

technical monograph 38

Control Valve Packing Systems

- PTFE-Based and Graphite-Based to Meet Legislated Emission Limits
- Graphite-Based for High-Temperature and High-Pressure Sealing Applications

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FISHER-ROSEMOUNT™

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OVERVIEW

This monograph describes the technology and performance of valve stem packing systems developed by Fisher Controls for use:

- Where valve stem leakage must be minimized to meet environmental, health and/or safety standards; and/or
- Where the down-time and maintenance costs associated with valve packing must be reduced.

These packing systems use technology and packing elements that defy many of the valve packing methods that have been practiced by valve and packing manufacturers for decades. They employ some proprietary and/or patented packing materials, live loading, and unique packing arrangements that were developed by Fisher over a four-year program of research and development (R&D).

Each of these packing systems will maintain its low leak rate for orders of magnitude longer than other packing sets currently available for most similar applications. And for many applications, including those involving high temperature, high pressure, and frequent thermal cycles, it is anticipated that the new Fisher packing systems will have a service life consistent with the normal maintenance cycle of the plant. That is, they will not exceed their design leakage limitations and will require no maintenance over the time between scheduled maintenance turnarounds.

This prediction of service life is based on a series of performance tests that were executed under laboratory conditions to compare the new Fisher packing systems with other, currently available packing sets.

The new valve packing systems from Fisher are available in two product lines:

- ENVIRO-SEAL™ packing intended to keep fugitive emission concentrations below 500 ppm (consistent with U.S. Environmental Protection Agency limits).
- HIGH-SEAL™ packing intended for high temperature control valve applications, such as superheated steam in power generation facilities.

Within the ENVIRO-SEAL product line there are presently four packing systems. Each of these systems meets EPA leak requirements for an extended period, typically exceeding the normal maintenance cycle of the valve:

1. PTFE-based packing system for *sliding stem valves* operating at moderate temperatures and pressures.
2. PTFE-based packing system for *rotary valves* operating at moderate temperatures and pressures.
3. Flexible graphite-based packing system for *sliding stem valves* operating at higher temperatures or requiring a fire-safe packing material.
4. Flexible graphite-based packing system for *rotary valves* operating at higher temperatures or requiring a fire-safe packing material.

The HIGH-SEAL packing system is designed for extremely high temperature and high pressure applications where conventional valve packing would frequently survive for only a matter of weeks or less. This unique packing system uses flexible graphite packing plus several additional features and materials to provide exceptionally long service life in high-pressure superheated steam service and other difficult applications.

INTRODUCTION

Historical Performance Criteria

For decades, the criteria for designing, constructing and evaluating valve packing has been quite simple—strike a balance between leakage and friction.

Leakage past the valve stem is not only inefficient and wasteful, but leakage of flammable or toxic gases can threaten worker health and safety as well as plant security. Valve stem leakage can also damage the packing and the valve stem through erosion and/or corrosion, thus causing even more leakage.

“Tight” packing—tight enough to reduce leaks—can increase stem friction, making the valve difficult to operate, especially with high-friction graphite packing. High friction can also damage the packing and reduce its life. In the case of PTFE packing, over-tightening can cause the packing to extrude out of the packing area.

Because of these adverse effects of “tight” packing, valve stems have historically been allowed to leak just enough to keep stem friction and extrusion loss manageable but not enough to threaten health or safety. Basically, the packings have been designed to balance leakage and friction.

This balance, however, often results in enough stem leakage to contribute to air pollution and reduce packing life. In severe service applications, such as high temperature, high pressure, corrosive fluids, and/or frequent thermal cycles, conventional valve stem packing arrangements are particularly subject to high leak rates as well as short service life.

New Performance Criteria

Events of the late 1980’s changed both the criteria and the source of responsibility for valve packing systems.

First, the United States Environmental Protection Agency (EPA) recognized that fugitive emissions, including valve stem leaks, were a major source of air pollution. The far-reaching 1990 Clean Air Act through its supporting regulations result in severe limits on the stem leakage rates of valves in certain chemical service. In addition, many operating companies are highly concerned about leaks of toxic and lethal substances, such that they are implementing leak-prevention plans independent of regulatory requirements.

Second, electric power generating stations, in their continuing drive to improve energy efficiency, increased steam generation pressure and required

new valve constructions to handle this high-pressure superheated steam. While newly-developed control valves have successfully handled these high temperatures and pressure, conventional stem packing sets have not.

Some hand-operated valves may meet the new EPA limits in some circumstances. In a hand-operated valve, excessive packing friction can be overcome by using a bigger lever. In addition, operation of hand valves is usually infrequent, so they are less sensitive to the friction-caused packing damage that occurs each time the valve is stroked.

Control valves, however, are often less successful at meeting the new requirements—especially in severe service applications involving high temperatures, high pressure, frequent thermal cycling, and/or frequent stem movement. Because of their frequent stem movement and the need to keep stem friction low, packing design for control valves presents a more difficult sealing challenge.

Newly-packed control valves usually can meet low-leak requirements. But after continual operation—even under moderate service conditions—the packing can soon leak and require tightening. After re-tightening several times, the packing can be tightened no more and has to be replaced.

For valves in severe service applications, such as high-pressure superheated steam, packing maintenance is often required weekly or even daily. There have been instances where valve packing in such service doesn’t even last long enough to be re-tightened; it has literally blown out of the packing box after a few weeks—or even days—of operation, causing an unscheduled shut-down of the power plant.

Fisher R&D Program

The challenge issued by new control valve applications and environmental regulations was clear; provide stem seal systems that last.

Valve users confronted with valve stem leakage problems typically ask packing suppliers for help, not their valve suppliers—an approach which often focuses primarily on finding the correct packing material. However, the Fisher packing R&D program demonstrated that selecting the correct packing material is only the first step in designing a low-leak, long life packing system.

In 1987, Fisher began a development and testing program on valve stem packing for high pressure superheated steam service. This program was initially directed at developing packing to solve problems experienced by the electric utility industry with control valves in high pressure, high temperature superheated

steam service. The program later expanded to include developing valve packing systems for more moderate service conditions and systems designed to meet EPA leak standards.

Using the traditional approach to solving valve packing problems, the team first tested various types of packing material in various amounts and in various arrangements. This approach failed to provide a packing system that would stand up to severe service conditions.

These failures also demonstrated to the R&D team that much of the conventional wisdom about valve stem packing was not suitable for severe service applications. Although conventional packing was often satisfactory for moderate temperatures and pressures, it could neither prevent leakage nor even maintain its physical integrity when subjected to high temperature and pressure. Under such severe conditions the packing is frequently damaged, and the high pressure can even expel the packing from the valve.

Similar shortcomings in existing packing technology surfaced when the R&D team explored less severe service conditions. While conventional packing technology could usually meet the strict EPA limits for stem leakage when initially installed, it often failed to meet those requirements over an extended period of valve operation.

So the R&D team went back to basic packing principles. Combining basic research with empirical studies, they confirmed and quantified the basic design principles for valve packing.

These design principles are:

- **Subject the packing to a constant and correct amount of stress to effect a seal.** This is best accomplished using live-load springs.
- **Use no more packing than the minimum required to effect a seal.** This minimizes the adverse effects of thermal expansion of the packing and reduces packing friction.
- **Install less-pliable anti-extrusion rings on either side of the packing.** This prevents the packing from extruding out of the packing area.
- **Install stem bushings or other type of stem guide.** This keeps the stem aligned within the packing set.
- **Use a smooth, polished valve stem.** This reduces packing friction and erosion and minimizes the occurrence of leak paths.

Applying these principles, the Fisher R&D team developed and tested a host of different types and arrangements of packing elements as part of a complete packing system.⁽¹⁾

While the valve packing principles are universally applicable to packing systems utilizing either graphite or PTFE materials, it is important to note that the relative importance of each valve packing principle, and the packing system elements required to implement it, depend on the valve design and its service conditions.

The application of these principles by Fisher engineers resulted in packing systems that have demonstrated reduced leakage, less stem friction, and superior life in both sliding stem and rotary valves in all types of service.

VALVE PACKING PRINCIPLES

Creating Packing Stress

Stationary loading

To create a stem seal, the resilient packing material inserted between the stem and the bonnet must be stressed so that it deforms to fill the voids. Axial load applied by pushing against the packing with a follower creates stress in the packing which is transmitted into radial deformation, creating a seal between the packing and the stem. The greater the stress, the stronger the sealing force between packing and stem.

The conventional way to push the follower into the packing is with studs and nuts threaded into the bonnet. Since the follower remains stationary, the valve stem seal relies entirely on the resilience of the packing itself to establish and control stress in the packing. If the packing loses some of its volume by compression, filling void spaces, or loss of material from erosion or extrusion, the stationary follower still does not move. Stress in the packing will drop precipitously and the packing will no longer deform to create a seal. The only remedy is to re-tighten the nuts to move the follower and re-establish stress in the packing.

A stationary follower also cannot accurately nor reliably produce the correct packing stress. Insufficient stress will result in a weak seal; too much stress will result in high stem friction and/or excessive loss of packing by extrusion or wear.

Live loading

A spring between the follower and its fastening studs and nuts provides a simple and effective way to

1. As an integral part of the packing R&D program, Union Carbide Corporation, manufacturer of Grafoil™ expanded graphite, and Argo Packing Co., fabricator of packing elements, provided technical assistance and test materials. The packing systems developed by Fisher contain elements from these two suppliers.

establish and maintain a controlled amount of stress in packing. The magnitude of the packing stress in this "live load" system can then be controlled by the type of spring used and how far the spring is compressed.

In a live-load packing system, the follower will continue to push against the packing even when packing volume is lost (by friction, extrusion, loss of entrapped air, etc.). This spring force will be slightly reduced from its original value as the spring expands slightly. However, the reduction in spring force will be too small to degrade the packing seal if the spring is properly selected for the type of valve and packing system.

Live loading also reduces the adverse effects of thermal cycling on packing extrusion, as detailed in the section on thermal cycling, consolidation and anti-extrusion rings.

Because of the operating stability of the packing components, live loading systems in Fisher ENVIROSEAL and HIGH-SEAL packing systems will rarely, if ever, require adjusting or re-tightening.

