technical monograph 47

Primary Seat Shutoff

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Typical Valve Assembly
(Push–Down–to–Close)

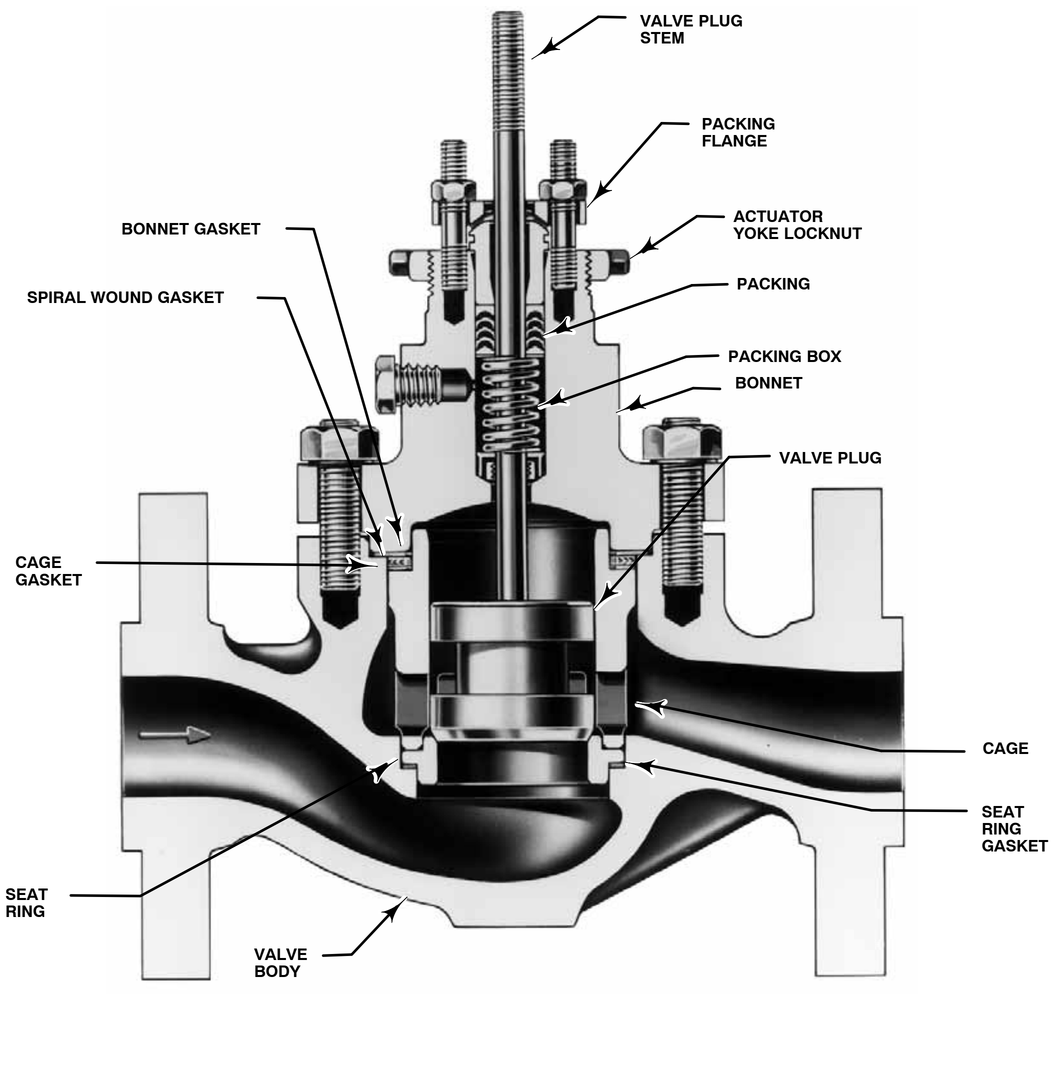

Figure 1. Major Components of Typical Control Valve Assembly

Table 1. Control Valve Leakage Class Matrix

Leakage Class	Maximum Seat Leakage	Test Procedure
Class I		None
Class II	0.5% of rated valve capacity	Type A
Class III	0.1% of rated valve capacity	Type A
Class IV	0.01% of rated valve capacity	Type A
Class V	5 x 10^{-4} ml per minute of water per inch of seat diameter per psi differential (5 x 10^{-12} m^3 per second of water per mm of seat diameter per bar differential)	Type B
Class VI	expressed in ml per minute versus seat diameter	Type C

