

FUNDAMENTALS OF PRESSURE REGULATION

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FUNCTION OF A REGULATOR

A regulator may be defined as a "mechanism for controlling or governing the movement of machines or the flow of liquids and gases, in order to meet a standard." The primary function of a gas or liquid regulator is to match the supply of the fluid moving through it to the demand for the fluid downstream. To accomplish this, it measures the downstream pressure and makes adjustments accordingly.

Take, for example, a furnace using some type of combustible fluid as a fuel (See Figure 1). In a steady state operation, the number of molecules of fluid being consumed by the fire must equal the number of molecules of fluid passing through the regulator. Should the load or demand for the molecules decrease, then the flow of the fluid through the regulator must decrease or too much fluid will be forced into the downstream piping causing its pressure (P_2) to increase. If the load increases, then the flow through the regulator must also increase to compensate for the increased loss of fluid molecules. Otherwise P_2 will decrease from a lack of fluid being available to replenish that being used. To meet these fluctuations in demand the regulator senses the downstream pressure, compares it to the set point pressure (its standard), and opens or closes as needed.

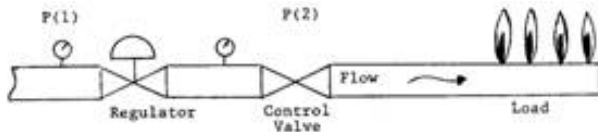


Figure 1. Gas Burner

Mathematically, the regulator operates on a very simply equation.

$$\text{SUPPLY} = \text{DEMAND}$$

The regulator solves this equation by maintaining the outlet pressure at the set point. Too much supply or flow through the regulator causes an increase in downstream pressure, while too little supply results in a decrease in downstream pressure. Graphically, the perfect regulator would behave as follows:

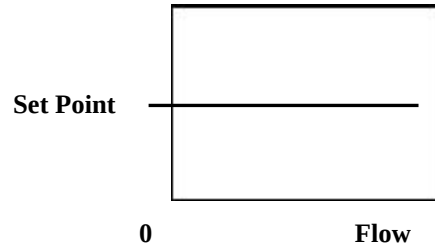


Figure 2. Outlet Pressure vs. Load

BASIC BENEFITS OF REGULATION

Regulation provides several benefits to the user:

1. Flexibility in system design by being able to have different operating pressures within a single network.
2. Efficient utilization of materials that are able to withstand specific criteria for individual applications. For example, a system designed for 45 psig does not need regulators designed for inlet pressures of 720 psig. Other materials, such as plastic pipe can also be used instead of steel and thereby cut costs.
3. Safety considerations are obtained when proper pressures are provided for customer equipment.
4. Measurement accuracy is achieved by measurement equipment when constant pressure is provided to the meter. A 1" water column error on 7" w.c. systems will result in a 0.25% measurement error or unaccounted for. A 2 psig error on a 10 psig system will result in a 2% measurement error.

THREE ESSENTIAL ELEMENTS

The basic design of a regulator is rather simple. It consists of a restricting element connected to a flexible diaphragm with a pressure applied to one side of the diaphragm and some type of loading force applied to the other side. These three elements would look like the following.

1. A restricting or regulating element which opens or closes to restrict the flow of fluid. Various types of restricting elements are:
2. A sensing or measuring element which responds to downstream pressure and acts against an adjustable loading force to position the restricting element. Types of sensing elements are:

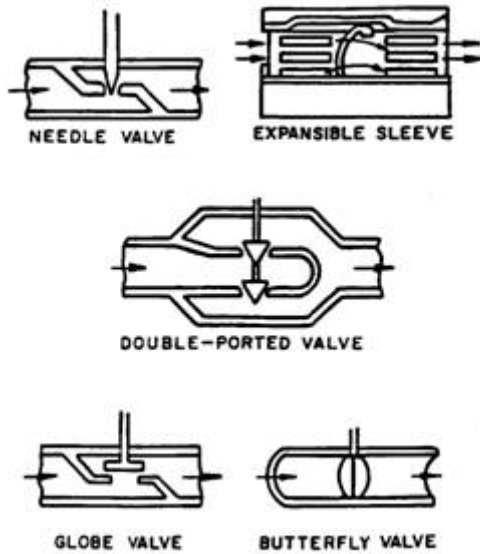


Figure 3. Restricting Elements

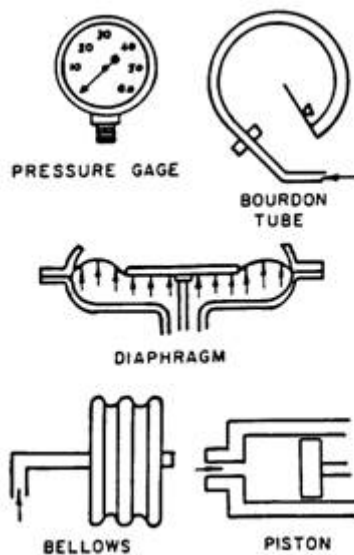


Figure 4. Sensing Elements

3. A loading element that applies a reference force to position the restricting element. Types of loading elements are:

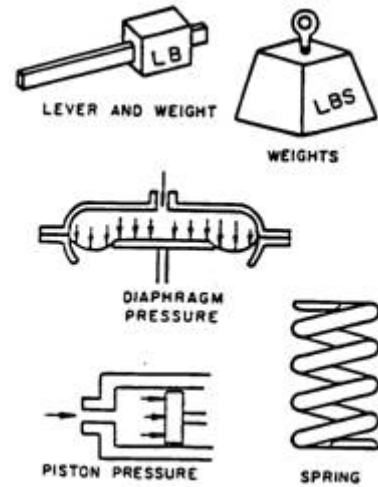


Figure 5. Loading Elements

A simple regulator is a combination of these three elements.

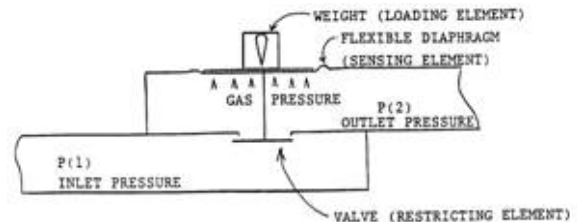


Figure 6. Simple Regulator

SEQUENCE OF OPERATION: SPRING-LOADED REGULATORS

When a demand or load starts, it immediately takes some fluid from the piping thereby reducing the pressure (see Figure 6). This slight decrease in pressure from the set point is also sensed on the bottom of the diaphragm (Sensing Element). As a result, the force exerted on the bottom of the diaphragm which is equal to the pressure times the effective area of the diaphragm ($F = P \times A$) becomes less than the force on top (Loading Element). The loading element can therefore push the diaphragm and the valve stem down and open the valve (Restricting Element). As the restricting element opens wider, additional fluid flows through the regulator to compensate for the increased demand.

When sufficient fluid is being supplied to take care of the load, the pressure in the piping will increase slightly to the original set point pressure. Then the force from the loading element is once again balanced by the force of the fluid pressure acting against the bottom of the diaphragm. The flow has thus increased but the outlet pressure has again reached the set point.

When the load shuts off or is reduced, the reverse action takes place. Since less fluid is now being taken out of the downstream piping than the regulator is supplying through

the restricting element, there is a slight increase in pressure. This increase in pressure will force the diaphragm upward and start closing the valve. It will continue to close the valve until the flow through the regulator is once again equal to the fluid being used.

At that point, the force from the pressure acting under the diaphragm will be equal to the force from the loading element, and the pressure will be back to its set point. The flow has been reduced and the outlet pressure will approach the set point. The regulator will act almost instantaneously when the load is decreased to provide outlet pressures that are almost constant.

SEQUENCE OF OPERATION: PILOT-OPERATED REGULATORS

In pilot loading, a small capacity regulator called a pilot regulator is used to load pressure onto the diaphragm of the main regulator. This loading pressure can be any type of fluid under pressure. In our case some type of gas is used almost exclusively. This gas loading pressure acts as the loading element just as the spring and weights do in self-operated regulators. With gas pressure imposed on both sides of the diaphragm, changes in its effective diaphragm area because of position are practically eliminated, permitting an almost constant outlet pressure. The pressure difference across the diaphragm can be very small so the diaphragm can be large and quite flexible. In addition, full travel can be used, generally allowing increased capacity over a self-operated regulator of the same valve and body design.

