SECTION TWO

O-RING GLAND DESIGN GUIDELINES

- O-Ring Seal Types
- Gland Dimension Calculations
- O-Ring Dimensions
- Selecting an O-Ring Cross-Section
- ID/OD Interference
- Reduction in Cross-Section
- Compression Squeeze and Compression Ratio
- Gland Fill
- Extrusion
- Back-Up Rings
- Additional Groove Details
- Installation

DICHTOMATIK

O-RING GLAND DESIGN GUIDELINES

THE O-RING DESIGN GUIDE

This o-ring gland design guide is intended for use in specifying o-ring and gland dimensions for static applications with pressures up to 1500 PSI. For dynamic applications and for pressure greater than 1500 PSI, please contact Dichtomatik North America.

The guidelines are for the nominal condition. The minimum and maximum stack-up conditions should also be checked. This entails evaluating the seal design dimensionally with the largest possible o-ring in the smallest possible gland and the smallest possible o-ring in the largest possible gland.

EXAMPLE: Consider an o-ring with a 1.78±0.08 mm cross-section and a radial o-ring gland with a 1.52±0.10 mm height. The formula for compression ratio (which will be introduced in this guide) is as follows.

Compression Ratio Calculation

$$\text{Compression Ratio} = \frac{\text{O-Ring CS} - \text{Gland Height}}{\text{O-Ring CS}}$$

The acceptable range is 5% to 30%.

Using the nominal values for the compression ratio yields the following result:

Compression ratio at nominal conditions:

$$\frac{1.78\text{ mm} - 1.52\text{ mm}}{1.78\text{ mm}} = 14.6\%\text{ compression}$$

A compression ratio of 14.6% falls within the acceptable range, so based on the nominal measurements, the design is good. Next we need to check the maximum and minimum conditions. The maximum compression ratio occurs when the largest o-ring is in the smallest gland. This calculation is as follows:

Largest possible o-ring in smallest possible gland:

$$\frac{1.86\text{ mm} - 1.42\text{ mm}}{1.86\text{ mm}} = 23.7\%\text{ compression}$$

We then check the minimum compression ratio which occurs with the smallest o-ring in the largest gland. This calculation is as follows:

Smallest possible o-ring in largest possible gland:

$$\frac{1.70\text{ mm} - 1.62\text{ mm}}{1.70\text{ mm}} = 4.7\%\text{ compression}$$

With this design the maximum compression ratio is 23.7% which is within the recommended range. However, the minimum compression ratio is only 4.7% which is not within the acceptable range. In this situation, the design should be modified to ensure that the minimum compression ratio is within the acceptable range or testing should be completed at this minimum condition to ensure that the seal will perform as required.

Throughout this reference guide the term “compression” is used to describe what happens to the o-ring. Since elastomers are essentially incompressible, the technically correct term would be “deformation.” “Compression” is used as the more common terminology in the sealing industry.

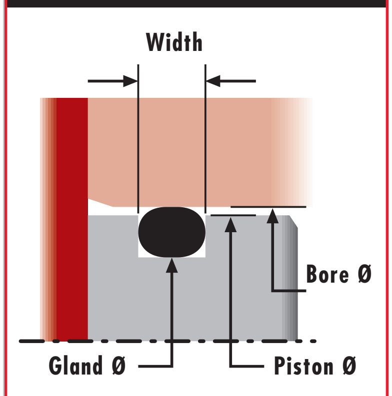
NOTE: It is critical to remember that most sealing applications are unique. Textbook guidelines regarding o-ring gland design are no substitute for actually testing the components and the seals in their real-world conditions to determine if the design is optimal and, more importantly, safe.

O-RING SEAL TYPES

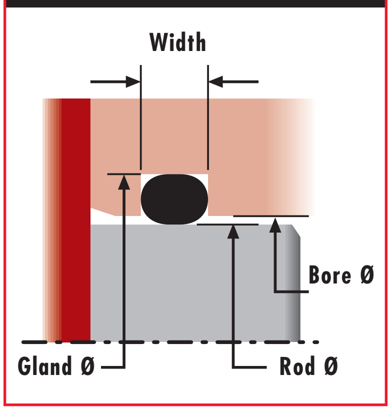
Most static o-ring seals are one of the three types shown below. In the male gland seal the groove for the o-ring is machined into the piston (the part that is inserted into the bore) and that part with the o-ring installed on it is inserted into the bore. The o-ring seals radially. In the female gland seal the groove for the o-ring is machined into the bore and a smooth rod is inserted through the installed o-ring. As with the male gland seal, the o-ring seals radially. For the face seal, the groove is machined into the face that is perpendicular to the piston or rod. The o-ring seals axially.

