of the various types of safety devices. From the conditions and results shown, it is easier to decide which type of overpressure equipment best meets your needs. Undoubtedly, compromises will have to be made between the conditions shown here and any others which may govern your operating parameters.

Principles of Relief Valves

Overpressure Protection

Overpressure protection is a primary consideration in the design of any piping system. The objective of overpressure protection is to maintain the pressure downstream of a regulator at a safe maximum value.

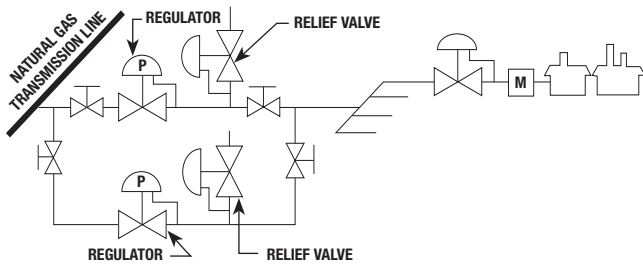


Figure 1. Distribution System

In the system shown in Figure 1, a high-pressure transmission system delivers natural gas through a pressure reducing regulator to a lower pressure system that distributes gas to individual customers. The regulators, the piping, and the devices that consume gas are protected from overpressure by relief valves. The relief valve's setpoint is adjusted to a level established by the lowest maximum pressure rating of any of the lower pressure system components.

Maximum Pressure Considerations

Overpressure occurs when the pressure of a system is above the setpoint of the device controlling its pressure. It is evidence of some failure in the system (often the upstream regulator), and it can cause the entire system to fail if it's not limited. To implement overpressure protection, the weakest part in the pressure system is identified and measures are taken to limit overpressure to that component's maximum pressure rating. The most vulnerable components are identified by examining the maximum pressure ratings of the:

- Downstream equipment
- Low-pressure side of the main regulator
- Piping

The lowest maximum pressure rating of the three is the maximum allowable pressure.

Downstream Equipment

The downstream component (appliance, burner, boiler, etc.) with the lowest maximum pressure rating sets the highest pressure that all the downstream equipment can be subjected to.

Main Regulator

Pressure reducing regulators have different pressure ratings which refer to the inlet, outlet, and internal components. The lowest of these should be used when determining the maximum allowable pressure.

Piping

Piping is limited in its ability to contain pressure. In addition to any physical limitations, some applications must also conform to one or more applicable pressure rating codes or regulations.

Relief Valves

Relief involves maintaining the pressure downstream of a regulator at a safe maximum pressure using any device that vents fluid to a safe pressure system (often the atmosphere). Relief valve exhaust must be directed or piped to a safe location. Relief valves perform this function. They are considered to be one of the most reliable types of overpressure protection available and are available in a number of different types. Fisher® relief valves are not ASME safety relief valves.



Figure 2. Types of Relief Valves

Principles of Relief Valves

Relief Valve Popularity

Relief valves are popular for several reasons. They do not block the normal flow through a line. They do not decrease the capacities of the regulators they protect. And, they have the added advantage of being an alarm if they vent to atmosphere.

Relief Valve Types

Relief valves are available in four general types. These include: pop type, direct-operated, pilot-operated, and internal relief valves.

Selection Criteria

Pressure Build-up

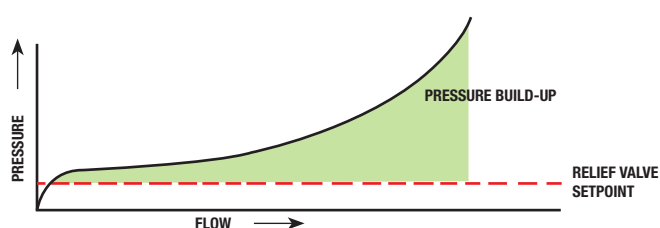


Figure 3. Pressure Build-up

A relief valve has a setpoint at which it begins to open. For the valve to fully open and pass the maximum flow, pressure must build up to some level above the setpoint of the relief valve. This is known as pressure build-up over setpoint, or simply build-up.

Periodic Maintenance

A relief valve installed in a system that normally performs within design limits is very seldom exercised. The relief valve sits and waits for a failure. If it sits for long periods it may not perform as expected. Disks may stick in seats, setpoints can shift over time, and small passages can become clogged with pipeline debris. Therefore, periodic maintenance and inspection is recommended. Maintenance requirements might influence the selection of a relief valve.

Cost Versus Performance

Given several types of relief valves to choose from, selecting one type is generally based on the ability of the valve to provide adequate protection at the most economical cost. Reduced pressure build-up and increased capacity generally come at an increased price.

Installation and Maintenance Considerations

Initial costs are only a part of the overall cost of ownership. Maintenance and installation costs must also be considered over the life of the relief valve. For example, internal relief might be initially more economical than an external relief valve. However, maintaining a regulator with internal relief requires that the system be shut down and the regulator isolated. This may involve additional time and the installation of parallel regulators and relief valves if flow is to be maintained to the downstream system during maintenance operations.

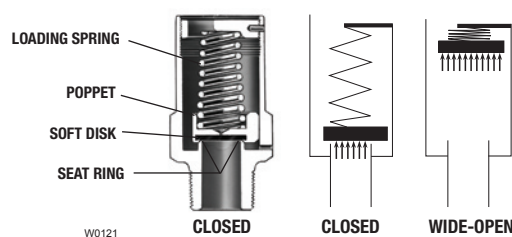


Figure 4. Pop Type Relief Valve Construction and Operation

Pop Type Relief Valve

The most simple type of relief valve is the pop type. They are used wherever economy is the primary concern and some setpoint drift is acceptable.