With the advantages of greater accuracy, increased capacity, and ability to be used at wider ranges of outlet pressures, pilot-loaded regulators appear to be superior to self-operated regulators. For many applications they are, but other important operating characteristics must be considered. Pilot-loaded regulators generally respond to load changes more slowly than self-operated models, require finer adjustment, and are generally more expensive. The pilot regulator, like any other regulator, may be subject to problems from spring effect, diaphragm effect, body effect, inlet-pressure effect, and valve imbalance. Although the operation of pilot regulators is generally at low flows which tend to minimize the above effects, nonetheless, there is some resultant net effect which causes loading pressure variations that can significantly alter main regulator outlet pressure. Finally, the methods used to bleed loading gas off the main regulator diaphragm can present problems.

Pilot-operated regulators have been developed that bleed the gas into the downstream piping. One such design is shown in Figure 7.

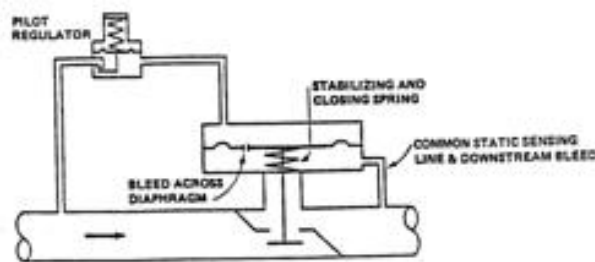


Figure 7. Downstream Bleed - Internal Path

With this regulator, the pilot supplies pressure to the top of the diaphragm and is opposed by the downstream pressure acting under the diaphragm along with the spring. Should there be a decrease in downstream pressure, the diaphragm will be pushed down to open the valve and increase gas flow. The opposite reaction takes place should the downstream pressure increase. The higher pressure under the diaphragm pushes it up and closes the valve. The bleed opening through the diaphragm lets the pilot regulator sense the downstream pressure and makes adjustments as needed. This type of operation is somewhat sluggish in its response since the pilot regulator cannot sense the downstream pressure change until the pressure is equalized across the small bleed opening. Regulators of this type should be limited to steady loads or at least gradually changing load conditions.

To improve operating characteristics, another bleed path can be provided that is external to the diaphragm and adjustable. This is shown in Figure 8.

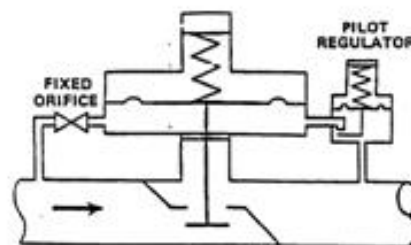


Figure 8. Downstream Bleed - External Path

There is a separate path for the pilot regulator so its response to a load change does not require equalization in the upper and lower diaphragm chambers before it can react. This allows for rapid and stable positioning of the valve that results in better control of downstream pressures.

The systems shown in Figures 7 and 8 will produce a lock-up pressure equal to that of the pilot regulator. At no-flow, the main regulator will lock-up slightly above the set point of the pilot and the pilot will continue to bleed downstream until it too locks up. This is an inherent characteristic of downstream bleed regulators.

In addition to these pilot-loading types, there are also pilot

unloading regulators that use a pilot to take pressure away from one side of the main diaphragm. Two such regulators are shown in Figure 9.