Fisher HIGH-SEAL and ENVIRO-SEAL packing systems use Belleville springs to apply stress to the packing. A Belleville spring is a formed metal washer with its I.D. pushed higher than its O.D. These compact disc springs can provide the high loads needed for live-loaded packing. Incorporated into the packing follower, they are sized and arranged specifically for each packing system. It is essential that the right number, and the right size, of Belleville washers be used for each packing system, and used in the correct arrangement, in order to provide the correct load. The correct load for each type of packing system was determined experimentally.

Several types of Belleville spring configurations are used in the Fisher valve packing systems. For example, a single stack of springs, as shown in Figure 1a, is frequently used because of its economy, simplicity, and compactness. For valves that do not have enough space on top of the stem for the correct size and number of Belleville washers, a spring pack consisting of multiple, shorter stacks of smaller Belleville washers can be installed between the packing studs, as in Figure 1b. Two large Belleville springs, as in Figure 1c, are used in high temperature applications to provide high packing stress with generous spring travel and load indication.

Live load springs are usually manufactured from 17-7 stainless steel, which is similar in corrosion resistance to 304 stainless steel. However, this type of alloy steel may not provide sufficient corrosion resistance for some plant environments. Corroded washers lose their strength, and corrosion products (e.g. rust) can constrict spring movement. Therefore, Inconel 718 is

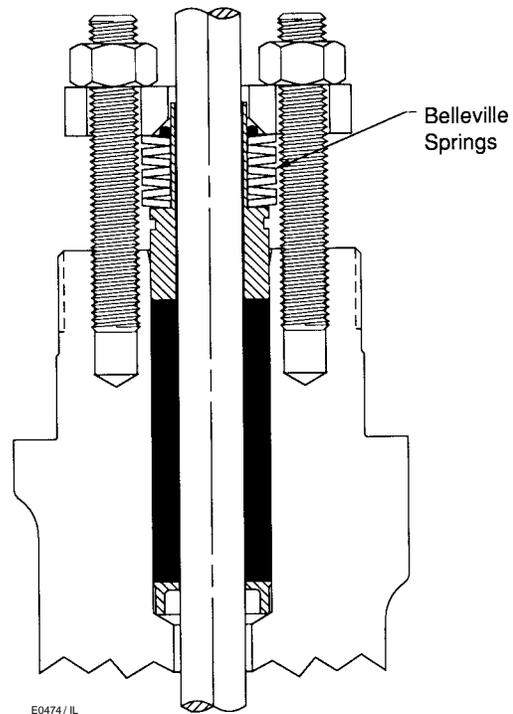


Figure 1a. Live-Loading Can Be Achieved Using a Single Stack of Springs



Figure 1b. Multiple Stacks of Springs Are Used in Limited Space Applications

the standard material for all ENVIROSEAL live load washers, and is an option for HIGH-SEAL packing systems.

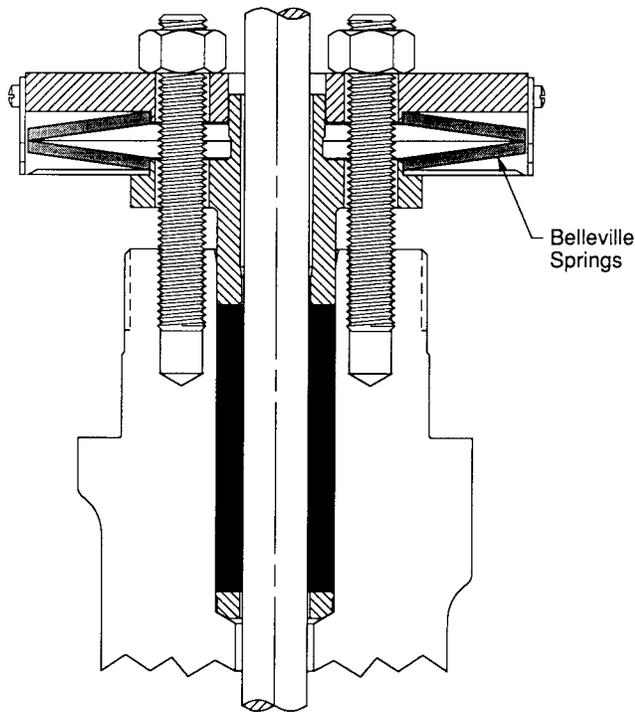


Figure 1c. Two Large Springs Provide Loading in High Temperature Situations

In most Fisher live-load packing systems, the springs are correctly compressed at 85% of their full travel. Some use an indicator to show the mechanic how far to compress them; others require that the mechanic compress them to a torque specified in the installation instructions. To help ensure that they are assembled correctly when packing systems are installed, replaced or adjusted, the Belleville springs in Fisher ENVIRO-SEAL valve packing systems are pre-assembled as a spring pack.

Live load controversy

Some controversy has surrounded the use of live loaded valve packing. Some studies have reported that live loading actually reduces packing life while not contributing to improved sealing.

Indeed, there are two problems with live loading which, if not solved in the design of the packing system, can be counter productive to packing service life and sealing efficiency.

First: In the absence of a correctly designed and applied anti-extrusion system, packing that is constantly stressed will continuously lose material by extrusion. Eventually, there will be no packing left to form a seal.

Live loading will not cause rapid extrusion loss of packing material and shorten packing service life if:

- Used in conjunction with the correct anti-extrusion system, and
- The force applied is correct, considering type of packing, type of valve, and type of anti-extrusion system.

For example, performance tests on graphite packing sets that contain braided-filament graphite show that the filament often breaks down and extrudes when subjected to the high live load required for many severe service applications.

Second: A high live load can cause stem alignment problems unless the packing system includes stem-alignment bushings installed near the packing.

Essentially, the use of live loading has appeared to many practitioners to be a "Catch-22". That is, using a live load to apply a low stress to the packing produced a seal that was little better than using no live load at all; the packing would leak. Yet, using live load to apply a high stress resulted in low packing life; the packing would soon leak.

But in spite of these potential difficulties surrounding the use of a live load, not using a live load will necessarily result in reduced packing stress (and increased leakage) if even a small amount packing volume is lost.

For example, packing typically loses at least 0.020 inches of its height in the early portion of its service life. If the packing were compressed with a static load, this loss in height is more than sufficient to relax the packing and all-but-eliminate the sealing force.

If the valve application is not severe (i.e. moderate pressure and temperature, no thermal cycles, in high-viscosity lubricating fluid service) the seal formed by low-stressed packing may even meet EPA leak standards. But when the packing must maintain low leak rates under severe process conditions, live loading is essential to maintaining the correct stress in the packing.

The case for using a "live load" is simple; a metal spring external to the packing is a better way to control and maintain the force on the packing than relying entirely on the resiliency of the packing itself.

How Much Packing

Understanding where sealing occurs

The quality and position of the seal that is formed between the packing and the sliding valve stem depends on:

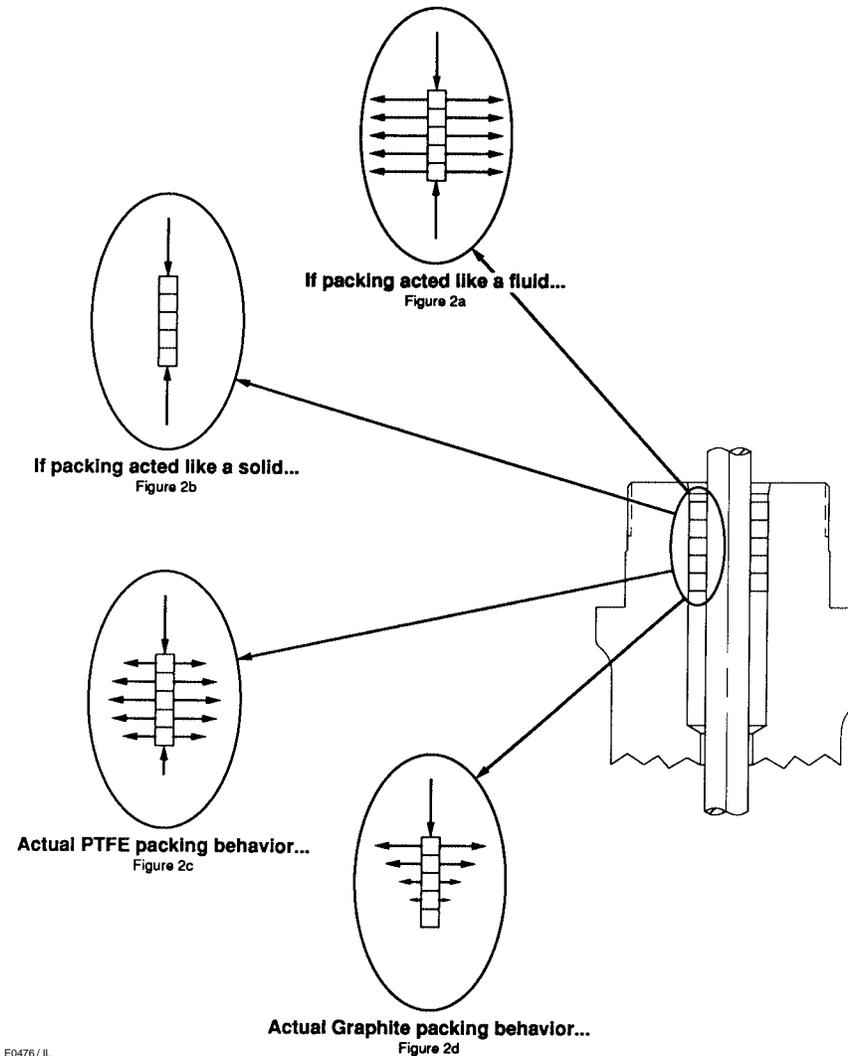


Figure 2. The Effect of Axial Pressure on a Packing Set

- The ability of the packing to deform,
- The compression load placed on the packing, and
- The friction between the packing and the stem.

(Note: The static seal between packing and bonnet is seldom an issue in packing design. If the packing deforms sufficiently to seal the moving stem, it will seal the stationary bonnet.)

