"Fluoropolymer Lined Ball Valve Design Breakthrough"

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Abstract:

The constant race for throughput and productivity improvements in modern chemical processes is changing the technical requirements of plant design and its equipment. Together with the challenge to ensure optimum plant safety while meeting environmental aspects driven by green legislation, the economic impact on the plant output is tremendous.

Fluoropolymer lined valves offer economical solutions for a vast majority of chemical applications while maintaining the highest possible degree of performance in minimizing in-line leakage and fugitive emissions.

A look at the market through our internal voice of customer surveys for fluoropolymer lined valves shows an overwhelming population of lined ball valves in various applications. While being one of the most accepted and popular valve types, the currently available ball valve designs still have their constraints that influence their performance and operating life.

The paper will present and explain a new ball valve design for fluoropolymer lined valves that will incorporate all the acclaimed and demonstrated benefits of the current design approaches, while implementing new approaches that alleviate prior design constraints.

INTRODUCTION

1. Current design status of lined ball valves and their characteristics

Fluoropolymer lined technology revolutionized ball valve development and design decades ago and continues to be pivotal for many products and valve solutions in diverse industries and applications, such as chemical process, pharmaceutical and others. Lined technologies offer a number of advantages, such as resistance to corrosion, while providing high performance, and preventing in-line leakage and fugitive emissions. Compared to high alloy alternatives, lined valves offer economical solutions for applications ranging from handling simple liquids to slurries and fluids in highly aggressive and demanding environments, and continue to be an integral part of design and development of valves.

Partially fluorinated polymers have certain improved properties, but there is always a trade-off, e.g. reduced temperature range. With respect to permeation, all polymers are permeable to varying extents, so the key to mitigating this challenge is based on material selection, and process parameter.

PFA fluoropolymer (which we have selected for lining of complex valve bodies) offers certain advantages because it is a melt processable plastic that will easily flow into all cavities of a valve body, including locking grooves/buttons to securely lock the liner to the body all in one process. Alternatively, to use a PTFE or TFM liner would require several steps, including a blow molding process. PTFE & TFM are compression molded materials that require a sintering process. A blowable tube would be formed and then sintered. Then a heating process and a high pressure air "blow" would be required to force the PTFE or TFM to fill out the basic inner cavity of the valve body. It would be very difficult to get the liner locked into the body, to the extent possible with PFA. Furthermore, PFA has shown better permeability resistance than PTFE over time. Although TFM was better than PTFE in terms of permeability (and slightly better than PFA), the same molding issues would pertain to TFM. (Bowser-Mourner INC. Lab in Dayton, Ohio, performed the said permeability comparisons with bromine.)

In general terms, the epxedient options for lining of complex valve bodies are FEP and PFA due to their similar processing characteristics outlined below.

FIGURE 1: FEP characteristics vs. PFA characteristics *(Ref 1)*

FEP (a polymer of tetrafluoro-ethylene and hexafluoropropylene) Offers chemical inertness, heat and weather resistance, exceptional electrical properties, toughness and durability.	**PFA** (a polymer of tetrafluoroethylene and perfluorovinylether) Has exceptional heat resistance, excellent electrical properties and excellent chemical and weather resistance.
• Service temperatures **up to 200°C (392°F)** • Excellent resistance to specific solvents and chemicals • Outstanding electrical properties • High limiting oxygen index: Does not support combustion • Extremely smooth surface	• Service temperatures **up to 260°C (500°F)** • Excellent <u>universal</u> resistance to solvents and chemicals • Outstanding electrical properties • High limiting oxygen index: Does not support combustion • Extremely smooth surfaces • High light transmission • Non-stick characteristics • Good low-friction properties

Current ball valve designs can contribute to performance challenges triggered by corrosion and abrasion. For example, in a traditional two-piece design the ball and stem are two separate lined components that act together when the valve is operated. The plastic-to-plastic joint between ball and stem can lead to “play” between the stem and the ball during opening or closing of the valve. When the media is under pressure the torque applied through the stem to the ball can increase and be transferred to the drive slot in the ball. This often results in the outer edges of the ball liner being heavily loaded. As the polymer is subjected to flows under pressure, the thickness of the polymer is reduced. With intensive use, the liner may become too heavily worn and corrosive material can attack the metal, leading to a potential failure.

