Introduction

Gas 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 in their own homes. As is frequently the case with many such familiar items, we all have a tendency to take them for granted. It is 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 fundamental of the regulator’s operation.

Function Of Gas Regulators

The primary function of any gas regulator is to match the flow of gas through the regulator to the demand for gas placed upon the system, while maintaining the system pressure within certain acceptable limits.

A typical gas pressure system might be similar to that shown in Figure 1, where the regulator is placed upstream of the valve or other device that is varying its demand for gas from the regulator.

Three Essential Elements

One of the essential elements of any regulator is a restricting element that will fit into the flow stream and provide a variable restriction that can modulate the flow of gas through the regulator.

Figure 2 shows a schematic of a typical regulator restricting element. The restricting element is usually some type of valve in a straight or angle body. When selecting the orifice of the restriction, always select the smallest orifice available that will still handle the maximum flow requirements of the system. This decreases the potential of stability problems and allows for the selection of a smaller size relief valve.

If the load flow decreases, then the regulator flow must decrease also. Otherwise, the regulator would put too much gas into the system and the pressure $P_2$ would tend to increase. On the other hand, if the load flow increases, the regulator flow must increase also in order to keep $P_2$ from decreasing due to a shortage of gas in the pressure system.

We noticed in our discussion of Figure 1 that the system pressure ($P_2$) was directly related to the matching of the two flows. If the restricting element allows too much gas into the system, $P_2$ will increase. If the restricting element allows too little gas into the system, $P_2$ will decrease. We can use this convenient fact to provide a...
simple means of measuring whether or not the regulator is providing the proper flow. In most cases, a diaphragm is used as the measuring element. The diaphragm will respond to changes in the measured pressure and the force of the diaphragm will open or close the restricting element.

The third essential element of a gas regulator is a loading element that can apply a needed force to the restricting element. The loading element can be a weight or a spring.

A spring, as shown in Figure 4, forms the most common type of loading element. $P_2$ is applied to the diaphragm to produce a loading force that will act to close the restricting element. The spring provides a reverse loading force, which acts to overcome the weight of the moving parts.

![Figure 4](Typical Self-Operated Regulator)

This illustrates that there are three essential elements needed to make any operating gas pressure regulator. They have a restricting element, a measuring element and a loading element. Regardless of how sophisticated the system may become, it still must contain these three essential elements. Now let’s study the operational performance of a gas regulator.

**Spring Effect**

Let’s look at a typical self-operated regulator, such as that in Figure 4, when it is operating under steady-state conditions. In this situation, the valve plug is in equilibrium with the pressure force exactly balanced with the spring force. For simplicity and to illustrate a point, the unbalance force on the valve plug is temporarily ignored. The pressure force is developed by the sensed pressure ($P_2$) acting against the diaphragm area. The spring force is developed from the compression that exists in the spring. We can express this relationship in the following equation:

$$P_2A = kX$$

We can rearrange this equation into a more convenient form by solving for $P_2$.

$$P_2 = \frac{kX}{A}$$

Let’s use this simple formula now to make some interesting observations about the regulator shown in Figure 4. An example is used to illustrate the basic principles. Assume that the regulator has the following values for its parameters:

- $k = 160$ lbs/in (spring rate)
- $A = 80$ in$^2$ (effective diaphragm area)
- $T = 2$ in (total valve travel)
- $X = 1$ in (initial spring compression)

We assume that the spring is adjusted so that it has one-inch of compression even in the fully extended wide-open valve position. This means that when the valve plug travels its full two-inches to the closed position, the spring compression will be three-inches.

Now apply our formula to the conditions at each end of the valve plug travel. Under very low load flow conditions, the regulator will not be required to supply much gas to the system and the valve plug will be essentially in the closed position where the spring compression is three-inches. The down-stream controlled pressure, which is acting upon the diaphragm, can be determined from our formula.

$$P_2 = \frac{kX}{A} = \frac{(160 \text{ lbs/in})(3 \text{ in})}{(80 \text{ in}^2)} = 6 \text{ psig (low load flow)}$$

If the demand on the system were to change now so that the regulator must supply a high flow, the valve plug would have to open up to its wide-open position. If we look carefully at our system in Figure 4, we see that it is the controlled pressure ($P_2$) that is actually holding the valve plug closed. In order for the valve plug to open, $P_2$ must decrease, thereby allowing the spring to push it open. When the valve plug gets open, there will again be a balance of forces and we can find the new value of $P_2$. Remember, the spring still has one-inch of compression in this open position.

$$P_2 = \frac{kX}{A} = \frac{(160 \text{ lbs/in})(1 \text{ in})}{(80 \text{ in}^2)} = 2 \text{ psig (low load flow)}$$
We see that the pressure had to decrease from 6 psig at low load to 2 psig in order to open the valve plug sufficiently to pass the full load flow. Since this 2 psig is the pressure that will just hold the valve plug in the open position, this value of the pressure will have to continue as long as the high load flow condition exists. The pressure will only return to the original 6 psig when the load flow demand returns to its original low value.