Operation

Pop type relief valves are essentially on-off devices. They operate in either the closed or wide-open position. Pop type designs register pressure directly on a spring-opposed poppet. The poppet assembly includes a soft disk for tight shutoff against the seat ring. When the inlet pressure increases above setpoint, the poppet assembly is pushed away from the seat. As the poppet rises, pressure registers against a greater surface area of the poppet. This dramatically increases the force on the poppet. Therefore, the poppet tends to travel to the fully open position reducing pressure build-up.

Principles of Relief Valves

Build-up Over Setpoint

Recall that pressure build-up relates capacity to pressure; increasing capacity requires some increase in pressure. In throttling relief valves, pressure build-up is related to accuracy. In pop type relief valves, build-up over setpoint results largely because the device is a restriction to flow rather than the spring rate of the valve's loading spring.

Fixed Setpoint

The setpoint of a pop type valve cannot be adjusted by the user. The spring is initially loaded by the manufacturer. A pinned spring retainer keeps the spring in position. This is a safety measure that prevents tampering with the relief valve setpoint.

Typical Applications

This type of relief valve may be used where venting to the atmosphere is acceptable, when the process fluid is compatible with the soft disk, and when relief pressure variations are allowable. They are often used as inexpensive token relief. For example, they may be used simply to provide an audible signal of an overpressure condition.

These relief valves may be used to protect against overpressure stemming from a regulator with a minimal amount of seat leakage. Unchecked, this seat leakage could allow downstream pressure to build to full P_1 over time. The use of a small pop type valve can be installed to protect against this situation.

These relief valves are also commonly installed with a regulator in a natural gas system farm tap, in pneumatic lines used to operate air drills, jackhammers, and other pneumatic equipment, and in many other applications.

Advantages

Pop type relief valves use few parts. Their small size allows installation where space is limited. Also, low initial cost, easy installation, and high capacity per dollar invested can result in economical system relief.

Disadvantages

The setpoint of a pop type relief valve may change over time. The soft disk may stick to the seat ring and cause the pop pressure to increase.

As an on-off device, this style of relief valve does not throttle flow over a pressure range. Because of its on-off nature, this type of relief valve may create pressure surges in the downstream system.

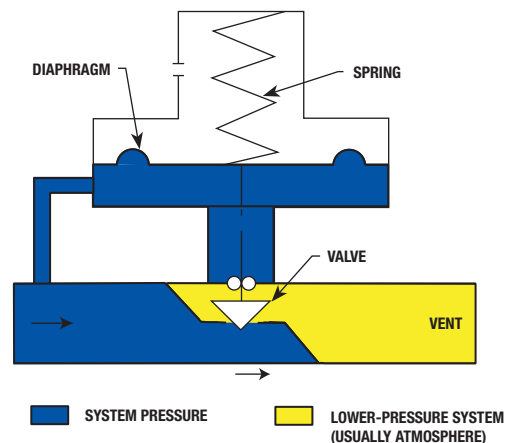


Figure 5. Direct-Operated Relief Valve Schematic

If the relief valve capacity is significantly larger than the failed regulator's capacity, the relief valve may over-compensate each time it opens and closes. This can cause the downstream pressure system to become unstable and cycle. Cycling can damage the relief valve and downstream equipment.

Direct-Operated Relief Valves

Compared to pop type relief valves, direct-operated relief valves provide throttling action and may require less pressure build-up to open the relief valve.

Operation

A schematic of a direct-operated relief valve is shown in Figure 5. It looks like an ordinary direct-operated regulator except that it senses upstream pressure rather than downstream pressure. And, it uses a spring-close rather than a spring-open action. It contains the same essential elements as a direct-operated regulator:

- A diaphragm that measures system pressure
- A spring that provides the initial load to the diaphragm and is used to establish the relief setpoint
- A valve that throttles the relief flow

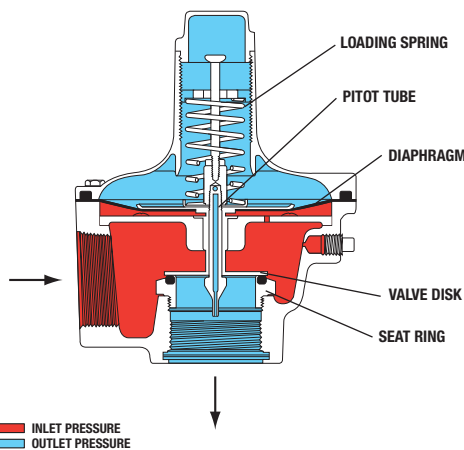
Principles of Relief Valves

Opening the Valve

As the inlet pressure rises above the setpoint of the relief valve, the diaphragm is pushed upward moving the valve plug away from the seat. This allows fluid to escape.

Pressure Build-up Over Setpoint

As system pressure increases, the relief valve opens wider. This allows more fluid to escape and protects the system. The increase in pressure above the relief setpoint that is required to produce more flow through the relief valve is referred to as pressure build-up. The spring rate and orifice size influence the amount of pressure build-up that is required to fully stroke the valve.