The variable names presented in these diagrams are used throughout the design guide.

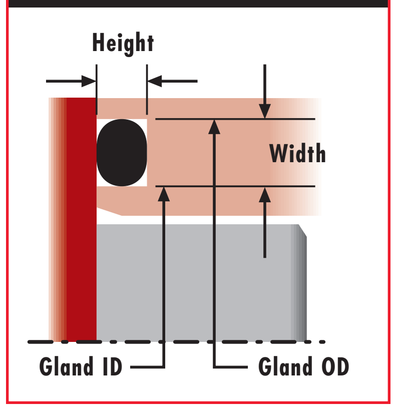
Male Gland Seal



Female Gland Seal



Face Seal



GLAND DIMENSION CALCULATIONS

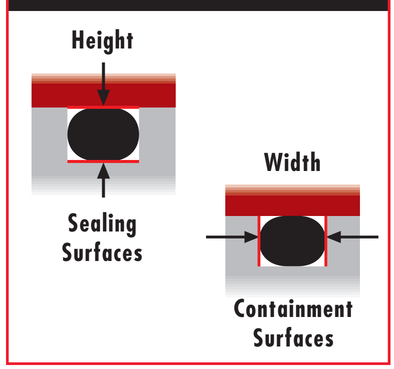
Although each physical arrangement is different, each involves the o-ring being captured in a rectangular gland which has two sets of opposing surfaces.

1. The first set of opposing surfaces is sealing surfaces, in that the distance between them, the gland height, is less than the o-ring cross-section (CS) so that the installed o-ring is compressed resulting in a sealing force.

2. The second set of opposing surfaces is containing surfaces, in that the distance between them, the gland width, is larger than the o-ring cross-section so that they only serve to keep the o-ring in place.

Gland height and width are used for compression and fill calculations. The formulas for calculating these gland dimensions for male gland, female gland and face seals are shown below.

Gland Dimensions



Male Gland Seal

$$\text{Height} = \frac{\text{Bore Ø} - \text{Gland Ø}}{2}$$

Width = Width

Female Gland Seal

$$\text{Height} = \frac{\text{Gland Ø} - \text{Rod Ø}}{2}$$

Width = Width

Face Seal

Height = Height

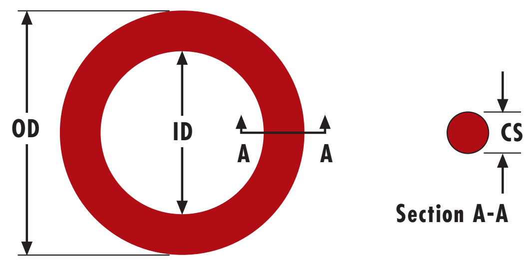
$$\text{Width} = \frac{\text{Gland OD} - \text{Gland ID}}{2}$$

O-RING GLAND DESIGN GUIDELINES

O-RING DIMENSIONS

Dimensionally specifying an o-ring is typically done with just two dimensions, the inner diameter (ID) and the cross-section (CS). Occasionally, an o-ring may be specified with an outer diameter (OD) and cross-section or an inner diameter and outer diameter. If two of the three dimensions are known, the third can be calculated using the formulas shown below.

O-Ring Dimensions



O-Ring Dimension Calculations

OD = ID + (2 x CS)

ID = OD – (2 x CS)

$$CS = \frac{OD - ID}{2}$$

SELECTING AN O-RING CROSS SECTION

Whereas the ID or OD of the o-ring for a design is significantly influenced by the diameter of the mating components (piston/rod and bore), the cross-section of the o-ring is usually fairly arbitrary. The following table describes some of the advantages when opting for a small cross-section or a large cross-section.

Advantages of Smaller Cross-Section

- More compact.
- Lighter weight.
- Less expensive—especially for higher cost elastomers like FKM or fluorosilicone.
- Less machining required for machined grooves since grooves are smaller.
- More resistant to explosive decompression.

Advantages of Larger Cross-Section

- Less prone to compression set.
- Less volume swell in liquid—on percentage basis.
- Allows for larger tolerances while still maintaining acceptable compression squeeze and compression ratio over full stack-up range.
- Less prone to leakage due to contamination—dirt, lint, scratches, etc.

