PREFERRED
RELIABILITY
PRACTICES

VACUUM SEALS DESIGN CRITERIA

Practice:

Well made, clamped, and temperature stabilized circular O-rings should be used in the design of reliable, reusable and long life seals in vacuum sealing applications.

Benefits:

Leak free flanges as well as low/undetectable outgassing of the elastomeric materials can be achieved at pressure levels as low as 10^{-8} Torr by using well made O-rings in a static vacuum seal environment. The use of O-rings has provided ease for running environmental tests on the ground using space simulation chambers.

Programs Which Certified Usage:

Since 1950, LeRC has been operating vacuum chambers (such as the 15 foot diameter vacuum chamber addressed herein) with reliable and long lasting vacuum seals.

Center to Contact for More Information:

Lewis Research Center (LeRC)

Implementation Method:

The most common type of seal used for sealing vacuum systems is the O-ring. In order for any O-ring to be suitable for high vacuum service, it must have a very low vapor pressure at the service temperature. It must not have any components or materials which will vaporize at the pressures and temperatures to which the joint will be subject. Butyl, Buna-N and Fluorocarbon (Viton® A) rubber materials have been used to vacuum seal large chambers (15 foot and 25 feet in diameter) at LeRC. These materials can, in well made, clamped O-rings and under temperature controlled conditions, seal vacuum as low as 10^{8} Torr. Small (6 foot diameter) and large (50 foot diameter) vacuum chambers have been successfully used on research programs at LeRC to simulate space pressure conditions and environment. Environmental testing, experiments, and pre-flight tests (all requiring large-volume vacuum environment) have been performed at LeRC in these chambers. For this pressure range, the following O-ring design considerations should be followed:

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Dimensional. To obtain the correct degree of compression for optimum O-ring sealing, careful consideration must be given to the size of the O-ring in relation to the size of the groove space into which the O-ring is being installed. Every groove has a slight gap (diametrical clearance) between the two mating surfaces forming the groove's internal cavity. It is important, therefore, for O-ring volume to be larger than the cavity, allowing seal compression to block the diametrical gap, preventing leakage and providing 25% compression in the O-ring. Butyl rubber has been tested in face type O-ring seals using grooves that provided 15%, 30% and 50% compression. For vertical O-ring applications (as a chamber), it is desirable to use an undercut groove similar to that shown in Figure 1. The O-ring is held firmly in place and has no tendency to drop out of the groove when the chamber is open.

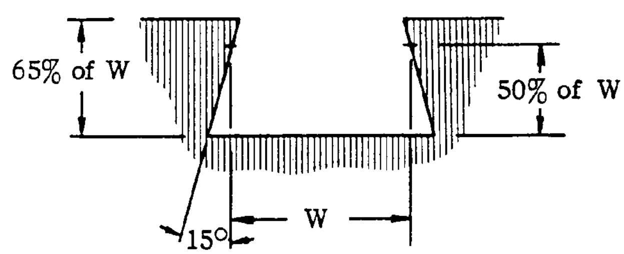

Figure 1. O-Ring Groove Dimensions for Vertical Position

Pressure. Total clamping pressure on the O-ring due both to the effects of vacuum on the parts being closed, and the effects of bolts or clamps used with the O-ring, should be approximately 800 pounds per lineal inch of O-ring. If the O-ring cannot resist increasingly high pressure, part of the O-ring will be forced (extruded) into the diametrical gap, causing tearing, pre-mature failure and leakage. To minimize O-ring movement and accompanying wear within the groove in face sealing, involving either internal or external pressure, the O-ring should always be seated against the low pressure side of the groove. The use of two O-rings on the chamber's sealing surface has proven successful in holding the required pressure applied on the 15 foot diameter seal as illustrated in Figure 2. The reason for the two O-ring design is that it is possible to pump out the space between the two O-rings. The effect of this technique is to make use of the outer O-ring for

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holding a relatively crude vacuum and subject the inner O-ring to only a small differential between the high vacuum system on its inner face and the partial vacuum on its outer face. As a result of this double pumped system, the leakage per O-ring can be greatly reduced.

