FLUID POWER SEALING SOLUTIONS

DESIGN GUIDELINES

POLYMER SEALS

CHESTERTON®
Global Solutions, Local Service.

Engineering Introduction

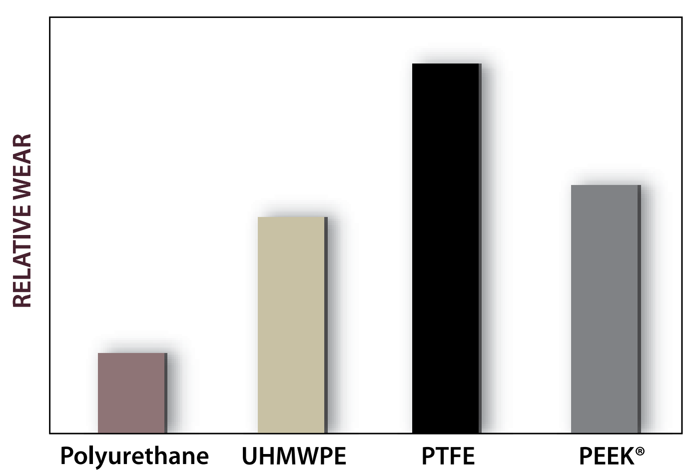
Determining the appropriate sealing device for a particular application is generally determined by operating parameters, such as pressure, speed, temperature, fluid compatibility requirements, available envelope, performance life, allowable leakage, and cost. In many instances particular sealing devices are utilized in certain applications due largely to legacy. That is, the prior and repeated use of a sealing device over many years in an application.

A sealing device can be broadly defined as a product that controls and, therefore, prevents the movement of fluid between adjacent locals within equipment or to the environment. At the basic level seals can be characterized as either *contacting* or *non-contacting*. Non-contacting seals are specified in applications where pressure differentials are not present and life is limitless due to the lack of a dynamic sealing interface.

The more prevalent sealing products address the interface between two equipment surfaces to create a positive seal. These seals can be placed in two categories: *static* and *dynamic*. Even though the term implies otherwise, a static seal generally does involve some very small movements. Examples include the expansion and contraction of equipment or pressure cycling within the system influencing the seal itself. Static seals represent the largest population of sealing devices: O-rings, gaskets, sealing compounds, and metal seals. Dynamic sealing is the more challenging of the two categories. Dynamic sealing applications are configurations where system components experience relatively high speed reciprocating or rotary motion. Such situations have more operating parameters to be considered in order to provide a suitable sealing solution.

The major categories of dynamic sealing devices include mechanical packing, mechanical seals, and polymer based seals. Among the several parameters that are used to determine the appropriate type of material and seal design utilization are *wear* and *pressure-velocity* (P-V) characteristics.

The chart indicates the wear characteristics of some of the major material groups used in polymer sealing. The lower values indicate better wear characteristics or longer life with respect to interfacing metallic surfaces. As an example, polyurethane-based materials have better wear characteristics than PTFE.



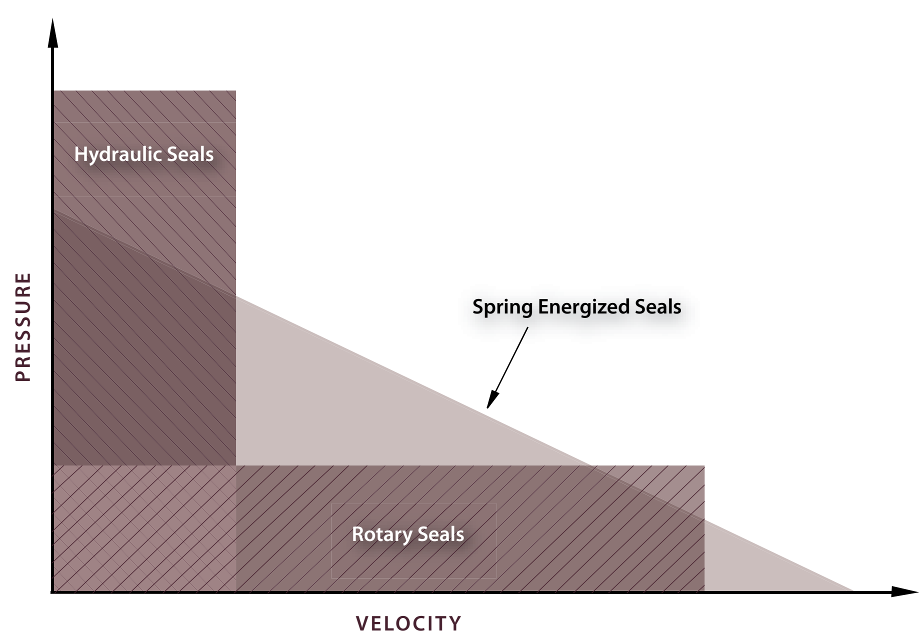
Although this chart provides some insight into the relative wear characteristics, the materials have limits to the level of pressure and velocity each material can withstand for suitable service.

A factor expressed as the product of pressure and velocity provides a reference value for the level at which materials and seal designs can practically endure. Such values relate to equipment operating parameters. It is convenient to integrate both material and seal design configuration to look at which provides appropriate performance. The chart below provides some general ranges by seal type relating to pressure and velocity.

