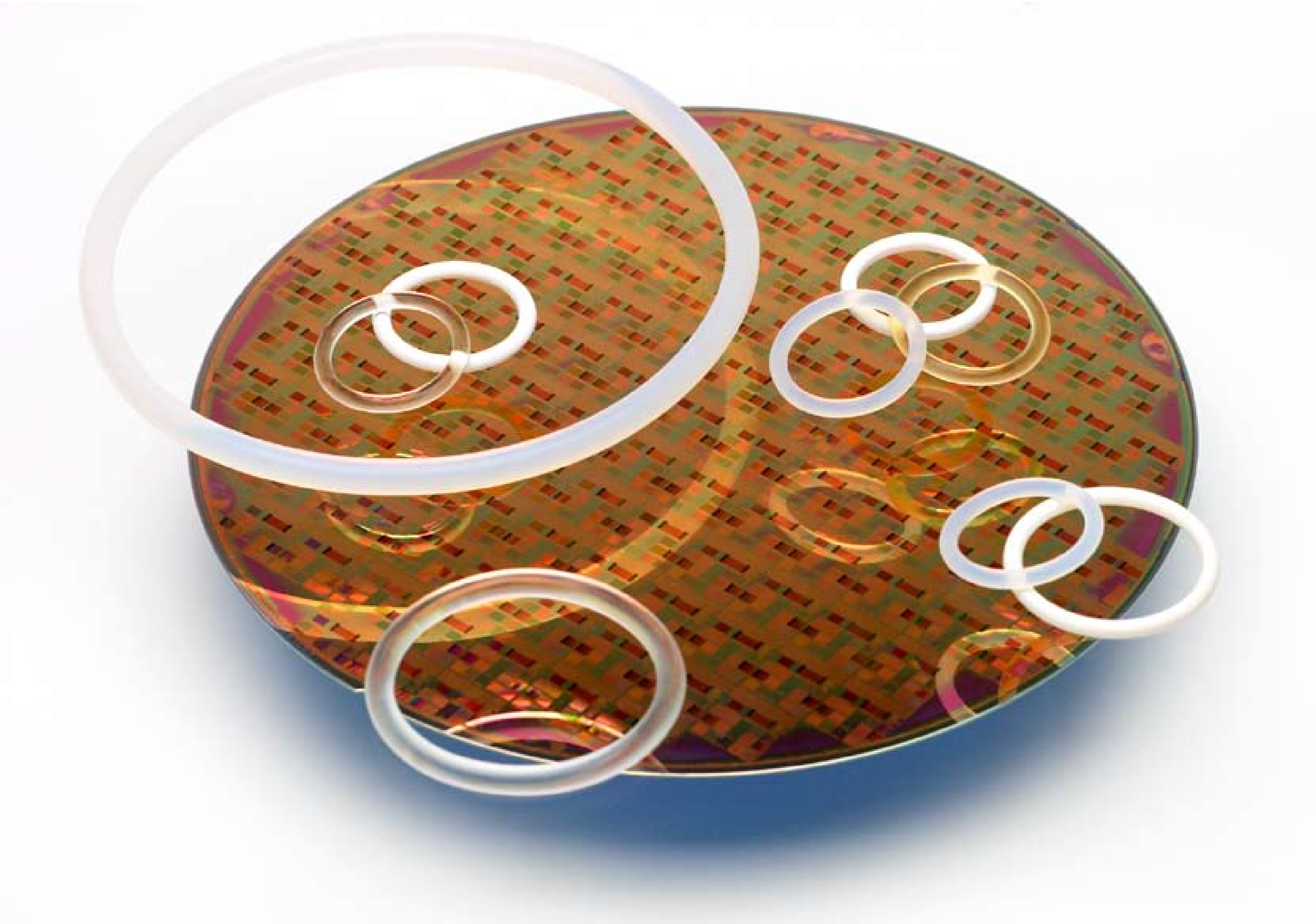

Parker O-Ring Vacuum Sealing Guide

ORD 5705

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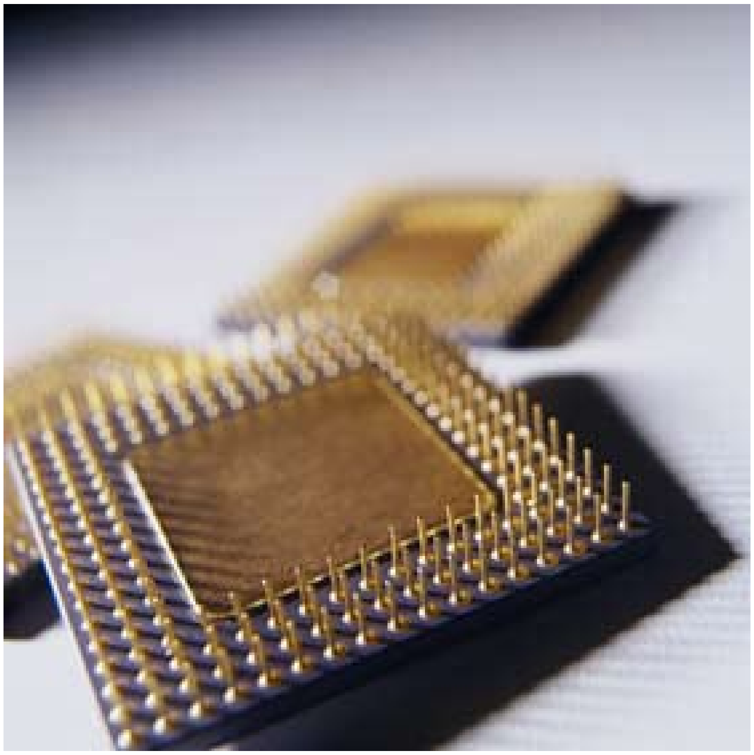


