Flexible Element Regulators

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Introduction

Flexible Element Regulators, also referred to as Unloading Design Regulators, utilize a rubber element that functions as both the actuator and valve of a self contained pressure regulator. This is in contrast to the more traditional style of regulators where a separate actuator, throttling valve and seat are used to regulate the pressure and provide shutoff.

Traditionally in pressure control applications using self-contained regulators, the restricting element of the regulator is a valve plug with an elastomer seat on the surface, which presses against a knife-edge orifice. The valve plug's function is to open and close in the flow stream when the flow demand fluctuates, and provide tight shutoff against the seat when no flow is required. This valve plug is coupled to a separate actuator component, which is actuated using pressure, and moves the valve plug to throttle or shutoff the flow stream (see Figure 1).

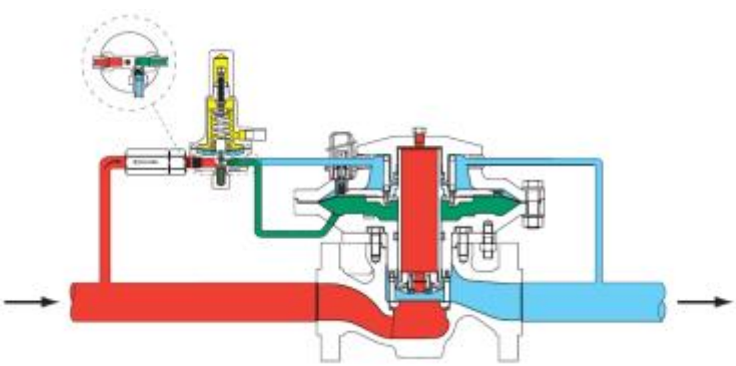

Figure 2

In contrast, a Flexible Element Regulator uses a single rubber element and a metal cage or sleeve to perform all of these functions required for pressure regulation (see Figure 2).

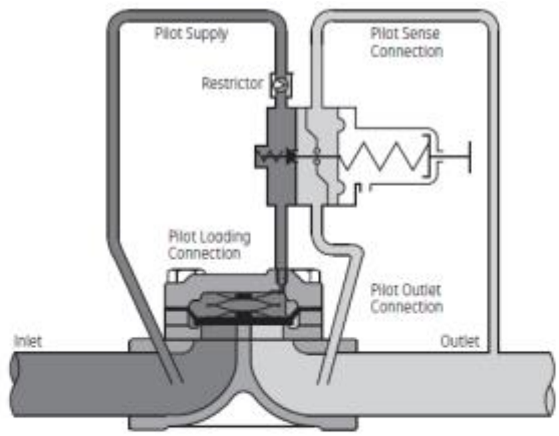

Figure 1

All Flexible Element Regulators are pilot operated and utilize the higher upstream pressure to load the rubber element to throttle flow, and provide shutoff against a metal cage or other metal component such as a sleeve. When flow is required, the pilot assembly "unloads" the rubber element, moving it away from the metal cage and allowing flow to pass. These regulators can be configured in either Pressure Reducing or Pressure Relief applications.

History

The first Flexible Element Regulator was developed in the 1950s by the Grove Regulator Company. The Grove Flexflo® is a rubber tube type regulator, also referred to as an expansible-tube type. This regulator uses a rubber tube stretched over a cylindrical metal sleeve, or core. The metal core component separates the upstream and downstream of the regulator, except for two sets of slots (one upstream and one downstream) around the circumference where the rubber tube sits (see Figure 3).

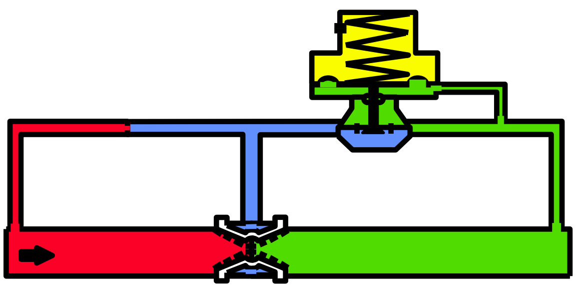

Figure 3

When the chamber behind the rubber tube is pressurized above or equal to the inlet pressure, it compresses the tube against the metal core, sealing against the slots so no flow can pass through the core. As the chamber behind the rubber tube is depressurized and the differential pressure (Inlet vs Outlet) is great enough, the rubber tube moves away from the core and flow is able to pass from the upstream to the downstream through the slots on the core.

