FCI Fluid Controls Institute

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FUNDAMENTAL PRINCIPLES OF SELF-OPERATED PRESSURE REDUCING REGULATORS

John R. Anderson – Emerson Process Management
Fluid Controls Institute

For pressure control in process or utility applications, control valves or regulators are commonly used. In many applications, a pressure regulator is more economical and simpler than a control valve. If electronic feedback to a distributed control system is not required, a pressure regulator could be considered a viable option over a pneumatically actuated control valve.

A pressure regulator is defined as a self-contained valve and actuator combination that uses the internal pressure of the pipeline for actuation. Therefore, there are no external power requirements such as a pneumatic supply, electricity, or hydraulics required for actuation.

Pressure regulators may be used in applications for gases, steam, water, and most other fluids. The fluid must be relatively clean for most regulator types. Most regulators are not suitable for slurries or high viscosity fluids which are usually better applications for control valves.

Most regulators have limitations with high temperature applications. A control valve should be considered in these cases. However, there are many regulator models suitable for cryogenic applications.

Most industrial pressure reducing regulators can be placed in either of two categories:

1. Self-Operated or Direct Operated
2. Pilot-Operated

The most commonly used regulator type is the self-operated because of its simplicity and most of all cost. A self-operated regulator is usually considered much faster reacting than a pneumatic control valve in many applications. For applications that require a fast response to load changes, consider selecting a self-operated regulator if it will meet the pressure, and flow, temperature, and accuracy requirements. There are dome or pressure loaded styles of regulators that are considered self-operated also.

FUNCTION OF REGULATORS

The primary function of any pressure regulator is to match a downstream flow demand, while maintaining the controlled pressure within certain acceptable limits. The pressure in which the regulator is trying to control is called the setpoint or controlled variable. The outlet or setpoint pressure is commonly referred to as P_2.

A typical pressure reducing control application might be similar to that shown in Figure 1 where the regulator is placed upstream of the valve or other load that will vary demand for fluid from the regulator.

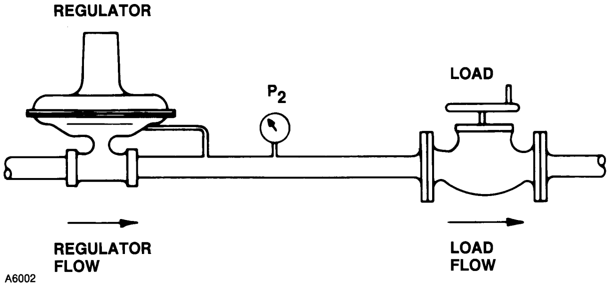

FIGURE 1
Typical Regulator System

If the demand decreases causing an upward change in the pressure being controlled, then the regulator must throttle to a closed position while maintaining a steady outlet pressure. Otherwise the regulator would put too much fluid into the downstream system and the outlet pressure, P_2, would tend to increase. On the other hand, if the demand increases, the regulator must throttle open in order to keep P_2 from decreasing due to a shortage of fluid in the downstream system.

THREE ESSENTIAL ELEMENTS

There are three essential elements of any regulator used in a pressure control system. One of the essential elements of any regulator is a restricting element that will restrict the flow of fluid within the flow stream.

Figure 2 shows a schematic of a typical regulator restricting element. The restricting element is usually some type of valve plug and orifice combination in a straight or angled body. Other technologies include the sliding gate design. When selecting the orifice and valve plug combination, always select the smallest orifice available which will still handle the maximum flow required by the application. This decreases the potential of instability in the system at lower flows. If required, it also allows for the selection of a smaller relief valve to protect the downstream components in the system from overpressure in the event of a system failure.

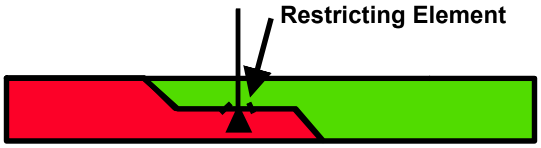

FIGURE 2
Typical Restricting Element

Restricting elements can be made of a variety of materials including elastomer, teflon, nylon, or metal. Selection is based on temperature, material compatibility with the process fluid, and maximum pressure drop. The lock up pressure of the regulator varies also by material selection. Lock up pressure is defined as the pressure rise above the regulator's setpoint to achieve the acceptable shut off class. Harder materials may have higher lock up characteristics and shut off classes. For further information on leakage class for pressure regulators, refer to ANSI/FCI 70-3.

So far we have a restricting element that modulates the flow through the regulator. But how do we know when the regulator flow is matching the downstream demand? We need some type of measuring element which will sense the correct downstream pressure and reposition the restricting element to match the flow demand.

With a pressure reducing regulator, we can use a diaphragm (Figure 3), bellows, or piston to measure the downstream pressure. Diaphragms are the most commonly used measuring element but are usually limited in pressure and temperature. Diaphragms can be made from a flat sheet or molded piece of rubber or stamped metal. Pistons and bellows offer high pressure and temperature capability for measuring pressure. The area under the measuring element creates a force which results in travel to both the measuring and the restricting elements.