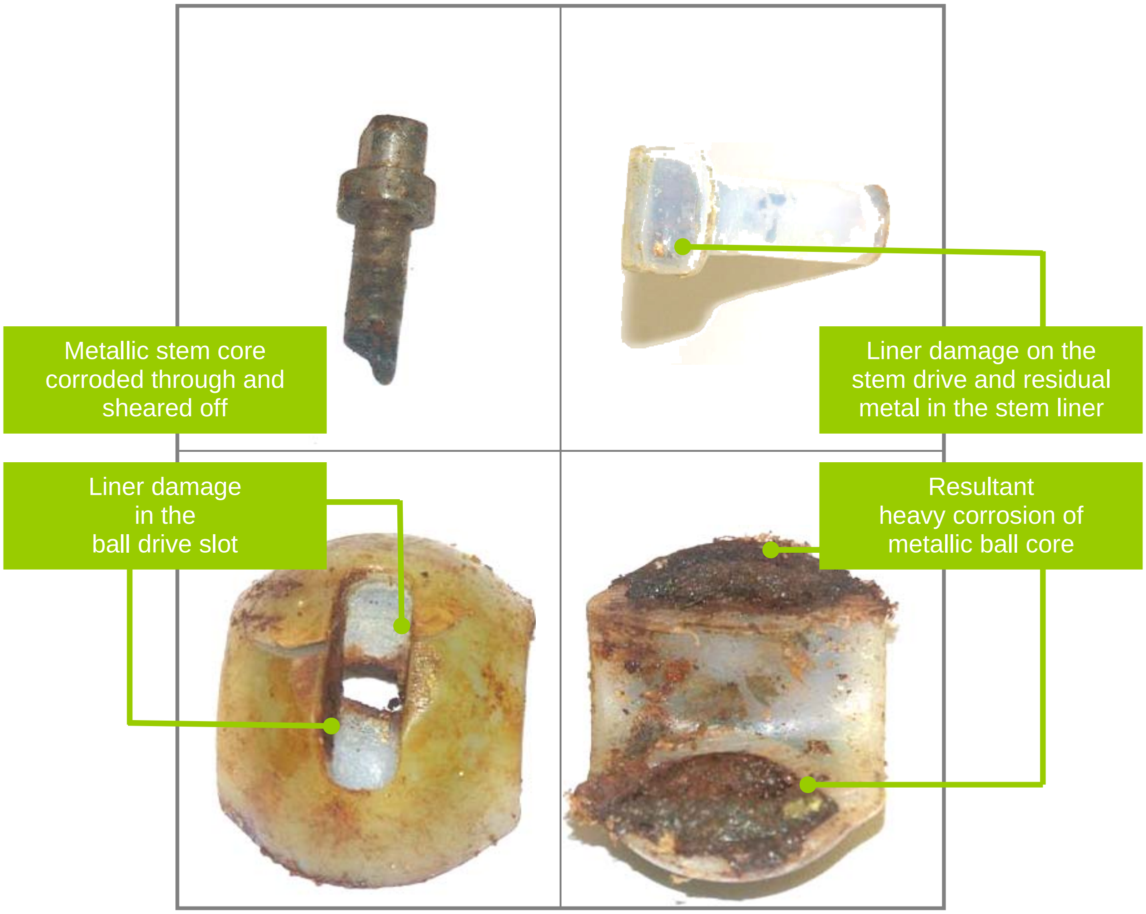
Side loading is another design challenge that directly impacts the lining and sealing capabilities. When a spherical ball is in the closed position, the face of the ball is subjected to pressure generated by the media and can create side loading. In both the two-piece and one-piece traditional ball valve designs, side loading creates a weakness, which increases the risk of leaks in-line or to the environment. More detailed characteristics of the two-piece ball and stem and one-piece ball-stem assemblies, including side-loading scenarios, are detailed in below.