Introduction to Vacuum Sealing

There has been much discussion recently about the best means for providing a good vacuum O-ring seal. Butyl elastomers have long been the preferred material for sealing vacuum applications. The primary reason for this popularity is butyl's excellent gas permeation resistance. This vital property, together with the fact that butyl compounds have low outgassing and weight loss characteristics, good physical properties, a temperature range from - 54°C to +124°C (- 65°F to +225°F) and good moisture resistance, has established butyl materials in this preferred position.

Other Environmental Factors
The need for special environmental or service considerations in addition to basic low permeability will often reduce the potential to utilize butyl. Requirements such as high temperature, radiation resistance, or certain combinations of fluid media may take careful study to ascertain the proper material recommendation. For instance, high temperature or acid resistance would require the use of a fluorocarbon material, which has a temperature range of - 26°C to +205°C (-15°F to +400°F) while still retaining its properties of low outgassing and low permeation. Where hot water, steam, or radiation is present, an ethylene propylene material should be considered. Ethylene propylene has a service temperature range of - 54°C to +149°C (-65°F to +300°F). Some Parker ethylene propylene compounds, however, can withstand exposure up to +260°C (+500°F) in steam. Or in high temperature applications up to 600°F, the use of perfluorinated elastomers would be best.

Deep Vacuum Weight Loss is particularly important in many space and other vacuum applications where optical surfaces and electrical contact surfaces must remain clean to serve their intended purpose. Some rubber compounds contain small quantities of oil or other ingredients that become mobile under high vacuum conditions and may deposit a thin film on all the surrounding surfaces. Table I (see page 3) indicates the weight loss of several Parker Seal compounds due to exposure to vacuum environments.

Where sensitive surfaces are involved, the higher weight loss compounds should be avoided in favor of the low weight loss materials. The small amount of volatile material contained in low weight loss Parker Seal compounds like FF370 or HF355, is primarily water vapor and is not likely to deposit on nearby critical surfaces.

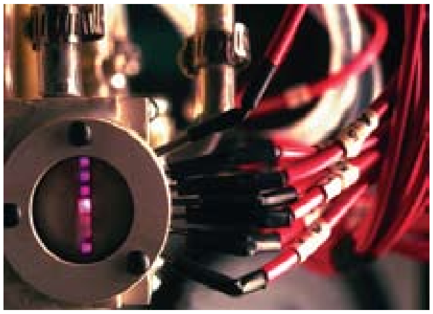
When the properties of a high weight loss compound are required in a vacuum sealing application, some customers have the O-rings vacuum baked to drive off any residual volatile components before the parts are assembled. Be aware however, that this procedure may shrink the O-rings and modify their low temperature resistance.

O-Ring Squeeze and Effects of Lubrication
A major vacuum sealing consideration is the rate of flow of gases from the pressure side to the vacuum side of an elastomeric O-ring. This flow rate depends to a great extent on how the O-ring is used. One butyl compound has been tested in face-type O-ring seals, using grooves that provide 15%, 30%, and 50% squeeze. It will be seen from the results plotted in Figure I (see page 3) that increasing the squeeze reduced the leak rate dramatically. Lubricating the O-ring with a high vacuum grease also reduced the leakage of the light (15%) squeeze rings significantly, but the effect of the grease was considerably less at 30% squeeze, while at 50% squeeze the beneficial effect of the grease was not detectable. Several other compounds were tested in this way with similar results.

Increased O-ring squeeze reduces flow rate by increasing the length of the physical path the gas has to travel (width of ring) and decreasing the area available to the entry of the gas (groove depth). Increasing squeeze also tends to force the elastomer into any small imperfections or surface finish marks in the mating metal surfaces, and thus prevents leakage around the seal. The application of vacuum grease changes the surface tension and may reduce the rate of surface absorption.

It is therefore recommended that dovetail or face type O-ring grooves be used whenever possible for static vacuum seals, employing a suitable vacuum grease as a sealing lubricant and surface coating in addition to a heavy squeeze on the O-ring cross-section. When a radial vacuum seal is required, or when a heavy squeeze is not possible for some design reason, it becomes even more important to use a suitable vacuum grease.