In the case of polyurethane, the material is generally used without external loading (e.g., springs) due to its unique characteristics, which allow it to return to its original shape. As indicated on the chart, polyurethane materials are generally recommended for use at lower speeds and higher pressures.

Rotary seals are generally not loaded with springs and typically utilize various PTFE compounds. Rotary seals can be used at higher surface velocities with lower pressures.

Spring energized seals, used in both rotary and reciprocating applications, cover a very broad range of pressure and velocity characteristics. These include various spring types (i.e., cantilever, helical and elliptical) and materials used to satisfy the equipment operating parameters. Spring energized seals can be used at relatively high pressures or surface velocities.



Recommended Seal Size

When selecting a seal, it is important to use an appropriate seal cross section according to hardware diameters of either bore or rod. Tables 1 and 2 give recommended seal cross section and height ranges used for Chesterton products. These can be applied to common industry applications for many U-cup type seals. The recommended seal height should be approximately 50% larger than the cross section for seal stability. For applications operating outside of typical industry conditions, it is strongly advised to consult Engineering to determine if these ranges are appropriate.

TABLE 1 **METRIC**

Diameter Range mm		Cross Section Range	Height Range
Min	Max	Min-Max	Min-Max
—	25	3,00-4,00	5,00-6,00
>25	50	3,00-5,00	5,00-7,00
>50	100	4,00-7,00	6,00-11,00
>100	150	5,00-10,00	7,00-14,00
>150	200	6,00-12,00	10,00-19,00
>200	300	10,00-16,00	14,00-24,00
>300	1250+	12,00+	19,00+

TABLE 2 **INCH**

Diameter Range inch		Cross Section Range	Height Range
Min	Max	Min-Max	Min-Max
–	1.000	0.125-0.156	0.187-0.250
>1.000	2.000	0.125-0.187	0.187-0.281
>2.000	4.000	0.156-0.281	0.250-0.437
>4.000	6.000	0.187-0.375	0.281-0.562
>6.000	8.000	0.250-0.500	0.375-0.750
>8.000	12.000	0.375-0.625	0.562-0.937
>12.000	48.000+	0.500+	0.750+

Standard Fits and Tolerances Data Chart

Fits and Tolerances – Based on ISO 286-1

These ISO standard tolerance classes are used to define an acceptable size range in the manufacturing or reworking of equipment. The chart below shows generally accepted industry standards for hydraulic and pneumatic equipment. However, caution must be observed that these values may not pertain to all applications.

A tolerance class is combined with a basic size to determine the allowable range. For example, a 420 mm bore with a tolerance class of H9, i.e., 420^{H9}, would have a basic size and tolerance of 420 +155/-0 which equals 420,15 to 420,00 mm allowable range of size.

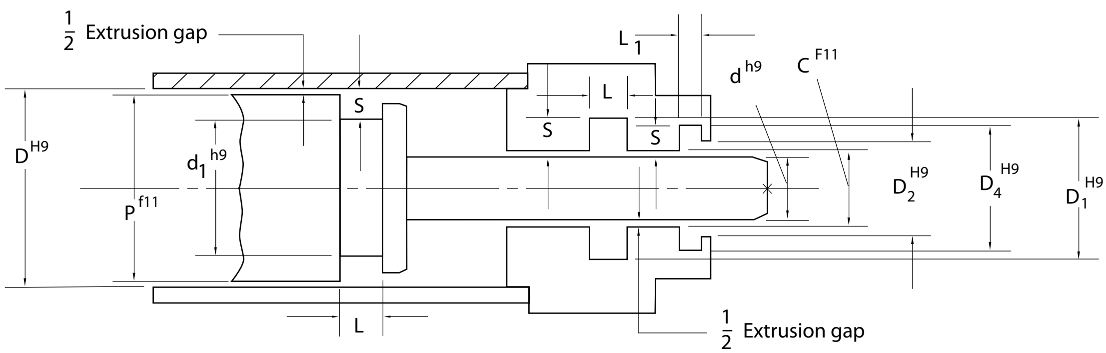
Consult with application engineering for suitability and use of this table.

