



**PREFERRED
RELIABILITY
PRACTICES**

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STATIC CRYOGENIC SEALS FOR LAUNCH VEHICLE APPLICATIONS

Practice:

Deflection actuated, pressure assisted coated metal seals, or spring energized Teflon® seals, along with prudent flange joint designs, should be used for high pressure static cryogenic sealing applications in launch vehicle engines and related propulsion system components.

Benefit:

Leak-free joints can be achieved in cryogenic lines, joints, valves, and pumps for launch vehicles through the use of proven, state-of-the-art static cryogenic seals. These seals adapt to wide ranges of temperature and continue to seal when subjected to high pressures, in-flight static stresses, and in-flight dynamic loads.

Programs That Certified Usage:

Saturn I, Saturn V, Space Shuttle External Tank (ET), and Space Shuttle Main Engine (SSME).

Center to Contact for More Information:

Marshall Space Flight Center (MSFC)

Implementation Method:

1. Introduction:

Low or zero fluid or gas leakage in flight and ground-based cryogenic systems can be achieved through meticulous joint design and testing, selection of the proper seal configuration and materials, thorough cleaning and inspection of seal and flange surfaces, carefully controlled installation, and carefully controlled fastener tightening procedures. The most widely used and successful cryogenic seal for NASA space flight applications has been the deflection actuated, pressure assisted coated metal seal. High nickel content steel alloys coated with a thin layer

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of Teflon® or plated with gold, silver, indium, palladium, lead, copper, nickel, or aluminum have provided good sealing properties at elevated as well as cryogenic temperatures. This practice covers experience with pressure assisted and spring energized cryogenic seals in the SSME and ET. Experience was derived from earlier programs (Saturn I and Saturn V) to develop these effective seals. Although the subject of this practice is cryogenic seals, the pressure assisted and spring energized seals described are also effective over the broad temperature ranges from liquid hydrogen (-423 deg.F) to hot gas (1000/1200 deg.F).

2. Nonspacer Type, Deflection Activated, Pressure Assisted Seals

The nonspacer type seal shown in **Figure 1**, fits into a groove in the flange. It can be used with a separate spacer to eliminate the need for a seal groove, but a retaining groove is preferred.

As shown in Figure 1, these seals have two sealing surfaces that mate with adjoining flanges.

Diameters range from 0.55" to 16.75" as used in the SSME. Cross sections of the seal ring vary from 0.200" x 0.164" to 0.150" x 0.120" in radial width and installed length, respectively, and the seals can be made in other diameters and other cross-sectional configurations. They are found throughout the SSME in both cryogenic and hot gas applications. The seals are machined from high nickel alloy steel and coated with either silver or silver with rhodium overcoat. The silver coated seals have a temperature range of -423 deg.F to +1000 deg.F, while the silver with rhodium can be used over a -423 deg.F to +1200 deg.F range. The seals are used in both fuel and oxidizer systems.

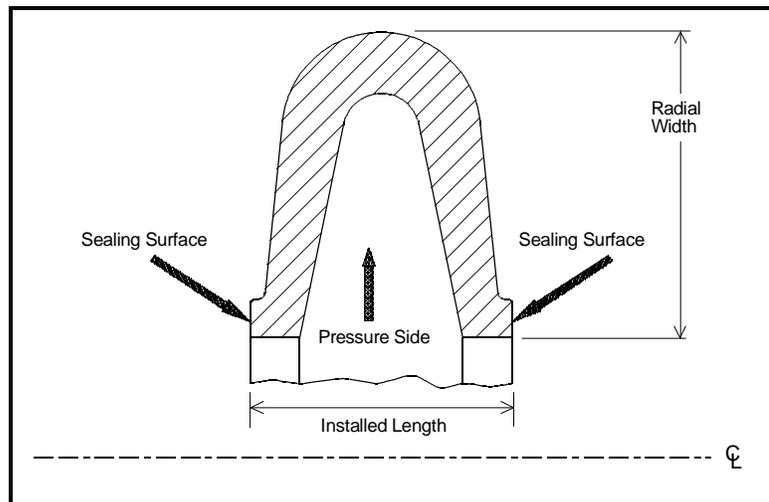


Figure 1. Nonspacer Type Deflection Actuated Pressure Assisted Seal.

