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Containment Vessel Closure Mechanism with Simplified User Torque Requirements

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Abstract

This study evaluates the feasibility of a Type B radioactive material package containment vessel closure with simplified user torque requirements. The closure design eliminates the need for calibrated tools or complex opening/closing instructions that are typically required for traditional bolted closures. The closure design features a notched lid for translating compressive only loads to the seal and a threaded locking ring to provide positive closure on the lid. Each vessel is match drilled during fabrication and secured to guarantee that clamping force requirements on the seal are consistently met. The closure design is cost-effective, simple to operate, and streamlines package operations.

Background

Bolted closures are commonly and reliably used to seal pressure vessels and radioactive material packages due to the ease of implementation, the robustness of the design, and the ability to incrementally achieve a large clamping force. Although bolted closures are easily implemented during fabrication, they can become burdensome during assembly due to rigorous operational and quality assurance requirements. Depending on the seal type, clamping force requirements, and flange closure, the number of bolts can be inconveniently large[1]. Bolted designs typically require stringent torque specifications for each bolt, require a tightening sequence to ensure preload uniformity, and are tedious to open or close. Consequently, bolted closures demand a substantial allocation of resources to the assembly, inspection, and maintenance of dedicated calibrated equipment.

A second disadvantage with bolted closures is that torque, the most common method for estimating preload, often ineffectively accounts for the true thread conditions. The thread conditions of the bolts have significant effects on the preload despite a constant torque input due to friction (Eq. 1). The coefficient of friction in threaded connections typically varies between 0.30 and 0.10 depending on the smoothness, accuracy, and lubrication of the threads[2]. If not properly considered, the clamping force will be inadequately approximated and, as a result, the vessel seals may be insufficiently compressed or the bolts may be overstressed.

$$T = KFd \qquad \text{Eq. 1}$$

Where: T – Torque; K - Coefficient of Friction; F - Force; d - Bolt Diameter

To compensate for these unknowns, Savannah River National Laboratory (SRNL) is designing and evaluating an innovative closure design concept for use in future Type B radioactive material packages. The closure design is intended to streamline and improve package operations by implementing a go/no-go style preload verification system, thereby eliminating the need for calibrated instruments and torque specifications. This process has been successfully demonstrated in the 9980 Type AF Radioactive Material Package[3]. The containment vessel closure described in this paper has the potential to cost-effectively increase the efficiency of package operations, while maintaining the high level of performance demanded of these package types during Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) testing[4].

Closure Design Components

The closure described in this paper is designed for a 16 inch outside diameter (O.D.) Type B containment vessel intended for tritium shipments. The package is designed to be cost-effective, simple to operate, and robust enough to withstand the regulatory NCT and HAC test conditions (Figure 1). The containment vessel is fabricated from stainless steel and features three primary closure components: an integral closure flange, a threaded locking ring, and the vessel lid. Each component of the package is fabricated from commercially available materials and parts to reduce material expenses.