Diameter Range — Basic Size mm*(inch)		Tolerance (Rod based)	Tolerance (Hole based)	Tolerance (Rod based)	Tolerance (Hole based)
Minimum	**Maximum**	**h9**	**H9**	**f11**	**F11**
>6 (.236)	10 (.394)	+ 0/-36 (+0/-.001)	+36/-0 (+.001/-0)	-13/-103 (-.0005/-.004)	+103/+13 (+.004/+.0005)
>10 (.394)	18 (.709)	+ 0/-43 (+0/-.002)	+43/-0 (+.002/-0)	-16/-126 (-.0006/-.005)	+126/+16 (+.005/+.0006)
>18 (.709)	30 (1.181)	+ 0/-52 (+0/-.002)	+52/-0 (+.002/-0)	-20/-150 (-.0008/-.006)	+150/+20 (+.006/+.0008)
>30 (1.181)	50 (1.968)	+ 0/-62 (+0/-.002)	+62/-0 (+.002/-0)	-25/-185 (-.0009/-.007)	+185/+25 (+.007/+.0009)
>50 (1.968)	80 (3.150)	+ 0/-74 (+0/-.003)	+74/-0 (+.003/-0)	-30/-220 (-.001/-.009)	+220/+30 (+.009/+.001)
>80 (3.150)	120 (4.724)	+ 0/-87 (+0/-.003)	+87/-0 (+.003/-0)	-36/-256 (-.001/-.010)	+256/+36 (+.010/+.001)
>120 (4.724)	180 (7.086)	+ 0/-100 (+0/-.004)	+100/-0 (+.004/-0)	-43/-293 (-.002/-.011)	+293/+43 (+.011/+.002)
>180 (7.086)	250 (9.842)	+ 0/-115 (+0/-.004)	+115/-0 (+.004/-0)	-50/-340 (-.002/-.013)	+340/+50 (+.013/+.002)
>250 (9.842)	315 (12.401)	+ 0/-130 (+0/-.005)	+130/-0 (+.005/-0)	-56/-376 (-.002/-.015)	+376/+56 (+.015/+.002)
>315 (12.401)	400 (15.748)	+ 0/-140 (+0/-.005)	+140/-0 (+.005/-0)	-62/-422 (-.002/-.017)	+422/+62 (+.017/+.002)
>400 (15.748)	500 (19.685)	+ 0/-155 (+0/-.006)	+155/-0 (+.006/-0)	-68/-468 (.003/-.018)	+468/+68 (+.018/+.003)
>500 (19.685)	630 (24.803)	+ 0/-175 (+0/-.007)	+175/-0 (+.007/-0)	-76/-516 (.003/-.020)	+516/+76 (+.020/+.003)
>630 (24.803)	800 (31.496)	+ 0/-200 (+0/-.008)	+200/-0 (+.008/-0)	-80/-580 (-.003/-.023)	+580/+80 (+.023/+.003)
>800 (31.496)	1000 (39.370)	+ 0/-230 (+0/-.009)	+230/-0 (+.009/-0)	-86/-646 (-.003/-.025)	+646/+86 (+.025/+.003)
>1000 (39.370)	1250 (49.213)	+ 0/-260 (+0/-.010)	+260/-0 (+.010/-0)	-98/-758 (-.004/-.030)	+758/+98 (+.030/+.004)
>1250 (49.212)	1600 (62.992)	+0/-310 (+0/-.012)	+310/-0 (+.012/-0)	-110/-890 (-.004/-.035)	+890/+110 (+.035/+.004)
>1600 (62.992)	2000 (78.740)	+0/-370 (+0/-.015)	+370/-0 (+.015/-0)	-120/-1040 (.005/.041)	+1040/+120 (+.041/+.005)

* mm values given in .001 mm

Application of ISO Standards Fits and Tolerances

Figure 1



Seal Grooves

Piston seal: d_1 = D- (2 x S)

Rod seal: D_1 = d + (2 x S)

Wiper: D_4 = d + (2 x S)

Figure 1 the examples below illustrate how fits and tolerances can be applied to dimensioning one or more components of the cylinder shown in Figure 1 for metric and inch sizes.

Bore Dimensioning
300,00 mm bore with H9 tolerance
D^{H9} = 300,00 mm + 130/-0
Allowable size range = 300,13 – 300,00 mm

Rod Dimensioning
3.00″ rod with h9 tolerance
d^{h9} = 3.00″ + 0/-.003
Allowable size range = 3.00 – 2.997″

Piston Diameter Running Clearance
Piston diameter P to fit 300,00 mm bore
P^{f11} = 300,00 – 56/-376 mm
Allowable size range = 299.94 – 299,62 mm

Gland Inside Diameter Running Clearance
Gland inside diameter to fit 3.00″ rod
C^{F11} = 3.00 + .009/+.001″
Allowable size range = 3.009 – 3.001″

Piston seal groove
300,00 mm bore, piston seal cross section S = 12,00 mm
d_1 = D – (2 x S) with h9 tolerance
= 300,00 – (2 x 12,00) = 276,00 + 0/-130
Allowable size range = 276,00 – 275,87 mm

Rod seal groove
3.00 inch rod, rod seal cross section S = .250″
D_4 = 3.000 + (2 x .250) with H9 tolerance
= 3.500 + .003/-0
Allowable size range = 3.503 – 3.500″

Extrusion gap
Note the resultant extrusion gap on the seal support lands should always be within published limits for the seal profile and material used. Reference “Allowable Extrusion Gap Table” for AWC material and profile ratings.

Piston seal: diametrical clearance = D – P
For above bore and piston
Maximum extrusion gap = Dmax – Pmin
= 300,13 – 299,62 mm = 0,51 mm

Rod seal: diametrical clearance = C – a
For above rod and gland
Maximum extrusion gap = Cmax – dmin
= 3.009 – 2.997 = .012″