Although a heavy squeeze is necessary to reduce leakage to an absolute minimum in an O-ring vacuum seal, this type of design may require heavy flange construction. Furthermore, extreme squeeze values may crush the O-ring. However, when an extra-shallow gland is desired in order to increase the squeeze, it must be made wide enough to accommodate the full O-ring volume.



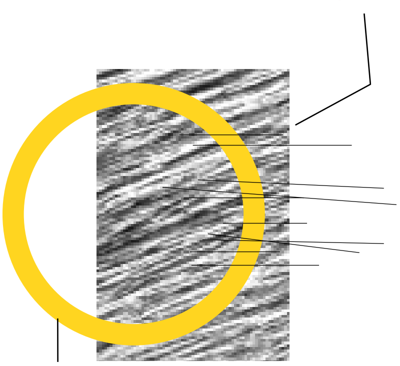
Parker elastomer seals are used in many specialized vacuum applications, from laser pumps to semiconductor processing.

For most purposes, the gland design shown for vacuum and gases in Design Chart 1 (see page 6) is a reasonable compromise in a face seal situation. The squeeze recommended in this design chart, however, is sufficiently heavy that a male or female gland assembly with the same dimensions may be very difficult to assemble. For these situations, O-ring grooves in accordance with the standard static seal glands found in Design Chart 4 (see page 9) may be more suitable.

Dovetail & Half-dovetail Grooves
It is often necessary to provide some means for retaining an O-ring in a face seal groove during assembly and maintenance. An undercut or "dovetail" groove has proven effective in many applications to keep the O-ring in place. A dovetail groove, however, is expensive to machine and thus should be used only when absolutely necessary.

It should be noted that although this type of gland has been used successfully, it is generally not recommended for applications othen than those in the Microelectronics industry. The inherent characteristics of the groove design limits the amount of void area. Therefore, normally acceptable

Avoid having tool marks perpendicular to the O-ring sealing line. This creates a built-in leak path.



O-ring Vacuum Seal

The ideal surface finish for any vacuum seal flange has a circular lay. (Preferrably lathe turned)

tolerance extremes, wide service temperature ranges, and fluid media which cause high swell of the elastomer are conditions which very often cannot be accommodated by a dovetail groove. Design Charts 2 & 3 (see page 7-8) provide dimensional recommendations for full and half-dovetail vacuum seal O-ring grooves.

Dynamic Vacuum Sealing
There is very little data available on dynamic vacuum seals, but reasonably low leak rates have been reported using two O-rings seals designed according to the standard radial dynamic design dimensions for reciprocating seals which are shown in Design Chart 5 (see page 10). In sealing gases and vacuum, it is quite feasible to use two O-ring seals in separate grooves. In reciprocating hydraulic applications, however, such redundant seals are not recommended because of the danger of creating a pressure trap between the two seals.

Gland Surface Finishes for Vacuum Sealing Service
Surface roughness of gland surfaces is more critical in sealing pressurized gases or vacuum than it is for liquids, because a gas will find its way through extremely minute passages. Therefore, surfaces against which an O-ring must seal should have a surface finish value smoother than usual. Surface finishes of 16 rms are recommended, with care being taken to insure that there are no machine or tool marks perpendicular to the seal as shown in the illustration below.

Vacuum Leak Rates
To determine the approximate leak rate for a vacuum seal, use the "Leak Rate Approximation" method. The leak rate of a gas through an O-ring seal may be roughly approximated when the permeability of the gas through the particular elastomer is known for the temperature at which the seal must function.

The following formula is useful for this approximation:

$L = .7FDPQ(1\text{-}S)^2$ where:

L = Approximate leak rate of the seal, std. cc/sec.

F = Permeability rate of the gas through the elastomer at the anticipated operating temperature. Std cc cm/cm^2 sec bar (Permeability rates for helium, hydrogen, and carbon dioxide through some representative Parker compounds are shown in Table 2 on page 4).

D = Inside diameter of the O-ring, inches.

P = Pressure differential across the seal, Ib/in^2.

Q = Factor depending on the percent squeeze and whether the O-ring is lubricated or dry. (From Figure 2)

S = Percent squeeze on the O-ring cross section expressed as a decimal. (i.e. for 20% squeeze, S = .20)

This formula provides only a rough order of magnitude approximation because permeability varies between compounds in the same polymer family, and because it is based on the assumption that:

