

FUNDAMENTALS OF PRESSURE REGULATORS

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Induction

This paper will review the fundamentals of pressure regulators as used in the natural gas industry. The word regulator as defined by Webster is; 1: a person or thing that regulates, 2: a mechanism for controlling the movement of machinery, fluids, gases, etc. In this paper we will look at the second definition of the word and talk about a mechanical device that is used for pressure regulators. There are two main types of regulators used with natural gas pressure reducing regulators and backpressure regulators (also referred to as relief regulators).

We can break these regulators down into two designs with only a few exceptions to this rule,

1. Self-Operated Regulators
(sometimes called spring loaded regulator)
2. Pilot Operated Regulators
 - loading type pilot system
 - unloading type pilot system

Both type regulators are very common in the gas industry the self-operated regulators are general used in lower flow and lower pressure system, and are less expensive regulators. While the pilot operated regulators are generally use in higher flow situation, like city gates, large customers, industrial accounts, ect.. and where you have higher pressure to control.

SELF OPERATED REGULATORS

Self Operated regulators consist of three primary components: a loading element, a measuring element and restrictive element (Refer to Fig. 1).

The loading element is typically a spring but it can also be a weight or pressure from some external source. When

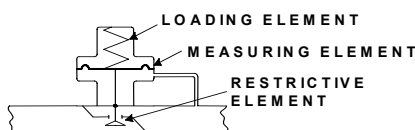


Figure 1. Self-Operated Pressure Reducing Regulator

Compressed the spring exerts a loading force. The measuring element or diaphragm is connected to the system that is being controlled and creates a force opposing the loading force.

The restricting element or valve is connected to the spring and diaphragm assembly and modulates the flow through the regulator

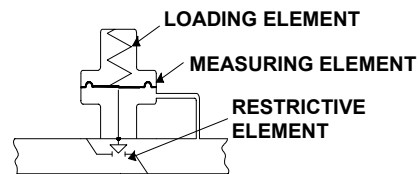


Figure 2. Self-Operated Back Pressure Regulator

A pressure regulator is a force balanced device that adjusts to changes in the system it is controlling. With a self operated pressure-reducing regulator, as downstream system pressure decreases the spring force overcomes the force of the gas acting on the effective area of the diaphragm and the valve opens increasing flow into the system. When system pressure increases, the measuring force (the force of the system gas acting on the effective area of the diaphragm) overcomes the loading force (spring force) and closes the valve reducing flow into the system.

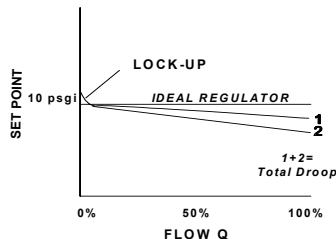
A self-operated backpressure regulator works in the same manner except the action is reversed. The main spring closes the valve and system pressure opens the valve (Refer to Fig. 2).

The accuracy of a regulator is defined by the deviation that occurs as the regulator travels from minimum to maximum flows. Ideally a regulator should provide a constant outlet but in actuality, the outlet pressure drops as the of flow gas increases through a regulator.

This drop in outlet pressure is referred to as droop. Another important term is Proportional Band, which is the inverse of droop and expressed as a percentage. Droop is caused, by primarily two variables: **spring effect** and **diaphragm effect**. As flow approaches zero the outlet pressure increases. The extra increase in pressure helps to provide bubble tight shut-off is referred to as the lock-up pressure (Refer to Fig. 3)

SPRING EFFECT

In order for a regulator to open there must be a drop in the outlet pressure (P2). When P2 decreases the spring is allowed to push the valve open. As the valve opens the forces in the regulator will balance to some new value of P2. The amount of decrease in the control pressure (P2)



1. SPRING EFFECT
2. DIAPHRAGM EFFECT

Figure 3. Components of Droop

caused by the spring (the “spring effect”) is related to the valve travel and the spring rate

Consider the following example to clearly illustrate the “spring effect”. A pressure reducing regulator as illustrated in Figure 1 has a spring rate of 200 lbs/inch and a diaphragm area of 5 square inches and is set at 10 psig. Now let us assume that the demand increases requiring the regulator to open .1 inches.

$$\Delta P_2 = \frac{k \Delta t}{A} = \frac{200 \text{ lbs / inch} \times .1 \text{ inch}}{5 \text{ inch}^2}$$

$$\Delta P_2 = 4 \text{ psig}$$

ΔP_2 : The change in outlet pressure

k: The spring rate (lbs/inch)

Δt : The valve travel

A: The diaphragm area

The 4 psi drop in outlet pressure is referred to as droop.

If we use a spring with a lower rate spring the outlet pressure will not droop as much. The spring effect can be minimized by using the lowest rate spring as possible.

$$\Delta P_2 = \frac{100 \text{ lbs / inch} \times .1 \text{ inch}}{5 \text{ inch}^2}$$

The outlet pressure droop is only 2 psig.

DIAPHRAGM EFFECT

Another component of droop or proportional band in a regulator is the “diaphragm effect”. In the previous examples the diaphragm area did not change, but, in reality the diaphragm area does change as the spring and diaphragm assembly moves the valve into a new position.