In 1970, the American Meter Company introduced a modified design of the tube type regulator called the Axial Flow Valve®, or AFV. The AFV was a more compact design using a smaller body, a 2-piece metal cage, and included a pilot mounting system.

The rubber tube type regulators were quite popular when introduced as they provided a low cost, simple device, with higher than average flow capacities compared to the traditional globe-style regulators of the day. Although this technology became popular for these reasons, they also had their limitations and drawbacks:

- A minimum differential pressure is required in order to stretch the tube away from the cage and achieve wide-open flow. The minimum differential pressure in the tube-type regulator varies with the tube thickness as it stretches during operation, and changes over time.
- Higher differential pressure applications require a thicker tube, which requires larger differential pressures to reach wide-open flow. Thinner tubes can be used for lower differential pressure applications, but are more susceptible to damage.
- Tubes are susceptible to damage from particulates in the gas and aromatics attacking the rubber, compromising flow control and shutoff capabilities.
- Shutoff can become an issue caused by the tube element stretching over time.
- Maintenance is time consuming and difficult because the regulator needs to be removed from the line.

The more common Flexible Element Regulator technology used today is the fabric reinforced rubber element or diaphragm regulator (also referred to as the "boot" style regulator). This technology was developed in the 1980s and was released as the Mooney Controls Flowgrid® and the Fisher Controls 399A. These regulators offer a much improved design over the tube type technology that preceded them. The major difference being the single rubber throttling element is reinforced with fabric to provide strength and prevent the rubber from stretching. They also employ a top entry design for ease of maintenance.

The fabric reinforced element eliminated the need for many different tube thicknesses for different pressure applications, and also eliminated the variability on differential pressure requirements as the older tube style stretched over time. The top-entry design (see Figure 4 and 2) allows for all critical components to be serviced with the regulator body in-line.

These technologies also have their limitations as they are still susceptible to damage caused by high velocity flow, particulates in the gas and aromatics attacking the rubber. Shutoff capabilities can still be an issue as the rubber element degrades over time. They also have a tendency to see damage at high flows with some manufacturers de-rating the flow capacities by up to 25% of their rated capacity to ensure stable control.

A third type of Flexible Element Regulators was introduced in the late 1990s – the internally actuated metal plug regulator. This regulator still uses the reinforced fabric as its primary throttling element, but added a metal plug to the center of the diaphragm (see Figure 4) and an internal spring actuator.

The addition of the metal plug improved the design of the traditional boot style regulator, reducing it's susceptibility to diaphragm erosion, and improving its shutoff capabilities. The metal plug is directly in the flow path and becomes the primary point of contact for any particulate passing from the upstream to the downstream, instead of impinging the softer, rubber diaphragm.

Tight shutoff is achieved by the addition of a

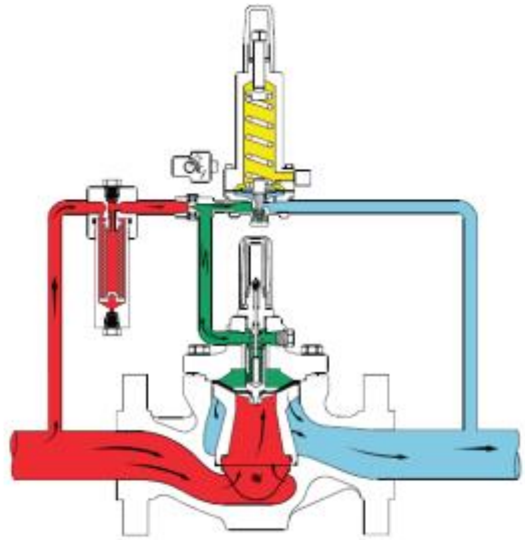

Figure 4

knife-edge seat and an internal actuator spring providing added seat load. A redesign of the flow geometry also assists in directing flow away from the reinforced Flexible Element to further protect it from erosion damage. With the addition of the actuator spring, this regulator can be operated at 100% of its rated capacity for stable control.

Principles of Operation

Although there are different designs of Flexible Element regulators as mentioned previously, the principle of operation is the same for all. All Flexible Element Regulators are pilot-operated, and use the 'Unloading' type of piloting system. An 'Unloading' type pilot uses full upstream pressure to load the regulator diaphragm when it is seated or closed. When the regulator is required to open, the Pilot "unloads" the pressure on the diaphragm and allows the Flexible Element to unseat allowing flow.