If the packing acted like a fluid, then axial pressure exerted by the follower would be transmitted as a uniform radial pressure, and the seal between stem and packing would be uniform. (Figure 2a)

If the packing were a solid such as steel, little or none of the axial pressure would be transmitted as radial pressure. The packing would not deform radially and thus would not form a seal. (Figure 2b)

Actual packing materials undergo plastic deformation when stressed. Being neither true fluids nor true solids, they convert the axial load into a non-uniform radial load. Under ideal conditions, the maximum radial stress—and thus the maximum radial deformation and the location of the maximum seal between stem and packing—will occur near the middle of the packing set. (Figure 2c) This is exactly what occurs in tests with PTFE packing.

Tests with graphite packing, however, show that the maximum radial packing stress (and maximum seal) occurs not near the middle of the packing but closer to the packing follower. (Figure 2d) This is because the high friction between the graphite packing and the valve stem and bonnet produces an upward axial force that counters the downward force from the follower. So for die-molded flexible graphite packing, the further away it is from the follower, the less axial stress will be

transmitted to it; the less axial stress, the less radial stress.

(The position of maximum stress of PTFE packing is not affected by stem friction because PTFE has a very low coefficient of friction.)

With graphite packing, stem friction reduces the axial stress exerted by the follower so significantly that a long section of graphite packing can support a several thousand psi stress in the packing, create a high sealing force between stem and packing, and yet need no bottom support. Friction alone is sufficient to support the packing. (Of course, this example is presented only to illustrate the magnitude of friction in graphite packing. It is not recommended that packing not have a bottom support.)

Quantity of packing used

Since radial deformation of packing is not uniform along the stem, the seal between stem and packing occurs only at the location of maximum radial deformation. The use of a long section of packing does not add to the sealing force or the area of the seal. In fact, the use of a longer section of packing than required can be counter-productive in three ways—extrusion loss, consolidation, and friction.

Increased consolidation

A packing set consists of a stack of ring-shaped elements fitted over the valve stem. There is air trapped between the rings when the packing is first installed. As the packing is stressed, the air is compressed. However, this compressed air is soon forced out of the packing system. In the case of flat, highly-stressed graphite packing rings, the air leaves almost immediately. With typical V-shaped PTFE packing rings, which usually require less stress than graphite packing, several hours are required for the air to leave. As the air leaves, the effective volume of the packing decreases—e.g. the packing “consolidates.”

If the follower is stationary (as when there is no live load), this reduction in packing volume reduces packing stress, thus reducing radial deformation and reducing the sealing force. If the follower is live-loaded, consolidation will cause only a small reduction in packing stress so long as the consolidation does not exceed the travel of the live load springs.

Consolidation can be minimized by using:

- The least number of packing rings required to effect a seal, and
- A packing ring design that minimizes voids.

Increased friction (applicable to graphite, not PTFE packing)

The greater the area of contact between packing and stem, the greater the stem friction. This increased friction occurs with no improvement in the sealing force of the packing. In the case of graphite packing, stem friction is already high. Adding friction to the system can require the use of a larger actuator and may result in slow stem movement and poor control.

(Note: with PTFE packing, stem friction is very low, so additional friction caused by excess packing is usually insignificant.)

Thermal cycling (applicable to PTFE, not graphite packing)

Although PTFE is a highly versatile and effective packing material, it has two major deficiencies:

- Its coefficient of thermal expansion is ten times (10X) greater than steel, and
- It tends to flow when stressed.

As a result, thermal cycling (heating and cooling) is a major cause of packing loss and the resultant leakage and short service life of PTFE packing.

When PTFE packing gets hot, it tries to expand beyond its allotted space. This expansion increases stress in the packing, causing the PTFE to try to flow (extrude) past any retaining rings and out of the packing area. The greater the amount of PTFE packing, the greater the force of the expansion, making it more difficult to retain the PTFE in the packing area.

To the extent that packing is lost by extrusion, packing stress will be reduced. When the temperature drops to ambient, the remaining packing will contract to less than its original volume, further reducing stress, reducing deformation, and reducing the sealing force. Conventional PTFE packing sets commonly lose their ability to seal at ambient temperature after a single temperature cycle.

Live load springs can alleviate some of the adverse effects of thermal cycling. They can compress to allow the packing to expand as it gets hot, thus abating some of the stress increase. They can also expand to help retain stress in the packing, even after some packing volume is lost by extrusion. However, multiple thermal cycles (sometimes as few as two or three) can cause enough packing material to be lost by extrusion such that no amount of stress applied by the follower will seal the stem.

(Note: loss of packing from thermal cycling is not an issue with graphite packing since the coefficient of

thermal expansion of graphite is very close to that of steel.)

Packing Retention

Packing can be lost two ways—wear and extrusion.

Wear, (or erosion) is caused by friction. It is generally a concern with graphite packing, but not with PTFE packing.

Extrusion loss will occur with any material that deforms under load. PTFE packing is especially susceptible to extrusion loss because of its tendency to “cold flow”. PTFE can extrude out of a packing box and past the follower even at low stress.

Although a live load can moderate stress reductions caused by packing loss, this loss of packing material through extrusion can continue to occur if the packing is continually stressed. Eventually most of the packing can extrude out of the packing area, and it will have to be replaced.

One way to counter the tendency of packing to extrude is to reduce the stress on the packing, thus reducing the sealing force. (Although unstressed packing will not extrude, neither will it seal.) The better way to prevent packing loss is to retain it with properly selected anti-extrusion elements (or rings) positioned on either side of the packing.

The anti-extrusion ring must be less pliable than the packing so that it transfers the load from the follower to the packing, yet it must be pliable enough so that it forms a seal to contain the packing material. It need not be pliable enough to seal the process fluid; it need only seal the packing.

The anti-extrusion ring must fit the shaft closely to prevent packing from extruding between it and the shaft. Yet, it must not scratch the shaft when it is installed nor can it be so tight that it clings to the shaft. By clinging to the shaft, it will add friction to the packing system and prevent the force imposed by the follower from reaching the packing.

The anti-extrusion ring must also maintain its physical integrity at whatever stress is required for the packing. For graphite packing arrangements, this requirement often precludes the use of braided-filament graphite as an anti-extrusion element. The fiber in braided-filament graphite can fracture at the high stress required for graphite packing to deform sufficiently to effect a seal. Also, since the braided-filament graphite is more pliable than the graphite packing rings, it will not transfer the load efficiently.

Depending on the magnitude of the load applied by the follower and the type of packing materials, the anti-extrusion ring may itself need to be retained by an additional ring of even less pliable material.

Stem Alignment

Valve stems and shafts can have a tendency for radial movement. The control element (ball, plug, etc.) in a rotary valve applies bending stress to the valve shaft, and any valve can have bending stem stress imposed by imperfect alignment of the actuator. Also, a high force applied to the packing with a follower can tend to move the stem out of center.

Sealing a stem that moves radially places additional burdens on the packing system. It requires that the packing be stressed more than otherwise required so that it can deform to fill the additional gap created when the shaft moves radially.

A close-fitting stem follower can serve as a stem-alignment bushing so long as it does not grab or score the stem. If the stem temperature is within the operating limits for PTFE, a PTFE-lined follower can serve as a very effective stem bushing. When the temperature is too high for PTFE (as is usually the case when graphite stem packing is used), hard non-deformable bushings should be added to the packing system. Bushings consisting of carbon rings work well since they can withstand the high compression stress required for graphite packing, will not scratch the stem, and are essentially non-deformable.

Stem Finish

A smooth, polished stem reduces packing erosion and friction and enhances the effectiveness of anti-extrusion rings with any stem packing arrangement in any type of valve. All Fisher sliding stem valves have stems polished to a 4 Ra finish or better.

APPLYING PRINCIPLES: GRAPHITE SYSTEMS FOR SLIDING STEM VALVES

Graphite Packing Material

Graphite packing was originally developed and marketed for its superior sealing abilities compared to asbestos. Although less forgiving than asbestos, its superior performance plus the abolition of asbestos by

Density Versus Stress for Die Formed Flexible Graphite

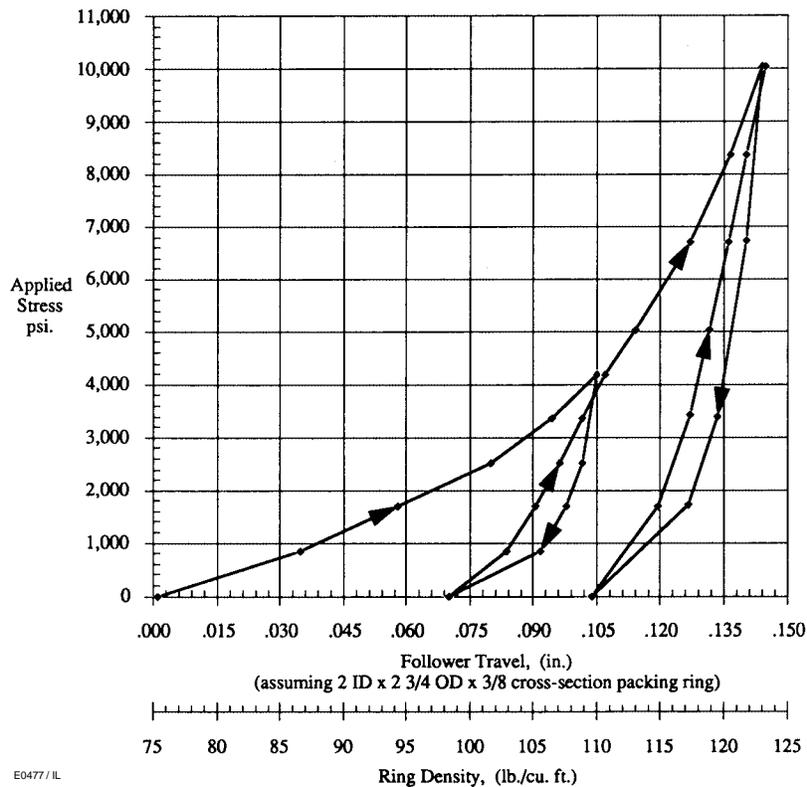


Figure 3. Effect of Compression Stress on Density of Die-Formed Flexible Graphite Rings

most packing users and manufacturers, has resulted in expanded graphite becoming the packing material of choice for high temperature and fire-safe applications.