The effective area of the diaphragm increases as the spring relaxes and the valve opens. The effective area decreases as the valve moves into the closed position. This change in area increases the droop as shown in the example below.

P_{2a} = Outlet Pressure with the valve open
(No change in Diaphragm area)

P_{2b} = Outlet Pressure with the valve open
(Change in Diaphragm area)

K = spring rate (100 lbs/inch)

C = initial spring compression (1)

T = valve travel=.25 inch

A_{d1} = Diaphragm area remains constant

A_{d2} = Diaphragm area increases with travel

$$P_{2a} = \frac{K(c-t)}{A_{d1}} = \frac{100(1-.25)}{5} = 15$$

$$P_{2b} = \frac{K(c-t)}{A_{d1}} = \frac{100(1-.25)}{6} = 12.5$$

$$P_{2a} - P_{2b} = 2.5 \text{ psig}$$

The droop due the increased diaphragm area is 2.5 psig.

REGULATOR BOOST

To counteract the spring and diaphragm effects that produce droop, regulator designers have used Roll-Out type diaphragms, pilot tubes, and contoured seats. These designs help to minimize the droop as flow increases through a regulator.

The Roll-Out diaphragm is the **opposite** of a conventional diaphragm in that the diaphragm area **decreases** as the valve opens and **increases** as the valve closes. The loading force overcomes the measuring force as flow increases through the regulator moving the valve into a more open position and minimizing droop because the pressure being controlled is acting on a decreasing effective diaphragm area.

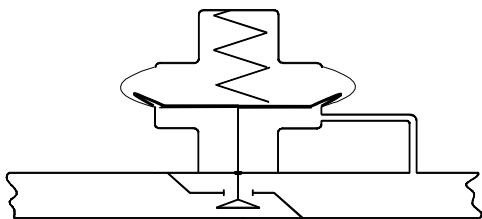


Figure 4. Self-Operated Regulator with a Rollout Diaphragm

A pilot tube properly positioned in the outlet side of valve body utilizes the lower pressure created by the body effect to act on the diaphragm and open the valve more than if downstream system pressure was measured by the diaphragm (Refer to Fig 5).

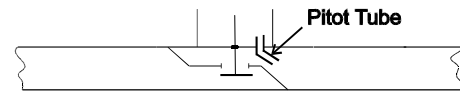


Figure 5. Self-Operated Regulator with a Pilot Tube

The design of a contoured seat, as shown below, allows inlet pressure to act on increased surface area of the plug as the valve opens creating an increased open force. Additionally, the design of the contoured seat redirects gas flow creating additional lifting force to open the valve (Refer to Fig 6).

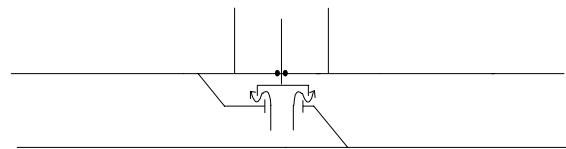


Figure 6. Contoured Seat

PILOT OPERATED REGULATORS

Pilot Operated Regulators utilize a high gain pilot system to position a valve mechanism that controls the flow of gas. The pilot system is responsible for measuring the system pressure, comparing it to the set point and providing the correct loading signal pressure to actuate the valve mechanism. The valve mechanism controls the flow through the regulator from the upstream (higher pressure) system to the downstream (lower pressure) system.

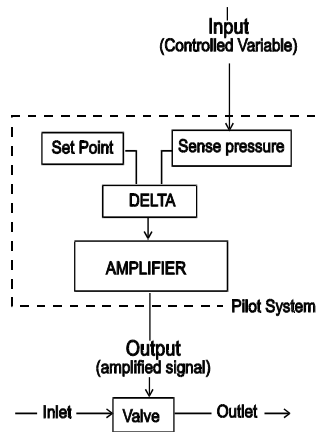


Figure 7. Pilot System Schematic

The pilot system produces an amplified loading pressure (output pressure) in response to small changes in the system pressure (input pressure) to operate a valve mechanism of almost any size.

Changes in the system pressure being controlled by the regulator can be defined as the “input” or “controlled variable” to the pilot system. The resulting loading pressure signal from the pilot system that actuates the valve can be defined as the “output” of the pilot system. The gain or amplification of the pilot system is defined as:

$$\text{GAIN} = \frac{\Delta \text{Output}}{\Delta \text{Input}}$$

Gain values of 50:1 are not uncommon, which means that the pressure can be controlled to within 2% of the set point.

The two primary components of a pilot system are a Fixed Orifice (FO) and a Variable Orifice (VO) in series with each other. The fixed orifice is always smaller than the variable orifice. The variable orifice is generally a small self operated regulator monitoring the system pressure being controlled. When the variable orifice opens in response to a change in the system pressure, the pressure between the FO and the VO varies greatly and it is that amplified pressure change that becomes the output from the pilot system and actuates the valve mechanism.

The FO can be either upstream or downstream of the VO. If it is downstream of the VO then it is referred to as a **loading** type pilot system. If it is upstream of the VO then it is referred to as an **unloading** type pilot system.