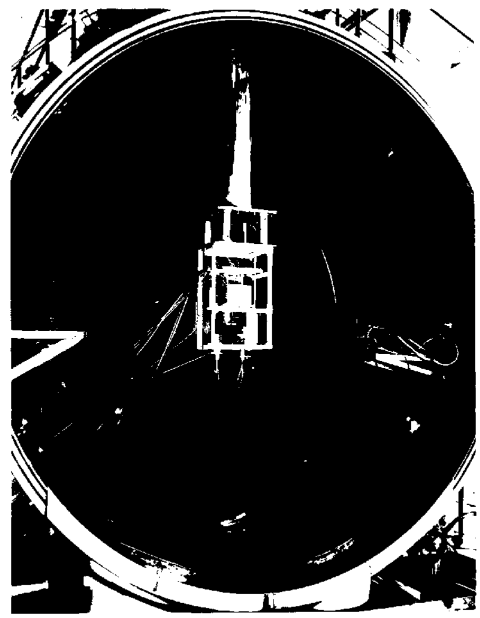

Figure 2. **Two O-rings are used on the 15 foot diameter chamber**

Vapor Pressure. The O-ring must have a very low vapor pressure at the service temperature. It must not have any components which will vaporize at the pressures to which the joint will be subject. Resilient organic material such as Viton®A is most commonly used to produce and hold vacuum as low as 10^{-9} Torr .

Temperature. The vapor pressure of most or all organic materials is proportional to temperature. It is therefore very important that O-ring's temperature be limited.The best of the materials must be held below 250°F, and for minimum outgassing an even lower temperature is recommended. For temperatures held below 65°F, it is possible to use carefully constructed O-ring joints at pressures as low as 10^{9} Torr. Excessive heat, over time, degrades O-ring materials physically, and/or chemically, which may render them non-functional as seals. The O-ring temperature must be reduced to values between zero and -10° F during ultra vacuum operation.

Surface. It is important that the groove surfaces be so ground and polished that no residual tool marks or scratches occur at right angles to the length of the groove. Even minute scratches can produce a leak, which is difficult to locate and repair. The mating flanges, which are flat and serve to compress the O-ring must have, at the point where the O-ring contacts them, an equally good finish. The surface finish in the O-ring groove and on the flat mating flange must be at least 32 micro inch and preferably 16 micro inch.

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Permeability. In vacuum applications, high material resistance to gas permeation is directly equated with low vacuum leakage of the O-ring. Butyl and Fluorocarbon excel as the most impermeable performers. Increased O-ring compression reduces permeability by increasing the length of the path the gas has to travel (width of ring) and decreasing the area available to the entry of the gas (groove depth). Increased compression also tends to force the rubber into any small irregularities in the mating metal surface, and thus prevents leakage around the seal.

Vacuum Weight Loss. It is particularly important in many space and other vacuum applications that optical surfaces and electrical contact surfaces remain clean to serve their intended purpose. Some rubber compounds contain small quantities of oil or other ingredients that become volatile under high vacuum conditions and deposit as a thin film on all the surrounding surfaces. Table 1 indicates the weight loss of several compounds due to vacuum exposure. Where sensitive surfaces are involved, the higher weight loss compounds should be avoided. In the low weight compounds, the small amount of volatile material that is indicated is primarily water vapor which is not likely to deposit on nearby warm surfaces.

