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Considerations in the Design and Selection of Bellows Seal Equipment Valves

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Application

Bellows seal equipped valves are frequently used to meet fugitive emission requirements in EPA-designated non-attainment areas where absolutely no additional emissions are allowed. To expand a process plant in a non-attainment area, it is necessary to further reduce emissions in the existing facility in order to “make room” for even very small emissions from the expansion. Since bellows valves allow essentially no emissions from the valve stem, they have often been used for expansions as well as to retro-fit existing plants.

With the advent of low-leak packing systems, the requirements for bellows seals should be reduced in the years to come. However, there are certain applications which will favor the use of bellows seals. These will often be toxic or lethal services. Indeed, the use of bellows valves is considered by many as good insurance against even the smallest release.

Service Life

Bellows seal valves have been available for decades in various forms. They all provide virtually zero leakage. A key issue is, “How long do they last?”

Since a bellows is fabricated of metal and flexes as the valve stem moves, it is subject to fatigue failure. Its service life can also be shortened by corrosion and erosion, excessive pressure or temperature, or by physical damage during shipping, storage and installation. The type of metal used for the bellows, as well as bellows fabrication techniques and process control tuning, also affect service life. In addition, the physical integrity of the design can be affected by the way the bellows is incorporated into the valve body.

Any bellows can eventually fail. Valve designs which incorporate bellows seals should safeguard against this failure. Monitoring ports should provide the ability to purge across the bellows to an analyzer or trip a pressure switch to detect leakage. Also, the packing box design should provide room for a full packing set above the bellows.

Because of the varied effects of process operations, being able to predict the installed service life of a bellows seal valve is difficult. However, laboratory cycle life testing can provide relative comparison between various bellows designs. Bellows seal valves which incorporate all the technology presently

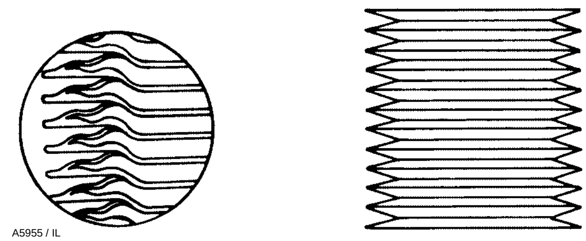

Figure 1A. Welded Leaf Bellows

available to extend service life can provide significant improvements in cycle life. The key to maintaining the physical integrity of a bellows seal valve and to obtaining long service life is to design every element of the valve, and make every design decision, to favor these two performance objectives.

Bellows design

Fabrication

There are two types of bellows— formed and welded leaf.

The welded leaf bellows is fabricated by welding together a stack of washer-like plates of thin metal. Each weld must be circumferential, and these circumferential welds must be made on both the O.D. and I.D. of each “washer.” (Figure 1A)

The I.D. welds are relatively difficult to access during welding, making consistency difficult. Also, with two circumferential welds made for each of the “accordion” folds, the welded leaf bellows has a high weld length and a greater number of welds compared to a formed bellows. The ultimate fatigue failure of a welded leaf bellows generally occurs at or adjacent to a weld.

The tight spacing and deep crevices of a welded leaf bellows can also provide sites for entrapping particles of solids or polymers. These particles can cause two major problems.

First, their presence can constrain bellows contraction and create a point of high stress, shortening fatigue life or even causing immediate failure.

Second, trapped particles can create stagnant areas that can hold corrosives in close contact with the bellows. Since the bellows metal is necessarily thin, corrosion rates that would be negligent for other metal parts can cause premature failure of a bellows.