ID/OD INTERFERENCE

The ID or OD of the o-ring should be chosen to minimize the potential for installation damage and to minimize wear during use. This can be accomplished by adhering to the following guidelines.

- For male gland seals the ID of the o-ring should be smaller than the OD of the gland so that the installed o-ring is always slightly stretched. As with all o-ring design calculations, this should be checked at the maximum and minimum stack-up conditions.
- For female gland seals the OD of the o-ring should be slightly larger than the ID of the gland so there is always some interference.

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ID/OD INTERFERENCE *–continued*

- For external pressure face seals the ID of the o-ring should be slightly smaller than the gland inner diameter (Gland ID) so when the pressure is applied, the o-ring is already where it would be as a result of the pressure.
- For internal pressure face seals the OD of the o-ring should be slightly larger than the gland outer diameter (Gland OD) so when the pressure is applied, the o-ring is already where it would be as a result of the pressure.

Male Gland Seal

$$\text{Interference} = \frac{\text{Gland Ø} - \text{ID}}{\text{ID}}$$

Maximum = 5% **Minimum = 0%**

External Pressure Face Seal

$$\text{Interference} = \frac{\text{Gland ID} - \text{ID}}{\text{ID}}$$

Maximum = 5% **Minimum = 0%**

Female Gland Seal

$$\text{Interference} = \frac{\text{OD} - \text{Gland Ø}}{\text{OD}}$$

Maximum = 2% **Minimum = 0%**

Internal Pressure Face Seal

$$\text{Interference} = \frac{\text{OD} - \text{Gland OD}}{\text{OD}}$$

Maximum = 3% **Minimum = 0%**

REDUCTION IN CROSS-SECTION

Since elastomers are essentially incompressible materials, if the ID of the o-ring is stretched (as a result of ID interference), the cross-section of the o-ring will decrease. The following tables give the o-ring cross-sections that result from ID interference. The new cross-section should be used for all compression and gland fill calculations.

The impact of OD interference on the o-ring cross-section varies and does not require design considerations.

For reference purposes the equation for the volume of an o-ring is as follows.

O-Ring Volume

$$\text{Volume} = \frac{\pi^2}{4} \times CS^2 \times [ID + CS]$$

AS568 Series	Original Cross-Section in Inches	Reduced Cross-Section at % ID Interference (inches)				
		1%	2%	3%	4%	5%
-0XX*	0.070 in.	.069	.069	.068	.068	.068
-1XX	0.103 in.	.102	.101	.100	.100	.100
-2XX	0.139 in.	.138	.137	.136	.135	.134
-3XX	0.210 in.	.208	.206	.205	.204	.203
-4XX	0.275 in.	.272	.270	.268	.267	.266

*Except for -001, -002 and -003 sizes.

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O-RING GLAND DESIGN GUIDELINES

REDUCTION IN CROSS-SECTION *—continued*

AS568 Series	Original Cross-Section in Millimeters	Reduced Cross-Section at % ID Interference (mm)				
		1%	2%	3%	4%	5%
-0XX*	1.78 mm	1.76	1.75	1.74	1.73	1.72
-1XX	2.62 mm	2.59	2.57	2.56	2.55	2.53
-2XX	3.53 mm	3.49	3.47	3.44	3.43	3.41
-3XX	5.33 mm	5.28	5.24	5.20	5.18	5.15
-4XX	6.99 mm	6.92	6.87	6.82	6.79	6.75

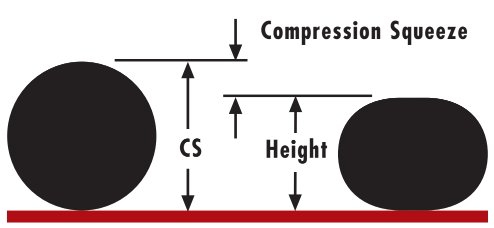
*Except for -001, -002 and -003 sizes.

COMPRESSION SQUEEZE & COMPRESSION RATIO

An elastomer is defined as a synthetic or natural material with resilience or memory sufficient to return to its original shape after a major or minor distortion. This resilience of elastomers is what makes o-rings work as seals. The design parameters that ensure this resilience is properly used and will probably have the biggest impact on o-ring sealing performance are compression squeeze and compression ratio.

Compression squeeze is the difference between the original o-ring cross-section (CS) and the gland height (Height) and is expressed in either inches or millimeters. Since almost all elastomers quickly take a 100% compression set with very light squeeze, it is essential that a minimum compression squeeze of 0.1mm (0.005 inches) be maintained.