1. The cross-section of a squeezed O-ring is rectangular.

2. The cross-sectional area of a squeezed O-ring is the same as its area in the free condition.

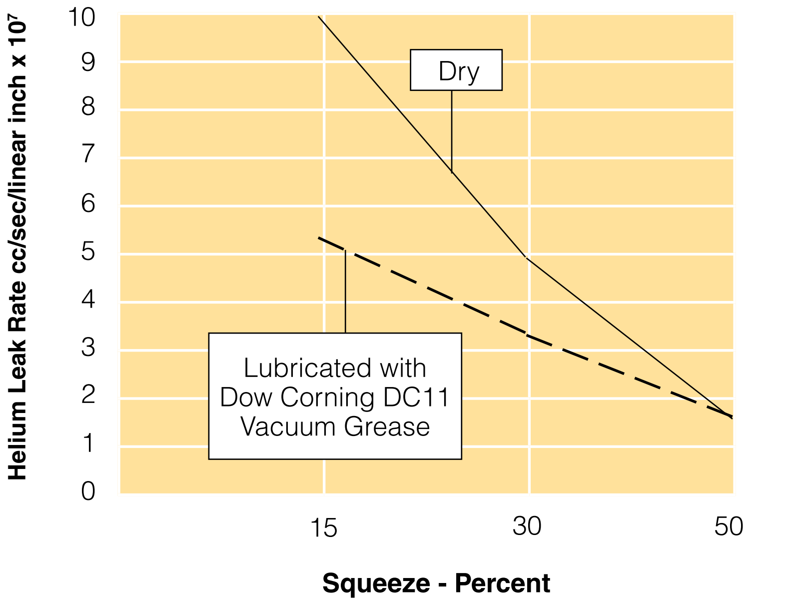
3. The permeability rate of a gas through an O-ring is proportional to the pressure differential across the seal.

Note: These assumptions are not entirely accurate.

For convenience, the formula contains mixed units. It was set up this way because in the United States, O-ring diameters are usually given in inches, and pressures in pounds per square inch, while permeability figures are usually shown in metric units. The .7 factor provides dimensional homogeneity.

Weight Loss and Leak Rate

Figure 1 O-Ring Leak Rate - Dry vs. Lubricated



Test Sample: O-ring I.D.= 4.850", W= .070"
Compound: Butyl
Pressure Differential: 60 psi
Temperature: 25°C (77°F)

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

Table 1 Weight Loss of Elastomer Materials in Vacuum			
Test Samples	Approximately .075" thick		
Time	336 hours (two weeks)		
Vacuum Level	Approximately 1 x 10^{-6} torr		
Temperature	Ambient - approximately 21°C (70°F)		
Polymer Type	**Percent Weight Loss**	**Polymer Type**	**Percent Weight Loss**
Butyl	.18	Fluorosilicone	.28
Ethylene Propylene	.39	Neoprene	.13
Ethylene Propylene	.76	Nitrile	1.06
Ethylene Propylene	.92	Nitrile	3.45
Fluorocarbon	.07	Polyurethane	1.29
Fluorocarbon	.09	Silicone	.03
Fluorosilicone	.25	Silicone	.31

Note: Varying weight loss figures within the same polymer family represent different formulations or compounds made from that base polymer.