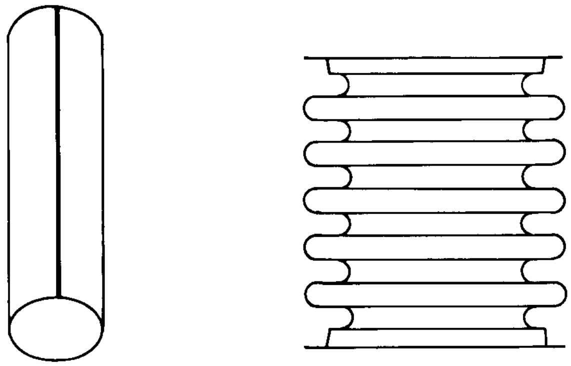

Figure 1B. Mechanically Formed Bellows

A formed bellows (Figure 1B) can be fabricated more consistently because the welds are fewer and easier to access. The formed bellows is made from a flat sheet that is rolled into a tube and then fusion welded longitudinally. This longitudinal butt weld is simpler and easier to make than the I.D. and O.D. welds required for a welded leaf bellows.

The welded tube is then mechanically or hydraulically formed into a bellows having shallow, rounded, and widely-spaced folds. These folds are less likely to entrap materials than the deep, sharp crevices of a welded leaf bellows.

A formed bellows and a welded leaf bellows each can accommodate about the same travel distance per fold, but the welded leaf design has more folds per unit length. Therefore, a mechanically formed bellows must be about three times as long as a welded leaf bellows to accommodate the same stroke length. However, with careful attention to all design details of the bellows system, the overall valve package height can be kept to a minimum—even with the use of the longer formed bellows.

The formed bellows has only about 1/8 the weld length per unit distance of travel as a welded leaf bellows. So it would seem that a mechanically formed bellows would have superior reliability compared with a welded leaf bellows because of its fewer and potentially better welds. Indeed, when both types of bellows are flexed until they fail, the mechanically formed, butt welded bellows lasts longer and fails at random spots on the bellows. welded leaf usually fails at or adjacent to a weld.

In side-by-side comparison tests of the same size valves equipped with welded leaf and mechanically formed bellows, the welded leaf design showed fatigue failure within 150,000 cycles. The formed bellows did not fail after more than 1,500,000 cycles.

Materials of Construction

Compared to more massive trim parts within the valve, the bellows is potentially more susceptible to failure from corrosion. Inconel[1] 625 (N06625) bellows generally have greatly improved corrosion resistance, as well as higher fatigue strength, compared with bellows fabricated from 316 stainless steel. Hastelloy[2] C22 (N06022) is another preferred bellows material. Compared to Inconel 625, it provides similar fatigue strength and slightly improved corrosion resistance in certain applications.

Physical Protection

The bellows should also be protected from physical damage during transportation, storage and installation. This protection can be provided by combining the use of a shroud with an anti-rotator pin (Figure 2). The shroud protects the entire bellows from contact with external objects, while the anti-rotation pin prevents twisting of the bellows and also serves as a travel stop to eliminate the possibility of over-extension during handling. Both the shroud and anti-rotation pin can be provided as permanent components of the bellows so that they remain in place even after the bellows is installed in the valve.

Stroke Length

Fatigue cycle life of any bellows is a direct function of the strength of the metal and the number and length of strokes. Cycle life can be improved by:

1. Using highly fatigue-resistant material such as Inconel 625 (N06625) and Hastelloy C22 (N06022)
2. Using multiple-ply bellows, placing less stress on each bellows fold. (This option is also used for high pressure applications.)
3. Reducing stroke length or using a larger diameter bellows.
4. Checking process controller tuning. (Many controllers are so tightly tuned that a valve will continually “hunt” as the controller seeks the perfect control point. Although this hunting may be small and not influence process operation, it can speed bellows failure from fatigue.)

To increase service life, bellows seal valves can be designed with a small reduction in stem travel. This slight travel reduction increases service life 2-4 times yet affects valve capacity only slightly. For cage trim valves, flow capacity reduction is generally insignificant when compared to its total available flow capacity. For stem guided valves, plug contours can be designed to provide flow capacity nearly equal to that given by valves without bellows seals.