Miscellaneous Hardware Guidelines—Reciprocating

Figure 1

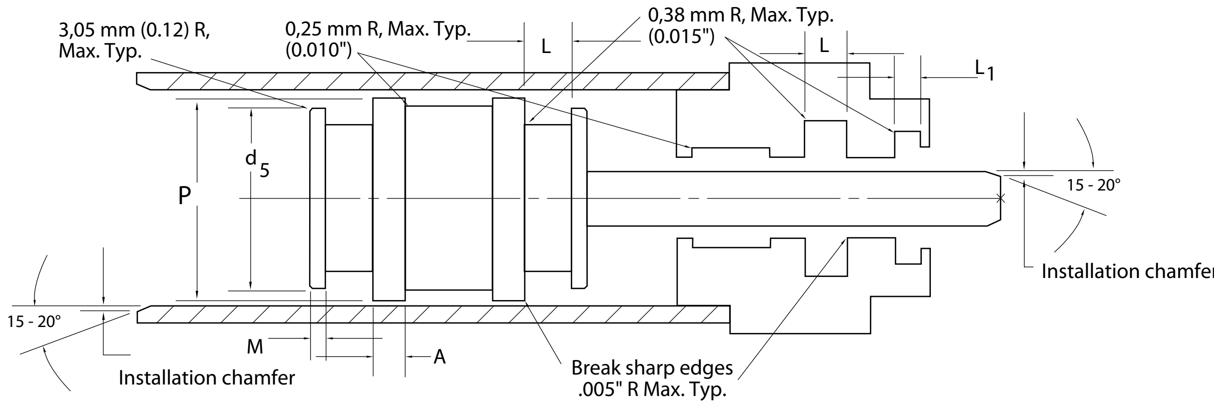


Table 1 shows common guidelines for hardware design used to ease installation and to prevent damage to seals for typical industrial hydraulic and pneumatic applications.

Note: Piston landing areas **A & M** = 3,18 mm (0.125 in) minimum.

TABLE 1

INSTALLATION CHAMFERS			
Seal cross section range mm	(inch)	**Chamfer size** mm	(inch)
< 3,17	(0.125)	1,52	(0.060)
> 3,17 - 6,35	(0.125 - 0.250)	2,03	(0.080)
>6.35 - 9,53	(0.250 -0.375)	2,54	(0.100)
>9,53 – 12,70	(0.375 -0.500)	3,30	(0.130)
>12,70 – 15,88	(0.500 -0.625)	3,94	(0.155)
>15,88 – 19,05	(0.625 – 0.750)	4,57	(0.180)
>19,05 – 22,23	(0.750 - 0.875)	5,08	(0.200)
>22,23 – 25,40	(0.875 - 1.000)	5,59	(0.220)
> 25,40	(1.000)	5,84	(0.230)

Table 2 provides recommended groove heights for popular Chesterton seal designs. Piston clearance diameter (d_5) will vary depending on seal profile.

TABLE 2

GROOVE HEIGHTS					
Profile	**Seal clearance height L = H + clearance**		**Wiper clearance height L1 = H2 + clearance**		**Ød5**
	L	Tolerance	L1	Tolerance	
22K, 22KE, 23K	= Seal height H + 0,76 mm (0.030)	+,38 mm/-0 (+.015/-0)	NA		= $\frac{\text{Seal I.D. + Seal O.D.}}{2}$
20K, 20KD, Cap seal	= Seal height + 0,25 mm (0.010)	+,25 mm/-0 (+.010/-0)	NA		Make equal to ØP
5K, 21K, 21KH, 5KT5, 21KT5, 21KR	NA		= Wiper flange height + 0,25 mm (0.010)	+,25 mm/-0 (+.010/-0)	NA
5K combo, 21KC	NA		= Seal height + 1,50 mm (0.062)	+,38 mm/-0 (+.015/-0)	NA
10K, 22KN	= Seal height + 1,50 mm (0.062)	+,38 mm/-0 (+.015/-0)	NA		= $\frac{\text{Seal I.D. + Seal O.D.}}{2}$

Miscellaneous Hardware Guidelines—Rotary and Reciprocating

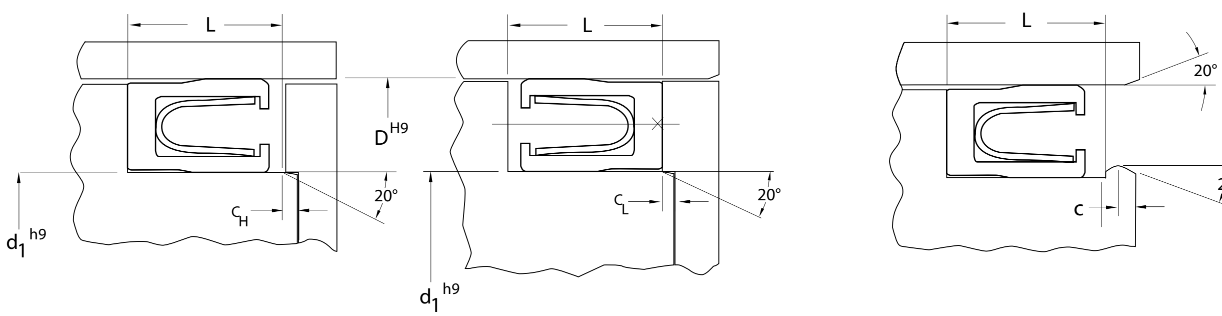
Seals made of PTFE and engineered plastic compounds, and usually spring loaded, are much more rigid as compared to elastomeric seals and can easily be stretched or compressed beyond their elastic limits at installation. Therefore, it is recommended to utilize an open housing like the two-piece and snap-in designs shown in Figure 1.