Vacuum Squeeze and Gas Permeability

Figure 2 Effect of Squeeze and Lubricant on O-Ring Leak Rate

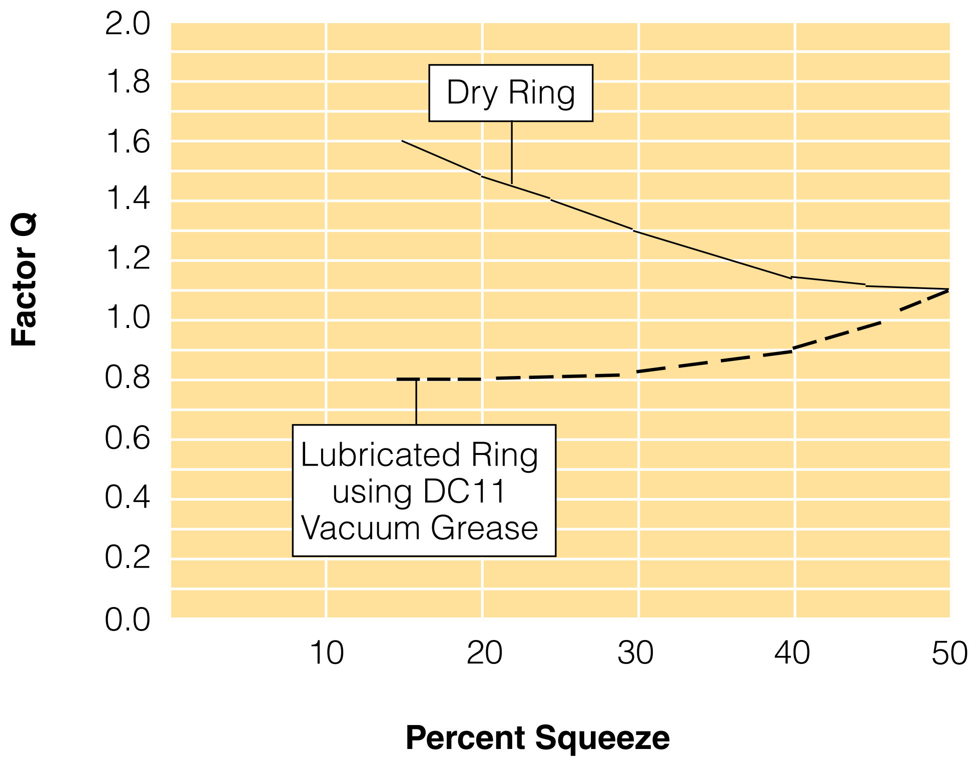


Table 2 Gas Permeability Rates			
Base Polymer	**Permeability x 10^{-8} cc cm/cm^2 sec. bar**		
	Helium	**Hydrogen**	**Carbon Dioxide**
Butyl	6.5 @77°F	16.1 @ 95°F	N/A
Fluorocarbon	12.7 @77°F	160.0 @ 200°F	N/A
Fluorosilicone	143.0 @ 77°F	N/A	444.0 @ 79°F
Neoprene	6.5 @ 77°F	180.0 @ 100°F	9.98 @ 72°f
Nitrile	8.0 @ 77°F	21.2 @ 100°F	47.7 @ 86°F
Polyacrylate	16.3 @ 77°F	49.6 @ 100°F	N/A
Silicone	238.0 @ 77°F	1010.0 @ 103°F	2280.0 @ 77°F
Ethylene propylene	19.7 @ 77°F	111.0 @ 104°D	N/A
Perfluroelastomer	23.8 @ 68°F	N/A	5.77 @ 68°F

Permeability rates listed above are for standard elastomers when tested with gases and temperatures as indicated.
N/A = no data currently available.

Design Recommendations for High Temperature Applications

Thermal Expansion
The thermal expansion coefficient of perfluorinated (FFKM) elastomers is much higher than that of conventional seal materials like nitrile (NBR) or fluorocarbon (FKM).

When designing a perfluorinated O-ring seal gland for high-temperature service, it is important to take into consideration the potential effect of thermal expansion and incorporate extra capacity in the gland cavity. The forces generated by excessive elastomer expansion in a confined space (gland) can severely damage the O-ring seal, and warp or distort the metal retainer and fasteners of the sealed assembly.

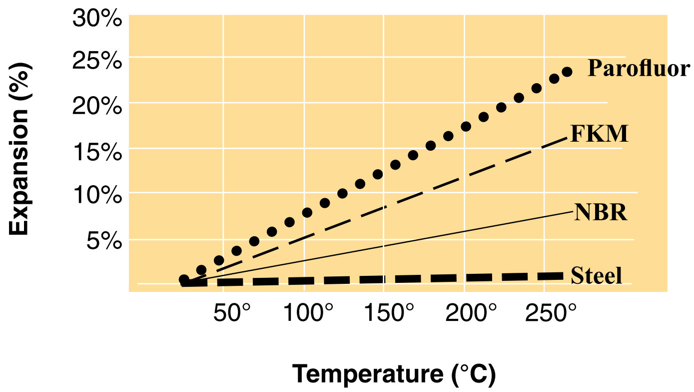
Figure 3 illustrates the relative volume change of several different elastomers and, for comparison, steel. Note that the volumetric expansion of perfluorinated rubber is about 22% when taken from room temperature to +250°C (+482°F).
In such a case, the gland fill of the seal assembly should not exceed 75% at room temperature to allow for thermal expansion and thus avoid generation of excessive internal forces which could result in O-ring extrusion and/or damage to mating parts.

Figure 4 illustrates an FEA plot of a Parofluor O-ring cross-section shown in:

(a) its original uncompressed state.
(b) after installation at room temperature.
(c) at elevated temperature of +250° C (+482°F).

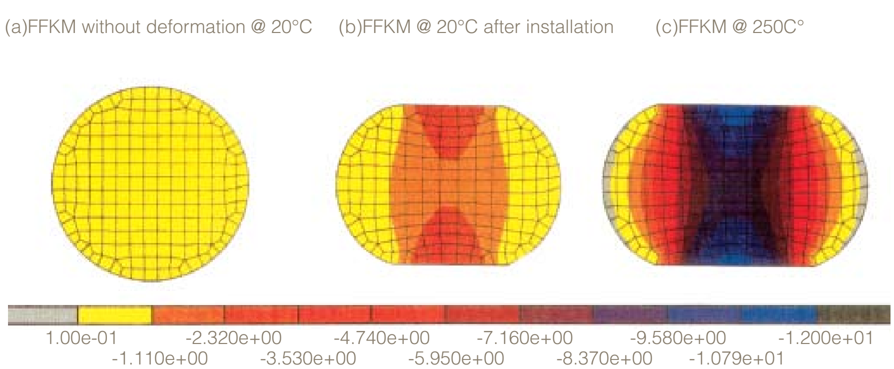
NOTE: the extreme amount of volumetric expansion is due to thermal stressing of the perfluorinated material.

Figure 3 Relative volume change due to thermal expansion



Finite Element Analysis (FEA)
Finite Element Analysis is a computer modeling process used to calculate strain and stress forces of a mechanical structure. These forces may be generated by external mechanical loading which induces internal stress as well as internal thermal loading which has the same effect when the O-ring is confined within its gland. FEA modeling uses a "mesh" of small elements as shown in (a). For each element, equilibrium conditions are then established relative to all other contacting elements. The finer (smaller) the mesh of elements defining the structure to be examined, the more accurate the analysis will be. On the other hand, the calculation time increases dramatically with the smaller, more numerous elements. Parker Seal was a pioneer in developing FEA techniques for use with true elastomeric materials. This analytical technique is now widely used to determine sealing force and pressure on the gland as well as model percent fill at application temperatures.