The decrease in controlled pressure that occurs as we increase the load is called droop. The amount of droop that occurs in the controlled pressure is defined as proportional band. This is frequently designated as PB. The proportional band in this example is equal to \( P_2 \) low load - \( P_2 \) high load or 6 - 2 = 4 psi.

The actual magnitude of the decrease in controlled pressure required to open the valve is a function of the design parameters for the given regulator and is caused by the required change in spring compression. This is why it is occasionally referred to as spring effect. The spring effect can be minimized by selecting the spring, which has the lightest spring range that meets the application’s needs.

**Velocity Boosting**

A method we can use to overcome droop is known as velocity boosting. Velocity boosting is frequently used in house service regulators.

If we refer to Figure 5, which shows the pressure profile across a typical regulator, we see that the vena contracta pressure occurs just a short distance downstream of the actual restriction. Further downstream, this pressure recovers to the value of \( P_2 \), which is the controlled pressure and the one that is normally applied to the diaphragm.

As the load flow starts to increase, the sensed pressure at the pitot tube begins to droop just as \( P_2 \) does. Since the sensed pressure is near the vena contracta and the gas velocity is greater there, this pressure, which is applied to the diaphragm, decreases more than \( P_2 \).

Consequently, the valve is allowed to open slightly wider than it would if \( P_2 \) were acting on the diaphragm. This has the effect of keeping \( P_2 \) relatively more constant and thus preventing a large droop with high load flow.

**Lock Up**

On any service regulator, there is always the danger that the customer may shut off all of his appliances including the pilot lights. If that happens, the regulator must shut off for zero flow. This is called lock up.

To get tight shut off, the regulator uses soft seats, which must be tightly compressed. This compression force can only come from the action of \( P_2 \) acting on the diaphragm, which means that \( P_2 \) must rise enough at zero flow to hold the seal tight. This lock up pressure can be seen on the performance curves in Figure 7. The amount of pressure rise that we get in this lock up region is directly dependent upon the stiffness of the elastomeric material on the valve plug.
Regulator Curves

A family of curves is shown in Figure 8 for a given orifice size, which illustrates that there is a different outlet pressure curve for each inlet pressure on a typical service regulator. Most house service regulators control pressures in the vicinity of a few inches of water column, yet since each individual gas company’s pressure setting may be slightly different, we need some method of adjusting the setpoint pressure.

We know from our previous discussions that $P_2$ acting on the diaphragm must provide a force that will balance the spring compression force. We can use the adjusting screw on top of the spring to increase the total compression force in the spring. $P_2$ must then also increase in order to balance the large spring force and hold the valve plug in the proper position. Thus, by changing the initial compression in the spring, we can adjust $P_2$ to operate at any setpoint value that we wish within a certain range defined by the load limits on the spring.

Installation

The upper casing of the regulator is designed so that it will hold the spring properly, but it also protects the regulator parts from exposure to the weather, dirt, etc. Just as important, it also keeps a cushion of air above the diaphragm. As the diaphragm assembly moves up and down, the air in the upper casing must move in and out through the vent hole, otherwise, the compression and rarefaction of air in the upper casing would interfere with the diaphragm movement. Therefore, the vent on the upper casing should always be oriented to assure the vent remains clear and also positioned to not allow debris or water to enter the casing. This may include external vent piping if the regulator is located in a pit. External vent piping should also be utilized if the regulator is placed inside a building. This prevents the possibility of gas collecting in an enclosed area.

For stability concerns, it is advisable that the outlet piping from the regulator be the same size as the outlet of the regulator for a minimum distance of 18” from the regulator or to the meter inlet.

The other type regulator we see used today is the Pilot-Operated.

The pilot, also called a relay, amplifier, multiplier, etc., has the ability to multiply a small change in downstream pressure into a large change in pressure applied to the regulator diaphragm. Due to the gain feature of the pilot, these types of regulators control pressure accurately.