Table 1. Weight Loss of Compounds in Vacuum

Test Samples: Approximately 0.075 thick   Time: 336 hours (two weeks)
Vacuum Level : Approximately 1×10^{6} torr Room Temperature

Compound Number	Polymer	Percent Weight Loss	Compound Number	Polymer	Percent Weight Loss
B612-70	Butyl	0.18	N674-70	Nitrile	1.06
C873-70	Neoprene	0.13	P648-90	Polyurethane	1.29
E515-80	Ethylene Propylene	0.39	S455-70	Silicone	0.03
E529-60	Ethylene Propylene	0.92	S604-70	Silicone	0.31
E692-75	Ethylene Propylene	0.76	V747-75	Fluorocarbon	0.09
L449-65	Fluorosilicone	0.28	V884-75	Fluorocarbon	0.07
L677-70	Fluorosilicone	0.25	V894-90	Fluorocarbon	0.07
N406-60	Nitrile	3.45			

Vacuum Seal Considerations. The rate of flow of gases from the pressure side to the vacuum side of a vacuum seal depends to a great extent on how the seal is designed. As mentioned earlier in this document, increasing the compression reduces the leak rate. Lubricating the O-rings with a high vacuum grease also reduces the leak rate significantly. The vacuum grease aids the seal by filling microscopic pits and grooves produced by small irregularities in the mating metal surface. The O-ring should first be cleaned to remove all dirt and foreign material utilizing a small amount

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of Alcohol on a cloth as a cleaning agent, and should be given a very thin coat of vacuum grease (i. e., Apiezon grease) applied by drawing it through fingers slightly coated with vacuum grease. It should be noted that vacuum grease should not be depended upon to provide any sort of vacuum seal.

Vacuum Leak Approximation. The leak rate of a gas through an O-ring seal may be roughly approximated when the permeability of the gas through a particular material is known for the temperature at which the seal must function. The following formula is useful for this approximation:

$$L \approx 0.7\ F\ D\ P\ Q\ (1-S)^2$$

- L = Approximate leak rate of the seal, std. cc/sec.
- F = Permeability rate of the gas through the elastomer at the anticipatedtemperature, std. cc cm/cm^2 sec bar. (example: Butyl's permeability at 77°F with Acetylene is 1.26 x 10^{-8} std. cc cm/cm^2 sec bar)
- D = Inside diameter of the O-ring, inches.
- P = Pressure differential across the seal, lb/in^2.
- Q = Factor depending on the percent compression and whether the O-ring is lubricated or dry (from figure 3 below)
- S = Percent compression on the O-ring cross section expressed as a decimal (i.e. for 20% compression, S = 0.20)

Note: This formula is a rough order of magnitude approximation and is based on the following assumptions:
1) The cross section of a compressed O-ring is rectangular.
2) The cross section area of a compressed O-ring is the same as its area in the free condition.
3) The permeability rate of a gas through an O-ring is proportional to the pressure differential across the seal.

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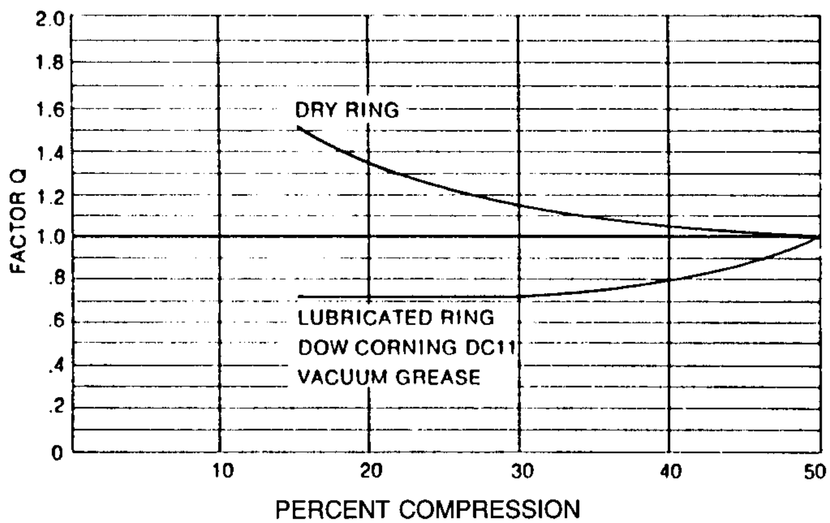

A variation of plus or minus 50% from the predicted values should be anticipated to allow for limitations in the accuracy of test equipment and available standards, and for variations between samples.

