A Review of the Principles for Creating Leak Free Vacuum Flanges with Elastomeric O-Rings

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Tested in space simulation chambers by NASA, leak free flanges with elastomeric materials can be achieved at pressure levels as low as 10^{-8} Torr, and beyond.

For any O-ring to be suitable for high-vacuum service, it must have 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 materials such as genuine Viton Type A are the right materials for service in low pressure environments, provided the O-ring is properly clamped and under temperature-controlled conditions.

Material and environmental considerations:

Butyl elastomers are a preferred material for vacuum sealing applications due to their excellent gas permeation resistance, low outgassing and weight loss characteristics, and moisture resistance. Where hot water, steam, or radiation is present, ethylene propylene materials can be considered. But the material with the best overall combination of permeation resistance, low outgassing and weight loss, and resistance to heat, is genuine Viton Type A.

In high temperature applications up to 315°C (600°F), the use of perfluorinated elastomers is best. However, it is important to note that the thermal expansion coefficient of perfluorinated elastomers (FFKM) is much higher than that of conventional materials like genuine Viton Type A. Therefore, it is important to incorporate extra capacity into the gland design. When taken from room temperature to 250°C (482°F), volumetric expansion of the perfluorinated elastomer falls between 20 – 25%. In such a case, the O-ring should not fill more than 75% of the gland at room temperature.

When the properties of high weight loss compounds are required in a vacuum sealing application, vacuum baking the O-ring can drive off any residual volatile components before the parts are assembled. But be aware that this procedure make shrink the O-rings and modify their low temperature resistance.

O-ring design considerations:

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 gland space into which the O-ring is being installed. Every groove has a slight gap (diametrical clearance) between the two mating surfaces forming the grooves 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 of the O-ring.

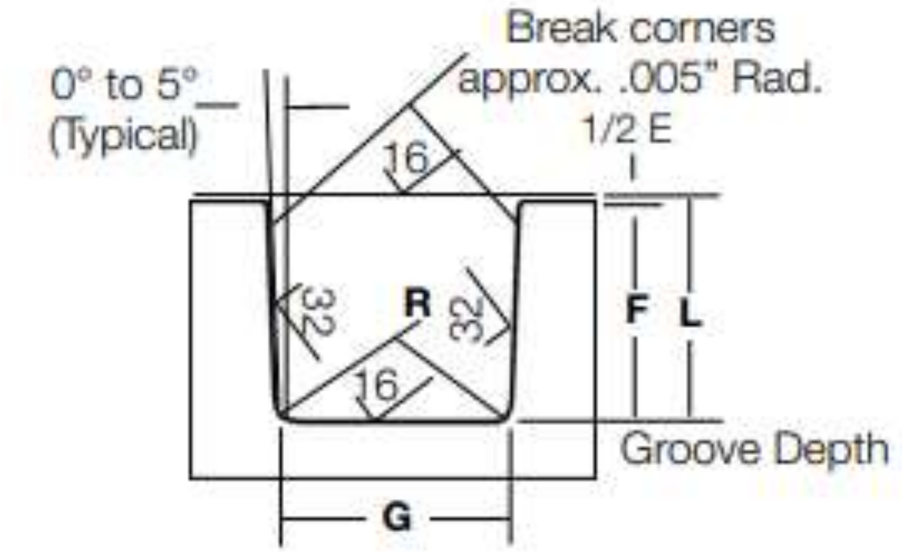

Figure 1: O-ring Static Face Seal Gland (credit: Parker)

Face-type O-ring sealing glands are commonly used on horizontal surfaces. For vertical surfaces such as chamber doors, undercut grooves will hold the O-ring firmly in place when the chamber door is open.