Figure 1 represents typical gland designs for PTFE/engineered plastic seals. Examples include common two-piece and open (snap-in) housing designs.

Figure 1

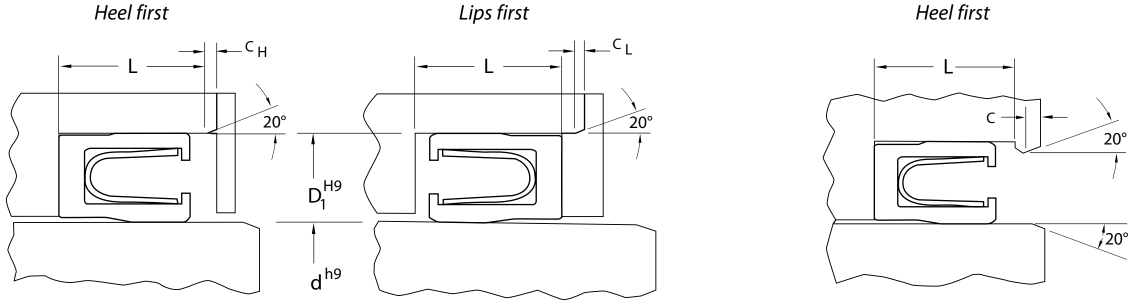
Piston Mount:

Two-piece housing *Snap-in housing*



Rod Mount:

Heel first *Lips first* *Heel first*



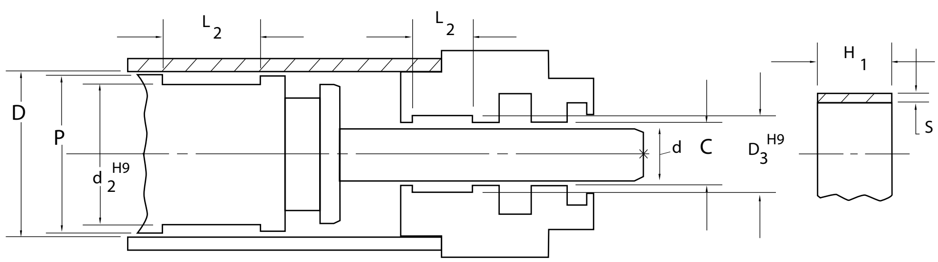
Note: maximum groove radius = 3,50 mm (0.020")

Seal orientation at installation will dictate how much chamfer is required. Seals going into the groove lips first require a longer chamfer to prevent damage during installation. Use the chart below for recommended chamfer.

Seal cross section range	Chamfer C	Installation chamfer C_H	Installation chamfer C_L
<2,36 mm (0.093")	1,14 mm (0.045")	0,51 mm (0.020")	1,27 mm (0.050")
> 2,36 mm (0.093") – 3,17 mm (0.125")	1,52 mm (0.060")	0,76 mm (0.030")	1,78 mm (0.070")
> 3,17 mm (0.125") – 6,35 mm (0.250")	2,03 mm (0.080")	1,02 mm (0.040")	2,29 mm (0.090")
> 6,35 mm (0.250") – 9,53 mm (0.375")	2,54 mm (0.100")	1,27 mm (0.050")	3,56 mm (0.140")
> 9,53 mm (0.375") – 12,70 mm (0.500")	3,30 mm (0.130")		
> 12,70 mm (0.500") – 5,88 mm (0.625")	3,94 mm (0.155")		
> 15,88 mm (0.625") – 19,05 mm (0.750")	4,57 mm (0.180")		
> 19,05 mm (0.750") – 22,23 mm (0.875")	5,08 mm (0.200")		
> 22,23 mm (0.875") – 25,40 mm (1.000")	5,59 mm (0.220")		
>25,40 mm (1.000")	5,84 mm (0.230")		

Note – seals above 2,70mm (0.500 in) cross section will utilize two springs.

Miscellaneous Hardware Guidelines—Replaceable Bearing Bands



Groove width L_2
$L_2 = H_1$ + 0,25 mm tol. +0,25/-0
(H_1 + 0.010" tol. +0.010/-0)

The chart below gives dimensional data for hardware clearances and groove design for all Chesterton replaceable bearing bands. The use of replaceable bearing bands necessitates larger clearance gaps for the prevention of metal to metal contact. Consequently, the resulting extrusion gap will be larger for the seal support land. Always ascertain the clearance obtained from this chart is within the allowable ratings for the seal material used.

Bearing band groove diameters

Piston mount:	d2 = D - (2 x S) - Rc with h9 tolerance
Rod mount:	D3 = d + (2 x S) + Rc with H9 tolerance

Piston and Gland clearance diameters

Piston diameter P = Actual bore – "piston to bore clearance" and "tolerance" from chart
Gland inside diameter C = Actual rod + "rod to gland clearance" and "tolerance" from chart

Example 1: 200 mm bore with S = 2,50 mm
d2 = [200,00 – (2 x 2,50) - 0,11] +0/-115 **= 194,89 +0/-115**
Size range with tolerance = 194,89 to 194,77 mm

P = 200,00 – 0,48 = 199,52 +0/-,10
Size range with tolerance = 199,52 to 199,42 mm
Extrusion gap = 200 mm – 199,88 = 0,22 mm