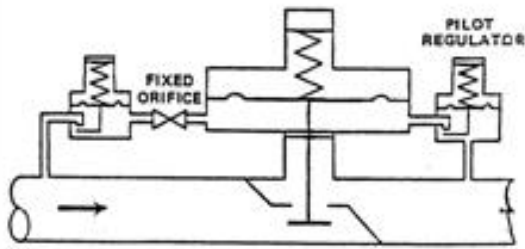


Figure 9a. Unloading-Pilot System

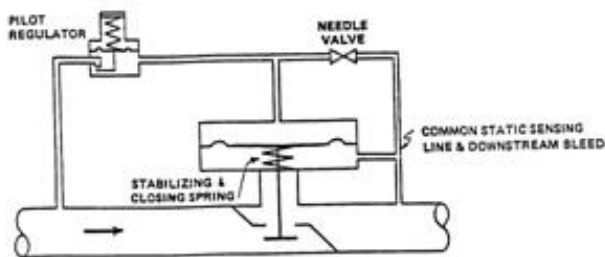


Figure 9b. Unloading-Pilot System

Pilot unloading systems make use of a fixed upstream orifice and a pilot regulator with a variable orifice downstream. In operation, any change in downstream pressure will reposition the pilot regulator resulting in a different flow rate through the pilot. For example, in Figure 9(a) should there be a decrease in downstream pressure; the pilot regulator will open to meet the load. The pilot can allow more fluid through its orifice than the fixed orifice will allow and therefore the pressure under the diaphragm will decrease. This decrease in pressure allows the spring to push the valve open in the main regulator letting more fluid through. An increase in pressure from set point will cause the pilot to close off. Since the fixed orifice allows fluid to continue to feed through, this will increase pressure under the diaphragm and push it up closing off the main valve and stopping flow. This type of loading shows many of the undesirable effects that have previously mentioned; i.e. diaphragm effect, inlet pressure effect, etc. The flow rate through the upstream fixed orifice will remain relatively constant as long as the upstream pressure remains constant. Variations in upstream pressure will change the flow through this orifice requiring repositioning of the pilot regulator to rebalance. This considerable movement of the pilot under varying inlet pressures could result in undesirable performance.

To counter these effects, a small supply regulator has been added in Figure 9(b) upstream of the fixed orifice. The purpose of the supply regulator is to provide a constant pressure on the inlet side of the fixed orifice. The set point of this regulator should be somewhat lower than the minimum inlet pressure to the main regulator but high

enough to provide the necessary closing force for the main regulator. With such a setting, the pilot regulator needs to position itself only to control the loading pressure on the main diaphragm as a result of changes in downstream pressure and not to also accommodate for changes in the upstream pressure.

Note that unloading pilot systems do not pressure load both sides of the main diaphragm. This limits applications to diaphragms that can withstand full upstream pressure that can limit diaphragm size and sensitivity. The upstream regulator shown in Figure 9(b) serves as a pressure limiter and permits the use of higher inlet pressures and larger and more sensitive diaphragms. The use of larger diaphragms provides for substantial increases in lock-up power. Unloading pilot systems are accurate, but not as fast in response and generally not as stable as the system shown in Figure 8.

For extremely high flows and outlet pressures flexible element valves are often used. These types have a sleeve or boot whose action is controlled by a pilot that manipulates the differential across the flexible element. As the downstream pressure fluctuates, the pilot will respond by either raising or lowering the pressure on the backside of the sleeve. If the inlet pressure is higher than that on the backside of the boot, it will force the boot open and allow gas to flow through the regulator. If the backside pressure is equal to the inlet pressure no flow can occur since the boot is designed and molded to shut off the flow when the backside and inlet pressures are equal.

SELECTION OF A REGULATOR

The following basic information needs to be considered when choosing a regulator:

1. Inlet pressure - minimum and maximum.
2. Outlet pressure.
3. Flow rate - standard cubic feet per hour.
4. Type of fluid to be controlled (natural gas, manufactured, LPG, etc.).
5. Specific gravity of the fluid.
6. Temperature of the fluid.
7. Load characteristics (gradual variations, quick on/off cycles, etc.).

From this information the pipe size, valve size, and type of regulator can be selected. The following points should be considered as well:

1. Accuracy of control required - keep the controls simple.
2. Rangeability - Choose a regulator and size it in a manner that will produce the best results for the majority of the operating time. Avoid selecting a regulator to meet a set of requirements which will occur only during a short period of time.
3. Lockup - Do not choose a regulator with a positive lockup unless actually required. Regulators not

requiring a positive lock-up can be equipped with metal or hard plastic valve seats that have a longer trouble-free service period. Regulators requiring a positive lockup must be fitted with a rubber or a relatively soft seat requiring more frequent inspection.