M1048

Figure 6. Type 289 Relief Valve with Pitot Tube

Product Example

Pitot Tube

The relief valve shown in Figure 6 includes a pitot tube to reduce pressure build-up. When the valve is opening, high fluid velocity through the seat ring creates an area of relatively low pressure. Low pressure near the end of the pitot tube draws fluid out of the volume above the relief valve diaphragm and creates a partial vacuum which helps to open the valve. The partial vacuum above the diaphragm increases the relief valve capacity with less pressure build-up over setpoint.

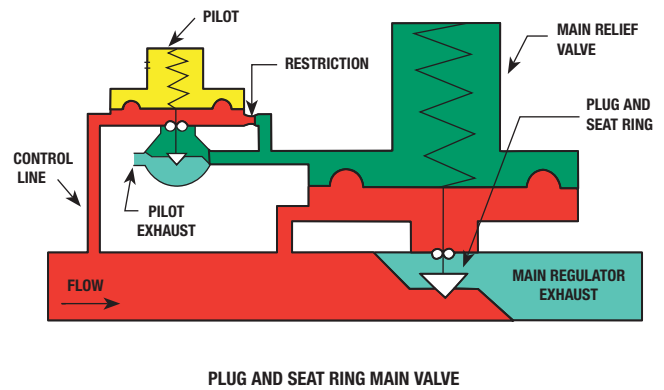
Typical Applications

Direct-operated relief valves are commonly used in natural gas systems supplying commercial enterprises such as restaurants and laundries, and in industry to protect industrial furnaces and other equipment.

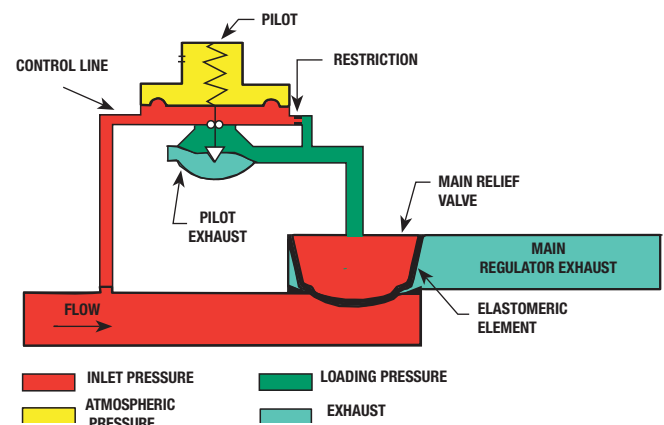
Selection Criteria

Pressure Build-up

Some direct-operated relief valves require significant pressure build-up to achieve maximum capacity. Others, such as those using pitot tubes, often pass high flow rates with minimal pressure build-up. Direct-operated relief valves can provide good accuracy within their design capacities.



PLUG AND SEAT RING MAIN VALVE



ELASTOMERIC ELEMENT MAIN VALVE

Figure 7. Pilot-Operated Designs

Principles of Relief Valves

Cost Versus Performance

The purchase price of a direct-operated relief valve is typically lower than that of a pilot-operated design of the same size. However, pilot-operated designs may cost less per unit of capacity at very high flow rates.

Pilot-Operated Relief Valves

Pilot-operated relief valves utilize a pair of direct-operated relief valves; a pilot and a main relief valve. The pilot increases the effect of changes in inlet pressure on the main relief valve.

Operation

The operation of a pilot-operated relief valve is quite similar to the operation of a pilot-operated pressure reducing regulator. In normal operation, when system pressure is below setpoint of the relief valve, the pilot remains closed. This allows loading pressure to register on top of the main relief valve diaphragm. Loading pressure on top of the diaphragm is opposed by an equal pressure (inlet pressure) on the bottom side of the diaphragm. With little or no pressure differential across the diaphragm, the spring keeps the valve seated. Notice that a light-rate spring may be used because it does not oppose a large pressure differential across the diaphragm. The light-rate spring enables the main valve to travel to the wide-open position with little pressure build-up.

Increasing Inlet Pressure

When the inlet pressure rises above the relief setpoint, the pilot spring is compressed and the pilot valve opens. The open pilot bleeds fluid out of the main valve spring case, decreasing pressure above the main relief valve diaphragm. If loading pressure escapes faster than it can be replaced through the restriction, the loading pressure above the main relief valve diaphragm is reduced and the relief valve opens. System overpressure exhausts through the vent.

Decreasing Inlet Pressure

If inlet pressure drops back to the relief valve setpoint, the pilot loading spring pushes the pilot valve plug back against the pilot valve seat. Inlet pressure again loads the main relief valve diaphragm and closes the main valve.

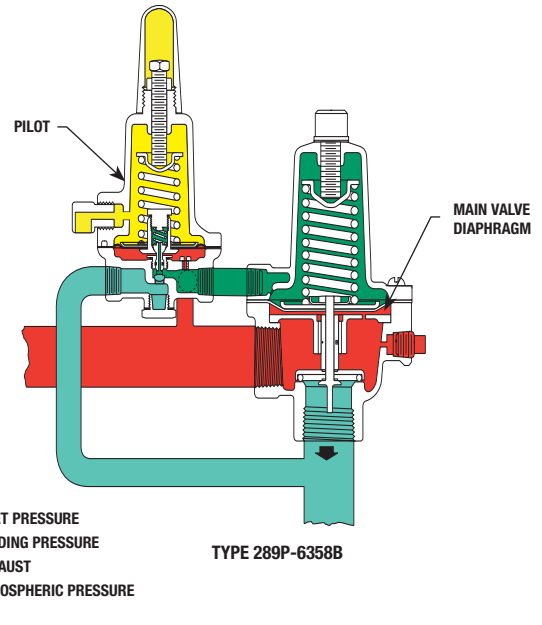


Figure 8. Pilot-Operated Relief Valve

Control Line

The control line connects the pilot with the pressure that is to be limited. When overpressure control accuracy is a high priority, the control line tap is installed where protection is most critical.