Example 2: 2.500" rod with S = .125"
D3 = [2.500 + (2 x .125) + .003] +.003/-0 **= 2.758 +.003/-0**
Size range with tolerance = 2.761 to 2.758"

C = 2.500 + .018 = 2.518 +.003/-0
Size range with tolerance = 2.521 to 2.518
Extrusion gap = 2.521 – 2.500 = 0.021"

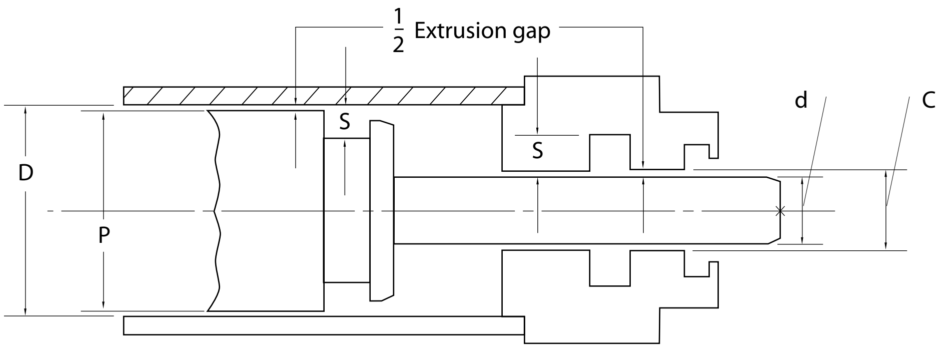
BEARING BAND GROOVE DIMENSIONS

Dia. Range Basic size mm*(inch)		Piston to Bore Clearance		Rod to Gland Clearance		Running Clearance	ISO Tolerance	
Min.	**≤ Max.**	**(D-P)**	**Tolerance**	**(C-d)**	**Tolerance**	**Rc**	**H9**	**h9**
	50 (1.968)	0,43 (.017)	+0/-,05 (+0/-.002)	0,43 (0.17)	+,05/-0 (+.002/-0)	0,06 (.002)	+62/-0 (+.002/-0)	+0/-62 (+0/-.002)
50 (1.968)	120 (4.724)	0,46 (.018)	+0/-,07 (+0/-.003)	0,46 (0.018)	+,07/-0 (+.003/-0)	0,08 (.003)	+87/-0 (+.003/-0)	+0/-87 (+0/-.003)
120 (4.724)	250 (9.842)	0,48 (.019)	+0/-,10 (+0/-.004)	0,48 (.019)	+,10/-0 (+.004/-0)	0,11 (.004)	+115/-0 (+.004/-0)	+0/-115 (+0/-.004)
250 (9.842)	500 (19.685)	0,51 (.020)	+0/-,12 (+0/-.005)	0,51 (.020)	+,12/-0 (+.005/-0)	0,15 (.006)	+155/-0 (+.006/-0)	+0/-155 (+0/-.006)
500 (19.685)	800 (31.496)	0,53 (.021)	+0/-,15 (+0/-.006)	0,53 (0.21)	+,15/-0 (+.006/-0)	0,20 (.008)	+200/-0 (+.008/-0)	+0/-200 (+0/-.008)
800 (31.496)	1000 (39.370)	0,56 (.022)	+0/-,18 (+0/-.007)	0,56 (.022)	+,18/-0 (+.007/-0)	0,23 (.009)	+230/-0 (+.009/-0)	+0/-230 (+0/-.009)

*mm values given in 0.001 mm

Allowable Diametrical Clearance

Figure 1



Diametrical clearance

Piston seal = D - P

Rod seal = C - d

Extrusion gap

The maximum clearance gap formed between hardware components must be held to a minimum to prevent seal extrusion and premature failure. See Figure 1 for typical rod and piston seal extrusion locations and reference Table 1 for maximum values according to system pressure vs. material used. For clearance gaps beyond the recommended values in Table 1 the use of a back up ring is recommended.

TABLE 1

PRESSURE vs. MAXIMUM ALLOWABLE DIAMETRICAL CLEARANCE *mm (inch)*										
Material	**Pressure bar (psi)**									
	100 (1450)	**200 (2900)**	**300 (4350)**	**400 (5800)**	**500 (7250)**	**600 (8700)**	**700 (10150)**	**800 (11600)**	**900 (13050)**	**1000 (14500)**
AWC800, 860	0,75 (0.030)	0,75 (0.030)	0,51 (0.020)	0,38 (0.015)	0,32 (0.013)	0,25 (0.010)	0,23 (0.009)	0,19 (0.007)	0,15 (0.006)	0,10 (0.004)
AWC830	0,74 (0.029)	0,56 (0.022)	0,32 (0.013)	0,15 (0.006)	0,13 (0.005)	**Contact Engineering**				
AWC700, 701, 727, 742	0,70 (0.028)	0,44 (0.017)	0,23 (0.009)							
PTFE Compounds*	0,43 (0.017)	0,33 (0.013)	0,23 (0.009)	0,18 (0.007)	0,13 (0.005)					
PEEK Compounds AWC630, 635	1,90 (0.075)	1,90 (0.075)	1,27 (0.050)	1,00 (0.039)	0,84 (0.033)					
UHMWPE Compounds AWC610, 615, 620, 625	0,75 (0.030)	0,75 (0.030)	0,51 (0.020)	0,38 (0.015)	0,32 (0.013)					

*PTFE Compounds include; AWC100, AWC220, AWC300, AWC400, AWC440, AW500, AWC510, AWC520, AWC530, AWC550 PEEK® is a trademark of Victrex plc.
Contact engineering for circumstances beyond the recommendations provided.