Figure 4 Radial tension developed due to thermal expansion in FFKM

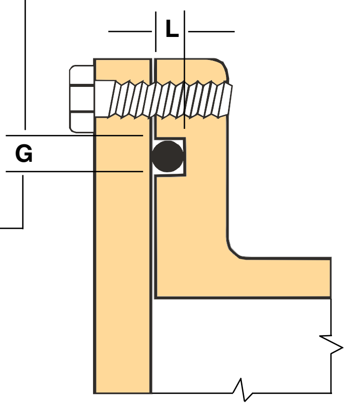


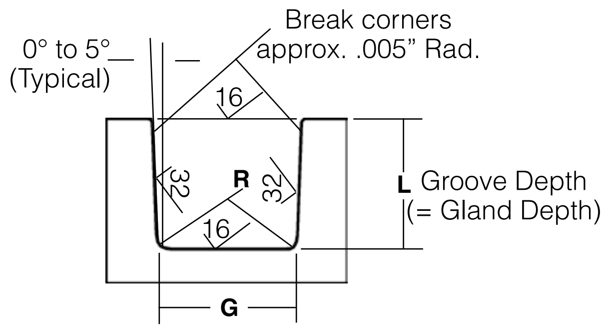
Vacuum Face Seal Glands

Design chart for O-ring vacuum face seal glands

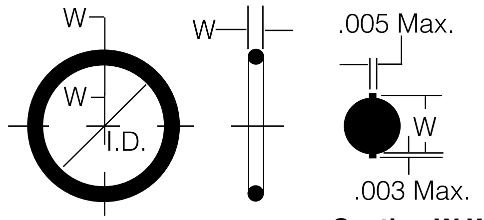
FOR EXTERNAL VACUUM
Dimension the groove by its outside diameter (H_O) and width:
H_O = mean O.D. of O-ring
Tolerance = Minus 1% of Mean O.D., but not more than -.060"

FOR INTERNAL VACUUM
Dimension the groove by its inside diameter (H_I) and width:
H_I = mean I.D. of O-ring
Tolerance = Plus 1% of Mean I.D., but not more than +.060"





Gland Detail

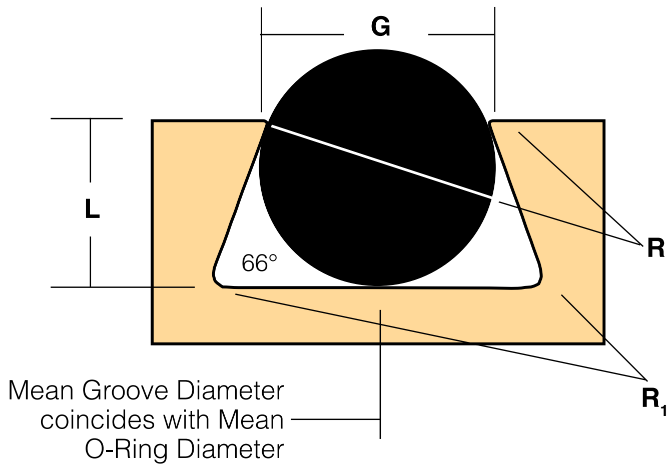


Section W-W

Design Chart 1 for O-Ring Vacuum Face Seal Glands Note: These dimensions are intended primarily for face type O-ring seals and low temperature applications.							
O-Ring Size AS568A	W Cross Section		L Gland Depth	Squeeze		G Groove Width	R Groove Radius
	Nominal	Actual		Actual	%		
004 through 050	1/16	.070 ± .003	.050 to .054	.013 to .023	19 to 32	.084 to .089	.005 to .015
102 through 178	3/32	.103 ± .033	.074 to .080	.020 to .032	20 to 30	.120 to .125	.005 to .015
201 through 284	1/8	.139 ± .004	.101 to .107	.028 to .042	.20 to 30	.158 to .164	.010 to .025
309 through 395	3/16	.210 ± .005	.152 to .162	.043 to .063	21 to 30	.239 to .244	.020 to .035
425 through 475	1/4	.275 ± .006	.201 to .211	.058 to .080	21 to 29	.309 to .314	.020 to .035
Special	3/8	.375 ± .007	.276 to .286	.082 to .108	22 to 28	.419 to .424	.030 to .045
Special	1/2	.500 ± .008	.370 to .380	.112 to .138	22 to 27	.560 to .565	.030 to .045