Other attributes of graphite packing include:

- It reacts only with very strong oxidizers, so it can be used with most process fluids.
- It is thermally stable over a wide range of hot and cold temperatures.
- It will deform under stress to effect a seal, and the magnitude of that deformation is independent of temperature.
- Its coefficient of thermal expansion is very close to that of steel, so it will not tend to extrude out of the packing area as a result of thermal cycling.
- It is fire-safe—an important attribute for refineries and many chemical plants.
- It has no binders to decompose upon exposure to chemicals or high temperatures

Graphite also has some properties which, if not considered in the design of the packing system, could make this outstanding material unacceptable as a packing.

- It can tend to stick to the valve stem, resulting in high friction and wear.
- Having no binders, it can be fragile and sensitive to rough handling during storage, transportation and installation.

Most graphite packing rings are produced by die-forming expanded graphite. In this process a prescribed length of graphite ribbon is wound onto a mandrel and then compressed in a die to produce a ring of the desired density. The stress used to form the ring is generally less than the stress required to effect a seal with the valve stem. Therefore, the final densification of the graphite ring occurs in the valve itself.

Figure 3 shows how the density of die-formed flexible graphite rings increases with compression stress. It is noteworthy that the rings exhibit some resiliency, since they expand slightly as the compression stress is relieved.

When a graphite ring is installed in a valve packing box and then stressed with the follower, it is compressed just as it would be in the die in which it was formed. That is, the packing box itself serves as a die to compress the packing. An often asked question is, "What is the correct density for die-molded flexible graphite packing rings?" The answer is simply that almost any density is acceptable since the ring will be compressed to the same stress regardless of its initial density.

However, the initial density will effect the distance the follower will have to travel to obtain the correct packing stress. Therefore, die-molded flexible graphite packing rings should be formed to a high enough density to keep the required follower travel within reasonable limits. Generally, die-formed flexible graphite packing rings should have a density of about 90-100 lb/cu ft.

Graphite Packing Systems

ENVIRO-SEAL and HIGH-SEAL graphite packing systems utilize identical technologies and use similar components. The only difference is that the ENVIRO-SEAL packing system incorporates a small amount of PTFE into its packing set to allow it to meet the exceptionally low leak rates required by the EPA. Of course, each of the packing systems must also have the correct live loading to achieve the required stress level for the specific application.

HIGH-SEAL (high temperature) packing

The challenge

The high temperature packing development program at Fisher was launched in 1987 to solve packing problems in a particular valve controlling high-pressure superheated steam. The control valve was a 20", sliding stem globe design with a 2" diameter stem and a 9-1/2" stroke. The valve design was intended to control the flow of 800°F steam at 4,000 psi.

These specially designed valves were themselves highly successful. But because of packing deficiencies, extra maintenance was required to keep the valves in service.

The original high temperature packing in these valves consisted of the five-ring arrangement shown in Figure 4. This was common industry practice for such high temperature, high pressure applications.

Under moderate conditions of temperature and pressure, this packing arrangement was satisfactory. But under severe conditions of temperature and pressure, the conventional five-ring packing arrangement would not reliably last more than a month.

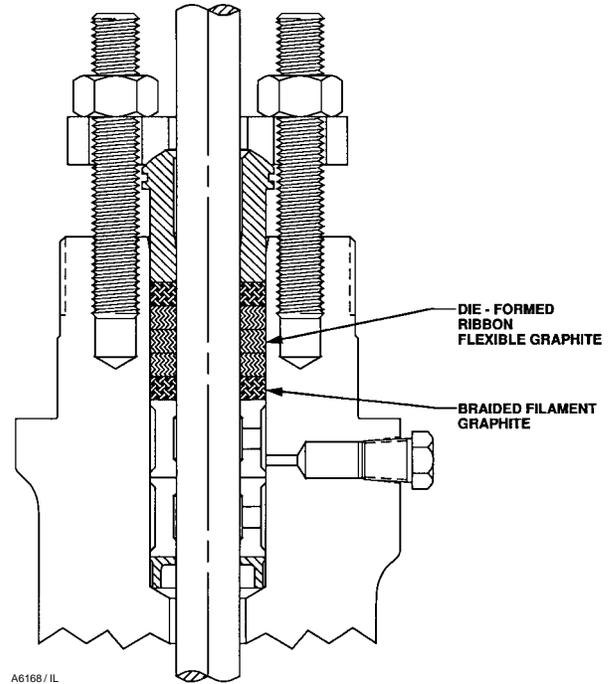


Figure 4. Typical Five-Ring Graphite Packing Arrangement Using Braided Filament Graphite

When the Fisher packing R&D team studied the conventional graphite packing arrangement used in the steam valve, it became apparent that the short service life was caused not by the flexible graphite packing material, but by the inadequacy of the other components in the packing set.

Flexible graphite packing requires a very high minimum stress (about 2500 psi) to deform the graphite enough to fill voids around the stem and packing bore and effect a seal. Even more stress (up to 4,000 psi or greater) is required to overcome internal friction and seal against high process pressure. (The exact stress required for each packing system was determined experimentally.)

In the conventional graphite packing set, (Figure 4) the flexible graphite packing is retained on each side with braided-filament graphite. Under moderate conditions of temperature and pressure, this packing set may be satisfactory. But deficiencies of the braided-filament graphite can cause this packing to fail when subjected to the severe conditions that are often encountered by a graphite-packed valve.

The braided-filament graphite surrounding the packing is intended to prevent the flexible graphite from extruding under load. However, it can fail to do so, and actually can be counter-productive for several reasons:

1. Braided-filament graphite breaks down under stress. As packing stress approaches 4,000 psi, filament breakdown becomes a serious problem.

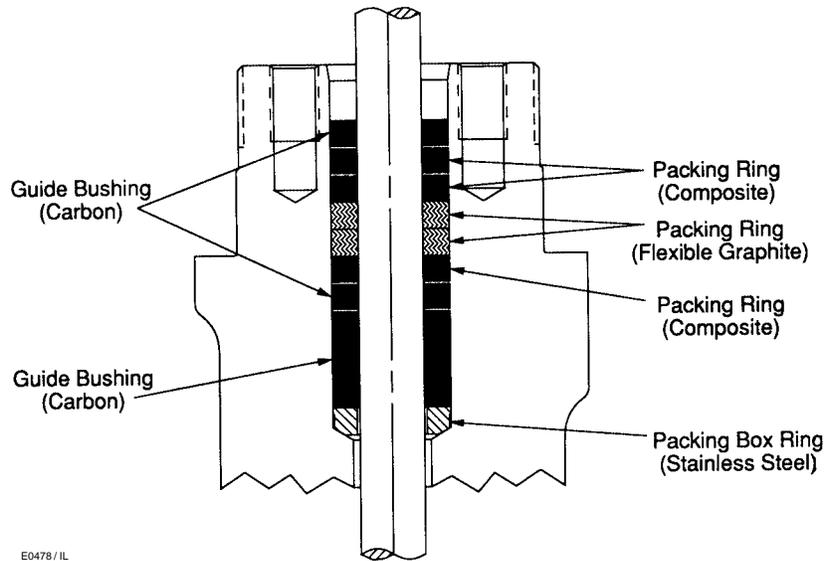


Figure 5. Components of the HIGH-SEAL Graphite-Based Packing System

2. The binders that are necessary to fabricate braided filament graphite can be incompatible with high process temperatures and can speed degradation of the braid.

3. Braided-filament graphite is more pliable than flexible graphite, so it will deform, squeeze against the stem, and increase stem friction. This increased friction prevents all the applied load from reaching the flexible graphite packing rings, thus further increasing the amount of applied load needed to deform the flexible graphite and effect a seal. This higher load further increases stem friction and the stress in the braided filament graphite.

All these deficiencies of braided-filament graphite indicate that a better packing retaining system is required for long life and low leak rates in severe service applications.

Packing components

The Fisher packing R&D program tested dozens of packing materials and packing arrangements and evaluated the technology and products available from packing suppliers. The resultant HIGH-SEAL and ENVIRO-SEAL packing systems use graphite composite technology developed and patented by Union Carbide Corporation.

Performance tests demonstrated that an anti-extrusion ring fabricated from a flexible graphite/amorphous carbon composite would be highly effective at retaining the die-molded flexible graphite packing. The tests also indicated that these composite anti-extrusion rings, although less pliable than the packing, should themselves be retained by harder-still carbon bushings. The composite rings confine the flexible

graphite, while the harder carbon bushings confine the composite rings and serve as a stem guide. (Figure 5) This packing arrangement of graduated deformability is essential to high-performance valve stem packing systems. Figure 6 illustrates the deformability of several components used in conventional and HIGH-SEAL graphite packing.

The carbon bushings serve several functions:

1. They confine the inner materials (flexible graphite and composite) to further prevent material loss by extrusion.
2. They wipe the stem free of any graphite particles. This keeps particles of flexible graphite contained in packing area, prevents contamination from the outside, and keeps the stem free of irregularities that could become new leak paths.
3. They serve as a stem guide.

In graphite packing systems, the stem guide function is extremely important. The high loading required to effect a seal with graphite packing will tend to drive a stem off-center unless it is guided. Although PTFE based ENVIRO-SEAL packing systems use a PTFE-lined follower as the stem guide, graphite packing systems are designed for use at temperatures beyond the limits of PTFE. Thus, carbon bushings are used.