In installing both the nonspacer type and the spacer type seals, the seals are compressed during joint assembly, which provides a load at the sealing circumference to effect sealing at low pressures. As the pressure increases, it

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acts on the internal surfaces of the seal, increasing the force on the seal tips to augment sealing capability as pressure increases. The seal coating presses into the flange surfaces, filling microscopic asperities and irregularities in the flange sealing surfaces. The combination of the installation deflection and the pressure on the internal surfaces permits the sealing faces to compensate for joint separation under system pressure and for shrinkage during exposure to cryogenic temperatures.

3. Spacer Type, Deflection Activated, Pressure Assisted Seals

This type of seal was originally used on the Saturn program and was later adapted for use on the Space Shuttle. The seal incorporates a flange, drilled to match the mating parts, which provides a positive stop to control seal compression and secondary pressure barriers on each side of the seal to facilitate leak checking. While some seals were originally silver plated, present use is confined to Teflon® coated high nickel alloy steel seals. The seals are used on the ET and on the piping connecting the Tank to the Orbiter.

Most have rated temperatures of -423 deg.F to +350 deg.F except for one which has a -423 deg.F to +800 deg.F rating. A typical seal installation as it is used on the ET is shown on **Figure 2**. Notice that the seal has both a dual-sided primary seal located at the interior periphery of the seal and a dual-sided secondary pressure barrier just inside the bolt circle. A Teflon® coated seal is used in the LH₂ and GH₂ systems while a silver plated seal is used in the LO₂ and GO₂ systems.

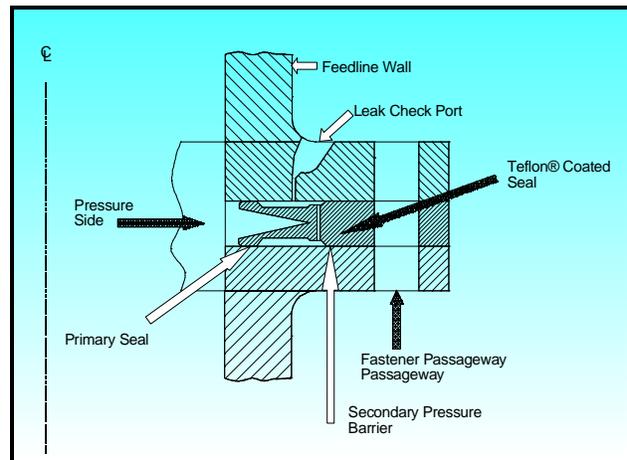


Figure 2. Spacer Type Deflection Actuated Pressure Assisted Seal. (Not to Scale)

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4. The Racó®/Creavey™ Seal Configuration

Figure 3 shows the combination Racó®/Creavey™ seal as used for 17-inch diameter feed lines on the ET. The primary Racó® seal consists of a metal hoop-spring inside an energized Teflon® jacket. The secondary Creavey™ seal is a metallic coil spring housed within an energized tubular Teflon® casing.

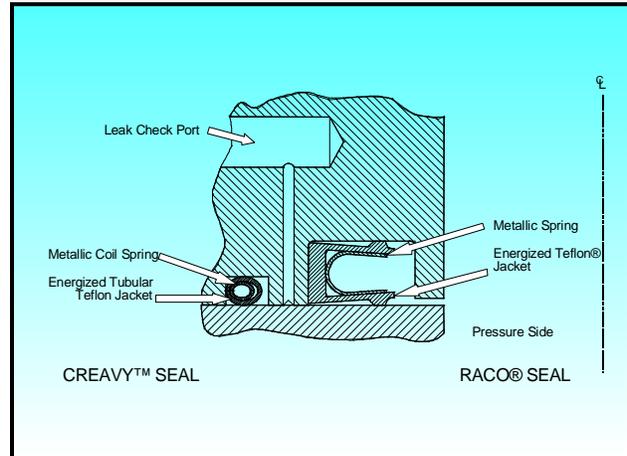


Figure 3. Racó®/Creavey™ Seal Configuration. (Not to Scale)

5. Recommended Practices

a. Design Practices

In general design practice, the development of a good leak-free joint design requires an integral look at the design of all the parts: seal(s), flanges, and fasteners. It also requires some foreknowledge of the degree of access required for leak checking, inspection, and potential disassembly and reassembly during downstream operations and particularly on the launch pad. Leak-free joint design is based on the seal maintaining contact between a surface on one flange and the mating surface on the other flange under all operating conditions. The fasteners take the dynamic loads and are installed in a preloaded condition to maintain seal contact with the flange surfaces. The seal in the joint must prevent leakage in excess of the allowable limit. The advantages of deflection actuated, pressure assisted seals are that they maintain a nearly constant fastener loading under pressurized and nonpressurized conditions and that they result in minimum flange deflection at the sealing surface. Sealing surfaces on flanges can be recessed to protect them from damage, and seal grooves can be configured for easy seal installation, centering of the seal, and for error-free assembly. The seal and joint can be designed with detents to prevent misaligned or reverse installation.