FIGURE 2: Two-piece ball and stem design

Typical challenges:

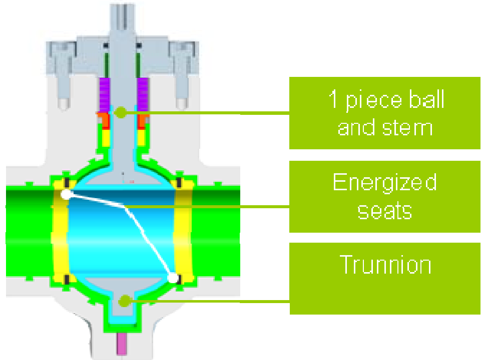
- High wear and exposure to excessive torque on the ball and stem joint area cause the lining to creep, which thins the lining, risking static deformation or destruction of the lining between the ball and the stem, potentially leading to corrosion of the ball and stem core and catastrophic valve failure
- Lost motion between ball and stem reduces positive rotational control
- Unpredictable ball movement (“tilting”) inside the valve body, leading to misalignment between ball and sealing area
- Misalignment of actuator or side loading of the lever tilts the stem, impacting the stem seal and leading to potential leakage to atmosphere

FIGURE 3: Effects of wear damage at ball/stem connection
on 2-piece lined ball and stem



In a two-piece traditional ball and stem design the ball can “float” downstream under pressure, imparting increased force on the seat (a stationary portion of the valve within which the ball sits to stop flow completely) to enhance the in-line seal. A common misunderstanding is that the stem remains in place and that the ball pushed by the fluid moves on the seat. The reality is that when the ball “floats” downstream, it is no longer aligned with the axis of the stem, creating side loading. If the valve is open under pressure, torque is introduced by the stem, which produces a rotation along a tilted axis, causing stress in the lining of the ball. These repeated actions can lead to lining wear.

FIGURE 4: One-piece ball-stem design

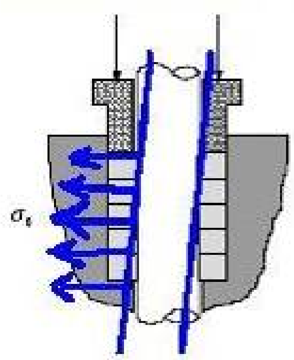


In the rigid one-piece design, downstream movement of the ball can lead to side loading of the packing. In high pressure scenarios, the ball stem leans against the packing, which acts as a bearing, allowing displacement of the ball. During the stem's slight movement the packing is deformed, temporarily negatively affecting the seal in this pressure condition.

Typical challenges:

- Ball is prevented from floating as in two-piece designs, the seats require to be energized to maintain a tight seal, leading to higher torque
- Trunnion must be used to reduce side loading when ball is under pressure in the closed position
- Any stresses caused by thermal cycles and high pressure on the ball and stem core assembly are fully absorbed by the lining material
- Higher exposure for wear of the atmospheric seal due to side loading, as the conventional design of a static stem packing can not compensate for side load effects over a long time without atmospheric leakage

FIGURE 5: Elastic behavior of PTFE (form memory of PTFE) being measured in hours.



Creep

$$\varepsilon(t) = \frac{\sigma(t)}{E_{isnt,creep}} + \int_0^t K(t-t')\dot{\sigma}(t')dt'$$

Relaxation

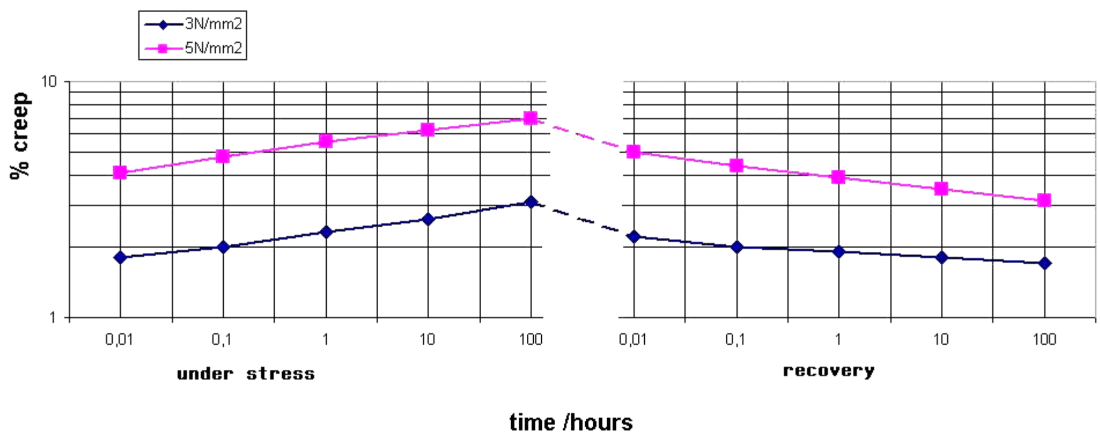
$$\sigma(t) = E_{inst,relax}\varepsilon(t) + \int_0^t F(t-t')\dot{\varepsilon}(t')dt'$$ with