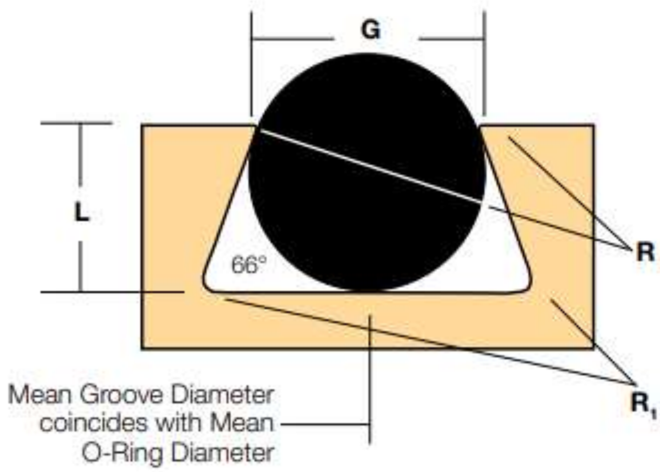

Figure 2: O-ring Groove Dimensions for Vertical Position (credit: Parker)

<u>Clamping pressure</u>:

Total clamping pressure on the O-ring, due both to the effects of vacuum on the parts being exposed and the effects of the bolts and clamps on 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 gland in face sealing, involving either internal or external pressure, the O-ring should always be sealed against the low-pressure side of the gland.

Dual O-ring design:

When using elastomeric O-rings to get to ultra-high vacuum conditions, using two O-rings on the chamber's sealing surface has proven successful. 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 holding 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 the double-pumped system, the leakage per O-ring can be greatly reduced.

Service temperature:

The vapor pressure of most organic materials is proportional to temperature. The best of the materials must be held below 121°C (250°F). Excessive heat, over time, degrades the O-ring materials physically and/or chemically, which may render them non-functional as seals.

For minimal outgassing, a lower temperature is recommended. For temperatures held below 18°C (65°F), it is possible to use carefully constructed O-ring joints at pressures as low as 10^{-9} Torr. The O-ring temperature must be reduced to values between -17°C (0°F) and -23°C (-10°F) during ultra-high vacuum operation.

Surfaces:

It is important that the groove and mating 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. Surface finishes that come in contact with the O-ring must be at least 32 micro inches, and preferably 16 micro inches.

Permeability:

Butyl and fluorocarbon materials excel as the most impermeable performers in vacuum applications. Increased O-ring compression reduces permeability by increasing the length of the path the gas must travel (width of the O-ring) and decreasing the area available to the entry of gas. Increased compression also tends to force the rubber into any small irregularities in the mating metal surfaces, thus preventing leakage around the seal.

Vacuum weight loss:

It is particularly important in vacuum applications that the optical 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 surrounding surfaces. Where sensitive surfaces are involved, higher weight loss compounds should be avoided. In low weight compounds, such as genuine Viton Type A, the small amount of volatile material that exists is primarily water vapor, which is not likely to deposit on nearby warm surfaces.

High vacuum grease:

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, increasing 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 surfaces. The O-ring should first be cleaned to remove all dirt and foreign material utilizing a small amount of alcohol on a cloth as a cleaning agent, and should be given a very thin coat of vacuum 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.

Static seal inside diameter calculation:

For inside diameter (hole diameter) calculation, measure the diameter of the part the O-ring will be stretched over during installation, and reduce this figure by 1-5% to undersize the O-rings I.D., allowing for stretch.

Static seal cross section calculation:

When calculating the cross section (C.S.) of an O-ring, consider the size of the gland to be filled as well as the amount of squeeze needed to create a good seal. Virtually every gland has a slight gap between the two mating surfaces, termed "diametrical clearance." Therefore, it is important for the O-ring cross-section to be greater than the gland height. The resulting O-ring squeeze prevents leakage by blocking the diametrical gap.

Conclusion:

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 damage and ineffective vacuum seals.

References:

1. NASA, Preferred Reliability Practices, Vacuum Seals Design Criteria, PD-ED-1223.
2. Parker O-Ring Vacuum Sealing Guide.