Product Example

Physical Description

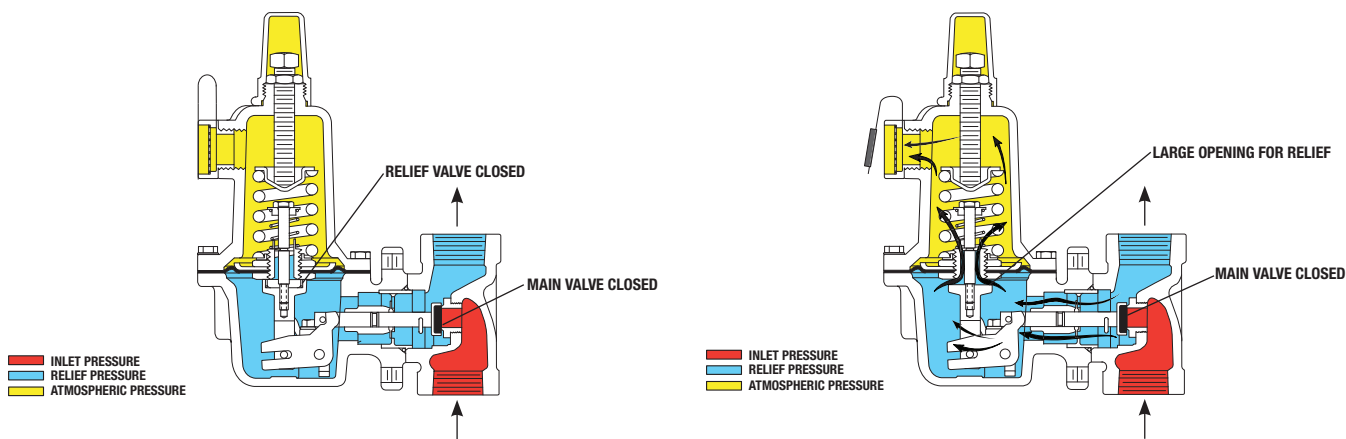
This relief valve is a direct-operated relief valve with a pilot attached (Figure 8). The pilot is a modified direct-operated relief valve, the inlet pressure loads the diaphragm and flows through a restriction to supply loading pressure to the main relief valve diaphragm.

Operation

During normal operation, the pilot is closed allowing loading pressure to register above the main relief valve's diaphragm. This pressure is opposed by inlet pressure acting on the bottom of the diaphragm.

If inlet pressure rises above setpoint, the pilot valve opens, exhausting the loading pressure. If loading pressure is reduced above the main relief valve diaphragm faster than it is replaced through the pilot fixed restriction, loading pressure is reduced and inlet pressure below the diaphragm will cause the main regulator to open.

Principles of Relief Valves



REGULATORS THAT INCLUDE INTERNAL RELIEF VALVES OFTEN ELIMINATE THE REQUIREMENT FOR EXTERNAL OVERPRESSURE PROTECTION. THE ILLUSTRATION ON THE LEFT SHOWS THE REGULATOR WITH BOTH THE RELIEF VALVE AND THE REGULATOR VALVE IN THE CLOSED POSITION. THE ILLUSTRATION ON THE RIGHT SHOWS THE SAME UNIT AFTER P_1 HAS INCREASED ABOVE THE RELIEF VALVE SETPOINT. THE DIAPHRAGM HAS MOVED OFF THE RELIEF VALVE SEAT ALLOWING FLOW (EXCESS PRESSURE) TO EXHAUST THROUGH THE SCREENED VENT.

Figure 9. Internal Relief Design

If inlet pressure falls below the relief set pressure, the pilot spring will again close the pilot exhaust, increasing loading pressure above the main relief valve diaphragm. This increasing loading pressure causes the main valve to travel towards the closed position.

Performance

Pilot-operated relief valves are able to pass large flow rates with a minimum pressure build-up.

Typical Applications

Pilot-operated relief valves are used in applications requiring high capacity and low pressure build-up.

Selection Criteria

Minimal Build-up

The use of a pilot to load and unload the main diaphragm and the light-rate spring enables the main valve to travel wide-open with little pressure build-up over setpoint.

Throttling Action

The sensitive pilot produces smooth throttling action when inlet pressure rises above setpoint. This helps to maintain a steady downstream system pressure.

Internal Relief

Regulators that include internal relief valves may eliminate the requirement for external overpressure protection.

Operation

The regulator shown in Figure 9 includes an internal relief valve. The relief valve has a measuring element (the main regulator diaphragm), a loading element (a light spring), and a restricting element (a valve seat and disk). The relief valve assembly is located in the center of the regulator diaphragm.

Build-up Over Setpoint

Like other spring-loaded designs, internal relief valves will only open wider if the inlet pressure increases. The magnitude of pressure build-up is determined by the spring rates of the loading spring plus the main spring. Both springs are considered because they act together to resist diaphragm movement when pressure exceeds the relief valve setpoint.