Introduction

As the cost of energy continues to rise, so has the demand for improved factory and power plant efficiency. Plant efficiency can be directly impacted by the ability of a control valve to achieve and maintain tight shutoff. Control valve seat leakage performance is influenced by many factors such as actuator force, seat design, plug design, and material selection. Utilizing the best combinations of these factors will greatly increase the ability of a control valve to achieve and maintain tight shutoff when faced with the rising pressure and temperature conditions seen in most factories and power plants today. This paper will discuss these factors and recommend the best practices for tight, reliable shutoff.

Seat Leakage Basics

Allowable control valve leakage is governed by ANSI/FCI-70-2-1998, “Control Valve Seat Leakage.” Allowable seat leakage is broken into six classes. Each class represents a maximum leakage rate that the valve must pass upon factory inspection. A summary of these leakage classes is provided in table 1.[6]

There are three different test methods used to check the leakage performance of a control valve, all of which are performed at 50° to 125°F.

- Type A tests are performed on valves designed to meet leakage class II-IV. This test is done with clean air or water with a test pressure that is 45-60 psig or within 5% of the maximum operating differential pressure, whichever is less. The pressure is to be applied to the normal or specified body inlet and the actuator force must be adjusted to meet the service conditions that the valve was designed for. After obtaining leakage results, the leakage class for the valve can be determined from table 1.

- Type B tests are performed on valves designed to meet leakage class V. This test is done by filling the valve body with clean water while the plug is in the open position. After the body is full of clean water, the plug is stroked close and the specified maximum actuator force is applied. With pressure applied to the normal specified body inlet, the stabilized leakage can be measured over a period of time. This leakage rate is then used to determine if the valve has met the requirements for class V specification.

- Type C tests are performed on valves designed to meet leakage class VI. This test is done with clean air or nitrogen. The maximum rated differential pressure rating for the valve is applied to the normal or specified body inlet, and the outlet is connected to a measurement device. With the valve adjusted to meet the operating conditions specified, stabilized leakage measurements can be taken and related to the maximum allowable rates called out in table 1.[6]

Many different plug and seat ring geometries are used to achieve tight shutoff. These geometries range from a radiused plug contacting an angled surface on the seat ring to angle on angle contact. For high pressure drop applications, these designs typically use metal-to-metal seats. Metal-to-metal seats require high contact stresses to achieve tight shutoff, but they are almost always the best choice when searching for a long-life trim set.

As the leakage classes indicate, a certain amount of primary seat leakage is permissible. However, it must be realized that once a leak path has formed, high velocity jets produced from the fluid moving through the small leak path will eventually erode the path resulting in a larger path, eventually leading to higher leak rates. This effect is only magnified when the initial small leak path is subjected to more severe service conditions such as high pressures and high temperature steam combined with water and entrained erosive particles. A corrosive service condition can also lead to an increasing leak rate. It is important to realize that erosion and corrosion are two different factors that affect primary seat performance.

Figure 2. Typical Appearance of Cavitation Damage

Figure 3. Typical Appearance of Flashing Damage

Corrosion is caused by the chemical properties of the fluid. If improperly addressed, the chemical makeup of the fluid can greatly hinder the valve's ability to maintain tight shutoff.

Erosion can be produced in many different ways. Three of the most common causes of erosion are abrasive particles, cavitation and flashing. Entrained erosive particles can cause severe damage to the valve trim. The high velocity jets produced as the fluid moves through the trim can be erosive alone, but adding tiny solid particles to these jets greatly increases the severity of the condition. The entrained particles act much like a sandblasting machine. However, instead of stopping at the outermost surface, the particles often erode a path right through the affected region. The presence of these entrained erosive particles is becoming more common in today's daily start/stop power plants.

Cavitation is the formation and subsequent collapse of vapor bubbles produced when a liquid experiences pressure fluctuations near the liquid's vapor pressure. When the bubbles collapse, they produce damaging localized forces which affect the adjacent surfaces. Severe noise and vibration can also result from cavitation.