The carbon bushing has a coefficient of thermal expansion similar to that of the metal valve stem, so it will neither grab the shaft nor loosen as the valve heats and cools. In some cases, the carbon bushing may crack when subjected to high stress of the packing system. However, since the bushings are under high compression stress, any cracks will not

Force Versus Deflection For Various Packing Materials

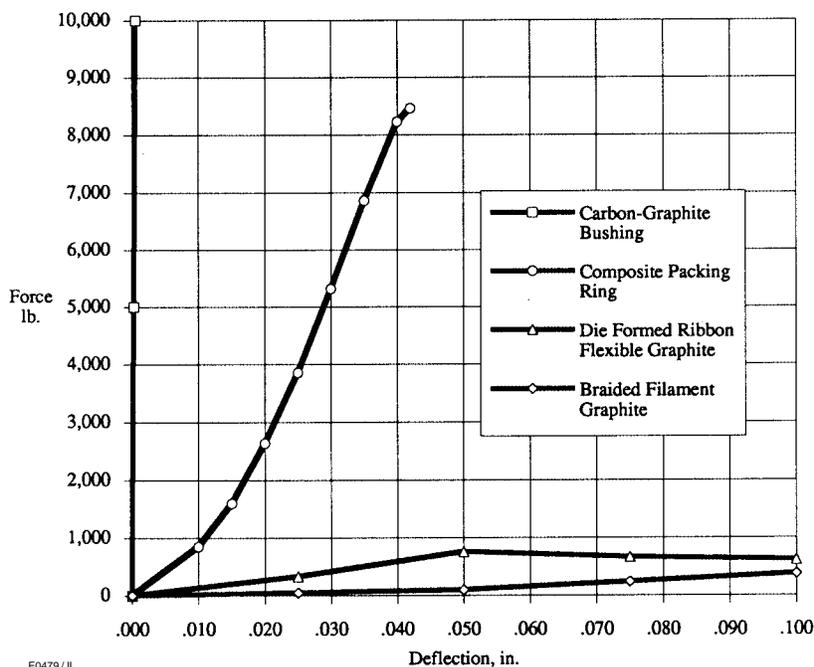


Figure 6. Deformity of Various Graphite-Based Packing Materials

compromise their integrity or their ability to perform their required functions. Of course, if a packing set is replaced, any cracked bushings must also be replaced.

The friction of a graphite packing system can be quite high, requiring large actuators. But the valve packing just described produces substantially lower and more consistent stem friction than a conventional graphite packing system with its multiple graphite rings and braided-filament graphite. Figure 7 illustrates the relative friction of this packing system compared to conventional graphite packing arrangements.

The packing system also has an exceptionally long life, as indicated in Figure 8.

Live load springs

For most applications, HIGH-SEAL and ENVIRO-SEAL graphite packing systems use the Belleville spring arrangement shown in Figure 1a. This arrangement is compact and economical and shares spring type (but not necessarily the same number or arrangement of springs) with other Fisher valve packing systems. However, where extremely high operating temperature and pressure require high packing stress, the high-force spring system shown in Figure 1c is used.

Stem corrosion

Under certain conditions, graphite packing can promote galvanic corrosion of the metal valve parts it contacts. Corrosion of the stem can reduce its smoothness and make the packing less effective by creating leak paths and increasing friction and packing wear.

Galvanic corrosion requires the presence of water, and the corrosion rate is a function of temperature, contact area and metal surface condition. In most applications that use graphite packing, the valve stem and packing area will be hot enough to drive off any water, thus preventing galvanic corrosion.

Galvanic corrosion is most likely to occur during storage of a packed valve, especially in humid regions such as the Gulf Coast. Galvanic corrosion during storage can be reduced by incorporating a sacrificial material or a passivating inhibitor into the packing materials. The best policy is to remove graphite packing when a valve will be in storage for a long period of time.

ENVIRO-SEAL and HIGH-SEAL packing sets use both methods to prevent galvanic corrosion during storage. The graphite packing itself contains inorganic passivating inhibitors, and sacrificial zinc wafers are placed between each graphite packing element. (The

Friction Comparison of Graphite Packings, 3/4 Inch Stem with Live Load

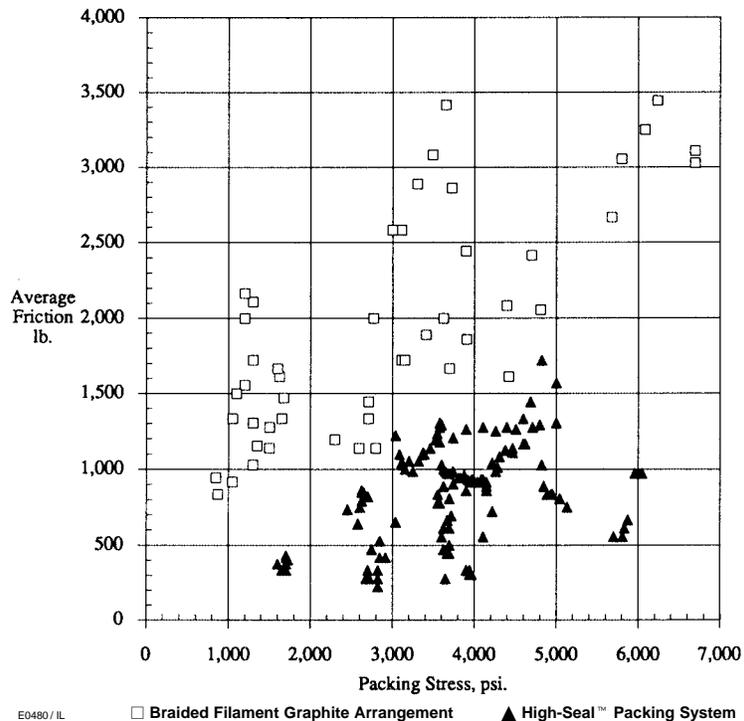


Figure 7. Comparison of Friction Encountered with HIGH-SEAL Packing System Versus Conventional Graphite Packing Arrangements

wafers have a large annular clearance so that they will not scratch the valve stem.)

ENVIRO-SEAL (graphite-based for high temperatures) Packing

The challenge

The HIGH-SEAL graphite packing system described above is designed to have a long service life and a low leak rate in high-pressure superheated steam service and other severe duty applications. Although its leak rate is substantially lower than the leak rate of other packing arrangements in severe-service steam applications, in some applications the leak rate may not always meet EPA standards for hazardous materials.

Packing components

The HIGH-SEAL packing system has been modified by incorporating a small amount of PTFE into the packing materials for applications that:

1. Need the high-temperature performance and/or fire-safety of graphite packing material, and
2. Must also meet EPA requirements for stem leakage,

With this modification the graphite packing system consistently meets the EPA 500 ppm emission concentration limit and thus earns the ENVIRO-SEAL trademark. As with HIGH-SEAL packing systems, the service life of the ENVIRO-SEAL graphite packing system far exceeds that of other high-temperature packing designs.

The mechanisms of how the PTFE further reduces leakage of the HIGH-SEAL graphite packing system are not specifically known. However, experience with packing suggests the following:

- First, when subjected to the high stress of graphite packing, (and usually high process temperatures as well) the PTFE will flow into microscopic channels in the stem and seal these leak paths.
- Second, the lubricity of PTFE will help maintain a smooth packing- to-stem interface and will prevent

Test Conditions: 800°F. & 4,000 psi. - Nitrogen

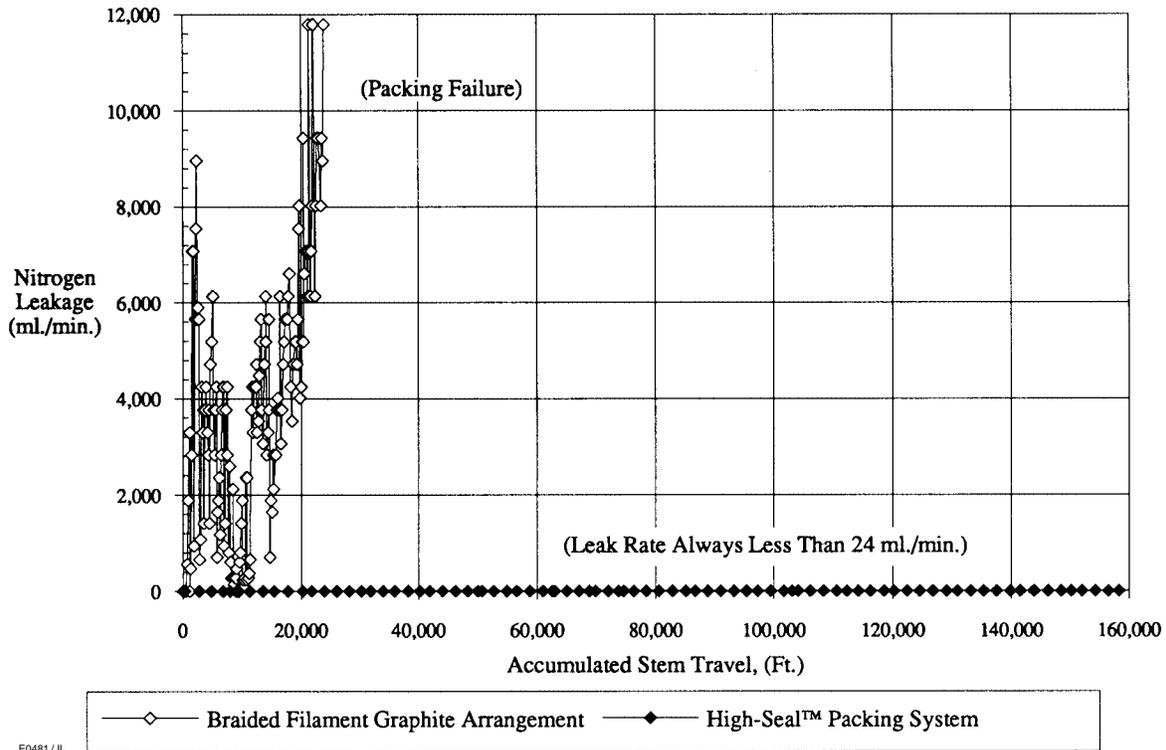


Figure 8. Comparison of Leak Rates Experienced with HIGH-SEAL Packing System Versus a Conventional Graphite Packing Arrangement

leak channels from developing as a result of packing and/or stem wear.

- Third, the PTFE helps keep the graphite from sticking to the stem, further reducing material loss and maintaining a smooth packing- to-stem interface. Indeed, it has been observed that after thousands of strokes, the valve stem in a graphite-based ENVIRO-SEAL packing system remains extremely smooth with no evidence of any transfer of graphite to the stem.

In the present design of graphite ENVIRO-SEAL packing systems, thin PTFE wafers are inserted between the elements in the packing set. Constituting only about 2.3% of the volume of the packing set, the PTFE allows the graphite packing system to consistently meet the EPA 500 ppm leak standards. So long as the operating temperature is below the thermal decomposition temperature of PTFE (about 650°-700°F), the PTFE will supplement the sealing provided by the graphite packing. Figure 9 shows the effect of temperature on the decomposition rate of PTFE.

The thermal decomposition temperature of PTFE is well above the temperature at which PTFE loses its mechanical properties. Thus, the maximum operating

temperature for packing system using PTFE sealing elements is well below this decomposition temperature.