where

- *t* is time
- *σ(t)* is stress
- *ε(t)* is strain
- $E_{inst,creep}$ and $E_{inst,relax}$ are instantaneous elastic module for creep and relaxation
- *K(t)* is the creep function
- *F(t)* is the relaxation function

(Ref 2): Generalized Maxwell Model

FIGURE 6: Elastic behavior of PTFE (form memory of PTFE) being measured in hours.



(Ref: 3)

One-piece designs held with a trunnion mounting do not allow for displacement of the ball but the seats are energized by a spring, likely creating a weak point in the mechanism of this type of lined valves. These systems lose the advantage of the pressure assisted seal and must compensate by using energized seats, which lead to increased torques.

In both design circumstances, these design weaknesses may lead to premature valve failure or leakage, presenting safety and fugitive emission concerns as well as incurring significant costs associated with unscheduled downtime and lost productivity.

2. Customer requirements for an "ideal lined ball valve" design

Close and ongoing work with customers has revealed that the inherent weaknesses in the designs created a growing need for a new paradigm in ball valve design – one that enhances safety, addresses fugitive emissions, and has a positive economic impact on plant output.

In short, the “ideal lined ball valve” from a customer’s perspective should offer a quantum advance in safety and reliability. <u>More specifically, a new design should address:</u>

- Superb in-line seal at varying temperature and pressure ranges
- Maintaining the highest possible atmospheric seal
- Corrosion resistance
- Lowest torque for automation (break torque and operating torque)
- “Zero” maintenance over the entire productive life-span
- Adaptability to different applications/processes

3. Technical Design Realization and Implementation

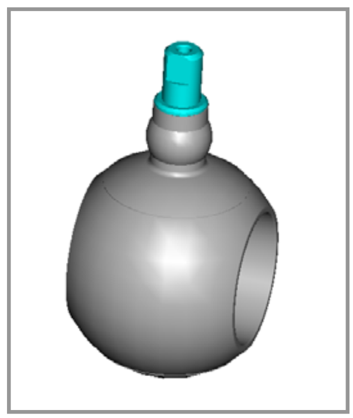
In response, Crane ChemPharma Flow Solutions™ developed a new design, the XLB® series of lined ball valves from XOMOX®. The new series is an industry first, offering a unique solution that integrates the design strengths of current ball valves while minimizing their weaknesses.

<u>Key changes of the new design include:</u>

1. An innovative stem sealing system that provides safety and long term fugitive emission control under extreme conditions
2. Dynamic body joint design allows the valve to retain pressure boundary during thermal cycles
3. Lower torque translates into reduced actuation costs and space saving

This design provides a universal means to manage corrosive chemicals through a cost effective lined solution, avoiding the need for expensive high alloy alternatives, and it is known as the global lined ball valve (GLBV). The GLBV features:

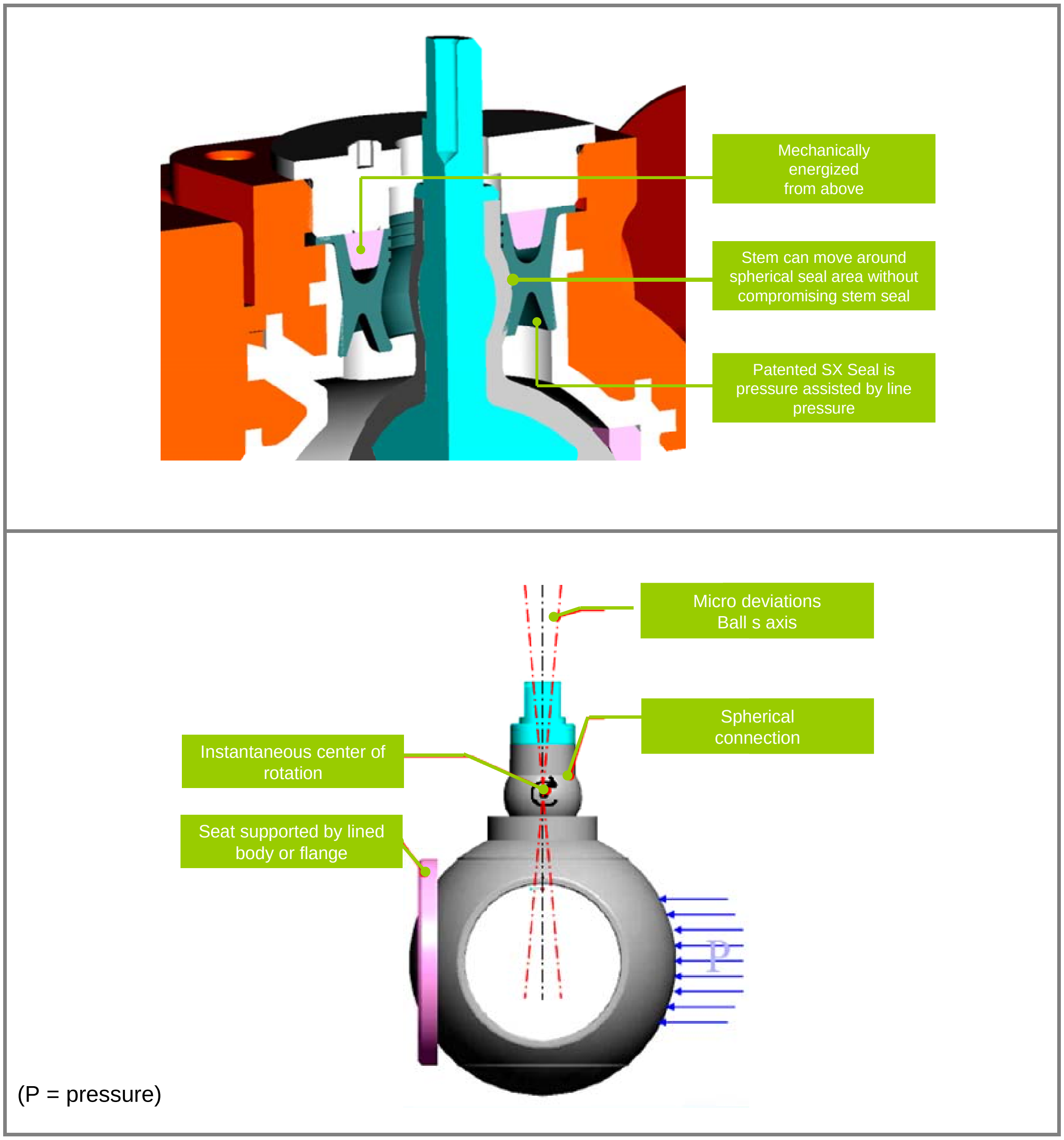
- One piece ball and stem to eliminate liner failure potential at ball/stem joint and resolves lost motion problems
- Metal-to-metal body joint
- Floating ball
- Pressure assisted in-line seal
- Dynamic atmospheric seal
- Mechanically energized stem seal
- Stainless steel lever
- Latching lever
- Standard locking
- Live loaded stem seal
- ISO 5211 actuator mounting
- Full port and reduced port
- Minimized internal cavities



The metallic core of the ball and stem is manufactured as one piece and lined with PFA. As stated previously, all liner technologies have restrictions, primarily associated with temperature and wear. In this case, PFA was chosen for its tighter molecular structure, which enables it to withstand higher temperatures and offers exceptional chemical resistance under demanding conditions. PFA also has a low coefficient of friction, reducing wear.

The GLBV's single-piece design features a second pivoting ball on the stem, which interfaces with a patented SX-seal. When the ball moves downstream to enhance the in-line seal, the pressure between the spherical surface of the stem and seal remains constant leading to a consistent and lasting atmospheric seal. The seal itself offers an x-shaped cross section to create a tight seal between the media and environment. As pressure increases, the seal is forced against the valve body and stem without damage or deformation. The seal is mechanically energized by an adjustable wedge ring, which creates a secondary sealing back-up and eliminates the need for springs and multilayer stem packing.