Product Example

A typical internal relief regulator construction is shown in Figure 9. The illustration on the left shows the regulator with both the relief valve and regulator valve in the closed position. The illustration on the right shows the same unit after the inlet

Principles of Relief Valves

pressure has increased above the relief valve setpoint. The diaphragm has moved off the relief valve seat allowing the excess pressure to exhaust through the vent.

Performance and Typical Applications

This design is available in configurations that can protect many pressure ranges and flow rates. Internal relief is often used in applications such as farm taps, industrial applications where atmospheric exhaust is acceptable, and house service regulators.

Selection Criteria

Pressure Build-up

Relief setpoint is determined by a combination of the relief valve and regulator springs; this design generally requires significant pressure build-up to reach its maximum relief flow rate. For the same reason, internal relief valves have limited relief capacities. They may provide full relief capacity, but should be carefully sized for each application.

Space

Internal relief has a distinct advantage when there is not enough space for an external relief valve.

Cost versus Performance

Because a limited number of parts are simply added to the regulator, this type of overpressure protection is relatively inexpensive compared to external relief valves of comparable capacity.

Maintenance

Because the relief valve is an integral part of the regulator's diaphragm, the regulator must be taken out of service when maintenance is performed. Therefore, the application should be able to tolerate either the inconvenience of intermittent supply or the expense of parallel regulators and relief valves.

Selection and Sizing Criteria

There are a number of common steps in the relief valve selection and sizing process. For every application, the

maximum pressure conditions, the wide-open regulator flow capacity, and constant downstream demand should be determined. Finally, this information is used to select an appropriate relief valve for the application.

Maximum Allowable Pressure

Downstream equipment includes all the components of the system that contain pressure; household appliances, tanks, tools, machines, outlet rating of the upstream regulators, or other equipment. The component with the lowest maximum pressure rating establishes the maximum allowable system pressure.

Regulator Ratings

Pressure reducing regulators upstream of the relief valve have ratings for their inlet, outlet, and internal components. The lowest rating should be used when determining maximum allowable pressure.

Piping

Piping pressure limitations imposed by governmental agencies, industry standards, manufacturers, or company standards should be verified before defining the maximum overpressure level.

Maximum Allowable System Pressure

The smallest of the pressure ratings mentioned above should be used as the maximum allowable pressure. This pressure level should not be confused with the relief valve setpoint which must be set below the maximum allowable system pressure.

Determining Required Relief Valve Flow

A relief valve must be selected to exhaust enough flow to prevent the pressure from exceeding the maximum allowable system pressure. To determine this flow, review all upstream components for the maximum possible flow that will cause overpressure. If overpressure is caused by a pressure reducing regulator, use the regulator's wide-open flow coefficient to calculate the required flow of the relief valve. This regulator's wide-open flow is larger than the regulating flow used to select the pressure reducing regulator.

Sizing equations have been developed to standardize valve sizing. Refer to the Valve Sizing Calculations section to find these equations and explanations on how they are used.

Principles of Relief Valves

Determine Constant Demand

In some applications, the required relief capacity can be reduced by subtracting any load that is always on the system. This procedure should be approached with caution because it may be difficult to predict the worst-case scenario for downstream equipment failures. It may also be important to compare the chances of making a mistake in predicting the level of continuous flow consumption with the potential negative aspects of an error. Because of the hazards involved, relief valves are often sized assuming no continuous flow to downstream equipment.

Selecting Relief Valves

Required Information

We have already reviewed the variables required to calculate the regulator's wide-open flow rate. In addition, we need to know the type and temperature of the fluid in the system, and the size of the piping. Finally, if a vent stack will be required, any additional build-up due to vent stack resistance should be considered.

Regulator Lockup Pressure

A relief valve setpoint is adjusted to a level higher than the regulator's lockup pressure. If the relief valve setpoint overlaps lockup pressure of the regulator, the relief valve may open while the regulator is still attempting to control the system pressure.

Identify Appropriate Relief Valves

Once the size, relief pressure, and flow capacity are determined, we can identify a number of potentially suitable relief valves using the Quick Selection Guide in the front of each application section in this application guide. These selection guides give relief set (inlet) pressures, capacities, and type numbers. These guides can then be further narrowed by reviewing individual product pages in each section.

Final Selection

Final selection is usually a matter of compromise. Relief capacities, build-up levels, sensitivity, throttling capabilities, cost of installation and maintenance, space requirements, initial purchase price, and other attributes are all considered when choosing any relief valve.

Applicable Regulations

The relief valves installed in some applications must meet governmental, industry, or company criteria.

Sizing and Selection Exercise

To gain a better understanding of the selection and sizing process, it may be helpful to step through a typical relief valve sizing exercise.

Initial Parameters

We'll assume that we need to specify an appropriate relief valve for a regulator serving a large plant air supply. There is sufficient space to install the relief valve and the controlled fluid is clean plant air that can be exhausted without adding a vent stack.

Performance Considerations

The plant supervisor wants the relief valve to throttle open smoothly so that pressure surges will not damage instruments and equipment in the downstream system. This will require the selection of a relief valve that will open smoothly. Plant equipment is periodically shut down but the air supply system operates continuously. Therefore, the relief valve must also have the capacity to exhaust the full flow of the upstream system.

Upstream Regulator

The regulator used is 1-inch in size with a 3/8-inch orifice. The initial system parameters of pressure and flow were determined when the regulator was sized for this application.