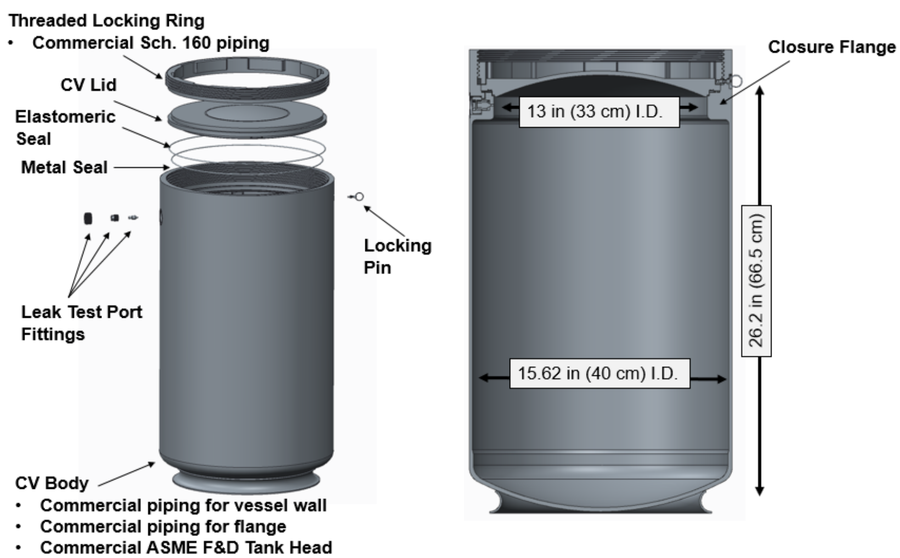

Figure 1. Type B Tritium Package with Closure Design Components

The closure flange is constructed from seamless pipe and is arc welded to the vessel body (Figure 2). The flange is designed to support the large bearing force that is required to seal a vessel of this diameter. The flange has two seal grooves: one for a metallic seal and the other for an elastomeric seal used for leak testing purposes. The flange features four grooves spaced 90° to interface with the lid and inhibit rotation between the surfaces that could affect the sealing surface of the seals. The flange features internal ACME threads for engaging with the locking ring. The internal threads are shielded from damage during Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) since they are recessed into the vessel body.

Figure 2. Containment Vessel Flange

Like the closure flange, the containment vessel locking ring is a hollow ring also fabricated from seamless pipe that is externally threaded with ACME threads. The locking ring features 8 grooves spaced 45° apart that are designed for gripping and turning the ring. The ring is nitrided after machining to prevent galling between the ring and vessel flange threads during opening/closing operations. The containment vessel lid is a compact design that is fabricated from stainless steel plate. The plate is rotationally restrained by four tabs spaced 90° to interface with the vessel body to prevent scoring and scratching of the seals.

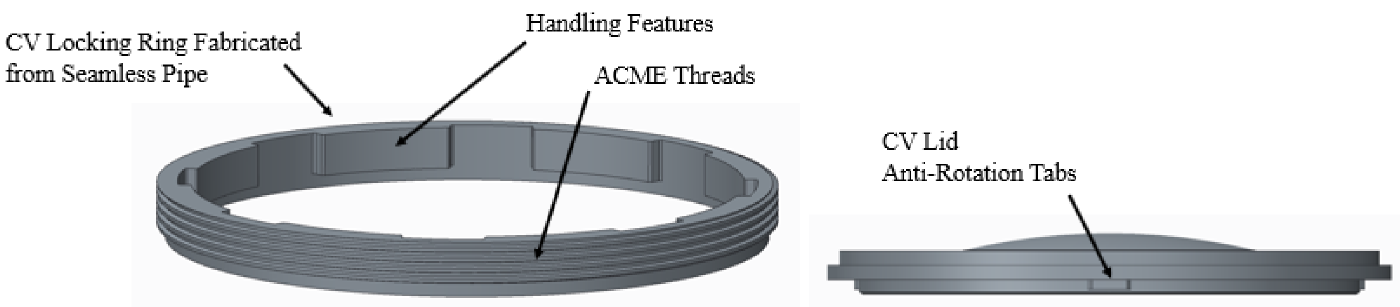

Figure 3. Containment Vessel Locking Ring and Lid

Preload Verification

Closure preload is determined during package fabrication using a match-drilled alignment pin. After fabrication of the vessel flange, locking ring, and lid, the containment vessel is assembled without the seals. The locking ring is then secured and the assembly is match drilled from the vessel flange to the locking ring (Figure 4). The hole is drilled without the seals in place to mark the position where the lid and flange meet, indicating that the seal has been fully compressed. Once drilled, a spring plunger is installed through the hole for alignment purposes.

The spring plunger acts as a type of go/no-go gauge that, once engaged, indicates to package users that the lid seal has been fully engaged. This closure method is a deflection-based indication of clamping force and is more consistent than torque-indicated preload. Furthermore, since package alignment is permanently established during fabrication, fewer inspections are required during opening/closing operations to verify that the package has been adequately closed.