There are two primary components used in this type of piloting systems: a fixed restriction and a variable restriction. On the upstream side of the loading chamber (the area behind the diaphragm), an adjustable orifice is installed on the supply line as the fixed restriction. The control pilot is installed downstream of the loading chamber and is the variable restriction. The pilot's wide-open position is always larger than the largest setting on the adjustable orifice (fixed restriction).

When the regulator is seated or closed, the variable restriction (pilot) is closed and the diaphragm loading chamber pressure is equal to the upstream or inlet pressure.

In a pressure reducing application, the control pilot monitors the downstream pressure through a sense line connected to the downstream piping. As the downstream pressure decreases below set-point, the pilot (variable restriction) opens and allows gas from the diaphragm loading chamber to escape downstream through a bleed and/or sense line. Because the variable restriction (pilot) is larger than the fixed restriction, the gas in the loading chamber is allowed to bleed faster than it can pass through the fixed restriction upstream. As the pressure in the loading chamber decreases, the inlet pressure on the opposing side of the diaphragm forces the diaphragm away from the seat allowing flow to pass through the regulator.

When the regulator reaches a steady state, the gas bleeding through the variable restriction (pilot) equals the gas flow through the fixed restriction and the pressure in diaphragm loading chamber is constant (the pilot system is at equilibrium).

As the downstream pressure increases to set-point, the pilot valve closes to eliminate the gas from being bled from the diaphragm loading chamber. While this happens, upstream pressure continues to pass through the fixed restriction increasing the pressure in the diaphragm loading chamber until it is equal to the upstream pressure; this forces the diaphragm against the seat, closing the regulator.

For pressure relief applications, the same principles of operation apply, except in this case the pilot senses the upstream pressure and has a reverse action: pilot opens when the system pressure increases above set-point, and closes as it decreases.

Unloading regulator designs can be slower than loading style regulators (two-path control), because the pilot must first react to changes in the system pressure, before the main regulator valve moves. Tuning adjustments can be made to the fixed and variable restrictions to adjust the regulator gain, speed of response, accuracy, etc. There are many variations of pilots for Flexible Element Regulators, some having better accuracy, control and tunability than others, and many of them are interchangeable between manufacturers.

Overpressure Protection –Monitoring and Relief Regulators

All designs of Flexible Element Regulators can be used for overpressure protection as a monitoring and/or a relief regulator.

Monitoring is the method of overpressure protection by containment (i.e. does not vent gas to atmosphere). Two regulators are installed in series and sense the same downstream pressure. The "worker" is the primary regulator that controls the downstream pressure to the desired set-point. The "monitor" is the safe-guard regulator that senses the same downstream pressure, but is set to a slightly higher pressure than the worker. In the event that the worker regulator fails to control the downstream pressure, the pressure would increase and approach the set-point of the monitor. The monitor would then take over and control to its set-point. During normal operation the worker controls the final downstream pressure, and the monitor sits idle ready to take over if the worker fails.

There are two types of monitoring configurations that can be used for overpressure protection – wide-open monitor and working-monitor. In a wide-open monitor system, the monitor operates as the name suggests – during normal operation the monitor regulator sits in the wide-open position, until it senses a pressure that reaches its higher set-point (an overpressure situation), then takes over control of the downstream pressure (see Figure 5). In the wide-open monitor configuration, the monitor regulator can be installed either upstream or downstream of the worker regulator.

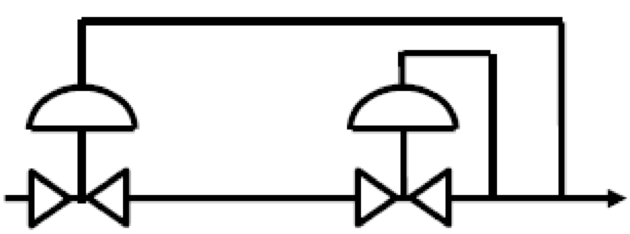

Figure 5

For some applications using Flexible Element regulators there are advantages to installing the wide-open monitor regulator downstream of the worker: faster speed of response for the monitor to take over as it's closer to the downstream pressure; prevent freezing from occurring; and to reduce the pressure on the wide-open monitor to decrease the chances of deforming the Flexible Element or "taking a set" from being held in the wide-open position. It should be noted that newer Flexible Element regulator designs, such as the internally actuated metal plug style, can be utilized as upstream wide-open monitors as these technologies are less susceptible to taking a set when held in the wide-open position.