The accuracy of the system is a function of the “GAIN” or multiplication of the pilot system which is primarily dependent on the ratio of the flow area of the FO to the Variable Orifice VO. In many systems the fixed orifice is adjustable so that the regulator may be adjusted in the field for the highest gain (greatest accuracy) possible.

LOADING TYPE PILOT OPERATED REGULATORS (Two Path Control)

A Loading Type System has a Variable Orifice upstream of the Fixed Orifice. The Loading pressure on the regulator increases as the regulator outlet pressure decreases and therefore the system is Reverse Acting (Refer to Fig 8).

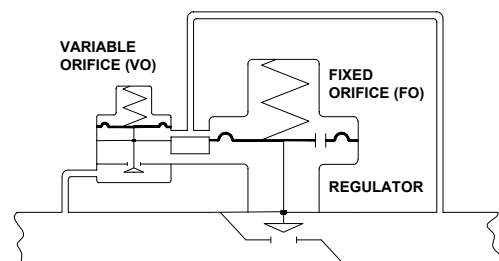


Figure 8. Loading Type Pilot Operated Regulator

Another term associated with Loading type regulators is Two Path Control. In a Two Path Control system, an initial change in downstream pressure is felt immediately by the main operating diaphragm and the valve begins to move in the desired direction. The pilot will supplement the moving action of the main diaphragm at a more precise level to attain a precise final control pressure. In other words, a Two Path Control system consists of 1. rapid adjustment from the main diaphragm in response to changes in outlet pressure and 2. slower but more precise adjustment from the controlling pilot.

UNLOADING TYPE PILOT OPERATED REGULATORS

The Unloading Type Pilot Operated Regulator has the Variable Orifice downstream of the Fixed Orifice (Refer to Fig. 9). The loading pressure on the regulator decreases when the outlet pressure decreases. Therefore, the Pilot system is referred to as Direct Acting .

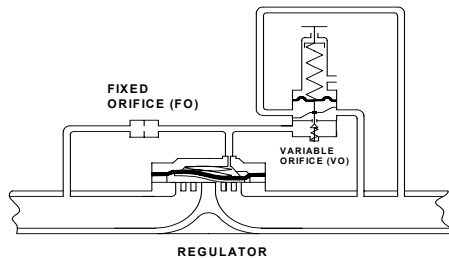
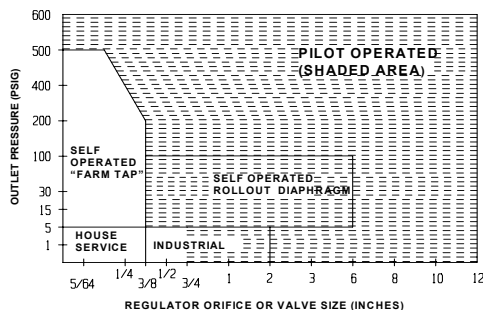


Figure 9. Unloading Type Pilot Operated Regulator

In a common Unloading Type operating system, an elastomeric diaphragm or boot is held against a grid plate by loading pressure passing through the pilot. This unique combination enables the diaphragm or boot to act as both a valve and an actuator. The throttling of the main valve is accomplished by exhausting or unloading the gas from the loading chamber downstream faster than the Fixed Orifice can fill the loading chamber.

The same GAIN relationship as previously discussed between the Fixed and Variable Orifice also applies to the Unloading Type system.

APPLICATION



**Figure 10. Regulator Selection Chart
Outlet Pressure versus Valve Size**

There are several engineering, cost, size, performance issues that must be taken consideration when selecting a regulator for an application. The chart summarizes graphically where self operated and pilot operated regulators are used in the gas industry (Refer to Figure 10).

Farm Tap Regulators are used in applications requiring high-pressure drops (over 200 psig) and high outlet pressures (15 psig to 200 psig and higher). Orifice sizes are limited to a maximum of 1". Smaller orifices are required as the pressure drop increases.

House Service and industrial regulators are used to handle outlet pressure from inches water column to 5 psig and orifice sizes up to 2".

Self Operated Rollout Diaphragm regulators are an exception in that they can control outlet pressure up to 100 psig and orifice sizes up to 6" in size.

Pilot Operated Regulators are generally used in applications requiring more accurate pressure control, larger orifice sizes.

Numerically self operated regulators are the most common in the gas industry because of the large number of end user applications that do not require high volumes of gas such as homes and small businesses. Pilot operated regulators are used in city gas stations, large industrial, and other applications that require larger volumes of gas and accurate pressure control.

CONCLUSION

A thorough understanding of the fundamental principles of pressure regulators and there application is of primary importance to the safe operation of any gas system. Every type of regulator represents a composite involving such factors as price, capacity, accuracy, stability, simplicity, safety, speed of response, personal choice, company standards, a long with a few I didn't mention. When picking a regulator be it Self Operated or Pilot Operated you must take into consideration many factors in your gas operating system, type of regulator, location, and many other items in picking the right regulator. The manufactures of the natural gas regulators have many tools and a lot of experience to assist you in the selection of the best regulator for your application so why not use them.