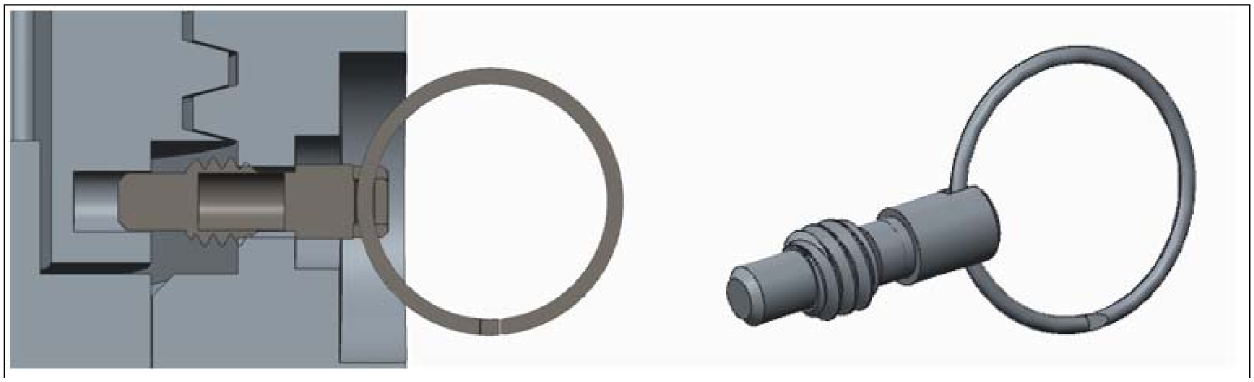

Figure 4. Containment Vessel Assembly Alignment Method

Compression Mechanism

The containment vessel is designed to make tritium shipments, which require a metal seal in place of an elastomer seal to retain tritium. Metal seals that meet the ANSI N14.5[5] leak requirements typically have large seating loads in the range of 500-3000 lbs per circumferential inch[6]. In order to achieve the required closure force for the 14" seal in this application, a unique, compact compression device was developed.

The compression device is a compact scissor mechanism (CSM) developed to preload the package lid sufficiently to compress the seal. The scissor mechanism consists of two bearing plates, several linkages and pins, a thrust bearing, and a cover plate. The device is designed to operate with the linkages at angles close to vertical (less than 10°), which creates a large mechanical advantage. Minimal input force is required to produce the large compressive force required for the package lid. Since metal seals typically require compression on the order of ~0.03 in, the device is suited for the application.

To use the CSM, the package lid is placed on the closure flange and the locking ring is installed hand-tight. The CSM is subsequently placed on the top surface of the lid and the cover plate is threaded over the locking ring. Operators can expand the CSM to compress the lid seal using the inner nut, which is accessible through the top of the device. Once the seal has been fully compressed, the CV locking ring installation can be completed, which will engage the spring pin.