Compression Squeeze



Calculation

Compression Squeeze = CS* – Height

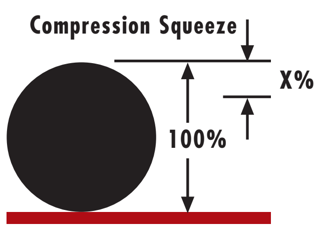
Recommended Minimum Value

Compression Squeeze > 0.1 mm (0.005 in)

* Note: Be sure to use the reduced cross-section in this calculation.

Compression ratio expresses what percentage the compression squeeze is of the uncompressed o-ring cross-section.

Compression Ratio



Calculation

$$\text{Compression Ratio} = \frac{\text{Compression Squeeze}}{\text{CS}} \times 100$$

Recommended Value

See Table

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COMPRESSION SQUEEZE & RATIO *–continued*

The compression ratio recommendations are for static sealing applications. Most dynamic sealing applications would use tighter tolerances on the mating components and then target a compression ratio range in the lower half of the static sealing recommended range (5% to 20%). The lighter compression squeeze is recommended due to friction and wear considerations.

Male or Female Gland Seal

Minimum 5%	Target 20%	Maximum 30%

Face Seal

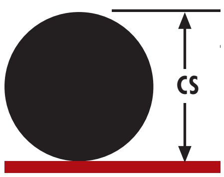
Minimum 10%	Target 25%	Maximum 35%

GLAND FILL

Gland fill is the percentage of the gland that is occupied by the o-ring. It is calculated by dividing the cross-sectional area of the o-ring by the cross-sectional area of the gland.

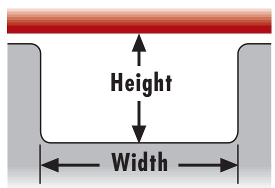
Calculations

O-Ring Cross-Sectional Area



O-Ring CSA = $\pi \times \left(\frac{CS}{2}\right)^2$

Gland Cross-Sectional Area



Gland CSA = Height x Width

Gland Fill

Gland Fill (%) = $\frac{\text{O-Ring CSA}}{\text{Gland CSA}} \times 100$

The following target gland fill recommendations take into account several hardware and o-ring related factors including but not limited to thermal expansion, volume swell due to fluid exposure and the effect of tolerance stack-ups.

Recommended Values

Minimum 50%	Target Minimum 65%	Target 75%	Target Maximum 85%	Maximum 90%

EXTRUSION GAP

Extrusion is a concern for radial seals where there is a gap between the piston and the bore for a male gland seal or between the rod and the bore for a female gland seal. Extrusion is not a concern for face seals where the metal parts to be sealed are typically in line-to-line contact. The concern is that at higher pressures, especially for softer o-ring elastomers, the o-ring can be forced by the pressure into the small gap between the piston or rod and the bore. Unless the bore and the piston or rod are ensured to remain concentric by the hardware, we have to assume that all of the gap possible can shift to one side (see diagram next page).

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O-RING GLAND DESIGN GUIDELINES

EXTRUSION GAP –*continued*

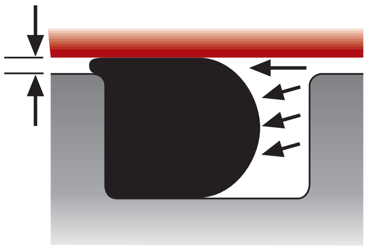
Male Gland Seal

Extrusion Gap = Bore Ø – Piston Ø

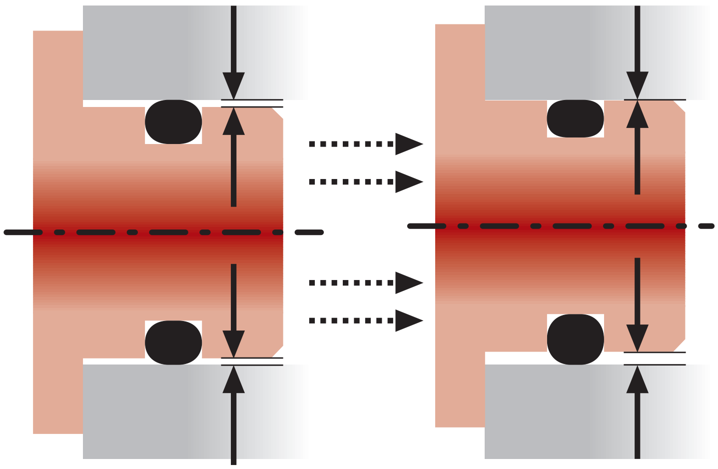
Female Gland Seal

Extrusion Gap = Bore Ø – Rod Ø

Extrusion



Concentricity & Diametric Clearance



The following table indicates the maximum recommended total diametric clearance for a given system pressure and elastomer hardness. For pressures or hardness values between those listed in the table, either interpolate to determine the value or use the next higher pressure and the next lower durometer.