1. Trademark of Inco International.
2. Trademark of Haynes International.

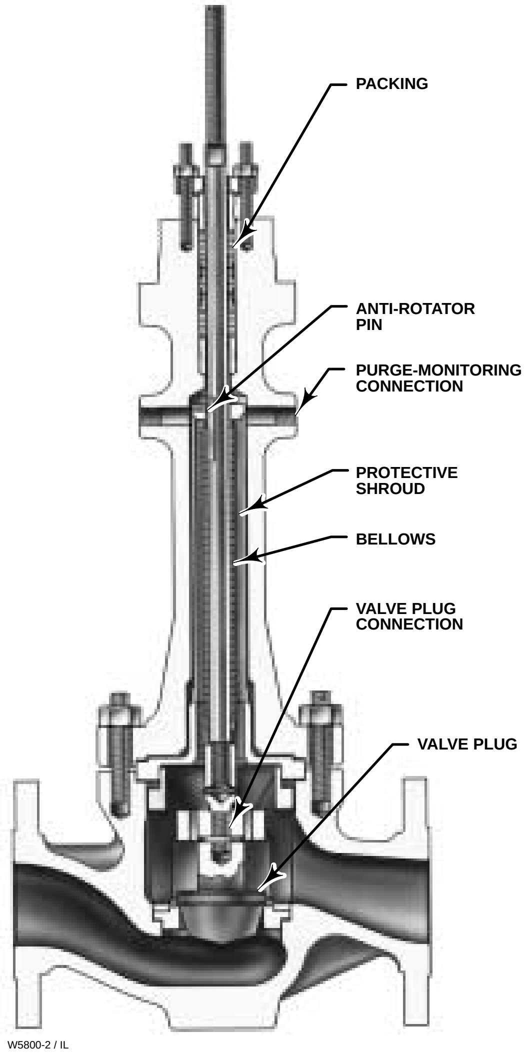

Figure 2. Control Valve Equipped with a Bellows Seal

Physical integrity of the valve

Bellows seal valves using formed bellows will generally require 3” - 6” more clear height than a valve with a standard bonnet. Although overall height of the valve can be reduced substantially through careful design of all the components, it should not be the primary design focus.

Instead, service life and safety are key areas of concern. For instance, to further improve operational safety the design should not utilize spacers, elongated bolts or additional gaskets that could provide opportunities for misalignment, leak paths, or fire relaxation. (The use of extra-long bolts can increase the likelihood of bolt weakening or failure during a fire.) Also, the bellows system can be designed so that only one gasket is exposed to the process fluid; the second sees process fluid only upon failure of the bellows.

Process tolerance

Bellows valves can be designed so that the process pressure is on either the inside or outside of the bellows. Due to its geometry, a bellows can tolerate higher pressure if pressurized from the outside. Designing the system so the process pressure is on the outside of the bellows often doubles the pressure rating of the bellows. External pressure on the bellows also allows the valve stem to help support the bellows and prevent it from “wandering”.

Many bellows seal valves incorporate a weep-hole between the process and the bellows chamber to allow circulation of process fluid around the bellows. However, the design should utilize a large annular area between the bellows and the bonnet bore that is open to allow heating of the bellows by the process fluid, particularly in applications where the fluid can thicken, crystallize, or even polymerize when cooled. However, the bellows still should not be immediately in the flow stream where it would be susceptible to erosion from process flow.

Valve Plug

Bellows seal valves which have the option of a pinned plug allow the plug to be replaced without replacing the bellows. This helps control costs and enhances availability when plugs are damaged or worn, or when control characteristics must be changed. It also provides greatly increased flexibility in meeting spare parts needs. Welded plugs should be used where required by plant standards or the application.

Summary

A bellows seal valve that provides a long service life will also reduce life cycle cost because of less maintenance and less frequent replacements. Construction details that contribute to this long service life include:

- Formed bellows
- Bellows constructed of high-strength, corrosion resistant Inconel 625 or Hastelloy C22
- Shorter stroke capability
- Fewer gaskets
- No long or exposed bonnet body bolting

- Anti-rotation protection
- Over-extension protection
- Protective shroud
- Dual leak-detection and purge ports
- Large annular area open to the process

Careful attention to these design details will result in a bellows seal valve that maximizes service life and physical integrity without compromising process performance.

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