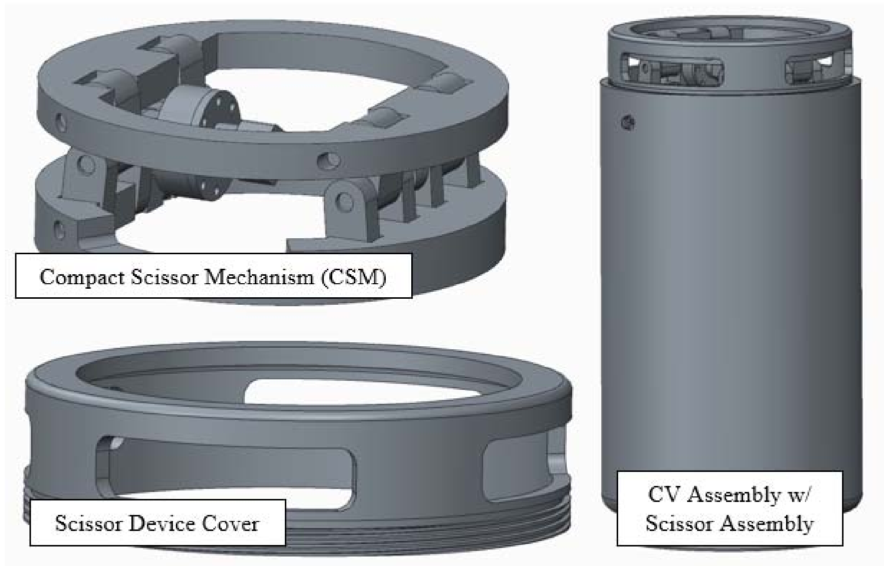

Figure 5. Package Compression Mechanism & Cover Plate

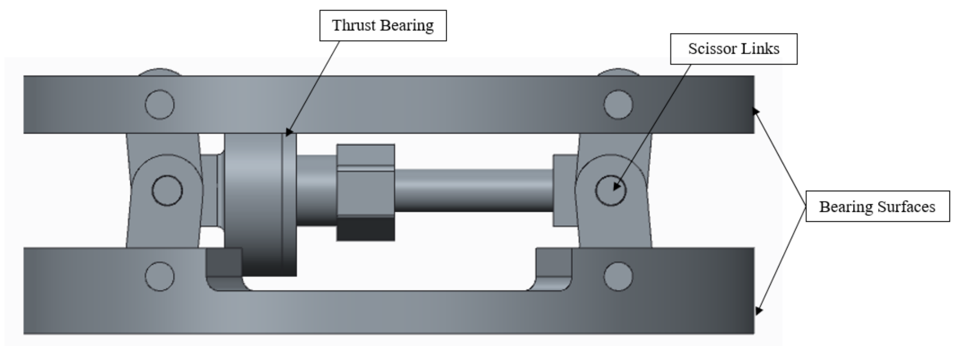

Figure 6. Compact Scissor Mechanism (CSM): Side View

Finite Element Modeling

Finite Element Modeling was performed to ensure that the CSM can adequately compress the seal without significantly deforming the packaging components by bending the lid upward or otherwise interfering with the fit of the closure ring. Results of the Finite Element Analysis (FEA) indicate that the end of the lid will vertically deflect approximately 0.0007 inches, which is approximately 2.3% of the required seal compression. Additionally, the lid stress is well within the allowable for 300 series stainless steel. Under these conditions, there will be insignificant interference between the lid and locking ring during compression. Once tightened, the locking ring will retain the preload developed by the CSM.