Surface Finish

Surface finish or roughness is a measure of the irregularities (peaks and valleys) produced on a sealing surface according to the manufacturing process used to create the surface. Adhering to recommended finish ranges can have a profound effect on seal performance by limiting the effects of friction and reducing abrasive seal wear. An optimal surface texture will have ideal pocket depths to retain lubrication in small enough volumes to provide a thin lubrication film between seal and surface, thereby reducing friction and seal wear. If the surface is too rough, it will abrade the seal surface by plowing grooves in it and create a leak path. Alternatively, a surface that is too smooth will increase friction and wear because it does not have the ability to retain enough lubrication to provide a boundary lubrication film.

The parameters defined in ISO 4287 and ISO 4288 are measured or calculated from the roughness mean line as shown in the representative profile texture sample in Figure 1. The most commonly used values of R (arithmetic average) and R_q (root mean square) are used to quantify the overall size of the profile and the values of R (max roughness height in sample length), R (max roughness valley depth), R (max average roughness height within multiple sample lengths), and Rmr (amount of surface contact at a zero reference line) are used to describe the nature of the peaks and valleys. Figure 2 shows an example of how the nature of a surface profile can differ with the same overall profile height (R or RMS) as Figure 1. See Table 1 for common industry standards for surface finish values.

Figure 1

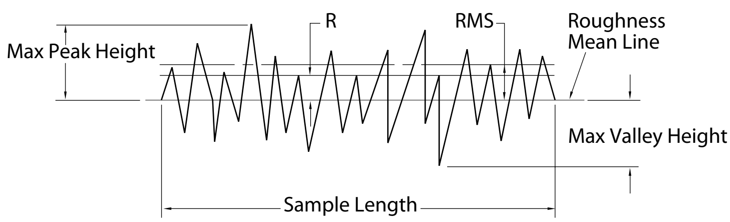


Figure 2

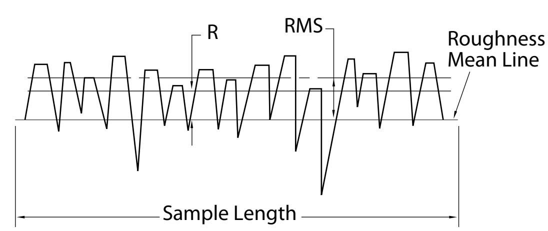


TABLE 1

RECOMMENDED SURFACE FINISHES FOR CHESTERTON MATERIALS			
Material	**Static µm R_a (µin R_a)**	**Dynamic µm R_a (µin R_a)**	**Conversion values**
AWC800, 860	0,76 – 1,17 µm (30 – 46 µin)	0,20 – 0,61 µm (8 – 24 µin)	1 µin = 0.0254 µm 1 µm = 39.37µin $R_q \approx R_a$ + 10 – 30%
AWC805	0,76 – 1,42 µm (30 – 56 µin)	0,20 – 1,17 µm (8 – 46 µin)	
AWC830	0,81 – 1,17 µm (32 – 46 µin)	0,20 – 0,61 µm (8 – 24 µin)	
AWC700, 701, 727, 742, 743, 750	0,81 – 1,17 µm (32 – 46 µin)	0,20 – 0,61 µm (8 – 24 µin)	
PTFE compounds*	0,40 – 0,80 µm (16 – 32 µin)	0,20 – 0,40 µm (8 – 16 µin)	
PEEK compounds AWC630, 635	0,40 – 0,80 µm (16 – 32 µin)	0,20 – 0,40 µm (8 – 16 µin)	
UHMWPE compounds AWC610, 615, 620, 625	0,40 – 0,80 µm (16 – 32 µin)	0,20 – 0,40 µm (8 – 16 µin)	

*Compounds include; AWC100, AWC220, AWC300, AWC400, AWC440, AWC500, AWC510, AWC520, AWC530, AWC550