Other methods for incorporating PTFE would likely also be effective. However, the graphite packing system into which it is incorporated must itself meet all the required criteria for low leakage and long life. Lab tests demonstrate that PTFE can enhance performance, but not correct deficiencies, of a graphite packing system.

Packing lubrication

Conventional lubricants, whether added to packing before installation or during operation, can also reduce friction and reduce the leak rate of graphite packing. However, their effect is highly variable. To be effective, a lubricant must be compatible with the process fluid, must not attract dirt and other abrasives, and must remain stable at high process temperatures. Conventional packing lubricants rarely met these criteria, and they often leave abrasive residues from thermal decomposition.

Conventional packing lubricants also have to be renewed periodically. But forcing lubricants into a packing set that is already stressed to several thousand psi can be counterproductive to the purpose of the packing — to effect a near - impermeable seal

Decomposition Rate of PTFE at Elevated Temperature

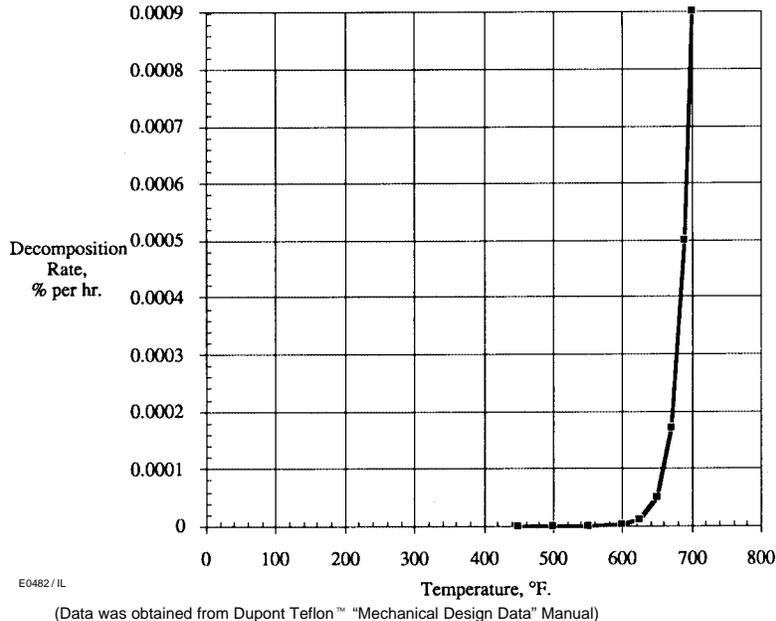


Figure 9. Effect of Temperature on Decomposition Rate of PTFE

between all the components in the packing area. Forcing lubricant into stressed packing may cause a leak path.

The performance of graphite ENVIRO-SEAL packing systems compared to conventional systems based on graphite-filament arrangements is shown in Figure 10.

Summary—Design and Installation Criteria, Graphite-Based Systems

1. Stress the flexible graphite packing ring(s) forming the seal to at least 2,000-3,000 psi or process pressure, whichever is greater.
2. Use a live-load spring on the follower to provide correct and constant stress in the packing.
3. Use a minimum number of graphite packing rings to effect the seal. (Tests indicate that optimum performance is provided with two packing rings.)
4. Surround the packing with a less-pliable composite material to minimize loss of the packing material by extrusion and wear and to wipe the stem.
5. Select the packing and the material surrounding it so it will withstand the high axial loads required to deform the packing.
6. Use non-deformable carbon bushings to guide the stem and serve as additional anti-extrusion ring for the composite rings.
7. Polish the stem to a smooth finish (4 Ra), and protect it against galvanic corrosion during both valve storage and operation.

APPLYING PRINCIPLES: PTFE SYSTEMS FOR SLIDING STEM VALVES

Preventing Extrusion Problems

The typical PTFE packing set in common use has five rings of PTFE. This is much more packing than is required to produce a high sealing force between stem and packing. The excess packing does not contribute to improved sealing, yet it increases the tendency to lose packing by extrusion.

Because of its high thermal expansion (10X that of steel), PTFE will extrude out of the packing area when its temperature increases. The effect of thermal cycling on PTFE is shown by Test #1.

In contrast to the five-ring packing arrangement, PTFE-based ENVIRO-SEAL packing systems use no more than three packing rings, and as little as one PTFE component in a packing set to minimize extrusion loss due to thermal cycling. As discussed in the Principles section above, this use of less packing does not affect the quality of the seal between stem and packing.

Graphite Packing Comparison

Enviro-Seal™ versus Live Loaded Filament Arrangement at 70°F.

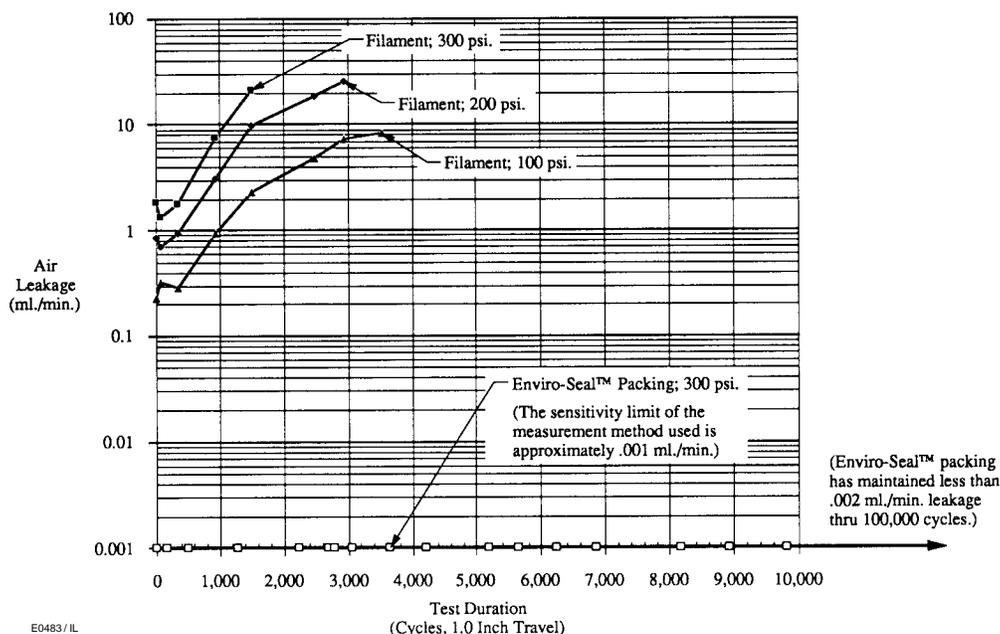


Figure 10. Comparison of Performance Given by ENVIRO-SEAL Packing System Versus Convention Live-Loaded Graphite-Filament Arrangements

Preventing Consolidation Problems

Some types of PTFE packing rings consolidate more than others. That is, some have more air or void space between them than others. This means that, after the packing is stressed, it will “relax” as the air diffuses out and packing volume reduces or “consolidates”. It usually takes up to 1 to 2 hours for most of the air trapped in the packing to escape.

One commonly used configuration of V-shaped PTFE packing ring is purposely designed so that the male and female V shapes do not exactly match when fitted together. This mis-match allows the rings to spread and form a seal under very light stress levels; it also causes an excessive amount of air to be trapped between the rings, resulting in significant consolidation. This packing is commonly used in a set of five rings. There is so much void volume between these rings that the packing set loses approximately 20- 30% of the recommended applied load within only 1 hour after the load is applied.

The V-shaped packing rings selected for ENVIRO-SEAL PTFE packing systems are shaped to match very closely, thus minimizing voids and the resultant consolidation.

Preventing Packing Loss with Anti-Extrusion Rings

Even when a minimum number of packing rings are used, it is essential that anti-extrusion rings be used to retain the packing within the packing area. Performance tests using dozens of anti-extrusion methods demonstrated that a two-component, anti-extrusion ring system would be highly effective at confining the PTFE packing.

Component #1 consists of anti-extrusion rings made of carbon-filled PTFE installed on both sides of the PTFE packing to confine the packing and wipe the stem of any material picked up from the environment or from the packing. The anti-extrusion rings are PTFE based and will not scratch the stem.

TEST 1:

The packing in this test consisted of two sets of PTFE packing rings, each containing five packing rings, with the two sets separated by a lantern ring. (This packing arrangement is commonly used on many types of valves.) The packing was stressed with a torque of 100 in.-lb on the packing flange studs. The follower torque was not re-adjusted during the tests.

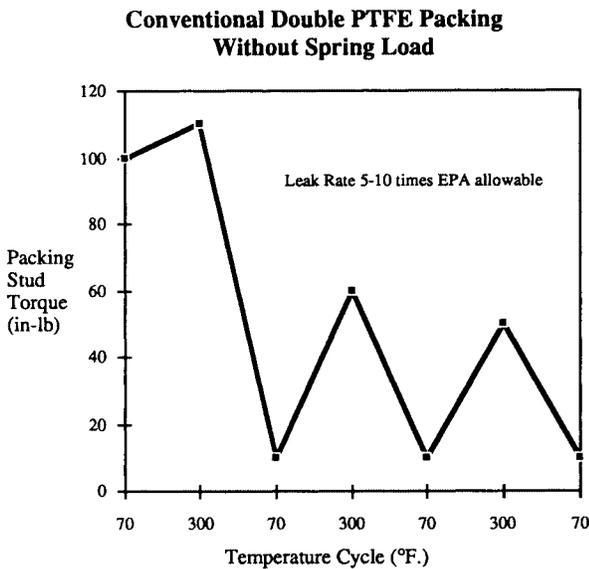


Figure 11. Effect of Temperature Cycles on Packing Stress

The effect of temperature cycles on the packing stress, as measured by follower torque, is shown in Table 1. (Figure 11 provides a visual depiction of the results shown in Table 1.)

As the table and figure show, packing load (measured by torque) increased as the PTFE tried to expand when heated. However, the higher load caused packing material to extrude out of the packing area, such that when the temperature dropped to ambient, the reduced packing volume caused the packing load to drop to near zero. As a result, the packing leaked. Each subsequent time the packing temperature was increased, the packing load increased, but not to as high a level as in the previous temperature cycle, again demonstrating the loss of packing material.