4. Variation of operating conditions – Inlet pressure fluctuations will cause a change in outlet pressure dependent upon the type of regulator, load conditions, and ratio of inlet to outlet. For large volume regulators reducing pounds to inches of water column, a change of 5 or 10 pounds on the inlet may result in only a slight change in outlet pressure (a few tenths of an inch of water column); in a single valve regulator as shown in Figure 6, reducing pounds to pounds, an outlet change of approximately 10% of the inlet change may be expected.
5. There are other factors which affect regulator performance. These include (1) the spring effect, (2) the diaphragm effect, and (3) the body effect.

Spring Effect - The spring exerts a force which varies, depending on how much the spring is compressed. When the spring is extended, it takes less force to stroke it a given distance of travel than when it is compressed. Since the spring is connected to both the diaphragm and the valve, the amount of valve opening is directly related to the amount the spring is extended. Whatever spring force is exerted must be balanced by the downstream pressure acting on the diaphragm.

Diaphragm Effect - Another limitation encountered in regulators is caused by the usual (flat-sheet) types of diaphragm and is termed diaphragm effect. As the diaphragm moves through the stroke, its effective area changes. Normally the effective area is larger at high flows, therefore the outlet pressure must be lower to balance the constant load from the spring force, neglecting spring effect.

Body Effect - Gas flow is caused by a differential pressure and is always from a high pressure to a lower pressure. If the flow is low, differential pressure will be low and as the flow increases, the differential pressure will increase.

In the body of a simple regulator, a differential pressure from the valve outlet to the outlet of the body must exist for flow to take place. This is termed “body effect” and causes a higher differential pressure at higher flows, producing a corresponding increase in droop.

There are other contributing causes to body effect which are usually of lesser magnitude. If the regulator configuration is such that gas can impinge directly on the diaphragm, an impact pressure is exerted on the diaphragm. This impact pressure, together with the downstream pressure, acts on the diaphragm to oppose and balance the spring loading force. Since the impact pressure is greater at higher velocity and thus greater flows, outlet pressure will be lower at higher flows.

Spring effect, diaphragm effect, and body effect all produce forces on the diaphragm which add to the force produced by outlet pressure. The total droop is determined by adding all three together as shown in Figure 10.

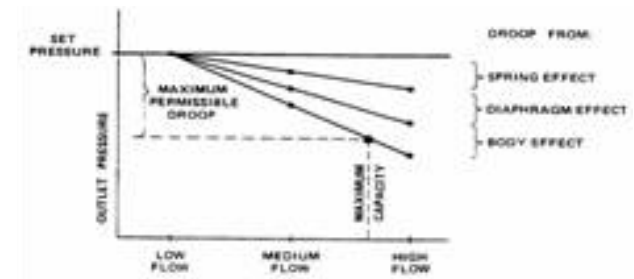


Figure 10. Diaphragm Forces

Regulators must regulate pressure within certain limits of accuracy throughout their operating capacity range. The dotted line in Figure 10 illustrates how capacity is restricted by outlet pressure droop.

To compensate for this droop, various principles can be used to provide a “boost” or increase in the outlet pressure.

By definition, velocity of gas in the regulator depends on the rate of flow and the size of the passage. Mathematically, velocity (V) = rate of flow (Q) divided by the cross-section area (A). Velocity is high when a given amount of gas flows through a small area, but decreases as the area increases. The velocity of the gas must change to adjust to various changes in area through the downstream section of the regulator. As the velocity of the gas changes, so too does its static pressure. As the velocity increases, the static pressure will decrease and this is called the Venturi effect. As the velocity decreases though, the static pressure will recover or increase. A regulator design which compensates for droop by using the Venturi effect is shown in Figure 11.