Dovetail Grooves for Vacuum Service

Design chart for dovetail grooves for vacuum service



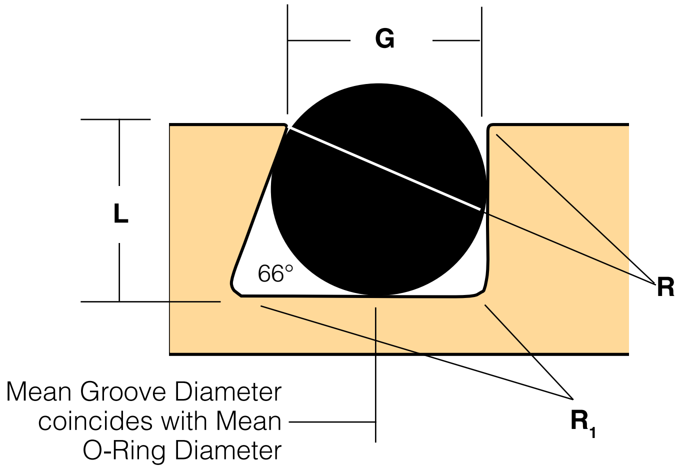
TIP: These design recommendations require metal-to-metal contact. In special applications, for example in the semiconductor industry, deviation from these recommendations may be necessary. For FFKM designs above 200°C, it is recommended to hold G & L constant, but change the dovetail angle to 50°. This allows room in the gland for thermal expansion.

Design Char 2 for O-Ring Vacuum Dovetail Grooves							
O-Ring Size AS568A	W Cross Section		L Gland Depth	Squeeze %	G Gland Width	R	R_1
	Nominal	Actual					
004 through 050	1/16	.070 ± .003	.050 to .052	27	.057 to .061	.005	1/64
102 through 178	3/32	.103 ± .003	.081 to .083	21	.083 to .087	.010	1/64
201 through 222	1/8	.139 ± .004	.111 to .113	20	.113 to .117	.010	1/32
309 through 349	3/16	.210 ± .005	.171 to .173	18	.171 to .175	.015	1/32
425 through 460	1/4	.275 ± .006	.231 to .234	16	.231 to .235	.015	1/16
Special	3/8	.375 ± .007	.315 to .319	16	.315 to .319	.020	3/32

Radius "R" is CRITICAL. Insufficient radius will potentially cause damage to the O-ring during installation, while excessive radius may contribute to extrusion.

Half-dovetail Grooves for Vacuum Service

Design chart for half-dovetail grooves for vacuum service



: These design recommendations require metal-to-metal contact. In special applications, for example in the semiconductor industry, deviation from these recommendations may be necessary. For FFKM designs above 200°C, it is recommended to hold G & L constant, but change the dovetail angle to 50°. This allows room in the gland for thermal expansion.

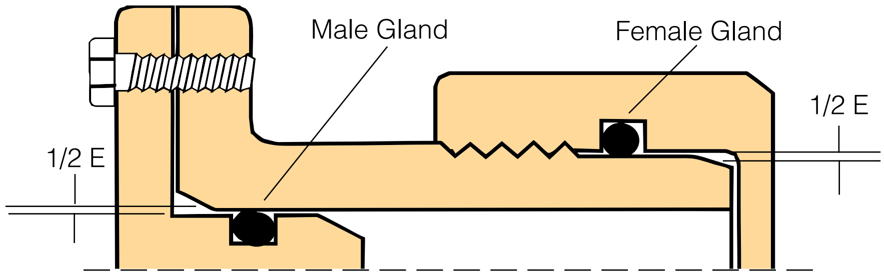
Design Chart 3 for O-ring Vacuum Half-Dovetail Grooves

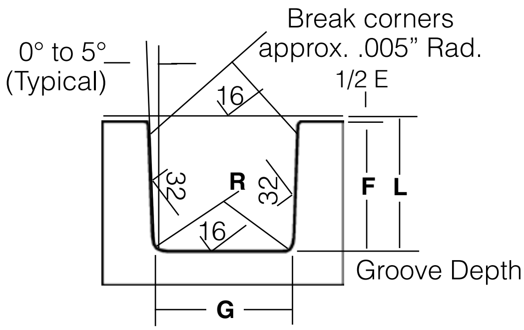
O-Ring Size AS568A	W Cross Section		L Gland Depth	Squeeze %	G Gland Width	R	R_1
	Nominal	Actual					
004 through 050	1/16	.070 ± .003	.052 to .054	25	.064 to .066	.005	1/64
102 through 178	3/32	.103 ± .003	.083 to .085	19	.095 to .097	.010	1/64
201 through 222	1/8	.139 ± .004	.113 to .115	18	.124 to .128	.010	1/32
309 through 349	3/16	.210 ± .005	.173 to .176	17	.190 to .193	.015	1/32
425 through 460	1/4	.275 ± .006	.234 to .238	15	.255 to .257	.015	1/16
Special	3/8	.375 ± .007	.319 to .323	14	.350 to .358	.020	3/32

Radius "R" is CRITICAL. Insufficient radius will potentially cause damage to the O-ring during installation, while excessive radius may contribute to extrusion.