Pressure Limits

The plant maintenance engineer has determined that the relief valve should begin to open at 20 psig, and downstream pressure should not rise above 30 psig maximum allowable system pressure.

Relief Valve Flow Capacity

The wide-open regulator flow is calculated to be 23 188 SCFH.

Principles of Relief Valves

Relief Valve Selection

Quick Selection Guide

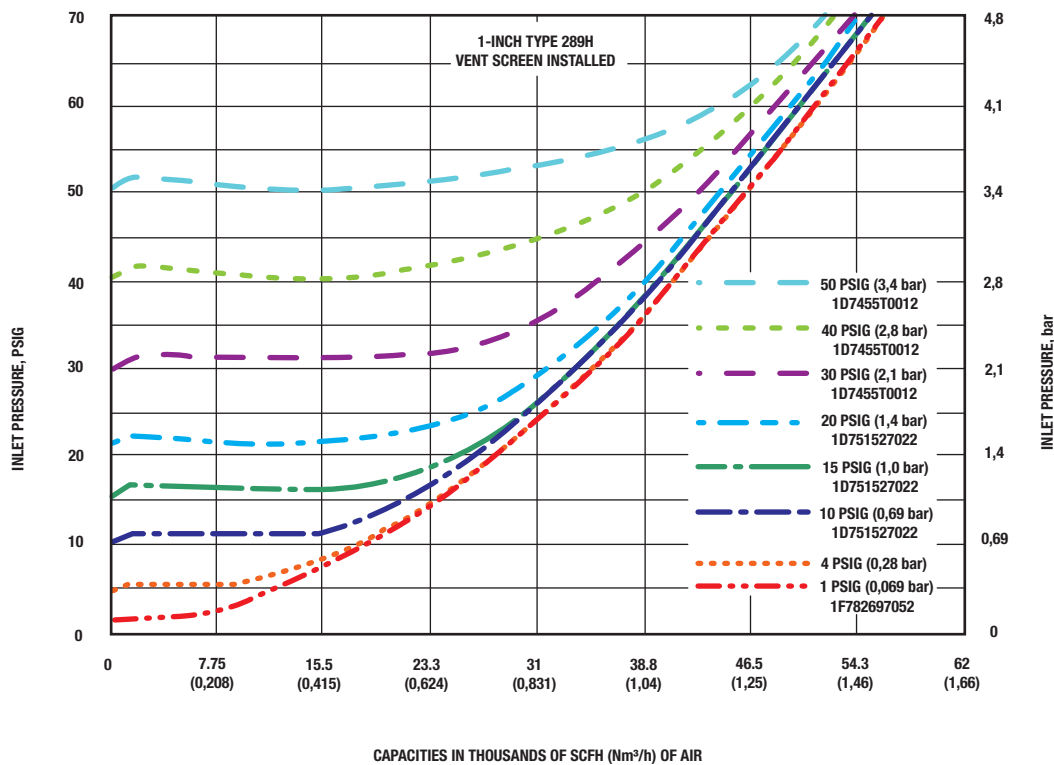
Find the Relief Valve Quick Selection Guide in this Application Guide; it gives relief set (inlet) pressures and comparative flow capacities of various relief valves. Because this guide is used to identify potentially suitable relief valves, we can check the relief set (inlet) pressures closest to 20 psig and narrow the range of choices. We find that two relief valves have the required flow capacity at our desired relief set (inlet) pressure.

Product Pages

If we look at the product pages for the potential relief valves, we find that a 1-inch Type 289H provides the required capacity within the limits of pressure build-up specified in our initial parameters.

Checking Capacity

Capacity curves for the 1-inch Type 289H with this spring are shown in Figure 10. By following the curve for the 20 psig setpoint to the point where it intersects with the 30 psig division, we find that our relief valve can handle more than the 23 188 SCFH required.



B2309

Figure 10. Type 289H Flow Capacities

Principles of Series Regulation and Monitor Regulators

Series Regulation

Series regulation is one of the simplest systems used to provide overpressure protection by containment. In the example shown in Figure 1, the inlet pressure is 100 psig, the desired downstream pressure is 10 psig, and the maximum allowable operating pressure (MAOP) is 40 psig. The setpoint of the downstream regulator is 10 psig, and the setpoint of the upstream regulator is 30 psig.

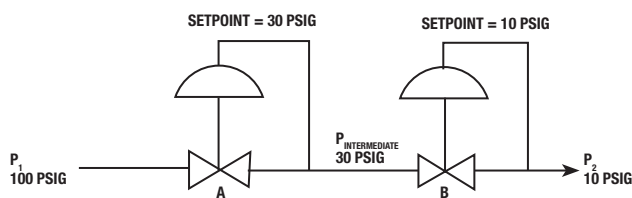


Figure 1. Series Regulation

Failed System Response

If regulator B fails, downstream pressure (P_2) is maintained at the setpoint of regulator A less whatever drop is required to pass the required flow through the failed regulator B. If regulator A fails, the intermediate pressure will be 100 psig. Regulator B must be able to withstand 100 psig inlet pressure.

Regulator Considerations

Either direct-operated or pilot-operated regulators may be used in this system. Should regulator A fail, $P_{\text{Intermediate}}$ will approach P_1 so the outlet rating and spring casing rating of regulator A must be high enough to withstand full P_1 . This situation may suggest the use of a relief valve between the two regulators to limit the maximum value of $P_{\text{Intermediate}}$.