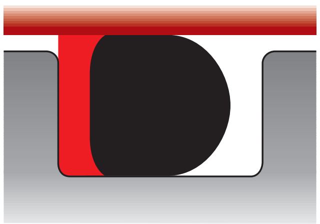
Pressure PSI	Elastomer Hardness (Durometer) 60	70	80	90
500	.010" (.25 mm)	.015" (.38 mm)	.020" (.51 mm)	.025" (.64 mm)
750	.005" (.13 mm)	.011" (.28 mm)	.016" (.41 mm)	.023" (.58 mm)
1000	.002" (.05 mm)	.008" (.20 mm)	.012" (.30 mm)	.018" (.46 mm)
1250	.001" (.02 mm)	.004" (.10 mm)	.009" (.23 mm)	.015" (.38 mm)
1500	Consult Dichtomatik	.002" (.05 mm)	.007" (.18 mm)	.012" (.30 mm)

BACK-UP RINGS

Back-up rings are used to prevent o-rings from extruding when the tight tolerances listed in the previous section cannot be maintained. Back-up rings do not provide any sealing function. They are simply intended to reduce the extrusion gap on the low-pressure side so that the o-ring can fulfill its sealing function without being damaged.

Back-up rings are made of materials with better extrusion resistance than most elastomers. Several common materials are high-durometer NBR (or other elastomers), Nylon and filled PTFE.

Use of a Back-up Ring



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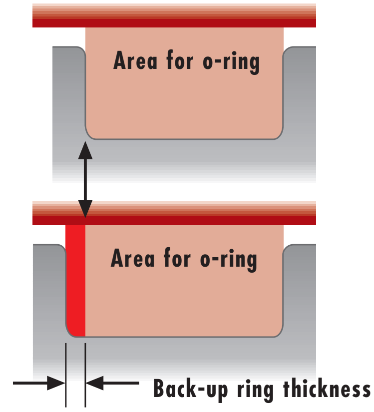
BACK-UP RINGS *–continued*

Since the materials used for back-up rings are basically non-compressible and non-deformable, they can typically be treated as though they are part of whatever the o-ring groove is machined into. That is, the width of the groove has to be increased just enough to accommodate the thickness of the back-up ring.

For back-up rings with a curved surface facing the o-ring, the effective thickness of the back-up ring can be determined by dividing the cross-sectional area of the back-up ring by the height of the back-up ring. This ensures that the o-ring has the same area to occupy.

Accommodating the Back-Up Ring



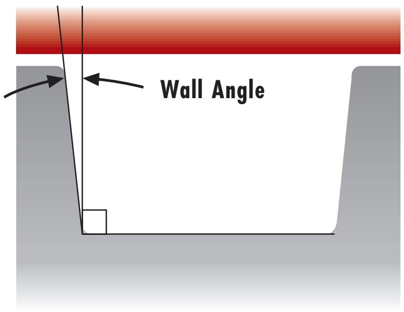
ADDITIONAL GROOVE DETAILS

Once the geometric arrangement and dimensions for the o-ring gland have been determined, the following details must be observed for correct sealing function.

Groove Wall Angle

The wall angle of the groove should be controlled to be between 0° and 5° as shown.

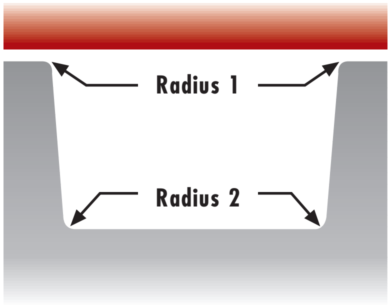
Wall Angle



Transition Radii

The transition from the piston, bore, or face to the groove edge and from the groove edge to the groove bottom must be slightly rounded as shown. Radii recommendations follow on the next page.