There are three basic types of pilot-operated regulators. They are:

1. the two-path control (loading system)
2. the unloading system, and
3. the instrument system

All three offer design and operating personnel some versatility. They all employ a pilot and are capable of very accurate control. Almost all pilot-operated regulators have downstream control lines that provide versatility in controlling pressure at a given point downstream from the regulator. A valve in the downstream control line can be used to create a lag to tune the stability of the unit.

Let’s examine the three modes of pilot operation more closely.

The Two-Path Control System, as shown in Figure 9, has the advantage of changes in forces associated with changes in downstream pressure acting quickly on two of the important elements of the regulator. The quicker action would be on the main operating diaphragm,
tending to move the main valve in the desired direction. This is a highly inaccurate movement and would not be satisfactory for final control. It is supplemented by pilot action that occurs as soon as the pilot senses the change in downstream pressure. Therefore, the combination of the rapid adjustment from the main diaphragm and the high gain, but slower adjustment from the pilot provides accurate, fast and stable control.

The pilot generally consists of a fixed and a variable orifice with the operating or loading pressure generated between them. This loading pressure gives the pilot its “gain”, which permits the use of the total available travel of the main valve. With a small change in downstream pressure, a high gain pilot can completely position the main operating valve anywhere from closed to fully open.

Two-path systems are equipped with springs closing the main valve. Increasing force of downstream gas also closes the main valve. Force of the loading gas must, therefore, overcome both the force of downstream gas and the closing force of the spring. The higher pressure loading gas bleeds downstream to close the valve. (When the main valve locks up, the force of downstream gas also closes the pilot.) The presence of gas at downstream and loading pressures in the spring cases adds an “actuator stiffness” factor to this type of unit that makes it exceptionally stable.

The response and control of the main regulator element in a pilot unloading system is directed solely by pilot action. A pilot unloading system is typically inlet pressure to open or spring to open, while the two-path system is spring to close. A common unloading system design utilizes an elastomeric diaphragm as its primary control element, a fixed restriction and the unloading pilot, as shown in Figure 10. Inlet pressure tends to open this device by pushing the elastomeric diaphragm away from the inlet and outlet flow slots. Increasing loading pressure (pressure between the fixed restriction and pilot) shuts off flow by pushing the elastomeric diaphragm against the slots.

The operation or throttling of the main valve is accomplished by the pilot change loading pressure. The pilot lowers pressure (main valve opens) by opening and exhausting gas downstream faster than the fixed restriction supplies it. As the pilot closes, the loading pressure increases (main valve closes), since the fixed restriction supplies more gas to loading pressure than the pilot is exhausting downstream.

The pilot unloading system does have the accuracy associated with pilot gain. Response time is somewhat less than two-path control systems because of the absence of direct action.

The Instrument Control System, as shown in Figure 11, although commonly called a regulator, is truly a diaphragm control valve and a pressure controller. These versatile devices are equipped with fixed and variable orifices and are characterized by high gain operation. Most are equipped with proportional and reset adjustments that provide system stability and accuracy. They have the disadvantage, however, of having to vent gas to atmosphere.

Although many manufacturers have made attempts to reduce the amount of vented gas, the instrument control system has the same problem as the atmospheric bleed, pressure-loading system.
The instrument control system encompasses a range of valves and instruments broad enough to be the subject of a separate discussion. Therefore, we will not explore them further.

**Regulator Type Analysis**

Every commercially available regulator falls into one of the categories previously mentioned. They may not look like the sketches, but the essential elements—the restricting, loading and measuring elements—all operate as shown. The sketches depict pressure reduction units only, not relief valves.

Occasionally, one hears of the adoption or the exclusion of a particular type of regulator because it is labeled “fail open” or “fail closed”. Such labels are easy to assign if one makes the basic assumption. “We can predict the failure that will occur.” That’s a tall order, because anything made by man can fail, and possibly will—and at the worst possible time.

If, then, any part of the regulator can fail, will the regulator always fail open—or closed?

For analysis purposes, some typical regulator failures are listed in Figure 12. Instrument control systems are omitted due to their many variations. Even these “failures” can be modified to show that the initial tendency of the regulator to open or close will be temporary until the regulator controls a new set point. The lesson to learn from this chart is that “in order to predict the failure mode, one must define the failure.” In fact, under close examination, the terms “fail-open” and “fail-closed” require so much qualification they become meaningless.

**Conclusion**

Every type of regulator represents a compromise involving such factors as price, capacity, accuracy, stability, simplicity, safety and speed of response. A careful analysis of large volume gas control applications usually reveals that more of these factors are available through the use of pilot-operated regulators.

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*Figure 12*

*Types of Regulator Features and Initial Effect on Regulator Action*

![Gregg Schneider](image)