In a working-monitor system, both the monitor-regulator and worker-regulator are "working" to reduce the overall pressure in two stages. This is done by introducing an intermediate pressure between the two regulators. The monitoring regulator is equipped with two pilots – one to sense the downstream pressure and control to its monitor set-point if required (slightly higher than the worker set-point), and a second pilot to take a first-stage pressure drop and control to an intermediate pressure between the monitor and

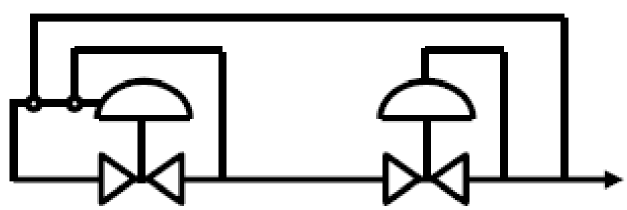

Figure 4

downstream worker (see Figure 6).

In the event that the worker regulator failed, and the downstream pressure increased to that of the monitor pilot, the monitor pilot would take over the working-monitor regulator and control the downstream pressure to its set-point. This configuration allows both the monitor and worker regulator to operate constantly, reducing the chances of the Flexible Element from "taking a set" as previously mentioned.

Using a working monitor has advantages over a wide-open monitor when using Flexible Element regulators:

- Keeps both regulator elements flexing continuously, reducing the chances of the flexible element from taking a set
- Can easily monitor and identify if one of the regulators has failed
- Can help reduce overall noise by splitting the pressure drop across both regulators
- Reduce trim wear by lower pressure drops across the regulators.

When using Flexible Element regulators in Monitoring applications on dead-end installations, it is good practice to use a token relief or "burping" valve (see Figure 7). A token relief valve provides a smaller (less than full capacity) relief capability should any damage to the flexible element occur, debris become stuck in the regulator, or if the flexible element takes a set and fails to provide bubble tight shutoff. The monitoring method of overpressure protection is growing in popularity as concerns over emission increase and regulations on venting natural gas become more strict.

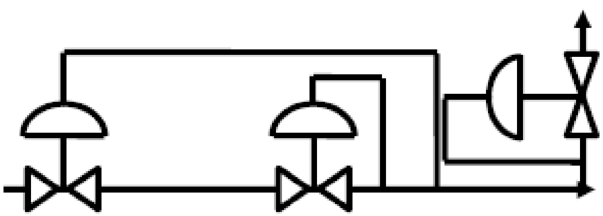

Figure 6

Another form of overpressure protection using Flexible Element regulators is as a full capacity relief valve. Relief valves offer an inexpensive solution for applications requiring high relief capacity. Usually the same body and trim can be used with a simple change of the pilot to switch from pressure reducing to relief operation.

Sizing, Selection and Installation

When sizing and selecting Flexible Element regulators it is important to take into account all of the industry standards for sizing regulators (line size, pressure ratings, accuracy, capacity, etc), as well as the following specific considerations for Flexible Element regulators:

- Size the regulators to ensure there is sufficient capacity for the application, and consider sizing it to allow for 20% more capacity than required. Flexible Element regulators have good turndown capabilities to handle this sizing margin; however careful consideration should be taken to ensure any Low-Flow conditions (like summertime load) are within the regulator's capabilities.
- Confirm the minimum and maximum pressure drops are within the published limitations. The minimum pressure drop is critical to ensure that there is enough differential pressure to fully open both regulators (in a monitor configuration). The maximum pressure drop cannot be exceeded as issues like diaphragm erosion, and instability can result. The minimum and maximum differential pressures will dictate the selection of the flexible element material, pilots and main valve spring.
- Size the regulator to ensure that the velocity does not exceed the manufacturer's limitations (typically 0.5Mach or 700ft/sec for natural gas). Velocities above this limitation can result in premature failure of the diaphragm. If velocities exceed the manufacturer's limitations, a larger regulator can be used to reduce the velocity.

- The material of the Flexible Element should be selected for the specific application. Ambient temperature, media/gas temperatures and pressure drop will all affect the selection of the Flexible Element material.
- Speed of response requirements of the application should be considered. Selection of the regulator will depend on the speed of response requirements as some pilots are available with more flexible tuning adjustments to allow for quicker responses.
- Noise should be considered when sizing a regulator system. Flexible element regulators can handle large flows and large differential pressures, which are the main contributors to noise. Two-stage pressure drops, like working monitor systems, can reduce noise, as well as noise abating trims. Noise levels above 110dBA can cause physical damage to regulator parts, as well as surrounding equipment.
- Overpressure protection in the form of monitors and/or relief valves should be considered to protect the downstream system. Token relief should also be considered to protect the system from any small seat leakage and thermal expansion of the gas downstream.
- Hydrates and Freezing can cause unpredictable responses from regulators and should be addressed if a concern. Line heaters, pilot gas heaters, or alcohol injection can be used to prevent issues.