The design of joint assembly and seal installation tooling, equipment, fixtures, and procedures should proceed concurrent with joint design. The designer must remember that a separable joint is used to permit later disassembly, inspection, and reinsertion of seals or refurbishment/replacement of systems or components either in the manufacturing shop, on the test stand, or on the launch pad. The joint design and the assembly tooling or fixtures should provide: (1) protection

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to the seal and mating surface; (2) concentric and accurate seal positioning; and (3) even pressures around the periphery of the seal and joint during the fastener tightening process. Circumferential indexing that will ensure relocation of impressed seal surface deformities over corresponding flange deformities is desirable if the seal is to be reused. A good design practice is not to depend entirely on flange bolt locations to position seal components radially. A notch or groove should be provided to retain the seal. Gaskets, seals, parts, and subassemblies should be designed to preclude improper alignment or rotation. Using seals very close to the same size in the same area should be avoided. The design should be adaptable to using the same size seal (or a very different size) in all locations which are in close proximity. This practice will reduce the potential of installing the incorrect size seal.

The following design suggestions pertain to seals for cryogenic and gaseous hydrogen and oxygen:

- Where feasible, secondary seals with a vent for direct measurement of leakage should be provided.
- The materials in cryogenic/gaseous hydrogen seals should be resistant to hydrogen embrittlement.
- Walls should be provided in the seal groove to carry the seal hoop load when pressurized.
- Designs of liquid oxygen seals should include LO₂ compatible materials.
- Designs of liquid hydrogen seals should include LH₂ compatible materials.
- Potential flange ovality resulting from flange stresses or temperature cycling must be taken into account in establishing the width of flange sealing surfaces.
- The seal material(s) must be compatible with any anticipated purge or cleaning material that may contact the seal during its intended use. Purge or cleaning material restrictions should be noted on engineering drawings and in procedural documentation.

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- A seal alignment provision should be incorporated in the design process.

Design optimization in metal seals for cryogenics can be accomplished with currently available general purpose finite element analysis programs such as ANSYS (produced by Swanson Analysis Systems, Inc., see reference #13) or by specially programmed finite element models (reference #14). Modeling of seals can take into account surface texture, gas transmission flow methods, seal load distribution, material properties, and dynamic environmental conditions (temperature, pressure, vibration, shock, etc.). New seal designs should be evaluated using these analysis and modeling techniques and qualified before use (see below).

b. Qualification Practices

Prior to incorporation into the production design, the entire joint system, which includes the flanges, seal(s), and fasteners, should be qualified for use in the specific environments expected to be encountered in operations. [As part of the qualification procedures for SSME seals, seals of 0.8", 1.1", and 3.8" diameter were chilled to -250 deg.F and pressure cycled from ambient pressure to 8,970 psig for 240 cycles while demonstrating their ability to continue to meet leakage requirements. Seals were also subjected to structural verification at pressures up to twice operating pressures after completion of 240 pressure cycles, while still meeting leakage requirements.] If different temperatures, pressures, or gases are used for qualification and/or leak checking, leak and nonleak conditions must be carefully calibrated and correlated with leak and nonleak conditions in the actual environments expected. These calibrations must be meticulously adhered to in interpreting leak test results.

c. Manufacturing Practices

Cleanliness and inspection at intermediate manufacturing steps are extremely important in the manufacture of deflection actuated pressure assisted seals as well as for other types of seals used in liquid oxygen and liquid hydrogen environments. Nonspacer type seals are usually silver plated with an initial gold undercoat. The gold undercoat prevents oxidation of the substrate at temperatures above 600 deg.F, when used in hot gas environments, and this prevents blistering of the silver plating. Silver is used for its low compressive yield strength and ductility required for effecting a seal, and for its corrosion resistance. Rhodium overplate is used to prevent bonding of the

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silver plate to the mating flange surfaces at high temperatures. A chromate coating is used to prevent discoloration of the seal or flange due to tarnishing of the seal's silver plating. Care must be taken to thoroughly clean and inspect each seal between the plating and coating operations. Adherence of the Teflon® primer coat and subsequent final coat to spacer type seals also requires stringent cleaning and inspection between each operation to prevent inclusions, voids, contamination, and surface defects.