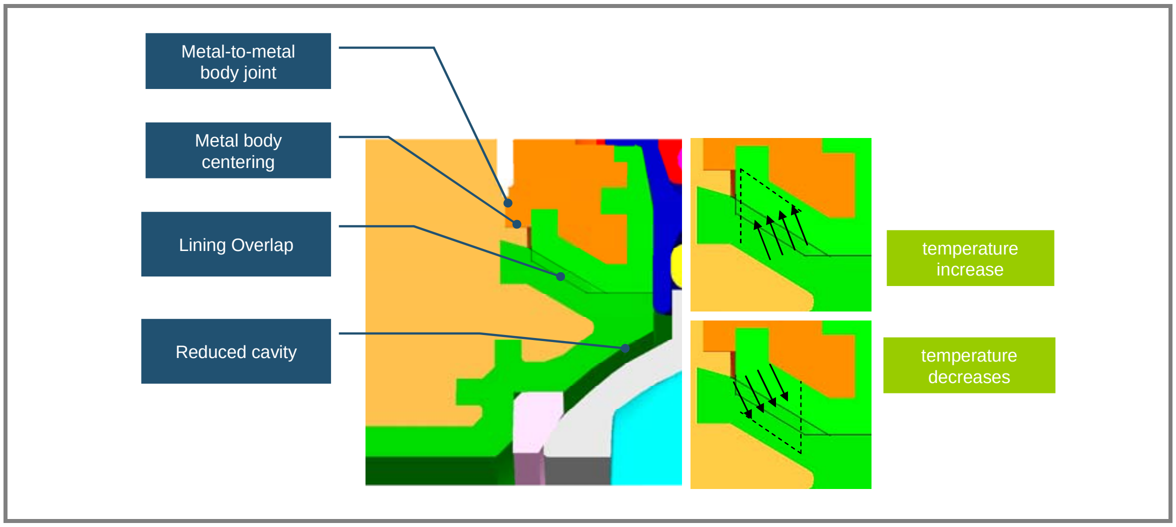
FIGURE 7: XLB® Stem Sealing



In previous one-piece designs, pressure variations caused the ball's axis to move slightly, resulting in seat or liner deformation which can lead to fugitive emissions. This newly patented seal and stem combination has the ability to handle heavy side-load effects without releasing the lateral forces into the stem packing. This makes it possible to provide a valve design that offers significant advantages including longer lifespan, greater leak prevention, and improved safety, which is especially important when handling hazardous media.

Another sealing improvement was accomplished through modification of the body parts. The body assembly has metal-to-metal connections that offer resistance against forces due to misalignment that may be created in the pipeline. This feature is designed to alleviate deformation and damage to the lining, even under pressure induced stresses.

FIGURE 8: The body joint sealing is provided with taper lining overlap, which is especially effective with high internal pressure and temperature variations.



Furthermore, the body parts have a broad, angled contact surface. The advantage of this is that during thermal cycles the plastic liner maintains its seal. This surface change combines side and radial actions, making the new design more leak resistant and reliable during years of operation, even under the most demanding conditions.

Lastly, the new design reduced the cavity around the ball, where debris or contaminants can collect and affect the performance of the valve. This change extends the valve life in applications where solids are present.

4. Practical Results

Extensive tests of the valve show superior performance compared to prior designs in all aspects regarding in-line and atmospheric sealing. The new GLBV is able to reduce the total cost of ownership by a reduced spare part count and minimize service turnaround time in the field by strictly following a modular design which adheres to commonly accepted standards (ASME, EN and JIS).

Seal testing

Industry standards and legislation imposed for limiting or minimizing emissions are becoming increasingly demanding for industrial plants worldwide. Leakage of critical media, or leakage of media with the consequence of energy losses, are no longer tolerated.

To be sure, the new design met the highest regulatory standards; it was tested against strict administrative regulation, ISO 15848-1, temperature class 200° C (400° F), through 2,500 mechanical cycles. The valve was entirely enclosed in an environmental chamber during temperature & pressure cycling, actuated through the side wall, and leakage detection was done continuously. Stem-sealing Tightness class BH (10^{-4} mg/s/m) was achieved during vacuum Helium test method as per ISO 15848-1. XLB® performance class: BH-C03- SSA1-t(-20°C,200°C)-PN16/CL150-ISO 15848-1

The GLBV's performance met or exceeded the metioned industry standards, preventing leakage at all stages of testing.