Flashing is much like cavitation; however, the bubbles do not collapse. Instead, they remain in the gaseous state until downstream pressure rises back above the liquid's vapor pressure. High velocity jets produced from flashing can cause damage to the trim. Special trim designs do exist to control or prevent cavitation and flashing. [7]

Actuator Force

The seat load resulting from the forces applied to the plug stem plays a significant role in reducing primary seat leakage. Seat load is usually expressed as pounds of force per linear inch of mean seat joint circumference. Recommended seat loads range between 20 and 1000 pounds per linear inch. Figure 4 shows the minimum required seat load for metal seated valves for improved seat life for Class II-V shutoff, and recommended seat load for optimum performance in boiler feedwater service.[5]

Trim sealing can be further improved by yielding the microscopic peaks and valleys of the materials, blocking direct leakage paths. The seat loads are initially applied only to the peaks of each surface, resulting in compressive stresses at these peaks. These stresses exceed the material's yield strength, resulting in plastic deformation at these peaks. As the peaks deform, the leak paths are eliminated and seating is improved.

It must be realized that seat load is not the only factor that can affect the actuator size required to actuate the valve. Packing friction, actuator friction, unbalance area effects, valve travel, flow direction, allowable stem force, and pressure drop all play important roles when determining the actuator size required for a given application.[3]

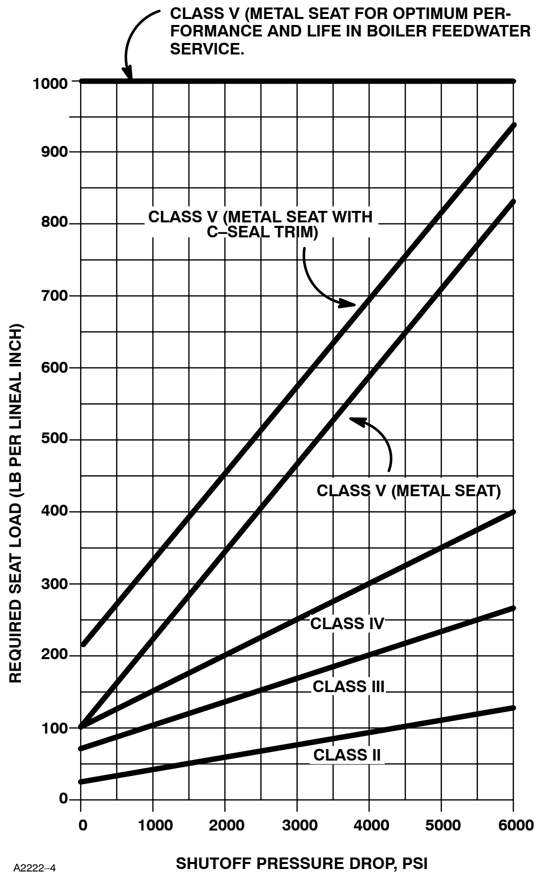

Figure 4. Minimum Required Seat Load for Metal Seated Valves.

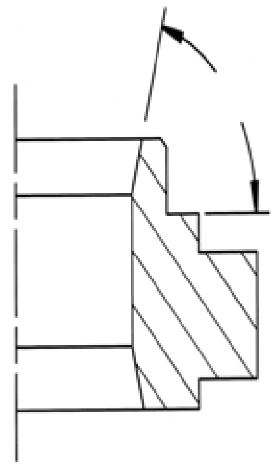

Figure 5. Seat Angle

Across the industry, many different seat angles and configurations have been utilized. In most cases, the seat angles range between 45° and 75° (shown in figure 5). Using a seat angle within this range will not only increase the valve's ability to shutoff, but can also help to remedy some of the effects of an imperfectly aligned trim set. Often times, the seating configuration will be devised of two similar angles on opposite surfaces, or an angle on one surface and a radiused edge on the other. Combinations like these provide for a single line of contact that has been proven to provide the tight seal required for good initial shutoff.

Seat Configuration

To achieve a tight seal, the plug must be perfectly aligned and then make full contact with the sealing surface of the seat ring as the actuator load is applied. If the plug strikes the seat slightly off center, it will likely remain off center until a high enough actuator force is supplied to make the plug shift into the full contact orientation. This shifting can damage the seating surface of both the plug and the seat ring resulting in poor shutoff. Both axial and concentric alignment is important to achieve tight shutoff across the primary seat.