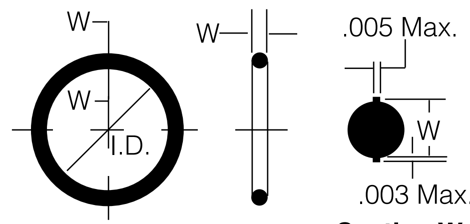
Static Vacuum Seal Glands

Design chart for O-ring static vacuum seal glands





Gland Detail



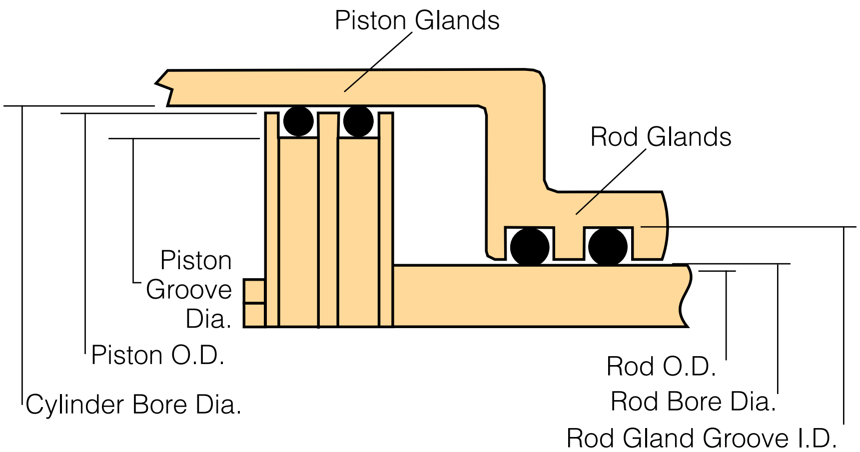
Section W-W

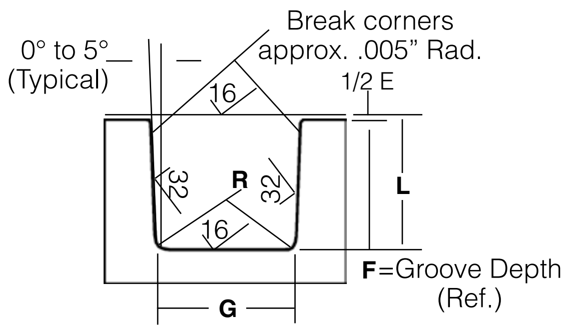
Design Chart 4 for O-ring Static Vacuum Seal Glands									
O-ring Size AS568A	W Cross Section		L Gland Depth	Squeeze		E Diametral Clearance	G Groove Width	R Groove Radius	MAX. *Eccentricity
	Nominal	Actual		Actual	%				
004 through 050	1/16	.070 ± .003	.050 to .023	.015 to .023	22 to 32	.002 to .005	.093 to .098	.005 to .015	.002
102 through 178	3/32	.103 ± .003	.081 to .083	.017 to .025	17 to 24	.002 to .005	.140 to .145	.005 to .015	.002
201 through 284	1/8	.139 ± .004	.111 to .113	.022 to .032	16 to 23	.003 to .006	.187 to .192	.010 to .025	.003
309 through 395	3/16	.210 ± .005	.170 to .173	.032 to .045	15 to 21	.003 to .006	.281 to .286	.020 to .035	.004
425 through 475	1/4	.275 ± .006	.226 to .229	.040 to .055	15 to 20	.004 to .007	.375 to .380	.020 to .035	.005

* Total indicator reading between groove and adjacent bearing surface.

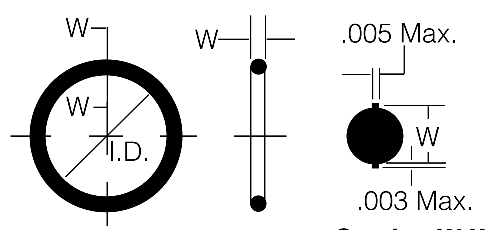
Reciprocating Vacuum Seal Glands

Design chart for reciprocating vacuum packing glands





Gland Detail



Section W-W

Design Chart 5 for Reciprocating O-ring Vacuum Packing Glands

O-ring Size AS568A	W Cross Section		L Gland Depth	Squeeze		E Diametral Clearance	G Groove Width	R Groove Radius	MAX. *Eccentricity
	Nominal	Actual		Actual	%				
006 through 012	1/16	.070 ± .003	.055 to .057	.010 to .018	15 to 25	.002 to .005	.093 to .098	.005 to .015	.002
014 through 116	3/32	.103 ± .003	.088 to .090	.010 to .018	10 to 17	.002 to .005	.140 to .145	.005 to .015	.002
201 through 222	1/8	.139 ± .004	.121 to .123	.012 to .022	9 to 16	.003 to .006	.187 to .192	.010 to .025	.003
309 through 349	3/16	.210 ± .005	.185 to .188	.017 to .030	8 to 14	.003 to .006	.281 to .286	.020 to .035	.004
425 through 460	1/4	.275 ± .006	.237 to .240	.029 to .044	11 to 16	.004 to .007	.375 to .380	.020 to .035	.005

* Total indicator reading between groove and adjacent bearing surface.

Parker's Total inPHorm

Take the guesswork out of seal design and material selection - download a copy of Parker's Total inPHorm software. Total inPHorm has many enhanced features, including an expanded media compatibility section and custom sizing capabilities that allow the user to design application-specific glands and seals.

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