d. Inspection Practices

Seal and flange mating surfaces should be visually inspected after manufacture and immediately before installation with a 10X magnification device. Very tiny scratches across the face of the seal's coated or plated sealing surface can cause leaks. [In one instance, a scratch .001" wide and .0005" deep extending across the radial length of the sealing surface was of sufficient size to cause a Class I leak.] The inspector should look carefully not only for nicks and scratches in seals, but also for metal or foreign particles on the seal or on the mating flange surfaces. NASA problem reports have indicated that, in at least one incidence, metal flange faces were allowed to contact each other and to rub together prior to seal installation, causing fine metal particles to be created which interfered with the seal's ability to seat properly against the flange sealing surface. Optical microscopy up to a power of 50X has been used to detect very small flaws and irregularities in flange and seal surfaces when leakage tests failed. Seal flatness or waviness can be confirmed or detected by the glass test in which the seal is placed against a plate glass sheet and observed from the underside. This method can be used to detect potential nonparallelism or small deviations in seal contact or coating thickness. Precision flat bars can be used with a light source to verify that flange faces are flat.

e. Protection Practices

Many of the leaks detected from joints of cryogenic and gaseous lines were possibly caused by scratching or nicking of the flange sealing surfaces or the seal, after initial manufacturing and inspection, but before assembly. Post manufacturing, in-transit, and preassembly protection of both the seals and the joint sealing surfaces have proven to be essential in ensuring leak-free or acceptable leakage rate joints. LO₂-compatible protection caps or plugs should be used to protect sealing surfaces between manufacturing inspection and final assembly. Liquid oxygen compatibility is required of materials protecting oxidizer system joints because small particles of the protection material can

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rub off against the seal or flange surface and could lead to a fire or explosion. Cleanliness is more easily maintained with proper protection while the joint is in a disassembled condition.

f. Preparation Practices

As with in-transit or in-storage protection, thorough cleaning of the seals and flanges, accompanied by preinstallation inspection, is required to ensure leak tight joints. If the flanges are to be in storage for an extended period, they require a protective grease or jelly. If so, this material must be removed and the flange cleaned and reinspected prior to assembly, as this substance may have picked up fine particles during storage. If a protective substance has not been used, thorough visual inspection must take place to ensure that there are no evidences of corrosion. If corrosion exists, it must be removed and the flanges or seals reinspected both dimensionally and visually.

g. Installation and Assembly Practices

Several of the unacceptable leaks of joints carrying cryogenic fluids reported in NASA's Problem Reporting and Corrective Action (PRACA) system resulted from scratches to the seal or flange faces *during the assembly process* after preassembly inspection. These scratches may have been caused by the flanges rubbing together or the seal rubbing against corners or edges of the flanges. Several methods have been proposed or implemented to reduce the potential of seal or joint sealing surface damage during assembly. One method is to place Teflon® shims on both sides of the seal while it is being inserted into place between the flanges, and then to remove the shims once the seal is in place. Procedures have been developed which would not allow the flanges to touch the seal until the bolt torque pulls the flanges together. Special seal retaining or insertion tools and other assembly equipment can be designed to minimize the potential of damage during assembly (see Design Practices). Operators must be thoroughly trained and certified in these procedures. To provide uniform compression of the seal and a final uniform load around the seal's circumference, fasteners should be tightened in stages in a prescribed alternating fashion, starting with fasteners located 180 degrees apart.

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h. Leak Checking Methods

The most common method of seal and joint inspection after assembly is the leak test. Several leak detection procedures are used to check the integrity of LH₂, GH₂, LO₂ and GO₂ joints and seals: (1) bubble method; (2) gas analysis method; (3) pressure decay method; and (4) flow meter method. The most prominent method of leak testing is the bubble method. In the bubble test, a leak test solution is applied to the periphery of the joint while the interior is being pressurized with liquid helium gas or nitrogen in a manner that has been calibrated against the operational fluid's temperature, pressure, and flow rate to provide acceptable or nonacceptable leak rates. The bubble test method is confined to gaseous systems or cold gas simulations of cryogenic joint pressures and temperatures.

Four classes of leakage have been defined. In general, they are:

Class I: Steady formation of very small, long persisting bubbles.

Class II: Mixture of random size bubbles of moderate persistence.

Class III: Large, fast-forming bubbles.

Blowing: Bubble formation does not take place because of large gas flow.