Once a suitable regulator has been selected for the application, there are installation considerations that should be taken into account to ensure the regulators perform optimally:

- Filtration should be considered either for the entire station and/or for the pilots. Because flexible element regulators are inherently susceptible to erosion damage from debris in the gas flow, filtration for the station should be considered if the gas flow is known to be dirty. Filtration for the pilots should also be used as pilots have small orifices for precise control, and are susceptible to plugging if debris is present.
- Connecting control lines should be planned in advance to ensure good performance and reliability. A rule of thumb for control lines is to locate these 6-10 pipe diameters downstream from any turbulence generators (regulators, elbows, swages, block valves, etc). When using a monitor, ensure both the monitor and worker regulator each have a control line with an independent tap to the downstream piping - control lines should never share tubing or a tap. This ensures complete redundancy.
- Connecting bleed lines should also be planned in advance. Some manufacturers require bleed lines to be installed directly downstream of the regulator's outlet so the diaphragm will not be damaged in a monitor application.
- Planning the installation of the main valve of the regulators should be taken into consideration, as most sleeve type regulators will need to be removed from the line for maintenance, and the top-entry design of boot style regulators can be serviced inline.

Maintenance and Troubleshooting

Shutoff or lock-up tests are the typical way to do an operation test on a regulator in the field. Although this is the easiest method for testing, it does not provide much information on the state of the regulator and its components. A full teardown and visual inspection of the components is the best method for a full evaluation. The top entry design of the boot style and metal plug style regulator makes this procedure less time consuming compared to the sleeve type regulators.

Flexible Element regulators can offer trouble free operation provided there is adequate filtration and gas is relatively free from aromatics. There are some issues unique to flexible element regulators that do not typically affect the traditional types of regulators:

- Tube or boot erosion – this is typically caused by debris in the pipeline. Debris can be: iron oxide, sand, dirt and/or weld slag. Adequate filtration can prevent the majority of this damage. The metal plug design can help to alleviate some of these issues.
- Tube or diaphragm swelling – slugs of liquids can pass through a flexible element regulator and could cause swelling, hardening, or degradation of the tube or diaphragm. Depending on the model this could cause the regulator to fail open or closed. A change in regulator type or elastomer material could solve this issue. Note that a change in elastomer can affect the differential pressure requirements.
- Blistering of the tube or diaphragm – high pressure gas can cause permeation of gas molecules to become entrained in the elastomer. In certain conditions, this entrained gas can expand and inflate the tube or boot causing the regulator to fail in an undetermined state (open, closed, or partially open).
- Tube or diaphragm "set" – when a flexible element remains in a single position for a long period of time, it can deform slightly and take on that shape permanently. When the regulator attempts to force the diaphragm into the closed position, the new shape or set doesn't allow it to seal against the seat, hence lock-up is compromised. As previously mentioned, the metal plug design can help to alleviate some of these issues.
- Flexible Element chunking or tears – when differential pressures exceed the manufacturer's limitation, the rubber can tear or "chunk" due to excessive forces on the diaphragm. Diaphragms that experience large differential pressures for extended periods of time, can also wear out as they are seeing elevated forces continuously.
- Flexible Element burns or fabric failure – a regulator that sees high cycling or frequent oscillations can see fatigue damage to the tube or diaphragm due to the heat and excess movement. Adjusting the regulator tuning (restrictors) can help to reduce the amount of cycling.
- Hydrates and Freezing - can cause plugging of the restrictor and/or pilot orifice causing the regulator to fail either open, closed, or lock in an undetermined position. As previously mentioned, line heaters, pilot gas heaters or alcohol

injection can prevent these issues from occurring.

Conclusion

Flexible Element regulators are a major part of the natural gas distribution industry. They have many benefits that make them ideal for specific applications: low upfront cost, ease of maintenance, large flow capacities, accuracy, and flexibility. It is also important to recognize that, like all technologies, flexible element regulators do have their limitations and care must be given when selecting and choosing installations for the technology. Most flexible element regulators work well in services that are continuous duty and have large volumes of downstream piping such as distribution systems.