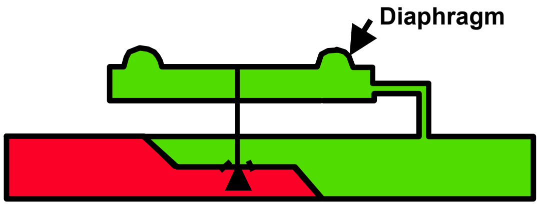

FIGURE 3
Typical Measuring Element

The third essential element of a pressure regulator is a loading element. The loading element can be a weight, spring, or pressure load above the measuring element.

A spring, as shown in Figure 4, forms the most common type of loading element. When the outlet pressure rises and the force created underneath the diaphragm exceeds the force of the spring, the restricting element will throttle closed. As outlet pressure goes lower, the spring force will push on the diaphragm opening the restricting element. The spring force adjustment is usually accomplished by an adjusting screw.

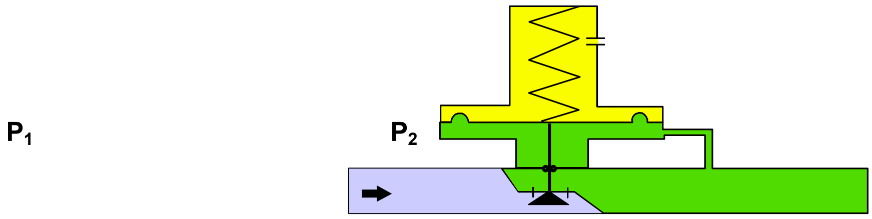

FIGURE 4

Self-Operated Regulator
Basic Design

Regulator models have many variations. They can be balanced or unbalanced, single-ported or double-ported. But common to all regulator valves is a control inaccuracy caused mainly by the “spring effect.” Spring effect occurs as the force of fluid acting on the diaphragm compresses the spring in the regulator. As spring compression increases, there is a greater increase in the amount of diaphragm force required to move the restricting element to the closed position. For example, the spring effect may cause the regulator valve plug to remain open even though downstream pressure equals or is greater than the setpoint.

When the flow demand goes to zero, the restricting element in the pressure regulator is required to close. In order for the valve plug to travel to a closed position, there must be an increase in downstream pressure over setpoint. The increase in outlet pressure over the set pressure is called the lock-up or shut-off pressure. This is normal with any pressure regulator to see some pressure rise downstream over setpoint when the regulator is in the closed position.

All springs have a spring rate. This is the amount of force required to compress a spring one inch. When selecting springs for regulator applications, the higher the spring rate, the more force that is required to move the restricting element to a closed position. Also, with higher spring rates there will be more inaccuracy in maintaining a set point over a given flow range.

Best accuracy in a self-operated regulator is defined by which regulator can pass the most amount of flow with the least deviation from the setpoint expressed as a percentage of a fixed unit of measure. Setpoint of a regulator is determined by the end user.

Manufacturers will present accuracy in a tabular or graphical format in their technical literature. See Figure 5, taken from ANSI/FCI 99-2 Regulator Pressure Capacity Standard, as an example of a flow curve that could be found in a manufacturer’s bulletin. The downward deviation from setpoint as flow increases is called offset. Offset is also referred to as droop. Offset is determined by multiple variables including spring rate, diaphragm area, pressure drop, unbalanced forces, etc… The desired result of any pressure regulator is to maintain pressure accurately throughout the flow range.

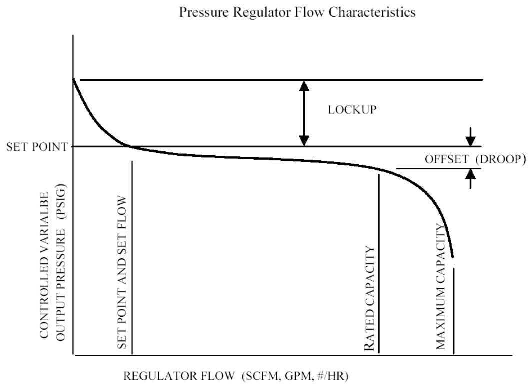

FIGURE 5

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During the testing process, manufacturers will make setpoint, usually with a small amount of flow anywhere from 1-10% of flowing capacity. From this initial flow, the flow curve is developed that determines the regulator capacity. Normally for self-operated regulators, a 5-20% deviation in setpoint is allowed and that will determine the rated capacity. Accuracy will vary based upon the type of regulator technology used. Some self operated regulator will maintain accuracy better than 1% while others are less than 50%. This will change based on application and regulator model. In most cases, the maximum capacity is much higher than the rated capacity.

To compare regulator models, always look at the rated capacity at a comparable offset and not the wide open capacity. The wide open capacity is typically used for relief valve sizing and is not reliable for determining regulating capacity.

Regulators are designed to minimize the droop or offset that occurs. When sizing and selecting a regulator, a rule of thumb is to use the lowest spring rate possible to achieve the highest accuracy. Most manufacturers will publish spring ranges that can be used from their upper to lower ranges.

If a pressure regulator is unstable, many times changing to a higher rate spring can alleviate the instability because it decreases the sensitivity.

CONCLUSION

Every type of regulator represents an evaluation involving such factors as price, capacity, accuracy, stability, simplicity, safety, and speed of response. A careful analysis of control applications usually reveals that more of these factors should be considered when selecting a pressure regulator. Regulators offer a lower installation cost compared to a control valve in simple pressure control applications.