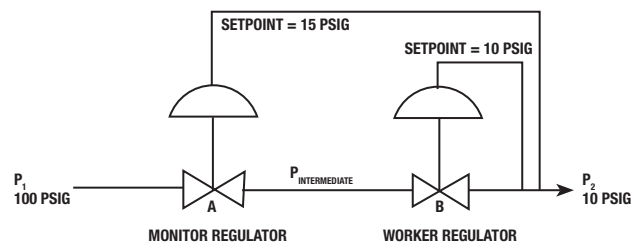
Applications and Limitations

A problem with series regulation is maintaining tight control of P_2 if the downstream regulator fails. In this arrangement, it is often impractical to have the setpoints very close together. If they are, the pressure drop across regulator B will be quite small. With a small pressure drop, a very large regulator may be required to pass the desired flow.

Because of the problem in maintaining close control of P_2 , series regulation is best suited to applications where the regulator station is reducing pressure to a value substantially below the maximum allowable operating pressure of the downstream system. Farm taps are a good example. The problem of low-pressure drop across the second regulator is less pronounced in low flow systems.

Upstream Wide-Open Monitors

The only difference in configuration between series regulation and monitors is that in monitor installations, both regulators sense downstream pressure, P_2 . Thus, the upstream regulator must have a control line.



IN WIDE-OPEN MONITOR SYSTEMS, BOTH REGULATORS SENSE DOWNSTREAM PRESSURE. SETPOINTS MAY BE VERY CLOSE TO EACH OTHER. IF THE WORKER REGULATOR FAILS, THE MONITOR ASSUMES CONTROL AT A SLIGHTLY HIGHER SETPOINT. IF THE MONITOR REGULATOR FAILS, THE WORKER CONTINUES TO PROVIDE CONTROL.

Figure 2. Wide-Open Upstream Monitor

System Values

In the example shown in Figure 2, assume that P_1 is 100 psig, and the desired downstream pressure, P_2 , is 10 psig. Also assume that the maximum allowable operating pressure of the downstream system is 20 psig; this is the limit we cannot exceed. The setpoint of the downstream regulator is set at 10 psig to maintain the desired P_2 and the setpoint of the upstream regulator is set at 15 psig to maintain P_2 below the maximum allowable operating pressure.

Normal Operation

When both regulators are functioning properly, regulator B holds P_2 at its setpoint of 10 psig. Regulator A, sensing a pressure lower than its setpoint of 15 psig tries to increase P_2 by going wide-open. This configuration is known as an upstream wide-open monitor where upstream regulator A monitors the pressure established by regulator B. Regulator A is referred to as the monitor or standby regulator while regulator B is called the worker or the operator.

Principles of Series Regulation and Monitor Regulators

Worker Regulator B Fails

If regulator B fails open, regulator A, the monitor, assumes control and holds P_2 at 15 psig. Note that pressure $P_{\text{Intermediate}}$ is now P_2 plus whatever drop is necessary to pass the required flow through the failed regulator B.

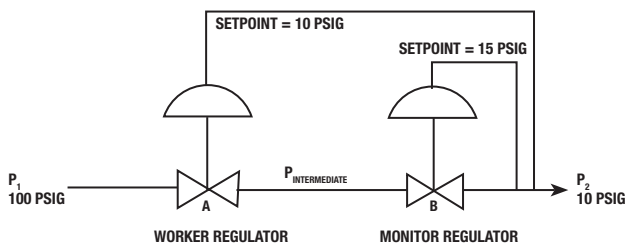
Equipment Considerations

Wide-open monitoring systems may use either direct- or pilot-operated regulators, the choice of which is dependent on other system requirements. Obviously, the upstream regulator must have external registration capability in order to sense downstream pressure, P_2 .

In terms of ratings, $P_{\text{Intermediate}}$ will rise to full P_1 when regulator A fails, so the body outlet of regulator A and the inlet of regulator B must be rated for full P_1 .

Downstream Wide-Open Monitors

The difference between upstream and downstream monitor systems (Figure 3) is that the functions of the two regulators are reversed. In other words, the monitor, or standby regulator, is downstream of the worker, or operator. Systems can be changed from upstream to downstream monitors, and vice-versa, by simply reversing the setpoints of the two regulators.



THE ONLY DIFFERENCE BETWEEN UPSTREAM WIDE-OPEN MONITOR SYSTEMS AND DOWNSTREAM WIDE-OPEN MONITOR SYSTEMS IS THE ROLE EACH REGULATOR PLAYS. WORKERS AND MONITORS MAY BE SWITCHED BY SIMPLY REVERSING THE SETPOINTS.

Figure 3. Wide-Open Downstream Monitor

Normal Operation

Again, assume an inlet pressure of 100 psig and a controlled pressure (P_2) of 10 psig. Regulator A is now the worker so it maintains P_2 at its setpoint of 10 psig. Regulator B, the monitor, is set at 15 psig and so remains open.

Worker Regulator A Fails

If the worker, regulator A, fails in an open position, the monitor, regulator B, senses the increase in P_2 and holds P_2 at its setpoint of 15 psig. Note that $P_{\text{Intermediate}}$ is now P_1 minus whatever drop is taken across the failed regulator A.