Transition Radii



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O-RING GLAND DESIGN GUIDELINES

ADDITIONAL GROOVE DETAILS –continued

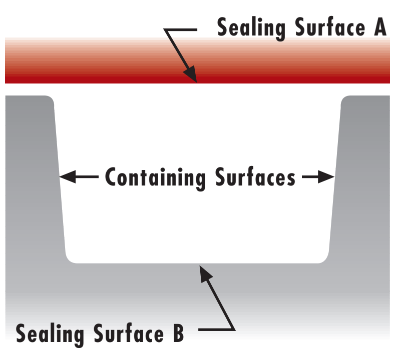
Transition Radii

TRANSITION RADII				
	Cross Section range		Radius 1	Radius 2
mm	1.0	2.0	0.10	0.30
inch	0.04	0.08	0.004	0.012
mm	2.0	3.0	0.20	0.30
inch	0.08	0.12	0.008	0.012
mm	3.0	4.0	0.20	0.50
inch	0.12	0.16	0.008	0.020
mm	4.0	5.0	0.20	0.60
inch	0.16	0.20	0.008	0.024
mm	5.0	6.0	0.20	0.60
inch	0.20	0.24	0.008	0.024
mm	6.0	8.0	0.20	0.80
inch	0.24	0.31	0.008	0.031
mm	8.0	10.0	0.20	1.00
inch	0.31	0.39	0.008	0.039
mm	10.0	12.0	0.20	1.00
inch	0.39	0.47	0.008	0.039
mm	12.0	15.0	0.20	1.20
inch	0.47	0.59	0.008	0.047

Surface Finish

The surface finish of the sealing surfaces and the sides of the gland should be controlled as shown.

Sealing Surface Finish



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ADDITIONAL GROOVE DETAILS *–continued*

Surface Finish

Surface Finish Acceptable Range for CONSTANT PRESSURE Applications		Max Ra	Max Rz	Max Rmax
Sealing Surface A	µm	1.6	6.3	10.0
	µinch	64	256	400
Sealing Surface B	µm	3.2	10.0	12.5
	µinch	128	400	500
Containing Surfaces	µm	6.3	12.5	16.0
	µinch	256	500	640

Surface Finish Acceptable Range for PULSATING PRESSURE Applications		Max Ra	Max Rz	Max Rmax
Sealing Surface A	µm	0.8	1.6	3.2
	µinch	32	64	128
Sealing Surface B	µm	1.6	3.2	6.3
	µinch	64	128	252
Containing Surfaces	µm	3.2	6.3	10.0
	µinch	128	252	400

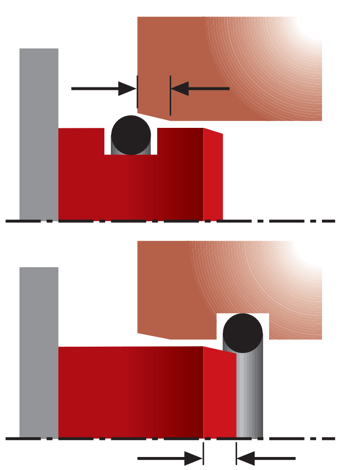
INSTALLATION

Installation Chamfer

A perfectly designed o-ring seal is of little use if the o-ring is damaged during installation. To prevent damage for male gland and female gland seals, a 15° chamfer on the bore or rod is recommended. The chamfer must be long enough to ensure that the o-ring sees only the chamfer when it is installed. Face seals do not require installation chamfers.

O-Ring CS		Chamfer Length	
Inches	mm	Inches	mm
.070	1.78	.083	2.10
.103	2.62	.122	3.10
.139	3.53	.157	4.00
.210	5.33	.236	6.00
.275	6.99	.283	7.20

Installation Chamfer Length



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O-RING GLAND DESIGN GUIDELINES

INSTALLATION *–continued*

General Installation Guidelines

The following general guidelines should be observed for installation of an o-ring to avoid damage and leakage.

- The o-ring must not be stretched beyond its elongation limit.
- Edges must be burr-free and all radii and angles should be applied smoothly.
- Dust, dirt, metal chips and other foreign material should be removed prior to installation of the o-ring.
- Tips of screws and installation housings for other sealing and guiding elements should be covered by an assembly sleeve.
- A suitable lubricant should be applied to the assembly surfaces and/or the o-ring.
- All installation tools (mandrels, sleeves, etc.) should be made of a soft material and not have any sharp edges.
- The o-ring should not be rolled over assembly surfaces.
- Ensure that the o-ring is not twisted during installation into the groove.