Seat contact width also affects the level of leakage across the primary seat. A minimum width is essential for establishing a tight seal; however, it is important that enough material is left to insure part integrity when faced with the high compressive stresses seen at shutoff. Narrow seat joints have proven to seal tighter than wide seat joints provided they meet the minimum width requirements.[4]

Surface Finish

Past experiences with primary seat shutoff has led to the idea that the smoother the two contacting surfaces are, the better they will shutoff under any given actuator load condition. However, extensive polishing or "super-finishing" of the seating surface has been deemed unnecessary and the cost is often unjustifiable. This is due to the fact that as the "super-finished" surfaces move in and out of contact with each other in cyclic applications, wear particles tend to ball up on the seating surface, returning the surface to its pre super-finished state. It is also possible for fluid contaminants to be pressed between the two seating surfaces where they can leave indentations in the sealing joint.

Having a good finish on the seating surfaces is very important to achieving and maintaining good shutoff. For metal-to-metal seats, the higher the leakage class is, the more important it is to have a good finish on the contacting surfaces. For most trim designs, a surface finish of 32rms or better is usually smooth enough to reach the required leakage performance. However, any defects in the seating surface such as dings or scratches can greatly hinder the valve's ability to pass the leakage requirements.

There are many different methods of machining the desired surface finish onto the seating surfaces. Some of the most common are polishing, diamond burnishing, lathe turning, grinding, and lapping. The resulting finishes from each manufacturing method are usually very similar. So, in most cases, manufacturing cost considerations is usually the deciding factor on which method to use.

Depending on the roughness of the surface, the direction of surface finish lay can also affect the valve's shutoff capabilities. A concentric lay is often used to break up any radial leak paths that may form. The concentric lay of finish across a leak path helps to reduce leakage by changing the straight line leak path into a torturous path which is more resistant to leakage flow.(4)

Trim Materials

Selecting the proper trim materials is a vital role in achieving tight and reliable shutoff. There are many factors that need to be considered when selecting trim materials, all of which can be divided into two main categories:

1. The environmental compatibility category covers the material's ability to resist corrosion and other environmentally assisted means of material degradation.

2. Mechanical factors such as material strength, wear resistance, and other physical material characteristics are covered under the mechanical suitability category.

The environmental conditions that the trim will be in must certainly be considered during the material selection phase. Corrosion resistance is usually the biggest factor when considering the environmental conditions. All types of corrosion resistance must be considered.

The use of Alloy 6 in boiler feedwater applications is a good example of why corrosion resistance must be considered during the material selection phase. Alloy 6 is known for its excellent ability to resist wear and cavitation damage due to its mechanical properties; however, these mechanical properties are heavily impacted by the material's ability to resist corrosion. Alloy 6 gets its corrosion resistant capabilities from a stable, chromium- containing oxide passive outer layer. This outer layer protects the underlying material from the service environment. If certain chemicals are present, as is the case in many boiler feedwater applications, this outer layer can be weakened to the point where it is no longer able to protect the underlying material. The underlying material is then suspect to corrosive and erosive damage, resulting in poor primary seat shutoff. These synergistic effects of corrosion and erosion must always be considered during material selection.

The service temperature conditions can also heavily impact the material selection process. Extreme high or low temperatures can cause drastic changes in a material's mechanical and physical characteristics.

When deciding what material to make the valve plug from, several factors must be considered. The seating surface on the plug must be strong enough to handle the seat loads being applied to it when the plug is seated. It must also be able to withstand the erosive forces generated by the fluid moving through the other trim components, and from low-lift throttling. The seating surface is not the only portion of the plug that is of concern. In cage guided assemblies, the guiding surfaces of the plug must be able to resist galling and frictional wear due to contact with the inner cage surface. It must also be able to withstand the erosive conditions produced from clearance flow between the plug and cage.

The seat ring must be able to handle the compressive seat loads required for shutoff. This ability can be achieved through an optimized combination of seat ring material and geometry. The seat ring must also be able to endure the erosive conditions that are produced across the seat line at low-lift throttling. If the plug/stem assembly is port-guided rather than cage-guided, then resistance to galling must also be considered when choosing the seat ring material.

A soft seat design is often used when a class VI shutoff requirement is designated. A soft seat insert is usually composed of an elastomer such as Viton® fluoroelastomer or a plastic such as PTFE, and can be located either in the seat or on the plug. If process conditions permit, the use of a soft seat insert can be very beneficial to achieving tight shutoff.