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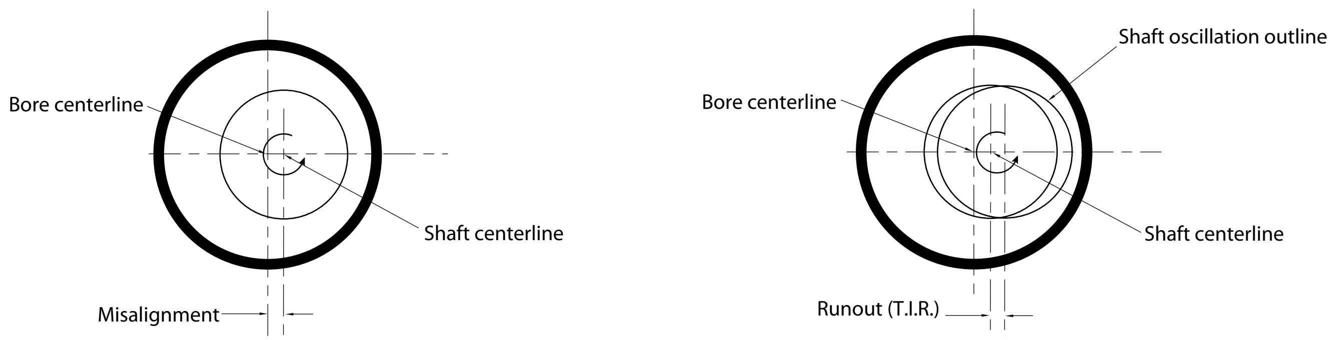
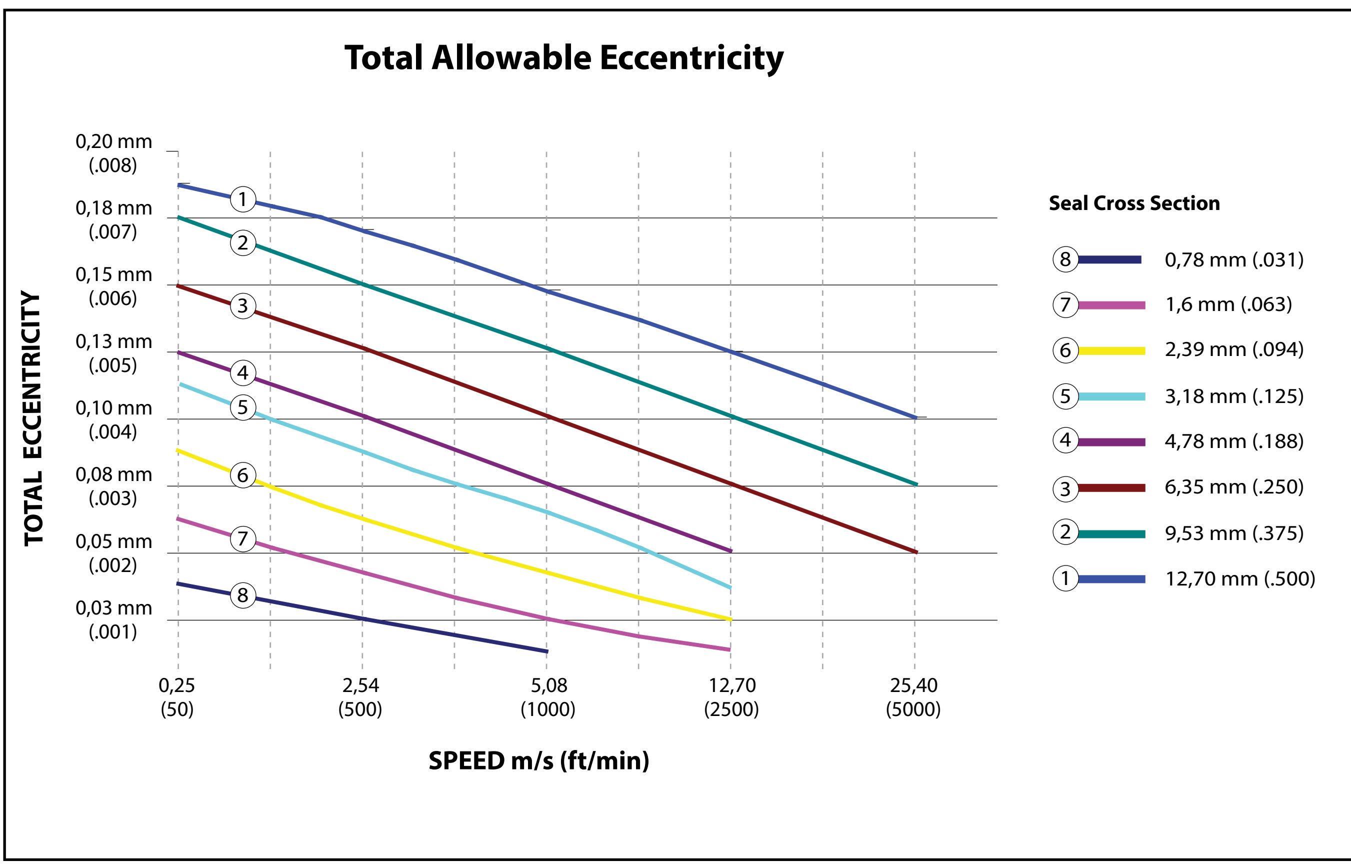
Eccentricity and Dynamic Runout for Spring Energized Seals

All rotating shafts will experience some degree of lack of concentricity or misalignment with the bore, resulting in eccentricity during operation. The amount of deviation can have a significant impact on seal performance especially with spring loaded seals with PTFE and engineered plastic jackets. Shown below are the two components, static misalignment and dynamic runout, that combined result in the total eccentricity.



Static: Shaft to Bore Misalignment
Misalignment occurs when the shaft centerline is offset from the bore centerline creating an asymmetrical clearance gap (e.g., shaft is not centered in the bore). This results in increased compression and wear of seal on one side and an enlarged extrusion gap on the other.

Dynamic: Runout (T.I.R.)
Shaft runout occurs when the shaft axis of rotation is different than the shaft centerline, resulting in shaft oscillating when it rotates. The effect on the seal is that it sees cyclic compression/decompression and accelerated wear on one side of the seal.



Reference material listing for limitations.

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