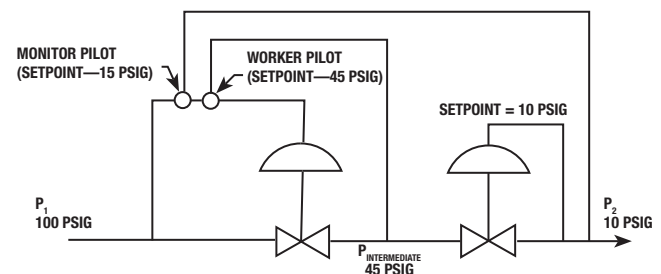
Upstream Versus Downstream Monitors

The decision to use either an upstream or downstream monitor system is largely a matter of personal preference or company policy.

In normal operation, the monitor remains open while the worker is frequently exercised. Many users see value in changing the system from an upstream to a downstream monitor at regular intervals, much like rotating the tires on an automobile. Most fluids have some impurities such as moisture, rust, or other debris, which may deposit on regulator components, such as stems, and cause them to become sticky or bind. Therefore, occasionally reversing the roles of the regulators so that both are exercised is sometimes seen as a means of ensuring that protection is available when needed. The job of switching is relatively simple as only the setpoints of the two regulators are changed. In addition, the act of changing from an upstream to a downstream monitor requires that someone visit the site so there is an opportunity for routine inspection.

Working Monitors

Working monitors (Figure 4) use design elements from both series regulation and wide-open monitors. In a working monitor installation, the two regulators are continuously working as series regulators to take two pressure cuts.



WORKING MONITOR SYSTEMS MUST USE A PILOT-OPERATED REGULATOR AS THE MONITOR, WHICH IS ALWAYS IN THE UPSTREAM POSITION. TWO PILOTS ARE USED ON THE MONITOR REGULATOR; ONE TO CONTROL THE INTERMEDIATE PRESSURE AND ONE TO MONITOR THE DOWNSTREAM PRESSURE. BY TAKING TWO PRESSURE DROPS, BOTH REGULATORS ARE ALLOWED TO EXERCISE.

Figure 4. Working Monitor

Principles of Series Regulation and Monitor Regulators

Downstream Regulator

The downstream regulator may be either direct or pilot-operated. It is installed just as in a series or wide-open monitor system. Its setpoint controls downstream pressure, P_2 .

Upstream Regulator

The upstream regulator must be a pilot-operated type because it uses two pilots; a monitor pilot and a worker pilot. The worker pilot is connected just as in series regulation and controls the intermediate pressure $P_{\text{Intermediate}}$. Its setpoint (45 psig) is at some intermediate value that allows the system to take two pressure drops. The monitor pilot is in series ahead of the worker pilot and is connected so that it senses downstream pressure, P_2 . The monitor pilot setpoint (15 psig) is set slightly higher than the normal P_2 (10 psig).

Normal Operation

When both regulators are performing properly, downstream pressure is below the setting of the monitor pilot, so it is fully open trying to raise system pressure. Standing wide-open, the monitor pilot allows the worker pilot to control the intermediate pressure, $P_{\text{Intermediate}}$ at 45 psig. The downstream regulator is controlling P_2 at 10 psig.

Downstream Regulator Fails

If the downstream regulator fails, the monitor pilot will sense the increase in pressure and take control at 15 psig.

Upstream Regulator Fails

If the upstream regulator fails, the downstream regulator will remain in control at 10 psig. Note that the downstream regulator must be rated for the full system inlet pressure P_1 of 100 psig because this will be its inlet pressure if the upstream regulator fails. Also note that the outlet rating of the upstream regulator, and any other components that are exposed to $P_{\text{Intermediate}}$, must be rated for full P_1 .

Sizing Monitor Regulators

The difficult part of sizing monitor regulators is that $P_{\text{Intermediate}}$ is needed to determine the flow capacity for both regulators. Because $P_{\text{Intermediate}}$ is not available, other sizing methods are used to determine the capacity. There are three methods for sizing monitor regulators: estimating flow when pressure drop is critical, assuming $P_{\text{Intermediate}}$ to calculate flow, and the Fisher® Monitor Sizing Program.

Estimating Flow when Pressure Drop is Critical

If the pressure drop across both regulators from P_1 to P_2 is critical (assume $P_{\text{Intermediate}} = P_1 - P_2/2 + P_2$, $P_1 - P_{\text{Intermediate}} \geq P_1$, and $P_{\text{Intermediate}} - P_2 \geq 1/2 P_{\text{Intermediate}}$), and both regulators are the same type, the capacity of the two regulators together is 70 to 73% of a single regulator reducing the pressure from P_1 to P_2 .

Assuming $P_{\text{Intermediate}}$ to Determine Flow

Assume $P_{\text{Intermediate}}$ is halfway between P_1 and P_2 . Guess a regulator size. Use the assumed $P_{\text{Intermediate}}$ and the C_g for each regulator to calculate the available flow rate for each regulator. If $P_{\text{Intermediate}}$ was correct, the calculated flow through each regulator will be the same. If the flows are not the same, change $P_{\text{Intermediate}}$ and repeat the calculations. ($P_{\text{Intermediate}}$ will go to the correct assumed pressure whenever the flow demand reaches maximum capacity.)

Fisher® Monitor Sizing Program

Emerson Process Management - Regulator Technologies offers a Monitor Sizing Program on the Regulator Technologies Literature CD. Call your local Sales Office to request a copy of the CD. To locate your local Sales Office, log on to: www.emersonprocess.com/regulators.