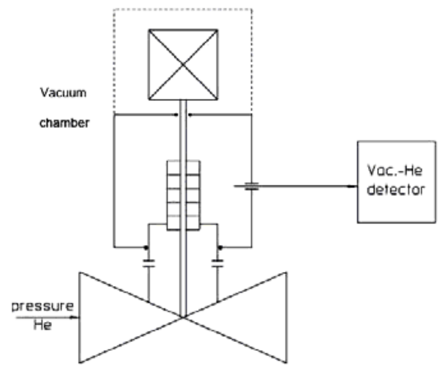
(Ref 4) ISO 15848 - Industrial Valves- Measurement, Test and qualification procedures for fugitive emissions; Part 1: Classification system and qualification procedures for type testing of valves
Emission from Body seals for Helium as per Table 3 in the standard (Less than 50 ppmv Helium)
Tightness Class for stem seal for Helium Class BH (Less than 10-4 mg.s-1.m-1)

Table 2 — Leakage from body seals

Measured concentration ppmv
⩽ 50
NOTE Expressed in ppmv measured with the sniffing method as defined in Annex B (1 ppmv = 1 ml/m^3 = 1 cm^3/m^3).

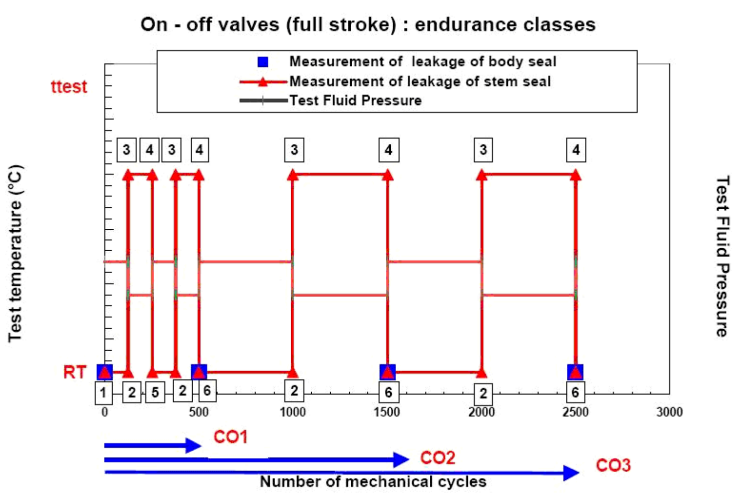
Source: International Standard ISO 15848-1:2006(E)

FIGURE 9: Principle of the vacuum method



(Ref.4)

FIGURE 10: Mechanical cycle classes on-off valves



(Ref.4)