The cage material must be able to withstand the various loading conditions produced in each method of cage retention. It must also be able to withstand the same erosive, frictional wear, and galling issues seen by the plug and seat ring. In addition to all of these parameters, the cage must be able to resist any vibrational forces that may exist, and must be able to handle the circumferential loads produced from the pressure differential resulting from the pressure drop being taken across the cage wall.(2)

Along with all of the previously mentioned material selection parameters, material hardness is also of importance. Hardness is defined as a material's ability to resist penetration, indentation, or scratching. A general impression exists that hardness is directly related to a material's ability to resist wear and from other damaging occurrences such as cavitation and flashing. This ability to resist wear, however, is based on many other factors than hardness alone. For example, the composition and crystalline structure of the material can have a bigger affect than hardness alone.

Weld deposited hardfacing is a very effective way to protect the trim parts from the service conditions surrounding them. Coatings and plating are other methods of protection, but are not as effective as hardfacing due to the fact that they are more susceptible to cracking and chipping. With a large selection of hardfacing and coating materials available, and various application techniques, there are a lot of different combinations that can be used to further protect a material or enhance its performance in a given service condition.

If the service conditions allow, alternative materials such as ceramics, composites, and plastics might also be capable of meeting the performance requirements of the valve.

When a list of suitable materials for each trim piece has been made, further investigation must be done on how each material will interact with each other. Improperly paired materials could result in severe galling, frictional wear, and other unwanted results between contacting surfaces.

More detailed information on methods for selecting valve trim materials can be found in the Materials chapter of ISA's book *Control Valves*, from the series Practical Guides for Measurement and Control.

Minimum Operating Point

A general rule of thumb applies to most control valves: Operating below 10% open is not recommended. Avoiding operation below a valve's suggested minimum point of operation can help protect against low-flow erosion. Operating above the minimum point ensures that the pressure drop will be taken across the trim and not across the primary sealing surfaces. If high pressure drops are taken across the primary sealing surfaces, the resulting high velocity jets can erode the sealing surfaces, leading to poor shutoff. Valves supplied with specialized trim, such as anti-cavitation trim, can be an exception to the 10% rule of thumb. Using a digital valve controller is a good approach to preventing low-flow erosion. [8]

The Fisher FIELDVUE® DVC product line offers a very effective product for controlling valve position and stability. With the ability to control the travel rate, set travel cutoffs and travel stops, apply characterized responses, perform calibration and diagnostic tests, and perform many other functions all through a user friendly digital interface, one can be assured that their valve will operate to the best of its ability.

Although the use of a DVC is recommended, it may not always be the solution to the problem. If the problem cannot be avoided through the use of a DVC, the use of erosion-corrosion resistant materials or coatings on the valve trim should be considered.

Summary

Understanding all of the factors that affect primary seat leakage is a key step to optimizing and maintaining the performance of your control valve. Allowable leakage rate is an important area of focus. Unlike Class V leakage tests, all other leakage performance testing is done with approximately 50 psig inlet pressure. Testing at actual service pressure drop conditions will help ensure that the valve will meet your expectations once brought into service. Understanding your shutoff needs is very important to valve selection.

With a properly selected valve, your focus can be moved to trim alignment and seating force. Near perfect alignment is necessary to achieve a good contact between the plug and seat ring. Attention must also be given to the applied seat load to ensure that the best possible shutoff is being obtained. To ensure that enough seat load is being applied, it is important that all parameters are considered during the actuator sizing process. An improperly sized actuator can greatly hinder a valve's ability to meet its leakage requirements.

Properly machined seating surfaces are also important to ensure good shutoff across the primary seat. A single line of contact, either achieved through the use of mismatched angles or by the use of an angle on one surface and a radius on the other, is usually the best method for sealing. Lapping of seats is a common practice in industry; however, lapping will not correct major flaws in the seating surfaces and should be used as finishing step only. Over-lapping may result in a wide seat line and poor shutoff.

With the previously mentioned factors as well as a properly selected trim design and appropriate material selections, shutoff performance should be satisfactory. Preventative maintenance and optimized control are additional ways to ensure that you will get the best possible performance from your control valve. By addressing every design parameter in the best way possible, a superior design can be produced to maximize the life and performance of the trim.

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