After a few thermal cycles, enough packing material was lost so that even the thermal expansion would not increase the load enough to prevent leaking. The packing material that extruded out of the packing area was clearly visible when the system was taken apart for inspection.

Table 1. Effect of temperature cycles on packing stress

Temperature Cycle No.	0	1	1	2	2	3	3
Temperature (°F)	70	300	70	300	70	300	70
Torque (in.-lb)	100	110	10 ⁽¹⁾	60 ⁽¹⁾	10 ⁽¹⁾	50 ⁽¹⁾	10 ⁽¹⁾

1. Leak rate 5 - 10 times EPA allowable.

The PTFE content of the anti-extrusion rings can extrude slightly, albeit much less than the unfilled PTFE packing rings. Component #2 consists of close-fitting, anti-extrusion composite washers added to the outside of the packing set to further contain the carbon-filled PTFE anti-extrusion rings. The resulting packing system is shown in Figure 12, which depicts a typical double packing set with lantern ring.

The PTFE-based ENVIRO-SEAL packing system works equally well with either a single or a double set of packing. Some users require a double set, and most sliding stem valves have sufficient space to accommodate them. Fisher has standardized on the double set for PTFE-based ENVIRO-SEAL packing systems for sliding stem valves.

As with graphite-based packing systems, PTFE-based ENVIRO-SEAL packing systems use a highly polished stem to reduce packing wear and increase the

effectiveness of anti-extrusion rings. All stems in Fisher valves are polished to an 4 Ra finish or better.

Live Loading

As with the graphite-based packing systems, live loading is essential to maintain low leakage rates with PTFE-based ENVIRO-SEAL packing. Live loading also reduces stress increases caused by increased temperatures. The live load springs for PTFE packing are designed to be compressed to only about 85% of their full travel. This allows the PTFE packing to expand thermally without causing severely increased stress.

Stem Alignment

Because the operating temperature of the valve is necessarily within the limits of PTFE, a packing follower lined with PTFE provides an excellent bushing for assuring that the stem stays aligned.

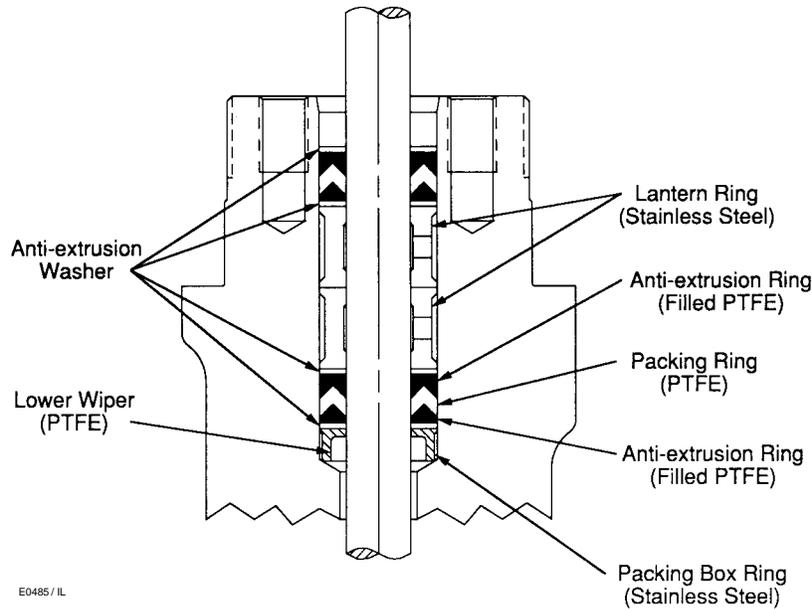


Figure 12. Components of the ENVIRO-SEAL PTFE-Based Packing System (Double Set) for Sliding Stem Valves

Summary—Performance of PTFE-Based ENVIRO-SEAL System

PTFE-based ENVIRO-SEAL packing systems virtually eliminate extrusion and thermal cycling problems that otherwise plague PTFE packing because they:

- Provide a live load (e.g. with springs) to maintain a relatively constant load on the packing,
- Minimize the amount of PTFE packing used,
- Employ special anti-extrusion rings to contain the PTFE material within the packing area,
- Keep the stem aligned with a PTFE-lined follower, and
- Use a polished valve stem.

The final form of each packing system — type, number and arrangement of packing and retaining rings, plus the type of live loading — is empirical. That is, although the final forms are based on the packing principles developed and demonstrated by the Fisher packing R&D program, they are ultimately based on testing. They are subject to change as new materials and new concepts are developed and tested. However, the present final forms meet the three major objectives of the program:

1. low leakage (well within EPA limits)
2. low maintenance, and

3. a service life orders of magnitude longer than other packing systems currently available.

All ENVIRO-SEAL packing systems meet EPA leak limitations even while the valve stem is stroking.

APPLYING PRINCIPLES: PTFE SYSTEMS FOR ROTARY VALVES

The basic principles of sealing a rotary shaft are the same as sealing a sliding stem:

- Use a live load (e.g. springs) to maintain stress on the packing.
- Minimize the amount of packing material.
- Prevent packing extrusion and loss by containing it with hard anti-extrusion rings.
- Keep the shaft aligned with bushings.
- Use a smooth, polished shaft.

Convention teaches that a rotary valve is easier to seal than a sliding stem valve because:

1. Rotary valves have less packing-to-shaft travel distance for each stroke of the valve, thus decreasing loss of packing material due to friction.
2. Dust and other abrasives are not “pulled in” from the environment as the shaft slides in and out of the packing, so the sealing surface between shaft and packing stays cleaner.

TEST 2:

Test 2 demonstrates the performance of the PTFE-based ENVIRO-SEAL packing system for sliding stem valves.

The ENVIRO-SEAL packing system consisted of two identical packing sets separated by a lantern ring and loaded to 1,500 psi stress with Belleville springs. Each set contained one low-consolidation V-shaped PTFE packing ring, retained by a carbon-filled adaptor ring on each side, and further retained by a composite washer on each side of the carbon-filled PTFE. (illustrated in Figure 12)

The valve was pressurized to 300 psi with air and mechanically stroked at a rate of 3-4 strokes per minute during the entire test. The valve was first subjected to three thermal cycles. (heated to 350 degrees, held at that temperature for 2 hours, and then cooled to ambient temperature). The valve then

continued to be mechanically stroked for the indicated number of cycles.

The live load springs maintained their load and torque throughout the 750,000 cycles, indicating virtually no loss of packing material through extrusion, erosion or wear.

Table 2. Effect of thermal cycles on ENVIRO-SEAL packing

ENVIRO-SEAL Packing	Leak Rate	
	Initial, before thermal cycle	Undetectable
After first thermal cycle	.05 ml/min	18 ppm ⁽²⁾
After second thermal cycle	.02 ml/min	6 ppm
After third thermal cycle	Undetectable	2 ppm
Total mechanical strokes ⁽¹⁾	750,000	

1. The leak rate varied throughout the test but was always well below the EPA limit of 500 ppm.
2. Concentration measurements were taken with a Bacharach TLV Sniffer following Method 21.

However, when attempting to meet EPA leak limits rotary valve packing is extremely difficult to retain in the packing area. Laboratory performance tests with a standard PTFE packing set (no live-load) showed that, operating at 4-5 cycles per minute, the packing had to be adjusted (tightened) daily for the packing to continue to meet EPA leak limits. After only 21,000 cycles, about 50% of the packing had extruded out of the packing area.

This short service life of conventional rotary valve shaft packing can be attributed to radial shaft deflection, lack of proper containment of the packing material, and lack of constant stress on the packing.

Due to forces on the closure element (i.e. ball, plug or disc) from process pressure and fluid momentum, radial shaft deflection in a rotary valve can be much greater, and much less constant, than in a sliding stem valve. As the shaft moves radially, the packing has to deform more to continue sealing. This radial movement can make sealing the shaft much more difficult and can only be tolerated if the packing is highly stressed so that it deforms to follow the shaft deflection.

Because of this high packing stress requirement, plus the additional high localized stress caused by radial shaft deflection, preventing packing extrusion loss is more difficult for rotary valves than for sliding stem valves.

Preventing Extrusion Problems

The Rotary ENVIRO-SEAL development program tested ten different types of anti-extrusion rings, including carbon-filled PTFE, various types of graphite, high-strength polymers, and even steel. As with sliding stem valves, a two-component anti-extrusion ring system was found to be highly effective.

Performance tests demonstrated that long service life and low-leakage rate in a rotary valve packing system can be achieved with a packing set consisting of:

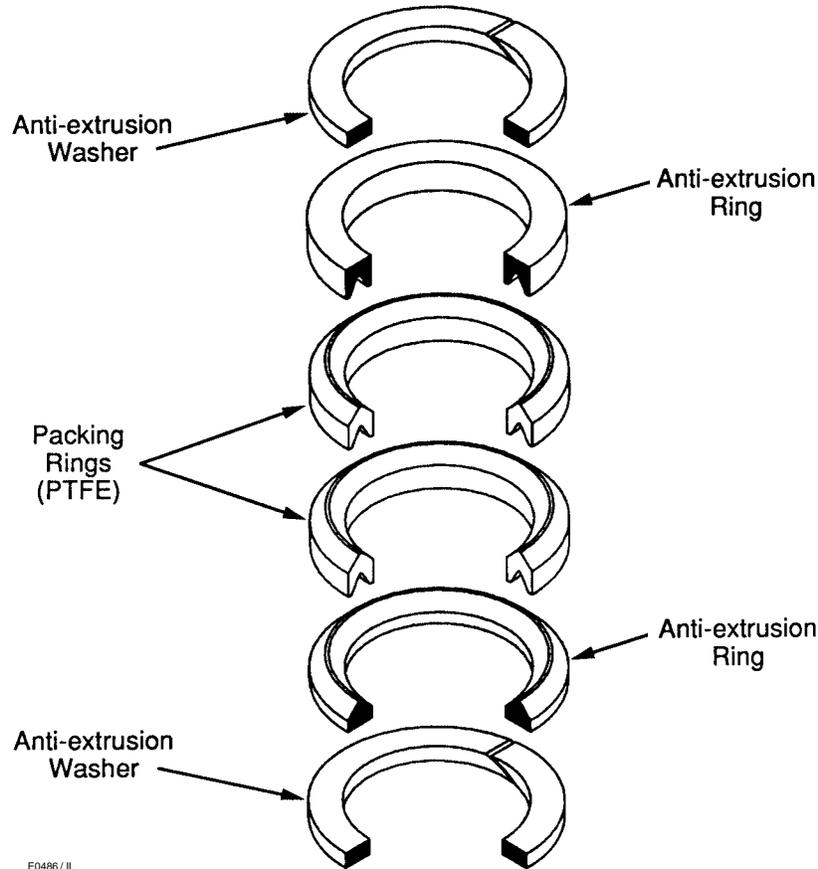
1. Two V-shaped PTFE packing rings, contained by
2. Two carbon-filled PTFE anti-extrusion rings,
3. Further contained with two scarf-cut, zero-clearance anti-extrusion washers made of a high-strength polymer.