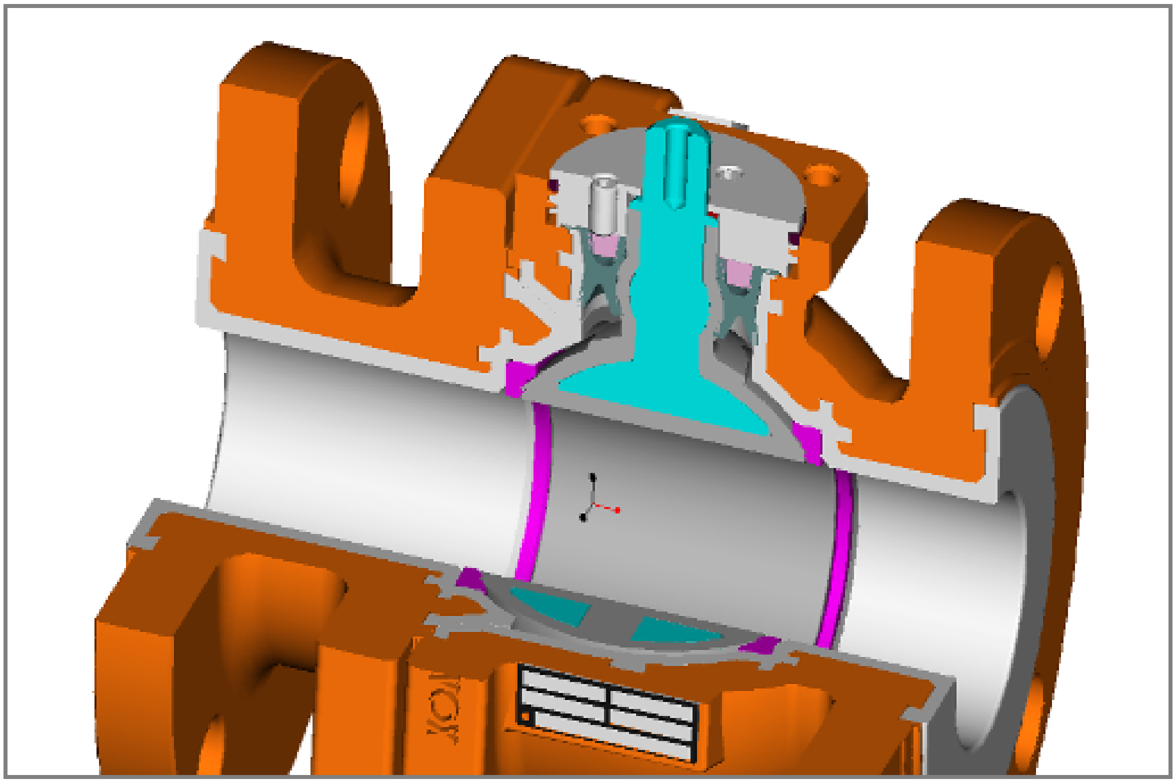


FIGURE 11: Xomox® XLB® (Crane ChemPharma Flow Solutions™)

The new desin allows lower torque:

1. Reduced friction against stem and SX seal instead of stem and packing
2. Energized seat for sealing used in single piece ball-stem causes higher torque
3. Trunnion & stem can increase higher torque

Low torques permit the use of small actuators while offering ease of automation and standardization with a fully ISO 5211 compliant valve actuator interface.

Furthermore, manual operation of the GLBV has also been improved. All valves up to 6 inch can be operated by lever as compared to some of the conventional 6 inch valves that require a gear mechanism.

Adding to the safety and performance of the GLBV, the stainless steel handle is lockable as standard. Accidental operation of the manual valve handle has been minimized by introducing an automatic latching mechanism, which engages in the open and closed positions. The spring loaded latch resists disengagement due to vibration even when the valve is installed upside down.

The new design is available in 1/2 to 6 inch (15 -150 mm) sizes (as per ASME, EN, and JIS). The entire valve is sized to have little or no extension beyond the flange diameter. This allows the valve to be used in parallel piping systems easily, and, importantly, without having to increase the dimensions of the system. It also has a smooth and painted surface allowing for effective wash down, limiting the potential for external corrosion.

5. Conclusions:

Through careful redesign of the ball and stem assembly, the new GLBV takes advantage of the internal pressure to create a better seal, demonstrating that even long-term designs like fluoropolymer lined ball valves can be significantly improved using modern process and design methodologies. The benefit for customers is that the main disadvantages of the current designs are addressed without compromising other design strengths.

To recap, the redesigned ball-stem assembly incorporates the sealing advantage of the "floating ball" found in a traditional two-piece design while overcoming the typical limitations of a body joint. Compared to a traditional one-piece design, where side loading is problematic for sealing, the GLBV's metallic core, PFA lining, and advanced sealing technology result in considerably reduced wear, limiting the danger of safety-related incidents.

In conclusion, Xomox's GLBV's revolutionary features translate into increased safety and better environmental safe guards, while delivering many economic advantages, including longer life performance and lower torque, without the need for exotic alloys.

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6. References

1. PFA & PTFE chemical and physical properties can be found at:
   http://www.texloc.com/closet/cl_pfa_properties.htm
   http://www.texloc.com/closet/cl_ptfe_properties.htm

2. Generalized Maxwell Model
   David Roylance, "Engineering Viscoelasticity" (October 24, 2001)
   http://ocw.mit.edu/NR/rdonlyres/Materials-Science-and-Engineering/3-11Mechanics-of-MaterialsFall1999/038732E6-CF1E-4BD0-A22E-39123ADD3337/0/visco.pdf

3. ASTM 621 Deformation under load (specimen 10mm d x10mm)

4. International Standard ISO 15848 - Industrial Valves Measurement
   Test and qualification procedures for fugitive emissions