Figure 3. Effect of Compression and Lubricant on O-ring Leak Rate

Static Seal Cross Section Calculation. To calculate correct cross section dimensions for static seals, list the gland depth and multiply by the minimum and maximum compression requirements (listed in Table A, Section 3 of Reference 5). For Inside Diameter (I.D., or hole diameter) calculation, list the diameter of the part the O-ring will be stretched over during installation, and reduce this figure by 1 to 5% to undersize the O-ring's I.D, allowing for stretch.

Vacuum Feedthroughs. Many types of vacuum feedthroughs are available from suppliers as Varian Vacuum Products (Reference 6). They are designed for pressure as low as 10^{11} Torr and provide leak-free performance in high and ultrahigh vacuum systems. With ceramic-to-metal seal construction, applications for these feedthroughs include: Instrument and Thermocouple Leads, RF Power Input, Coaxial Input, Mask and Substrate Handling, Target Movement, Liquid Cooling, High Voltage Conduction and High Current Conduction.

As an example for using one type of feedthrough, electrical circuits carried into and out of ultrahigh vacuum systems must be of ceramic-to-metal seal construction. A tight bond is made between a ceramic and a kovar transition sleeve which is then welded into the stainless steel of the vacuum vessels. The actual electrical feedthroughs come through the center of the ceramic

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insulator and are bonded to it by special bonding techniques to achieve gas tightness. It is important that electrical leads inside ultrahigh vacuum systems must be insulated by means of non-outgassing materials. These leads should be limited to ceramic beads since all of the elastomeric type insulating materials outgas a considerable amount in vacuum systems.

Rotating Seals. O-rings are used as seals for rotating shafts, with the turning shaft protruding through the internal diameter of the O-ring. The inside surface of the O-ring is continuously exposed to friction generated heat from the rotating shaft. The most important factors to consider when designing rotating seal glands are frictional heat buildup, O-ring stretch, compression, application temperature limits, and shaft glandular machining.

O-rings should be comprised of compounds featuring maximum heat resistance and minimum friction generating properties. To help minimize O-ring heat buildup, the following mechanical design safeguards should be considered where applicable:

1) Reduce compression to 0.002 inch to minimize friction.
2) Select the O-ring with the smallest possible cross section.
3) Select an O-ring comprised of a hard, self-lubricating compound (such as graphite).
4) Avoid applications requiring lower than -40° F, or higher than +250° F operating temperatures.
5) Locate the gland as close as possible to the lubricating fluid and as far away as possible from the shaft support bearings.
6) Assure that relative motion occurs only between the O-ring internal diameter and the rotating shaft, not between the O-ring and the gland. This can be accomplished by minimizing eccentric shaft rotation (machining shafts concentric to within 0.0005 inch TIR); by finishing shaft surfaces to 16 micro inch (for smooth, non-abrasive running); and machining gland surfaces to a rougher 32 micro inch (to discourage O-ring movement within the gland).

Technical Rationale:

Vacuum chambers (ranging from 6 to 50 feet in diameter) have been utilized at LeRC for over 30 years to simulate space conditions. The reliable, reusable, long lasting, and round configuration vacuum seals demonstrate the success of using rubber O-rings to vacuum seal these small and large chambers. Environmental testing, experiments, and pre-flight tests have been fruitfully conducted in these chambers in space simulated environment. These practices were gained from LeRC's experience with vacuum seals and sources listed in the references.

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Impact of Nonpractice:

Incompatible O-ring elastomer and environmental elements, incorrect O-ring size, improper gland design (including rough surface finish), and inadequate O-ring lubrication may result in O-ring failure, joint leakage and ineffective vacuum seals. Leakage in vacuum seals can be detrimental to space crew, vehicles and equipment.

Related Practices:

"Static Cryogenic Seals for Launch Vehicle Applications" PD-ED-1208.

References:

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4. Parker Seals, "Parker O-Ring Handbook", ORD 5700, Parker Seal Group, O-Ring Division, Lexington, KY, 1991.

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