Another common method of leak detection is the gas analysis method using a mass spectrometer. Although this method will determine that a leak exists, it is difficult to measure or to calculate the leak rate from mass spectrometer test results. Advanced methods of leak detection using palladium sensors, colorimetric methods, and nonintrusive sensors are being studied, but none has yet been as successful in both detecting the leak and indicating its magnitude as the leak test solution method.

The solution test method is simple, easy to use, and readily observable with the naked eye. Two precautions are important, however: (1) complete coverage of the joint with the leak test solution; and (2) close observation of the complete periphery of the joint. The technician should observe the leak test solution immediately after application so that a blowing leak is not missed. The general practice is to re-leak test whenever a joint is disturbed. In the case of the SSME, all joints are leak tested both before and after final hot firing acceptance. A total engine leak test is conducted at final acceptance to determine the total

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leakage from all 154 joints (80 oxidizer system joints, 44 fuel system joints, and 30 hot gas joints), which must be less than six standard cubic inches per minute.

In general, ambient temperature leak checks are not as accurate as testing in the chilled condition. Therefore, at least in initial development and checkout, the system must be cooled to its operating temperature, and realistic pressures and flow rates must be provided to identify potential leak conditions. The alternative is to use a different cryogenic or gas with prior accurate calibration of leakage results with the operational fluids, as mentioned earlier.

i. Storage Practices

Joints, flanges, or seals in storage must be protected against corrosion and against inadvertent damage of the seal or sealing surfaces. The protection device or substance must be compatible with the fluid for which the joint was designed and with which it will be operated. In-storage protection devices or substances must be completely removed and the parts must be recleaned and inspected prior to assembly.

j. Refurbishment and Reuse Practices

Seals can be refurbished by replating and reinspecting them to the original manufacturing standards. Seals that are reused without refurbishment should be indexed to provide reassembly in the same position as originally installed. Seals with damaged coating can be stripped and recoated or replated as long as the parent metal seal is dimensionally correct.

Technical Rationale:

These practices were derived from a review of Unsatisfactory Condition Reports (UCRs) of the PRACA system at Marshall Space Flight Center; from sources listed in the references including professional journal articles, presentations, books on cryogenics, and Government reports; and from over 30 years of experience in designing propulsion systems and stages incorporating cryogenic sealing requirements.

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Impact of Nonpractice:

The principal impact of nonpractice is unacceptable joint leakage of cryogenic and/or gaseous propellants from propulsion systems and stages. These leakages, if entrapped in specific areas of launch vehicles in the presence of ignition or heating sources, sparks, or rocket system exhausts could result in catastrophic loss of the vehicle and of lives of astronauts or ground crew. These catastrophic events, or location of leaks at critical times in the schedule can also cause program delays and can result in excessive program costs. Table 1 is a generic listing of selected typical conditions which could result in excessive leakage rates.

Related Practices :

Related practices pertaining to other sealing types and situations are planned for future editions of this manual.

References:

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Table 1. Impact of Nonpractice

CONDITIONS THAT COULD RESULT FROM NONPRACTICE (Any of the following could result in leakage in excess of specification requirements.)

1. Scratched or Nicked Seals
 2. Warped or Deformed Seals
 3. Improper Initial Leakcheck Test Procedures
 4. Improper Seal Alignment
 5. Improper Torque on Joint Bolts
 6. Metal Particles on Seals and Flanges
 7. Flaking off of Teflon® Coating
 8. Silver Plating Wavy or Thin
 9. Improper Assembly/Reassembly on Pad
 10. Corrosion of Seal or Joint Flanges
 11. Scratched, Damaged, or Warped Flange Surfaces
 12. Improperly Designed Seal or Flanges
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Definitions

cryogenics. Temperature region of liquified gases below 123 deg.K (-150 deg.C).

ET. External tank.

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GH₂. Gaseous hydrogen.

GO₂. Gaseous oxygen.

high nickel alloy steel. A heat-treatable, nickel-base (53 percent) steel alloy with good properties at both cryogenic and elevated 922 deg.K (1200 deg.F) temperatures.

leak. Defined in text on page 8.

LH₂. Liquid hydrogen.

LO₂. Liquid oxygen.

scim. Standard (atmospheric) cubic inches per minute; volumetric flow rate.

scratch, nick, or gouge. A damaged area in which material has been removed, or moved, with a resultant decrease in wall thickness.

SSME. Space Shuttle Main Engine.

static seal. A device used to prevent leakage of a fluid through a mechanical joint in which there is no relative motion of the mating surfaces other than that induced by changes in the operating environment.