Figure 7. Package Lid Loading Conditions

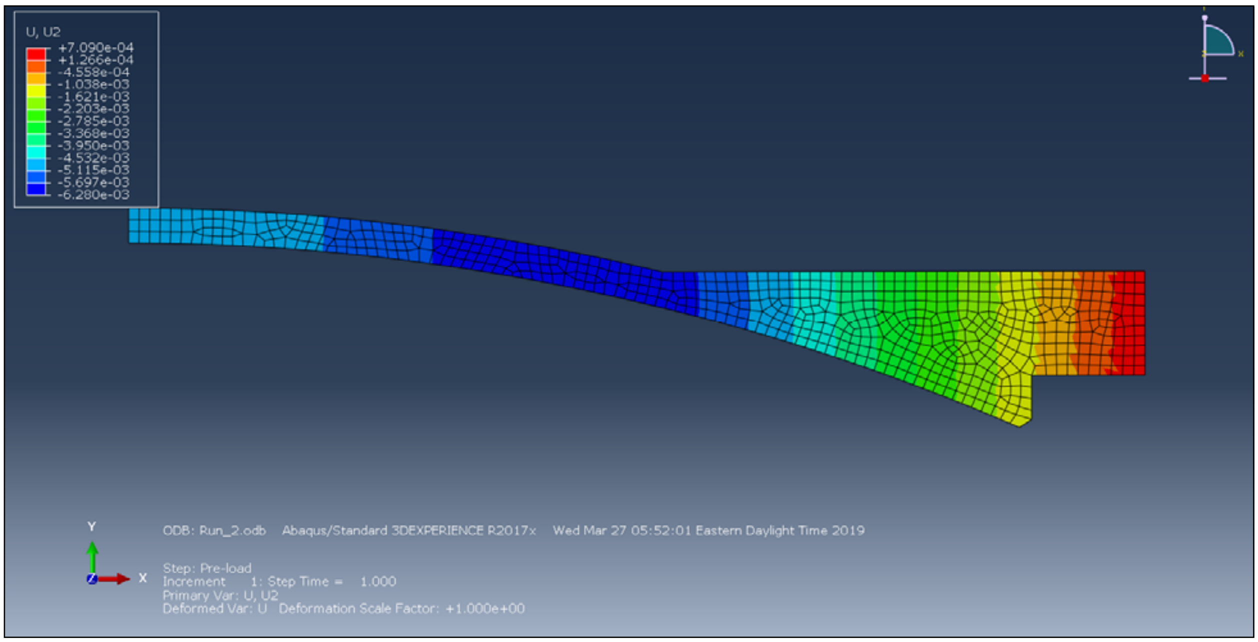

Figure 8. Lid Deflection due to Preloading

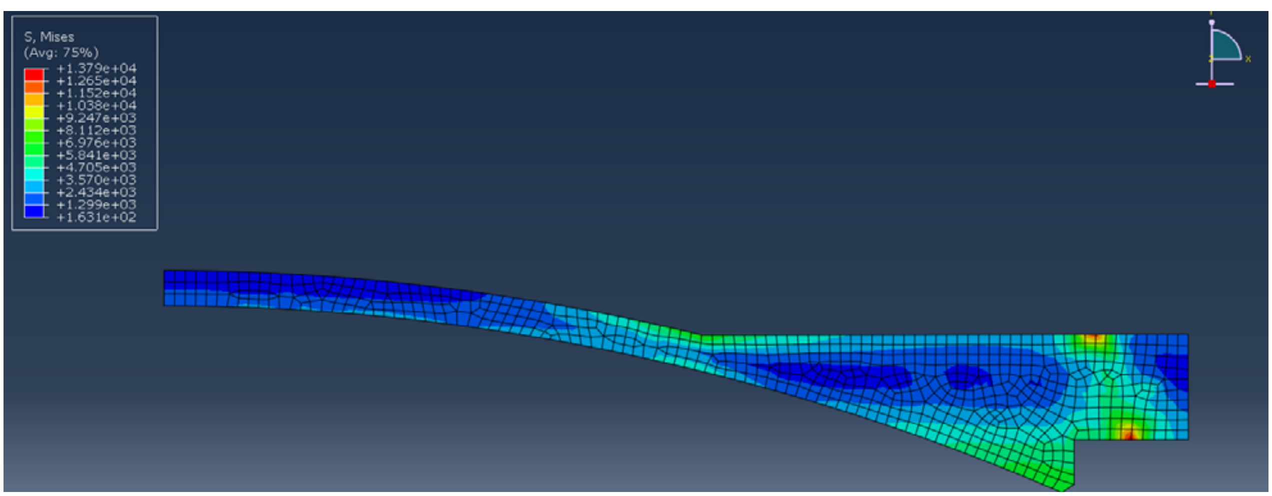

Figure 9. Lid Stress due to Preloading

Conclusions

This paper demonstrates that a containment vessel closure with simplified closure requirements is feasible and can be advantageous over traditional bolted closures. The deflection-based closure requirements yield a significantly more accurate and precise indication of adequate seal preload. Furthermore, the closure mechanism is simple to operate and verify proper assembly. Finite Element Analysis (FEA) demonstrates that the packaging components can structurally withstand the required compressive force to seal the vessel.

Disclaimer

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