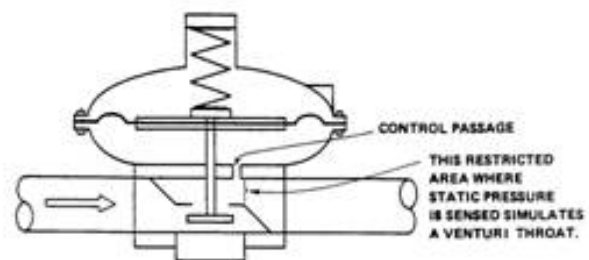


Figure 11. Regulator with design-in boost

The diaphragm senses the static pressure through the control passage which is located in a restricted area to simulate a Venturi throat. As the gas leaves the regulator through this restricted area, its velocity increases and therefore its static pressure decreases. As a result, the diaphragm responds to this decreased static pressure and opens more. This allows more gas through the regulator and increases the downstream pressure. Since there is a greater pressure recovery in the downstream piping at high flows, a greater

boost is seen as the flow increases. This effect of boost is shown in Figure 12.

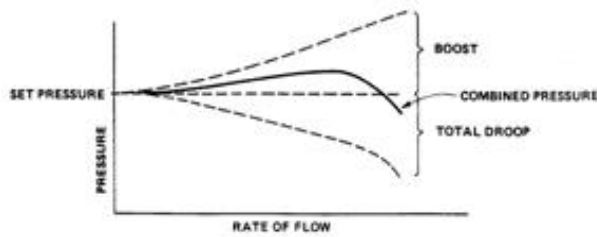


Figure 12. Effects of Boost

When these points have been considered, the type of installation can be established considering the following points:

1. Single or multiple stage reduction.
2. Regulators in series, parallel, or series parallel.
3. Type of loading.
3. Kind of valve trim.
5. Type of pilot regulator, if used.
6. If pilot is used, atmospheric or downstream bleed.
7. Type of filter, if required.
8. Over/under pressure protection.

MAINTENANCE

Regulators can go years without maintenance. Here are some tips when problems do arise.

Problem: Failure to hold set point

1. Check technical data and operating conditions against the connected load. Has the connected load changed?
2. Check pressure gauge and any valves in gauge lines to insure they are open. Check for leaks.
3. Check inlet pressures to make sure fluctuations are not caused by elevation effect.
4. Ensure all valves that should be open are fully open.
5. Check differential across any filters or strainers to ensure they are not obstructed.
6. Inspect internal moving parts for binds or friction.

Problem: Failure to lock up or shut off

1. Damage to seat, disc, sleeve, or orifice.
2. Overpressure of diaphragm.
3. Leakage around orifice, seat gage, gage, or seat bolt.
4. Defective body castings. Leakage between inlet and outlet chambers.
5. Vent plugged.
6. Spring coil bound.
7. Diaphragm center bolt leaking.
8. Lock up experience in monitor lockup.

Problem: Leakage from diaphragm vent.

1. Holes in diaphragm.
2. Internal relief operating.
3. Internal relief leaking.
4. Internal relief improperly set.
5. Internal relief not assembled correctly.

Problem: No control at all.

1. Valve seat missing.
2. Orifice missing.
3. Sleeve missing.
4. Control/loading line blocked or not connected.
5. Pilot supply insufficient.
6. Inlet valve closed.
7. Control valve closed.
8. Outlet valve closed.
9. Wrong spring for the application.
10. Diaphragm ruptured.
11. Control line incorrectly positioned.
12. Moisture in diaphragm chamber frozen.
13. Control line is blocked or obstructed.
14. Main valve or controls frozen.

Problem: Vibration or humming with no drift from set point.

1. Investigate increase in vent line diameter or length.
2. Ensure vent dampener or vent valve is in place.
3. Vents from two separate regulators should not be tied together.
4. Is adjusting cap or seal cap in place or loose?
5. Location of regulator relative to other apparatus, i.e., rotary meter, compressor, other stations, etc.
6. Too tight of spring.

Problem: Slow drift from set point.

1. Oversized orifice for inlet pressure. (Inlet pressure elevation effect.)
2. Binding/friction in moving parts.
3. Load exceeds capacity of regulator.
4. Moisture freezing for short periods in control line.

CONCLUSION

The two types of regulators, spring-loaded and pilot-operated, have been used for years whenever a pressure or fluid has to be controlled. Knowing how each design works along with their individual strengths and weaknesses will go a long way in selecting the right regulator and having it work in the field. They require little routine maintenance, but should problems arise being able to recognize the symptoms will usually aid in correcting the situation.