This arrangement is illustrated in Figure 13.

The scarf-cut in the high-strength polymer anti-extrusion ring allows there to be zero clearance between the ring and the valve shaft. The scarf cut also serves two other purposes:

1. It opens to allow the zero-clearance ring to be slipped over the shaft.
2. It prevents the zero-clearance ring from grabbing the shaft. (If it grabbed the shaft it would increase the axial friction in the packing set and reduce transmission of the live load to the PTFE packing.)

The high-strength polymer used for the scarf-cut ring is hard enough that it will not extrude, yet it will not score



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Figure 13. Components of the ENVIRO-SEAL PTFE-Based Packing System for Rotary Valves

the valve shaft. PTFE cannot extrude between the anti-extrusion ring and the shaft because there is no clearance; it cannot extrude into the space between the scarf cuts because this gap closes when the packing is stressed.

Live-Loading for PTFE Rotary Valve Packing

The live load spring arrangement used for rotary ENVIRO-SEAL packing systems is depicted in Figure 1a. This is the same type of live load arrangement used in most other ENVIRO-SEAL packing systems.

Double Packing Option

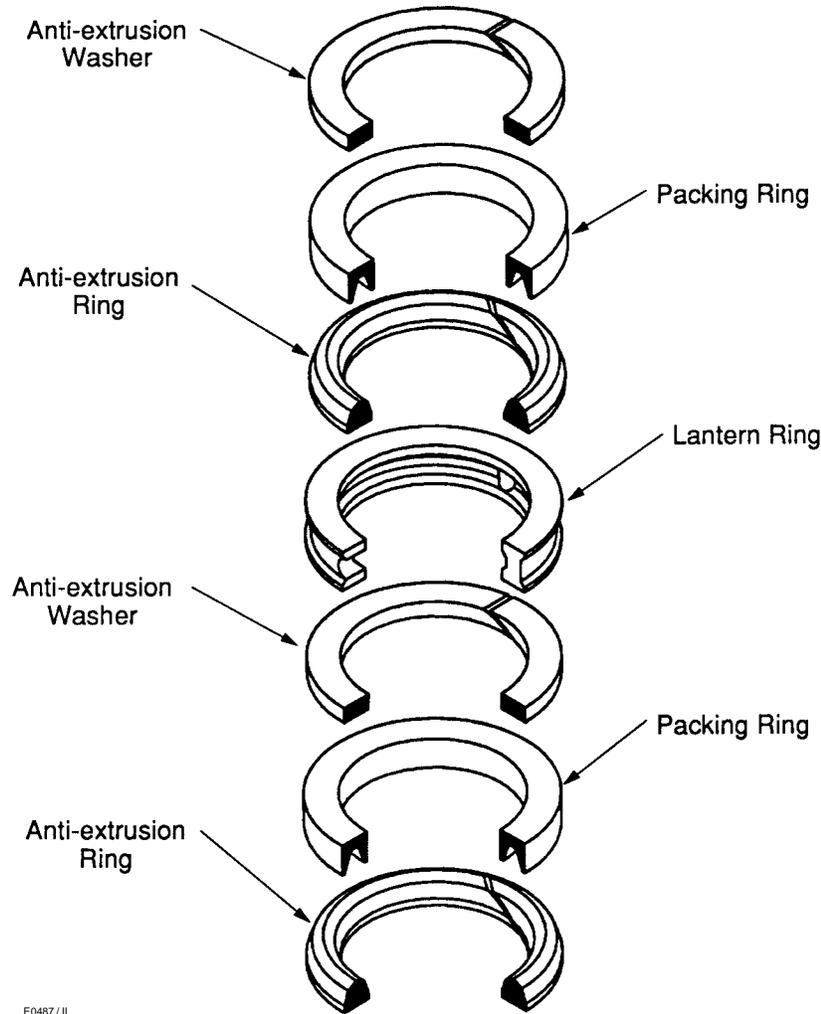
A rotary valve ENVIRO-SEAL packing system is also available for users who prefer two packing sets separated by a lantern ring.

Packing box depth is limited in most rotary valve designs. So in order to fit into the packing box, each packing set in a double packing system must have fewer elements than the single-set packing system.

The arrangement of each packing set in the double system is shown in Figure 14 and consists of a single carbon-filled PTFE adaptor serving as the packing ring retained by two scarf-cut high-strength polymer anti-extrusion rings. The carbon-filled PTFE, if sufficiently stressed, can deform enough to produce a good seal.

APPLYING PRINCIPLES: GRAPHITE SYSTEMS FOR ROTARY VALVES

The principles for PTFE-based systems also apply to graphite packing systems for rotary valves. However, with the high inherent friction of graphite packing, rotary valve packing systems using graphite must be designed, and the packing material specified, to minimize packing damage due to graphite adhering to the metal rotating shaft. This adhesion occurs because of the high force between the two materials, and similar to galling, it causes two serious problems. First, small graphite particles will adhere to the shaft and create a very rough surface that erodes the packing. Second, the adhesion can rip off large sections of the packing, which makes it mechanically unstable.



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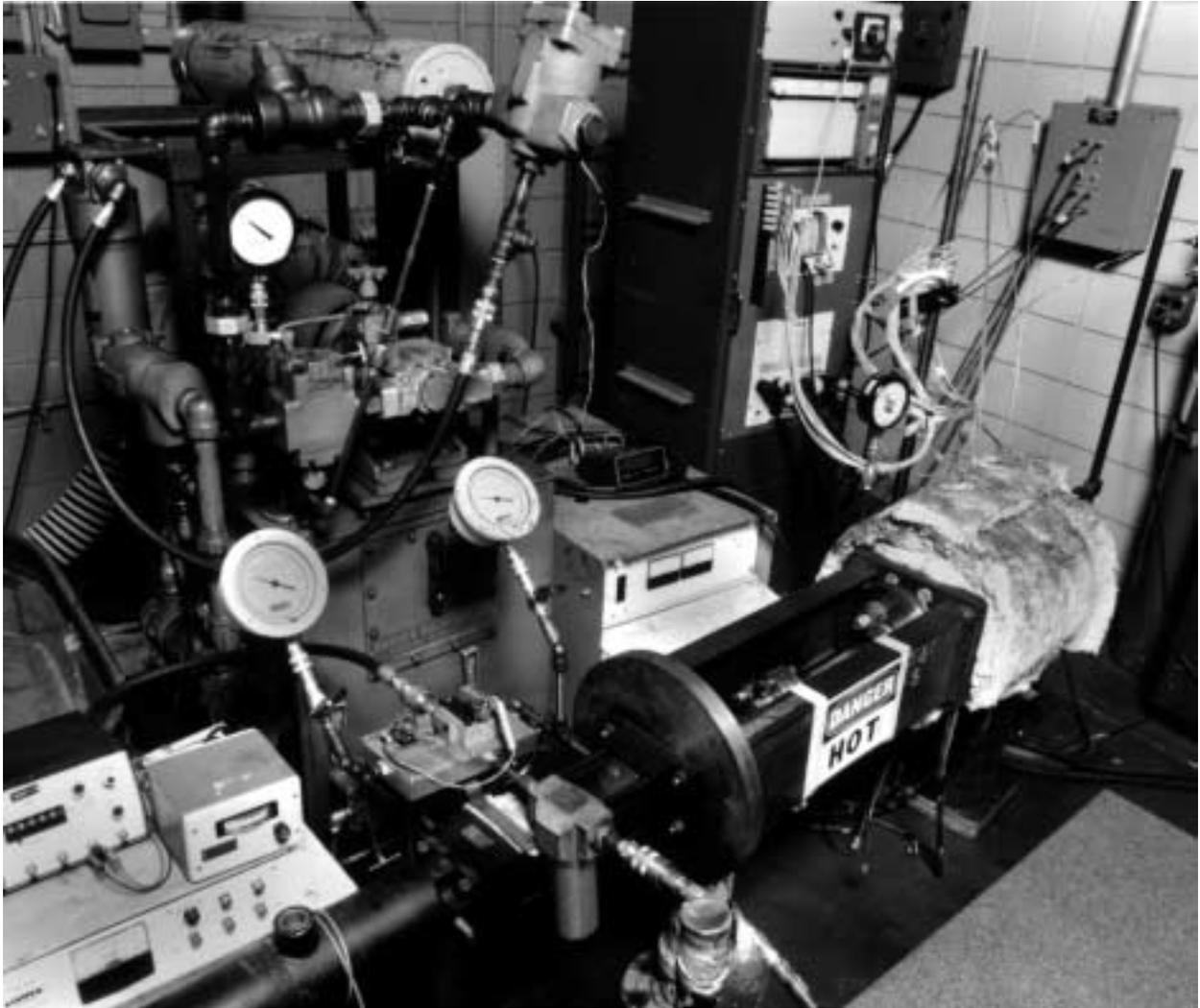
Figure 14. ENVIRO-SEAL PTFE-Based System in a Double Packing Arrangement (for Rotary Valves)

PACKING SYSTEM VERIFICATION

The test equipment shown above was utilized to verify performance capabilities of graphite packing systems. The test system consists of a 2" diameter valve stem with a stroke length of 7-1/4 inches operating at six strokes per minute. The test fixture was heated to 800°F and pressurized to 4,000 psi. Leak rates, as well as packing deflection (consolidation) is measured periodically. The more successful packing systems were tested to 262,000 strokes or 158,000 feet of travel (Figure 8.)

Acknowledgment

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